(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 December 2005 (01.12.2005)

PCT

(10) International Publication Number
WO 2005/113419 A2

(51) International Patent Classification[7]: B67D 5/00

(21) International Application Number: PCT/US2005/013728

(22) International Filing Date: 21 April 2005 (21.04.2005)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/564,497 21 April 2004 (21.04.2004) US

(71) Applicant *(for all designated States except US)*: **EKSIGENT TECHNOLOGIES, LLC** [US/US]; 2021 Las Positas Court, Suite 151, Livermore, CA 94550 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **ANEX, Deon, S.** [US/US]; 3049 Chateau Way, Livermore, CA 94550 (US). **PAUL, Phillip H.** [US/US]; 258 Daisyfield Drive, Livermore, CA 94550 (US). **NEYER, David, W.** [US/US]; 5020 Vannoy Avenue, Castro Valley, CA 94546 (US). **HVALKA, Edwin, K.** [US/US]; 40 Kent place, Palo Alto, CA 94301 (US).

(74) Agents: **SHAY, James, R.** et al.; Wilson Sonsini Goodrich & Rosati, 650 Page Mill Road, Palo Alto, CA 94306-1050 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: ELECTROKINETIC DELIVERY SYSTEMS, DEVICES AND METHODS

(57) Abstract: Devices, systems and methods according to the present invention utilize electrokinetic pumps capable of generating high and low pressures flow for various medical applications, including drug delivery and analyte sampling. The EK pumps and systems are configured and constructed to be low cost, compact and precise.

WO 2005/113419 A2

ELECTROKINETIC DELIVERY SYSTEMS, DEVICES AND METHODS

CROSS-REFERENCE

This application is a continuation-in-part application of Appl. Ser. No 10/273,723, filed October 18, 2002; Appl. Ser. No. 10/322,083, filed December 17, 2002; Appl. Ser. No. 10/198,223, filed July 17, 2002; and PCT application PCT/US2003/032895, filed October 17, 2003, which are incorporated herein by reference in their entirety and to which we claim priority under 35 USC § 120. This application also claims benefit under 35 USC § 119 of Appl. Ser. No. 60/564,497, filed April 21, 2004, which is also incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

In many diagnostic and therapeutic medical applications (including drug delivery and analyte sampling/monitoring), precise transport of a drug, blood and/or other bio-fluid is important. However, with most conventional diagnostic and therapeutic medical systems, precise movement of large and small aqueous volumes of drugs and other bio-fluids is difficult to achieve. This difficulty arises because conventional systems employ mechanical components to effect fluid transport and delivery. Re-configuration of these systems, to enable highly precise movement of small and large aqueous volumes of a solution containing biomaterials, would be impractical, as the complexity of such systems would make their manufacture expensive, time consuming and labor intensive.

Presently, electrokinetic ("EK") or electro-osmotic manipulations of fluids represent the state-of-the art in controlled, high precision, small volume fluid transport and handling. Electro-osmosis involves the application of an electric potential to an electrolyte, in contact with a dielectric surface, to produce a net flow of the electrolyte.

While electro-osmosis has found widespread and wide ranging applications in chemical analysis (e.g., high-speed liquid chromatography and other chemical separation procedures), its medical applications, such as for drug delivery and analyte sampling, have been limited, despite its advantages over conventional, mechanical approaches. Design challenges, including gas generation in the EK pump fluid, insufficient hydraulic pressure generation, and chemical degradation of the transported material caused by an applied electrical field, need to be overcome. When configured for non-medical use, these drawbacks do not pose major issues because the consequences are minimal, unlike in medical applications.

Accordingly, the present invention is directed to low-cost, high precision, reliable and compact EK pumps and systems adapted for medical applications, including, but not limited to, drug delivery and/or analyte sampling.

SUMMARY OF THE INVENTION

Generally, the present invention contemplates the use of controlled electrokinetic fluid flow techniques for efficient, reliable and highly precise movement of a pump fluid. In addition, various low-cost, precise, reliable and compact medical systems and device for drug delivery and analyte sampling are provided.

In some embodiments, the invention is a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir at a pump fluid flow rate substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the third reservoir and through a pump outlet at a dispensed fluid flow rate as the pump fluid moves from the first reservoir into the second reservoir, the dispensed fluid flow rate being between about .1 times and 10 times the pump fluid flow rate.

In other embodiments, the invention is a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid, the electrokinetic pump having a volume no greater than 250% of an initial volume of dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir.

In still other embodiments, the invention is a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir

containing pump fluid, a second reservoir, and a syringe containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the syringe and into a patient as the pump fluid moves from the first reservoir into the second reservoir. This embodiment may also include the step of adding dispensed fluid to the syringe prior to the moving step.

Still other embodiments of the method include the following steps: providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; moving dispensed fluid out of the third reservoir and through a first electrokinetic pump pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid, a second reservoir, a third reservoir and a dispensed fluid disposed in the third reservoir; connecting the electrodes of the second electrokinetic pump to a power source; and moving dispensed fluid out of the third reservoir and through a second electrokinetic pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump. The step of moving dispensed fluid from the first electrokinetic pump may be performed at a first rate and the step of moving dispensed fluid from the second electrokinetic pump may be performed at a second rate different than the first rate. The first electrokinetic pump and the dispensed fluid of the second electrokinetic pump may be the same kind of fluid or different kinds of fluid.

Other embodiments of the invention provide a method of pumping fluid including the steps of providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into

the second reservoir substantially without the occurrence of Faradaic processes in the pump; moving dispensed fluid out of the third reservoir and through a pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid, a second reservoir, a third reservoir and a dispensed fluid disposed in the third reservoir; connecting the electrodes of the second electrokinetic pump to a power source; and moving dispensed fluid out of the second electrokinetic pump third reservoir and through the pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump. The first electrokinetic pump and the dispensed fluid of the second electrokinetic pump may be the same kind of fluid or different kinds of fluid.

Yet other embodiments of the invention provide a method of pumping fluid including the steps of providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; moving dispensed fluid out of the third reservoir and through a pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid and a second reservoir; connecting the electrodes of the second electrokinetic pump to a power source; and moving dispensed fluid out of the third reservoir and through the pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump.

Still other aspects of the invention include a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the

electrodes to a power source; determining a patient's need for a dispensed fluid; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the third reservoir and through a pump outlet into the patient as the pump fluid moves from the first reservoir into the second reservoir in response to the determined need. The dispensed fluid may be insulin and the determining step may include determining the patient's blood glucose concentration, with the moving step comprising injecting a quantity of insulin into the patient in response to the determined blood glucose concentration. The moving step may also include automatically injecting a quantity of insulin into the patient in response to the determined blood glucose concentration. The determining step may include sampling a fluid taken from the patient with a second electrokinetic pump.

Other aspects of the invention provide a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and monitoring a parameter related to an amount of dispensed fluid moved out of the third reservoir during the moving step (e.g., flow rate, position of a pump element). The monitored parameter may be used to provide feedback control of the moving step, to provide an indication related to the dispensed fluid, to calculate a desired amount of dispensed fluid to be dispensed, and/or to indicate the presence of an occlusion in the pump outlet.

Yet other aspects of the invention provide a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the third reservoir and through a pump outlet for a fixed

time interval to dispense a fixed volume of dispensed fluid as the pump fluid moves from the first reservoir into the second reservoir.

Still other aspects of the invention provide a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and adjusting an amount of dispensed fluid moved out of the third reservoir.

Yet another aspect of the invention is a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid; connecting the electrodes to a power source; loading a dispensed fluid into the third reservoir; treating the electrokinetic pump to alter a characteristic of the dispensed fluid; moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir. The treating step may include irradiating the electrokinetic pump.

Still another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source; and moving substantially all of the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a flow rate of less than about 1 microliter/minute and with a steady state flow rate error of no more than about 5% over the entire method step.

Yet another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power

source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source; generating a pump fluid pressure between about 1 and about 1000 psi; and moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

Another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid, a power source connectable to the electrodes and a housing containing the electrodes, dielectric material, reservoir and power source, the electrokinetic pump having a volume of at most about 11 cm^3; connecting the electrodes to a power source; and moving at least about 0.2 milliliters of pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump. The moving step may include moving the pump fluid at a rate of less than about 10 nanoliters/min. and may also include the step of moving the pump fluid substantially continuously for about 30 days.

Still another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; supporting the electrokinetic pump on a patient; connecting the electrodes to a power source; and moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump. This method may also include implanting the electrokinetic pump in a patient. In embodiments in which the electrokinetic pump has a shape, the implanting step includes placing the electrokinetic pump adjacent to an anatomical feature of the patient having a shape complementary to the electrokinetic pump shape.

Another aspect of the invention provides a method of pumping fluid including the steps of providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source; moving pump fluid out of the reservoir at a first rate into a patient substantially without the occurrence of Faradaic processes in the first pump; providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material

disposed between the electrodes and a reservoir of a pump fluid; connecting the electrodes of the second electrokinetic pump to a power source; and moving pump fluid out of the second electrokinetic pump reservoir at a second rate into the patient substantially without the occurrence of Faradaic processes in the second pump. The first electrokinetic pump and the pump fluid of the second electrokinetic pump may be the same kind of fluid or different kinds of fluid.

Still another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source in a time modulated manner; and moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

Yet another aspect of the invention provides a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source by alternating the power source between an on state and an off state; and moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

Another aspect of the invention is a method of pumping fluid including the steps of providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid; connecting the electrodes to a power source by alternating the power source between a normally off state and a periodic on state in response to a computer program; and moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

Still another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second

reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a controller adapted to control delivery of power from the power source to the electrodes to move a fixed volume of dispensed fluid out of the third reservoir.

Yet another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a controller adapted to control delivery of power from the power source to the electrodes to move dispensed fluid for a fixed period of time.

Still another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a controller adapted to control delivery of power from the power source to the electrodes to move dispensed fluid out of the third reservoir at a fixed time interval.

Another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into

the second reservoir; and a controller adapted to control delivery of power from the power source to the electrodes to move an amount dispensed fluid out of the third reservoir in response to a user input.

Yet another aspect of the invention is an electrokinetic pump system including a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a first pump outlet; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the first pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; and a second electrokinetic pump comprising a second pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the second pair of electrodes, a fourth reservoir containing pump fluid, a second reservoir and a sixth reservoir containing a dispensed fluid, and a second pump outlet, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the second electrokinetic pump dispensed fluid through the second pump outlet into the patient when the second electrokinetic pump electrodes are connected to a power source without the occurrence of Faradaic processes in the second pump, the system further comprising a controller adapted to control the first and second electrokinetic pumps. The first electrokinetic pump may be further adapted move dispensed fluid at a first rate and the second electrokinetic pump is further adapted to move dispensed fluid at a second rate different than the first rate.

Another aspect of the invention is an electrokinetic pump system including a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet into a patient as the pump fluid moves from the first reservoir into the second

reservoir; and a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the electrodes, a fourth reservoir containing pump fluid, a fifth reservoir and a sixth reservoir containing a dispensed fluid, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the second electrokinetic pump dispensed fluid through the pump outlet into the patient when the second electrokinetic pump electrodes are connected to a power source substantially without the occurrence of Faradaic processes in the second pump. The first electrokinetic pump may be further adapted move dispensed fluid at a first rate and the second electrokinetic pump is further adapted to move dispensed fluid at a second rate different than the first rate.

Still another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a first electrokinetic pump comprising a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; and a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the electrodes, a fourth reservoir containing pump fluid and a fifth reservoir, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the dispensed fluid through the pump outlet into the patient when the second electrokinetic pump electrodes are connected to a power source substantially without the occurrence of Faradaic processes in the second pump.

Yet another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the

dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a movable member comprising a hydraulic amplifier disposed between the second reservoir and the third reservoir adapted to move as pump fluid moves from the first reservoir into the second reservoir to move the dispensed fluid out of the third reservoir.

Another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a sensor adapted to determine a patient's need for the dispensed fluid. The system may also include a controller adapted to control delivery of power from the power source to the electrodes in response to a signal from the sensor. In some embodiments, the sensor comprises an electrokinetic pump adapted to sample a fluid from the patient.

Still another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; an external port communicating with the third reservoir; a movable member disposed between the second reservoir and the third reservoir adapted to change an effective volume of the third reservoir as an effective volume of the second reservoir changes; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a laminated housing, the electrokinetic pump system having a volume no greater than 250% of the largest effective volume of the third reservoir.

Yet another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; an

external port communicating with the third reservoir; a movable member disposed between the second reservoir and the third reservoir adapted to change an effective volume of the third reservoir as an effective volume of the second reservoir changes; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a sensor adapted to monitor a parameter (e.g., flow rate, syringe position using, e.g., a magnet and a magnetostrictive sensor) related to an amount of fluid dispensed from the third reservoir. The system may also include a feedback control element adapted to control power delivered to the electrodes by the power source in response to a signal from the sensor, a controller adapted to control application of power from the power source to the electrodes in response to a sensor output signal, and/or an indicator adapted to provide an indication related to fluid dispensed from the third reservoir, such as the existence of an occlusion of the external port.

Another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a flow rate of less than about 1 microliter/minute and with a steady state flow rate error of no more than about 5%.

Still another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a pump fluid pressure between about 1 and about 1000 psi.

Yet another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the

occurrence of Faradaic processes in the pump; and a housing having a volume of at most about 11 cm^3 and wherein the electrodes, dielectric material and power source are further adapted to move at least about 0.2 milliliters of pump fluid from the reservoir. The electrodes, dielectric material and power source may be further adapted to move pump fluid from the reservoir at a rate of less than 10 nanoliters/min. The electrodes, dielectric material and power source may be still further adapted to move pump fluid from the reservoir from the reservoir substantially continuously for about 30 days. The housing may be a laminated housing.

Yet another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; wherein the electrodes, dielectric material and power source are further adapted to be implanted in a patient.

Another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and an indicator adapted to indicate an amount of pump fluid present in the reservoir.

Still another aspect of the invention provides an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and a controller adapted to provide power from the power source to the electrodes in a time modulated manner.

Another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the

occurrence of Faradaic processes in the pump; and a controller adapted to alternate the power source between an on state and an off state.

Still another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and a controller adapted to alternate the power source between a normally off state and a periodic on state in response to a computer program.

Yet another aspect of the invention is an electrokinetic pump system including a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a reservoir containing pump fluid; a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and a housing containing the electrodes, reservoir, dielectric material and power source, the housing being adapted to be worn on a human or animal body.

Another aspect of the invention provides a displacement pump including a dispensed fluid reservoir; a pump outlet; a displacement mechanism; a power source adapted to operate the displacement mechanism; and a housing containing the reservoir, pump outlet, power source and displacement mechanism, the housing having a volume no more than 250% of the volume of the dispensed fluid reservoir; the displacement mechanism and power source being further adapted to dispense substantially all of dispensed fluid from the reservoir through the pump outlet at a flow rate no more than 1 microliter/minute with a steady state flow rate error of no more than about 5%. The displacement mechanism may include a movable member, and the pump may further include an electrokinetic assembly comprising a pair of electrodes connectable to the power source, a porous dielectric material disposed between the electrodes; and pump fluid in contact with the electrodes, such as double-layer capacitive electrodes.

Yet another aspect of the invention is a pump including a reservoir of pump fluid; a pump mechanism operable on the pump fluid; a pump outlet; a power source connectable to the pump mechanism to move pump fluid from the reservoir through the pump outlet at a flow rate no more than 1 microliter/minute with a steady state flow rate error of no more than

about 5%; and a housing containing the reservoir, electrodes, pump outlet and power source, the housing having a volume no more than 150% of the volume of the reservoir. The electrodes may be a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2.

INCORPORATION BY REFERENCE

All publications and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

FIG. 1 illustrates a cross-sectional view of one embodiment of a direct EK pump;

FIG. 2 illustrates a cross-sectional view of a direct EK pump comprising a split reservoir design;

FIG. 3 illustrates a cross-sectional view of an indirect EK pump;

FIGS. 4a – 4c schematically illustrate operation of the EK pump provided in **FIG. 3**;

FIGS. 5a – 5c schematically illustrate controlled collapse of impermeable membranes during operation of the EK pump illustrated in **FIGS. 3** and **4**;

FIG. 6 illustrates a cross-sectional view of another indirect EK pump embodiment;

FIG. 7 illustrates a cross-sectional view of one embodiment of a hydraulic amplifier;

FIG. 8 illustrates one embodiment of an EK delivery system comprising a syringe;

FIG. 9 illustrates the dependence of fluid flow rates on voltage of an EK pump;

FIG. 10 illustrates the relationship of pressure and fluid flow rate of an EK pump;

FIG. 11a illustrates one embodiment of a flow indicator;

FIG. 11b illustrates one embodiment of a flow meter;

FIG. 12a illustrates an exploded, enlarged view of one embodiment of an EK delivery system;

FIG. 12b illustrates a schematic view of the EK delivery system illustrated in **FIG. 12a**;

FIG. 13a illustrates an exploded, view of another EK delivery system embodiment;

FIG. 13b illustrates a schematic view of the EK delivery system illustrated in **FIG. 13a**;

FIG. 14 illustrates a schematic view of one embodiment of a shielded delivery system;

FIG. 15 illustrates a schematic view of one embodiment of an EK sampling system;

FIG. 16 illustrates a system block diagram of a dual drug delivery and sampling system;

FIG. 17 illustrates system block diagram of a multi-drug delivery and sampling system;

FIG. 18 illustrates a system block diagram of a multi-drug, multi-pump externally controllable delivery system;

FIG. 19 illustrates a system block diagram of a distributed, multi-drug, multi-pump externally controllable delivery system; and

FIGS. 20 – 24 illustrate pump performance wherein:

FIG. 20 graphically illustrates rapid loading and delivery flow rates of an EK pump;

FIG. 21 graphically illustrates the constant steady-state flow rates during operation of an EK pump at any instantaneous time; and

FIGS. 22 and **23** graphically illustrate constant steady-state flow rates during operation of an EK pump configured to operate over a period of hours or days.

DETAILED DESCRIPTION OF THE INVENTION

The invention described herein provides EK systems for efficient, reliable and precise movement of a pump fluid for drug delivery and/or analyte sampling. Before describing these systems, the designs and characteristics of a few exemplary EK pumps suitable for use in said systems are provided below.

FIG. 1 is a cross-sectional view of a small, compact EK pump **100**. In this example, EK pump **100** comprises a first fluid reservoir **102** and a second fluid reservoir **104**. First fluid reservoir **102** is coupled to second fluid reservoir **104** by through-vias **106**, **110** and porous dielectric material **108**. Through-vias **106** and **110**, along with porous dielectric material **108**, provide a fluidic path between first reservoir **102** and second reservoir **104**. In this example, porous dielectric material **108** is encapsulated within a bonding material **114**, between upper and lower substrates **116a** and **116b**, respectively, as further described in Ser. No. 10/198,223.

Each fluid reservoir further comprises a fluid port **118** (which can be an inlet or outlet port) and capacitive electrode **120a** and **120b**. An electrical lead (not shown) is placed in contact with electrodes **120a, 120b** to couple them to a power supply (not shown). During operation, reservoirs **102** and **104**, including the space between porous dielectric material **108** and electrodes **120a** and **120b,** is filled with an electrolyte or pump fluid **122**. The fluid **122** may flow though or around electrodes **120a** and **120b.** As a voltage (correlated to the desired flow rate and pressure profile of pump **100)** is applied, pump fluid **122** is moved from one fluid reservoir to the other via electro-osmosis, without electrolysis, gas generation or substantial capacitive de-ionization during operation of the pump **100**. As will be recognized by one skilled in the art, gas formation or pH change due to changes in pump components (e.g., the pump fluid and/or electrodes), can introduce system error and decrease the precision of a fluid transport system or prevent the pump from working altogether.

Generally, the problem of gas formation and pH change in prior EK pumps results from electrochemical changes in the pump components, which are induced when a high enough electric field or voltage is applied to create a desired EK flow. For example, the pump fluid may be oxidized or reduced and produce gas and/or change the pH. Additionally, the electrodes of prior art EK pumps can be changed by oxidation-reduction reactions at the electrode-pump fluid interface. As will be recognized by one skilled in the art, these Faradaic processes decrease the precision and operability of EK pumps over time. To prevent or minimize Faradaic processes, several techniques can be employed in this invention, including but not limited to, implementing drive strategies to limit Faradaic processes and careful material selection of pump electrodes.

For example, a system voltage and the duration of the applied system voltage should be maintained sufficient to charge the electrodes and generate current flow to support a desired fluid flow rate for a given length of time, but below an electrode charging potential beyond which Faradaic reactions (such as oxidation/reduction) are induced. However, current flow is required in order to provide pump fluid flow. What is needed is a non-Faradaic process for maintaining current flow and fluid flow. This challenge can be met by employing electrodes having high double layer capacitance. Use of high double layer capacitance electrodes ensures that an applied system voltage will be sufficiently high to charge the electrodes and support the desired current and fluid flow of most pump fluids (such as water, saline, etc.) but be below an electrode charging potential beyond which oxidation-reduction is induced. Accordingly, configuration of an EK pump to move a pump fluid without the occurrence of Faradaic processes includes the incorporation of electrodes

made of materials having a high double-layer capacitance of at least 10^{-4} Farads/cm^2, more preferably of at least 10^{-2} Farads/cm^2, and most preferably of at least 1 F/cm^2. Preferably, these high double-layer capacitance electrodes are compatible with a wide range of pump fluids.

In general, high capacitance of double-layer materials arises from their comparatively large microscopic surface area. In one example, carbon paper impregnated with a carbon aerogel can be used as a high capacitance double-layer electrode. Other forms of carbon also have very large microscopic surface areas and exhibit double-layer high capacitances, and thus may be employed herein. For example, shaped carbon aerogel foam, carbon mesh, carbon fiber (e.g., pyrolized poly(acrylonitrile) or cellulose fiber), carbon black and carbon nanotubes, all of which have significant double layer capacitances.

While double-layer capacitive electrodes may also be formed of materials other than carbon, carbon is the preferred electrode material, as it is also inert and inhibits or slows reactions detrimental to EK transport of a fluid, i.e., Faradaic reactions (such as oxidation reduction of the electrodes or pump fluid). Further, the use of carbon based electrodes (for example, carbon paper) provides flexibility in EK pump design and configuration, as these materials are shapeable and conformable into a variety of shapes (e.g., can be punched, cast or cut easily into a variety of shapes) and are inexpensive, thus lowering the production costs of the EK pumps provided herein.

With respect to drive strategies to minimize Faradaic processes, a pump can be operated at system voltages, and the system voltages applied for durations, below a potential, or threshold, beyond which Faradaic processes such as electrolysis of the pump fluid is induced . Pump fluid electrolysis potentials for most pump fluids are less than a few volts; for example, the electrolysis potential for water is about 1.2 V while the electrolysis potential for propylene carbonate pump fluid is about 3.4 V. By maintaining a voltage drop across the electrodes of a pump below this electrolysis potential, pump fluid electrolysis can be prevented or minimized. The use of double layer high capacitance electrodes allows high or low system voltages to be used to support EK fluid flow through the pump without causing Faradaic processes in the pump fluid or electrodes. If the threshold for electrode oxidation or reduction is lower than that of the pump fluid, driving strategies can be employed that apply a system voltage and the duration of the applied system voltage sufficient to charge the electrodes and generate current flow to support a desired fluid flow rate for a given length of time, but below an electrode charging potential beyond which Faradaic reactions (such as oxidation/reduction) of the electrodes are induced.

In addition, to prevent capacitive deionization of a pump fluid (which is a non-Faradaic process but can still impact pump performance), it may also be preferable to employ a pump fluid having a sufficiently high enough ionic strength, so that during operation, the pump fluid's ionic strength does not fall below a minimum pump fluid ionic strength needed to support electro-osmotic flow since deionization of a pump fluid occurs over time, reducing the conductivity of the pump fluid. Yet another approach can be to limit the volume of pump fluid (or other fluid) in a pump reservoir that can be transported during a given run time of a pump before complete deionization of the pump fluid occurs.

In yet another embodiment, the pump design itself can be adapted to minimize the effect of deionization processes that can decrease the operability of a pump over time. For example, in the embodiment illustrated in **FIG. 2**, the shape of the first fluid reservoir **102** may be tapered in the portion of said reservoir immediately surrounding an electrode, creating a low volume fluidic path over the electrode. As will be recognized by those skilled in art, this low volume reservoir **124** configuration creates a steady state ion concentration adjacent to the electrode **120a**, as the rate of ions passing into a low volume reservoir **124** is generally proportional to the rate of deionization of the pump fluid **122** which usually occurs during operation of a pump. In this way, the effects of deionization of the pump fluid **122** on pump flow rate and current can be minimized and controlled during pump operation.

FIG. 3 illustrates yet another embodiment of an EK pump **200** in accordance with the present invention. In this example, pump **200** is configured as an indirect pump. As provided herein, an indirect pump is a pump where movement of a pump fluid **122** causes flow of a second fluid in a separate part of the pump. This second fluid is referred to herein as a working fluid **126**, which may be a drug or other fluid to be dispensed by pump **200**.

In this embodiment, EK pump **200** generally comprises a first chamber **202** comprising: a first flexible barrier **204** separating first reservoir **206** and second reservoir **208**; and a second chamber **210** comprising a second flexible barrier **212** that separates third reservoir **214** and fourth reservoir **216**. Either of ports **118** may be an outlet for the working fluid, an inlet for the working fluid and/or a vent for one of the working fluid reservoirs. Preferably, flexible barriers **204** and **212** are impermeable to prevent mixing of a pump fluid **122** (disposed in second **208** and fourth **216** reservoirs) and working fluid **126**. This pump configuration may be used when a working fluid (e.g., drug, reagent, etc.) is not compatible with electrokinetic flow; when the working fluid does not support a zeta potential, has a low electrolysis potential, has a high viscosity, or has or carries suspended particles or cells; or in cases where long-term storage, or useable lifetime, of the working fluid requires that it be

separate from the pump fluid. In pump **200**, a fluidic pathway exists between second **208** and fourth **216** fluid reservoirs by means of porous dielectric material **108**, which may be encapsulated within a bonding material disposed between upper and lower substrates (as in **FIG. 1**) or disposed within a conduit, or plurality of conduits. Electrodes **120a** and **120b** surround openings leading to and from porous dielectric material **108**.

FIGS. 4a – 4c are provided to illustrate what happens during operation of pump **200** as a voltage is applied across electrodes **120a** and **120b** disposed within second **208** and fourth **216** reservoirs respectively. In general, as pump fluid **122** is pumped from second reservoir **208**, through porous dielectric material **108**, and into fourth reservoir **216**, first flexible member **204** is collapsed while second flexible member **212** disposed with the second chamber **210** is distended. As the second flexible member **212** is distended working fluid **126** (which may be a drug, etc) disposed within the third reservoir **214** will be displaced and pumped out of third reservoir **214** through a fluid port **118b**. The volume in first reservoir 206 may be filled through port **118a** with additional working fluid, air, etc., as flexible member **204** moves to expand first reservoir 206 and contract second reservoir **208**.

In pump configurations where flexible members **204**, **212** are employed, it may be advantageous to utilize flexible members having highly ordered movement during collapse or expansion as depicted in **FIGS. 5a – 5c**. As illustrated in **FIGS. 5a-c**, a pump may be configured to comprise a flexible member that has a single flexure joint **300** (indicated by arrows) giving rise to a simple geometry during collapse (or expansions), as shown in **FIG. 5a**, or multiple or compound geometries during collapse, as pictured in **FIGS. 5b** and **5c**. As will be appreciated by those skilled in the art, this feature will ensure precise and maximal fluid movement effected by the pump, especially if the pump is adapted for small volume movement of liquids, low flow rates or low pressures.

In general, the pumps provided herein (including both direct and indirect pump embodiments) are highly compact and not much larger than the volume of a fluid to be transported by the pump. Accordingly, in the present invention the various systems incorporating these pumps for fluid transport can be correspondingly small. For example, for a drug delivery pump system (i.e., the electrodes, dielectric conduit, and reservoirs without the power supply or control electronics), the volume of said system need not be greater than about 250% of the largest effective volume of a drug reservoir if an indirect pump configuration is employed. For a pump system comprising a direct pump configuration such as the one shown in **FIGS. 1** and **2**, the volume of a pump system need no be more than 150% of the largest effective volume of a drug reservoir.

FIG. 6 illustrates another technique that can be employed to ensure maximal and precise fluid delivery from an EK pump. Through-vias **106** and **110** extend through a laminated substrate **116a** and **116b** to form upper and lower parts **208a**, **208b**, **216a**, **216b** of the pump fluid reservoirs. In this example, the flexible members **204** and **212** define the upper reservoir parts **208a** and **216a** while the electrodes **120a** and **120b** of pump **300** are placed within lower reservoir parts **208b** and **216b** so that flexible members **204** and **212** are not in contact with the electrodes **120a** and **120b** during collapse. As will be appreciated by one skilled in the art, this placement of electrodes inside of reservoirs **208** and **214** increases the fluid volume/capacity of the pump. Filling ports **119** are used to fill the reservoirs **208a** and **208b** and reservoirs **216a** and **216b** with pump fluid **122** during pump manufacture and are sealed during pump operation.

FIG. 7 illustrates another feature that may be incorporated to modulate fluid flow rates from an EK pump, a hydraulic amplifier **400**. In one embodiment, hydraulic amplifier **400** comprises a first piston **402** having a first cross-sectional area **A1** and diameter **D1** and a rigid shaft **404** that couples first piston **402** to second piston **406** having a second cross-sectional area **A2** and diameter **D2**.

During operation, fluid (e.g., a pump fluid) from a pump may be directed against the first piston **402**, which displaces the first piston **402** and the second piston **406** in a first direction. Alternatively, fluid may be directed against the second piston **406** to displace it and the first piston **402** in the opposite direction. As will be recognized by those skilled in the art, hydraulic amplifier **400** may be used to create pressure amplification or de-amplification as well as flow reduction or increase as may be needed. Accordingly, by appropriately choosing the relative piston sizes, the pressure and flow characteristics of a pump may be modulated.

In the embodiment shown in **FIG. 7**, linear displacement of the pistons **402** and **406** is generally equal. However, because of the differing cross-sectional areas of the respective pistons provided by the differences in diameters of the pistons, pressure amplification (or de-amplification) proportional to the ratio of the cross-sectional areas is created. In one example, the use of hydraulic amplifier can be used to alter the flow rate of a dispensed fluid vs. the flow rate of a pump fluid; for example a hydraulic amplifier can be used so that a dispensed fluid flow rate of a drug is between about .1 times and 10 times a pump fluid flow rate.

Further detailed descriptions of various compact, precise and low-cost medical systems for drug delivery and/or analyte systems are provided below. As further described

herein, these EK systems are smaller, lighter and more cost-effective than comparable prior systems and offer advantages in design flexibility and simplicity due to the incorporation of EK pumps for general fluid transport to effect drug delivery, analyte sampling, etc.,

FIG. 8 is a schematic diagram of one embodiment of an EK delivery system **500** in accordance with the present invention. EK delivery system **500** preferably comprises EK pump **502** having an inlet **504** and outlet **506** fluid port; a reservoir **508**; a syringe **510** having a pump fluid chamber **512**, plunger **514**, a syringe port **516**; a power source **518**; and a system controller **520** having one ore more feedback sensors **522**. In this embodiment, inlet fluid port **504** is coupled to reservoir **508** and outlet fluid port **506** is coupled to a syringe **510**, containing, for example, a drug such as insulin, pain medication or other therapeutic or diagnostically useful agent.

In one embodiment of system **500**, pump **502** is configured to move a drug out of syringe **510** and into a patient. Reservoir **508** can contain a pump fluid **122** while syringe **510** may be loaded with a drug. During operation, EK pump **502** (via direction of controller **520**) causes movement of the pump fluid **122** into pump fluid chamber **512** of syringe **510** and creates hydraulic pressure that pushes against syringe plunger **514**, causing movement of the plunger **514** and effecting drug delivery.

As will be recognized by those skilled in the art, syringe **510** can be configured to couple to any patient access device, such as a conventional infusion set, port-a-catheter, IV needle and the like, for transdermal, transvascular, intramuscular delivery of a drug into a patient. Alternatively, system **500** can be configured as a small ambulatory system contained in a bio-compatible, preferably inert housing, which is hermetically sealed to prevent leakage of any system components. As will be appreciated by one skilled in the art, because the EK systems of the present invention do not require mechanical components to cause fluid transport and drug delivery, these devices are small and lightweight and can be configured in any shape so that they can be easily carried or worn by a patient and hidden from view. Moreover, syringe **510** and reservoir **508** can be adapted to be refillable. In yet another embodiment, system **500** can be coupled to a transcutaneous adhesive pad having a plurality of micro-needles to adapt system **500** as a transdermal delivery system.

As will be further appreciated by those skilled in the art, system controller **520** serves to control the operation of pump **502** (e.g., to effect fluid flow rates, pressures, etc.), preferably in response to one or more system feedback sensors **522**. These feedback sensors **522** can be installed in any location, and their signals can be transmitted through a sensing circuitry, which can be integrated into system controller **520**. Various signals from these

feedback sensors **522** can be configured to provide feedback regarding drug volume displacement; measurements of flow rate or delivery rate over time; battery life; drug and pump reservoir conditions; system component malfunctions; the presence of an occlusion or other flow obstruction or failure; and other data. Preferably, the feedback data is transmitted quickly so that dynamic responses by the system controller **520** in response to feedback data can be initiated.

In one specific embodiment, a feedback sensor **522** can be coupled to syringe plunger **514** to detect and monitor displacement of plunger **514**. In one exemplary embodiment, feedback sensor **522** may be a magnetostrictive sensor available from MTS Sensors, of Cary, North Carolina, and the plunger **514** may contain an embedded permanent magnet. As will be recognized by one skilled in the art, these sensors can provide absolute distance measurements of plunger **514** without needing to be zeroed to an external reference. By monitoring the distance moved by plunger **514** at a given time, the amount of a substance delivered by system **500** can be compared to the desired amount of a substance to be delivered and the operation of the pump modulated at selected time intervals to ensure precise accurate delivery. Pump modulation may involve modifying drive voltage, current or duration of pump operation. Preferably, data from feedback sensor **522** is relayed to controller **520** where displacement of the plunger **514** can be correlated to the amount of agent/drug delivered by system **500**. Depending on the desired drug dosage regime, the controller **520** can modulate operation of pump **502** (by regulating current and voltage applied to the pump) to achieve the appropriate drug delivery profile. In one embodiment, depending on whether less or more drug delivery is required, operational parameters of the pump may be modulated.

For example, flow rates can increase or decrease based on feedback from sensors **522** disposed on plunger **514** by altering the voltage applied to the electrodes disposed in pump **502**. **FIG. 9** graphically illustrates this concept and depicts the direct relationship of an EK pump voltage with the pump flow rate. **FIG. 10** is provided to illustrate the relationship between pressure and flow rate. **FIGS. 9** and **10** also depict performance aspects of the EK and demonstrate the precision and consistent flow rates and pressures during steady state fluid flow using the EK pumps of the present invention. Alternatively, controller **520** can simply apply power to the electrodes according to a preset on and off cycle (e.g., where the power is normally off and is turned on to dispense fluid from the syringe) according to a computer program, timer or other control. Use of a timing circuit or other timing control to turn the power on for a period of time can be used to deliver a fixed volume or bolus from the

syringe. The system controller can also be provided with a user interface so that a user can indicate or change the volume or size of the bolus delivered.

In yet another embodiment, as illustrated in **FIGS. 11a** and **11b**, flow indicators **600** and flow meters **602** may be disposed in, or coupled to, one or more fluid paths of an EK system, to provide indication of the amount (volume) of a drug dispensed, the amount of agent still remaining in a syringe, the amount of fluid pump fluid remaining in a system reservoir, flow rate, etc., In some examples, said flow indicators **600** and flow meters **602** can provide a visual indication to a system user, or can be functionally coupled to a controller and adapted to supply electronic signals indicative of such information to enable modulation of a EK pump, as needed. In yet another embodiment, pump chamber **512** can be adapted as a hydraulic amplifier to alter the flow rate of a drug from syringe **510** and/or the flow rate of the pump fluid into pump chamber **512.**

In yet another embodiment, feedback mechanisms can be employed in order to create a feedback loop directly to the EK pump to control activation of a voltage from a battery or power source to the electrodes. For example, a small processor can be designed to produce an activation signal for a selected signal duration, e.g., 1-4 seconds, at selected time intervals to run the EK pump directly,

FIGS. 12a-12b illustrate an exploded, enlarged view and a schematic view, respectively, of a self-contained indirect EK pump delivery system **700** in accordance with the present invention. In this example, delivery system **700** is enclosed within housing **702**, which includes a first cover **704** and a second cover **706**, which can be adhesively bonded together. First cover **704** comprises a first pump fluid aperture **708** and a second pump fluid aperture **712**. Apertures **708** and **712** each have a silicone septum which may be pierced by a needle for adding pump fluid to the system. After filling the system with pump fluid, apertures **708** and **712** may be sealed, such as by covering with epoxy.

Second cover **706** houses the internal circuitry of the system in the cavity **715**, including a system controller disposed on circuit board **718** and a power source **720**. Second cover **706** also houses a first pump fluid reservoir **709** communicating with a second pump fluid reservoir **724** through a through-via **728b**, a third pump fluid reservoir **726** communicating with a fourth pump fluid reservoir **713** via a through-via **728a** (located in the first cover **704**—not shown in **FIG. 12a**). Apertures **708** and **712** communicate with reservoirs **724** and **726**, respectively. Porous double layer capacitive electrodes **120a** and **120b** are disposed in reservoirs **726** and **724**, respectively, and the pump fluid in those reservoirs can be moved between reservoirs **726** and **724** (and through reservoirs **709** and

713) through a porous dielectric material **730** (such as packed bed of silica beads) disposed in channel **732** extending between reservoirs **726** and **724** by applying a voltage to electrodes **120a** and **120b** from the power source via electrical connections (not shown).

Flexible impermeable diaphragms **734a** and **734b** are disposed in second cover **706** to form fifth and sixth reservoirs **710** and **714** adjacent the first and fourth reservoirs **709** and **713**, respectively. A vent **799** communicates fifth reservoir **710** with the exterior of the pump, and a cannula **722** serves as an outlet from sixth reservoir **714**. In addition, fluid aperture **798** with a silicone septum on the underside of cover **706** provides a way to fill the sixth reservoir **714** with a drug or other fluid to be delivered.

In operation, after filling reservoirs **709**, **713**, **724** and **726** with pump fluid via, e.g., ports **708** and **712,** and sixth reservoir **714** via aperture **798** with a drug, power may be supplied to electrodes 120a and 120b to move pump fluid from reservoirs **709** and **724** into reservoirs **726** and **713**, thereby moving flexible diaphragm **734b** to dispense the drug from reservoir **714** through cannula **722**.

In accordance with this embodiment of the invention, the system **700** is small, having an overall dimension of about 2 x 0.8 x 0.4 inches and is configured to deliver about 300 microliters of a drug employing about 300 microliters of a pump fluid. As exemplified in this embodiment, generally the overall size or volume of system **700**, (i.e., the volume of the pump less the volume of the power source and circuit board) need not be much greater than the volume of drug to be delivered or the volume of the drug reservoir **714**.

FIGS. 13a and **13b** illustrate yet another embodiment of an EK pump delivery system **800** in accordance with the present invention. In this embodiment, the system is adapted for high flow-rate (about 1-10mL/min) transport of fluid and which generally comprising electrodes having a porous dielectric material disposed, preferably laminated, between the electrodes so that pump fluid movement is through or perpendicular to the face of the pump as best illustrated in **FIG. 13b**.

FIG. 13a illustrates exploded view of one embodiment of EK pump system **800**. A flexible diaphragm **820** held between a top housing **812** and a spacer **816** defines a first fluid reservoir **808** and a second fluid reservoir **810**. A second flexible diaphragm **830** held between a bottom housing **824** and spacer **828** defines a third fluid reservoir **811** and a fourth fluid reservoir **821**. A porous dielectric material **802** separates the second and third reservoirs, which contain EK pump fluid.

Fluid reservoirs **808** and **821** each have fluid inlet and a fluid outlet ports, which couple reservoirs **808** and **821** to fluid pathway **832** (best illustrated in **FIG. 13b**) comprising a plurality of check valves **834, 836, 838** and **840**.

As best shown in **FIG. 13b**, system **800** is configured to provide high flow rate unidirectional transport along fluid pathway **832**, e.g., movement of fluid from a drug source **846** (such as, e.g., a collapsible IV bag) to system inlet port **842** to system outlet port **844** (which may be coupled to a patient access member **848**, such as a needle, infusion set, etc.) and to a patient. As will be appreciated by one skilled in the art, unidirectional fluid transport through system **800** is aided by the one-way check valves **834, 836, 838** and **840** coupled to fluid pathway **832**.

In this configuration, voltage from power source **850** is applied to electrodes (not shown) disposed in reservoirs **810** and **811** to cause movement of pump fluid (as indicated by shading) disposed between flexible diaphragms **820** and **830**, i.e., from fluid reservoir **810** to fluid reservoir **811,** and the direction of flow may be reversed by reversing the polarity of the applied voltage. Movement of the pump fluid from reservoir **810** to reservoir **811** will cause flexible member **820** to move downward, which in turn will draw fluid from drug source **846** to system inlet port **842** and through fluid pathway **832** into reservoir **808**. Check valve **836** prevents fluid from being drawn into reservoir **808** from outlet **844**. Likewise, fluid in reservoir **821** will be expelled as flexible member **830** moves downward, and check valve **838** prevents the expelled fluid from flowing toward drug source **846**. The operation is then reversed by reversing the polarity of the applied voltage, so that pump fluid flows from reservoir **811** into reservoir **810** and diaphragms **820** and **830** move upward. This movement draws the drug into reservoir **821** via check valve **838** and expels drug from reservoir **808** via check valve **836**. Check valves **840** and **834** prevent the fluid from flowing in an undesired direction.

The operation of this pump system can be controlled by a controller coupled to the pump, which modulates operation of the pump (by regulating current and voltage, for example amplitude and period or duration, applied to the pump, electrodes, etc.). As will be appreciated by one skilled in the art, the voltage and current applied to the pump and electrodes can be accomplished employing simple or complex drive strategies so that the appropriate pressure, fluid flow rates, drug delivery regimes of the system can be accomplished. Continuous oscillation provides for continuous flow of drug from the drug source to the outlet.

In one exemplary embodiment, system **800** is a small (about 1.6 x 1.2 x 1.7 inches) ambulatory system configured to deliver fluids at flow rates of about 1 mL/min at about 1-2 psi. System **800** can be used in place of conventional infusion pump, for example PCA pumps and the like, which are typically coupled to 1L saline bags. Also, the high accuracy of a low flow rate EK pump can be used to deliver a concentrated version of a drug to a saline stream provided by a higher flow rate pump to provide accurate dosing. EK system **800** can be used similarly and configured for continuous fluid delivery or operation or for intermittent fluid delivery (e.g., by intermittent activation of a system voltage from a battery coupled to turn the system **800** on and off). EK system **800** may also be controlled by feedback (e.g. vary voltage and or current based on a flow sensor reading).

FIG. 14 illustrates yet another embodiment of drug delivery system **900**, wherein delivery system **900** is adapted for the delivery of radioactive drugs or other toxic diagnostic or therapeutic compounds that require special handling to minimize a patient or user's exposure to those compound(s). In this example, delivery system **900** comprises a protective or shielded housing **902**, which surrounds an EK pump **904**; a power source **906**; and controller **908**. Delivery system **900** further comprises a patient access means **910**, which can be a cannula or needle adapted to provide subcutaneous, transvascular or other access to a patient, dosimeter **913**, which can be disposed and coupled to a fluid path, reservoir or the like of EK pump **904** to provide indication to a patient/or user regarding a substances delivered, etc., Preferably, the patient access means **910** is shielded to protect the patient or user from the radioactive or toxic material while it is being pumped into a patient.

Delivery system **900** further comprises an internal liner **912**, preferably a removable liner, adapted to shield the patient or user from the radioactive or toxic compound contained within the system. To further minimize the need to handle the system during operation, system **900** can further comprise other system components, such as a flow indicator or meter **914**; dosimeter **913** (as mentioned above); or other indicator to signal the amount of the toxic substance that has been delivered, how much is left, etc., in order to obviate or minimize the need to handle the system **900** during operation. In one example, indicator **914** can be adapted to be easily viewable by a user or can optionally be omitted and instead an electronic flow meter employed. Moreover, pump **904** and system **900** can be configured to be remotely activated and/or programmable in response to user or automatic control by a pre-programmed controller with feedback control provided by a dosimeter **912**, flow indicator dosimeter **914** or the like.

In yet another embodiment, system **900** can be adapted to withstand irradiation to activate a non-radioactive drug preloaded into system **900**. Upon irradiation of a preloaded drug within system **900**, it is converted into a radioactive form. Therefore, radioactive materials do not need to be handled in order to load a radioactive drug or substance into delivery system **900**. Moreover, because of the low cost of the delivery system and EK pump, the entire system **900** can be discarded after use. Yet another advantages to system **900** is that radioactive waste can be minimized because the systems provided efficient fluid delivery where no significant residual amount of a radioactive drug left within system **900**.

Table 1 provides a list of some radiopharmaceuticals that may be delivered using a system of this invention.

TABLE 1

Radiopharmaceutical	Trade Name	Primary Uses
Cobalt-57 cyanocobalamin	Rubratope; Dicopac	Schilling test
Cobalt -58 cyanocobalamin	Dicopac	Schilling test
Chromium-51sodium chromate	Chromotope	for labeling RBCs
Flourine-18 FDG		positron emission tomography imaging
Gallium-67	Neoscan	soft-tissue tumor and inflammatory process imaging
Indium-111 chloride	Indiclor	for labeling monoclonal antibodies and peptides (OncoScint & Octreoscan)
Indium-111 pentetate (DTPA)		imaging of CSF kinetics
Indium-111 oxyquinoline (oxine)		for labeling leukocytes and platelets
Indium-111 Capromab pendetide	ProstaScint	monoclonal antibody for

		imaging prostate cancer
Indium-111 Imciromab pentetate	Myoscint	monoclonal antibody for diagnosis of myocardial necrosis
Indium-111 pentetreotide	Octreoscan	imaging of neuroendocrine tumors
Indium-111 satumomab pendetide	OncoScint CR/OV	imaging of metastatic disease associated with colorectal and ovarian cancer
I-123 sodium iodide		thyroid imaging & uptake
I-125 iothalamate	Glofil	measurement of glomerular filtration
I-125 human serum albumin (RISA)	Isojex	plasma volume determinations
I-131sodium iodide		thyroid uptake, imaging, & therapy
I-131 iodohippurate	Hippuran; Hipputope	renal imaging and function studies
I-131 iodomethylnorcholesterol (NP-59)		adrenal imaging
I-131 metaiodobenzylguanidine (MIBG)	I-131 MIBG	imaging of pheochromocytomas and neuroblastomas
Krypton-81m gas (from Rb-81 generator)		pulmonary ventilation imaging

P-32 chromic phosphate	Phosphocol®P32	therapy of intracavitary malignancies
P-32 sodium phosphate		therapy of polycythemia vera
Rubidium-82 (from Sr-82/Rb-82 generator)	Cardio-Gen-82	positron emission tomography imaging
Samarium-153 Lexidronam (Sm-153 EDTMP)	Quadramet	palliative treatment of bone pain of skeletal metastases
Strontium-89	Metastron	palliative treatment of bone pain of skeletal metastases
Tc-99m pertechnetate		imaging of thyroid, salivary glands, ectopic gastric mucosa, parathyroid glands, dacryocystography, cystography
Tc-99m Apcitide	AcuTect	peptide imaging of DVT
Tc-99m Arcitumomab	CEA-Scan	monoclonal antibody for colorectal cancer
Tc-99m albumin colloid	Microlite -no longer on market	imaging of RES (liver/spleen)
Tc-99m bicisate (ECD)	Neurolite	cerebral perfusion imaging
Tc-99m Depreotide	Neotect	somatostatin receptor-bearing pulmonary masses
Tc-99m disofenin (DISIDA)	Hepatolite	hepatobiliary imaging
Tc-99m exametazine (HMPAO)	Ceretec	cerebral perfusion imaging

Tc-99m Gluceptate	Glucoscan	renal imaging
Tc-99m Human Serum Albumin (HSA)		imaging of cardiac chambers
Tc-99m Lidofenin (HIDA)	Technescan® HIDA	hepatobiliary imaging
Tc-99m Macroaggregated Albumin (MAA)	Pulmolite; Macrotec	pulmonary perfusion
Tc-99m Mebrofenin	Choletec	hepatobiliary imaging
Tc-99m Medronate (MDP)		bone imaging
Tc-99m Mertiatide	Technescan MAG3	renal imaging
Tc-99m Nofetumomab Merpentan NR-LU-10	Verluma	monoclonal antibody Fab fragment for imaging small cell lung cancer
Tc-99m Oxidronate (HDP)	Osteoscan HDP	bone imaging
Tc-99m Pentetate (DTPA)	Techneplex, Technescan DTPA	renal imaging and function studies; radioaerosol ventilation imaging
Tc-99m Pyrophosphate (PYP)		avid infarct imaging
Tc-99m Red Blood Cells (RBCs)	Ultratag	imaging of GI bleeds, cardiac chambers
Tc-99m Sestamibi	Cardiolite Miraluma	myocardial perfusion imaging breast tumor imaging
Tc-99m Succimer (DMSA)		renal imaging

Tc-99m Sulfur Colloid (SC)		imaging of RES (liver/spleen), gastric emptying, GI bleeds
Tc-99m Teboroxime	Cardiotec	myocardial perfusion imaging
Tc-99m Tetrofosmin	Myoview	myocardial perfusion imaging
Thallium-201		myocardial perfusion imaging; parathyroid & tumor imaging
Xenon-133		pulmonary ventilation imaging

FIG. 15 illustrates yet another aspect of the invention, specifically an EK sampling system **1000**, which can be adapted to draw, analyze and/or store (within the system) a physiological fluid, such as blood (e.g., for glucose monitoring) or other body fluid containing a target analyte from a patient. In this embodiment, sampling system **1000** comprises an indirect EK pump **1002**, which is coupled to a sampler **1004** and an analyzer **1006**, which are fluidly coupled to EK pump **1002** via external fluid loop **1008**. During use, pump can be operated to effect transport of a physiological fluid taken from a patient by sampler **1004** to analyzer **1006** where the physiological fluid may be evaluated for the analyte. In one example, the Ringers solution, saline or other appropriate fluid can be pumped through fluid loop **1008** where the solution can be mixed with the extracted physiological fluid at sampler **1004** and transported to analyzer **1006**.

Sampler **1004** may be any conventionally known system or device for obtaining a physiological fluid. In one embodiment, sample 1004 may comprise a EK pump adapted to hydraulically draw a physiological fluid from a patient. One embodiment of an EK pump system and pump configuration suitable for such an application is described with reference to **FIGS. 13a – 13b**. Likewise analyzer **1006** may be any conventionally known system for testing the obtained sample. For example, analyzer **1006** can be reagent system for determination of a patient's glucose concentrations in the sampled physiological fluid, as

further described in U.S. Pat. No. 3,298, 789, and U.S. Pat. No. 3,630,957, the entire contents of which are hereby incorporated by reference.

FIG. 16 illustrates a system block diagram of another embodiment, wherein the EK system **2000** is a dual analyte sampling and drug delivery system. In this example, system **2000** broadly comprises a system controller **2002**; an analyte sampling subsystem **2004** comprising a first EK pump **2006**; and a drug delivery subsystem **2008** comprising a second EK pump **2010**. The system controller **2002** serves to control the operation of the sampling and delivery subsystems **2004** and **2008** by controlling voltage being applied to the EK pumps.

In a preferred embodiment, system **2000** comprises two separate fluid paths **2012** and **2014**. Fluid path **2014** is coupled the second EK pump **2010** and adapted to electro-osmotically pump a drug from within drug reservoir **2016** to a patient. Fluid path **2012** is coupled to the first EK pump **2006** and adapted to electro-osmotically pump a physiological fluid from sampler **2018** to analyzer **2020** where it can be evaluated. However, while the fluid paths are preferably configured to be separate, the control of drug delivery subsystem **2008** by controller **2002** is based on feedback from sampling subsystem **2004**. Controller **2002** is adapted to send and/or receive data to and from the sampling and drug delivery subsystems **2004** and **2008** to modulate drug delivery and determine an appropriate drug delivery profile or regime depending on monitoring and analysis of a patient's physiological and/or chemical state by sampling subsystem **2004**.

As will be appreciated by those skilled in the art, in this embodiment, the sampling subsystem **2004** can be configured to measure a specific analyte and/or a change in analyte parameter and to compare it to a known values stored within a memory component of controller **2002**, so that the EK system **2000** can effect drug delivery in response to any physiological, physiochemical or chemical changes in a patient. In one example, depending on input from the sampling subsystem **2004**, controller **2002** can execute a command signal to the delivery subsystem **2008** to initiate, control and/or terminate of an operation.

For example, system **2000** can be configured for the treatment of diabetes and adapted to deliver insulin. Insulin delivery can be initiated after a patient's blood glucose concentration has been determined by sampling subsystem **2004**. Delivery subsystem **2008** can be configured to deliver a quantity of insulin into the patient in response to the determined blood glucose concentration. Delivery of insulin in response to the determined blood glucose concentration may comprise automatically effecting delivery of insulin or can be configured to require user initiation of insulin delivery or both. In addition, delivery

subsystem can be adapted to deliver more than one type of insulin, insulin at different delivery rates to effect basal and bolus delivery. In addition, the system can be adapted to deliver a frequent micro-volumes or microboluses of insulin in order to maintain a constant glucose concentrations in a patient to effect better or effective diabetes management.

In yet another embodiment, the various systems and pumps provided herein may be multiplexed to provide delivery of more than one drug, comprise more than one fluid path, flow rate or EK pump as schematically depicted in **FIGS. 17 – 19**. For example, **FIG. 17** illustrates a system block diagram for a multi-pump, multi-reservoir drug delivery system **3000**. In this embodiment, the various EK pumps of the invention may be multiplexed and adapted to provide a system capable of delivering more than one drug $\mathbf{D_1...D_n}$, for example, in order to deliver a drug cocktail or for delivering one or more drugs at differing flow rates $\mathbf{FR_1....FR_n}$ or for delivering one drug at differing flow rates (e.g., for basal, bolus delivery) or the like.

In one embodiment, for example, EK system **3000** can be adapted to deliver more than one compound, to mimic or functionally augment or replace diseased or organ, such as a pancreas. In this example, drug delivery subsystem can comprise one or more EK delivery pumps **3002** that can be configured to deliver one or more compounds or drugs (e.g., trypsin, steapsin, amylolytic ferment) and which are coupled to a sampling subsystem **3010** for providing feedback control of the multi-pump delivery subsystem **3012** (through, e.g., diagnostics sampling blood or other biological fluids) controlling how much of each substance is needed. Other organs may be mimicked or augmented in this way. Alternatively, system **3000** can be configured to deliver a single drug from drug reservoir **3014** which is common to all pumps **3002**, for delivery at differing flow rates, etc.,

FIG. 18 illustrates yet another embodiment of a multi-reservoir, multi-pump drug delivery system **4000** comprising an external controller **4002**. Operation of the implanted delivery system **4000** can be operationally controlled by external controller **4002** having a user interface **4004**. Signals (such as RF, IR or other electronic transmissions) between external controller and implanted delivery system **4000** are provided to allow interface with, and/or control, by external controller **4002** of one or more of the components of the delivery system **4006** such as a controller, battery, electrodes, feedback sensors, etc. Signal transmission lines **4008** illustrate one method of controlling the multiple pumps **4010** system **4000**. In this embodiment, the fluid paths **4012** of system **4000** are illustrated. As shown, the various fluids (e.g., drugs) can be combined for delivery to a target treatment site inside a

body. Alternatively, an external pump or pumps located outside of the patient may be remotely controlled to deliver one or more fluids to the patient.

As will be appreciated by one skilled in the art, this embodiment may be useful for medical applications where the delivery of multiple agents is required, e.g., for diagnostic imaging studies, for cancer treatment where multiple chemotherapeutic agents need to be delivered simultaneously or in a particular timing or order, where one agent counteracts unwanted side effects of another agent, etc., For example, Agent A is a chemotherapy cocktail called Taxotere used in early or late stage breast cancer. The unwanted side effect is a reduction in white blood cells. Agent B is an antibiotic that is provided in proportion to the reduction in white blood cell activity or white blood cell count. Agent B could be provided at a first, higher rate immediately following the highest dosage of chemotherapy, then tapered off as the body's ability to produce white blood cells improves or is restored.

Other examples include a multi-drug cocktail to treat AIDS (reservoirs contain AZT, reverse transcriptase inhibitors and protease inhibitors) and multi-drug cocktails to treat tuberculosis, hepatitis B, hepatitis C, and tissue rejection after an organ transplant.

Generally, because of their small size, and because they may be formed in a variety of shapes, the EK pumps of this invention may be implanted in proximity to the portion of a body being treated by the agent delivered by the pump. For example, the pump may have a form factor adapted to the shape of the liver and may be implanted to treat hepatitis B. Other potential organs include the kidneys, the gall bladder, etc., **FIG. 19** is a system block diagram of an implantable "distributed" drug delivery system **5000** comprising one or more implantable drug delivery subsystems **5002** and an external controller **5004**. As illustrated, the various delivery subsystems **5002** can be implanted at different locations inside a patient's body for drug delivery at more than one treatment site. In this embodiment, each of the subsystems **5002** is configured to be operable by external controller **5004**. Alternatively, an external pump or pumps located outside of the patient may be remotely controlled to deliver one or more fluids to the patient.

Other embodiments of indirect pumps may be provided. For example, instead of using a diaphragm or syringe to isolate a reservoir, the drug or other fluid to be delivered may be loaded into a collapsible bag placed within a rigid chamber. Delivery of the EK pump fluid into the portion of the rigid chamber outside the bag collapses the bag to dispense the drug out through an outlet, such as a plastic tube. This approach may be used to deliver high viscosity drugs, for example.

In addition, dried (e.g., lyophilized) versions of drugs may be preloaded into the pump's drug delivery reservoir for shipment and storage of the pump and drug, then reconstituted immediately prior to use.

Pumping system embodiments of the present invention may include electronics and communications that allow for various level of control authority, for example the prescribing physician may have a greater authority over dosing, while the patient has a lesser authority. This authority my include electronic key authentication for granting such authority as well as for activation (e.g., for cases where the device dispenses controlled substances requires specific license to prescribe/distribute, such as for a scheduled narcotic). As another example, the device can be configured to deliver only a total amount of drug over a period of time, regardless of how much drug is delivered at each of one or more times during that period. Alternatively, the device can be controlled to operate for only a set period of time, no matter how much drug has been delivered. The device can also provide a display showing the amount of drug remaining in the reservoir, the amount of dose delivered at one time or overall, etc.,

Other manners of automatic feedback control of the EK pumps of this invention may be provided. For example, physiological inputs, such as limb movement during Parkinson's-induced tremor or epileptic seizure, may trigger the release of a drug from the EK pump to treat the condition.

The device may include electronics and communications that provide for making a historical record of device operation that may be complemented with records of various physiological responses or conditions (e.g., heart rate, blood pressure, EKG, blood gases, serum levels of specific compounds). These records can be downloaded for analysis and use in optimizing treatment and/or judging response to treatment. Various levels of authority can be included if desired to allow some, all or none of the download features.

FIGS. 20-23 are provided to illustrate the performance aspects of the EK systems and pumps provided herein. For example, **FIG. 20** is provided to illustrate fast loading and delivery flow rates plotted over time for a typical EK pump in accordance with the present invention. As illustrated it is possible to configure the various EK pumps and systems to provide fast loading and delivery of a pump fluid to effect transport and movement of fluid out of or through an EK fluid system.

FIG. 21 is provided to illustrate the overall reliability and precision of fluid transport by the EK pumps of the present invention. In this example, constant fluid flow rates can be maintained during pump operation, little or no error in flow rates at any given time. As

previously described above, by employing certain techniques (e.g., controlled release of and uptake of ions in the pump fluid, controlling the voltage applied below a pump fluid voltage potential, careful selection of electrode materials), flow rate errors can be maintained at less than 5% during steady-state flow. **FIGS. 22** and **23** are provided to illustrate the constant and precise steady-state flow rate can be maintained over a period of hours or over a period of days as may be required.

Pumps of the present invention may be advantageously used to dispense agents of wide ranging physical characteristics. For example, embodiments of the present invention may be used to pump agents having a viscosity of 10 to 100 poise, 100 to 1,000 poise or 1,000 to 10,000 poise. In each of these various viscosity ranges, pumps of the present invention maintain the precision and micro-delivery aspects described herein. For example, pumps of the present invention may provide 1-10 microliters per hour flow rates for agents ranging from 10 to 10,000 poise.

The EK pump systems of this invention may be used to deliver many different drugs or other substances to treat a variety of disorders. For example, in a patient diagnosed with a disorder in the autonomic and/or somatic motor nervous systems or whose treatment requires agent or agents that have a therapeutic effect on the autonomic and/or somatic motor nervous systems, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: muscarinic receptor agonists and antagonists; anticholinesterase agents; agents acting at the neuromuscular junction and/or autonomic ganglia; catecholamines, sympathominmetic drugs, and adrenergic receptor antagonists; and 5-hydroxytryptamine (5-HT, serotonin) receptor agonists and antagonists.

In a patient diagnosed with a disorder in the central nervous system (CNS) or whose treatment requires agent or agents that have a therapeutic effect on the central nervous system and/or act at synaptic and/or neuroeffector junction sites, the agent dispensed by the pump may include by way of illustration and not limitation: general anesthetics, local anesthetics, analogs of benzodiazepine and barbiturates, a hypnotic, a sedative, aliphatic alcohols, ethanol, nonbenzodiazepine sedative-hypnotic drugs, sedative-hypnotic agents of diverse chemical structure (e.g., paraldehyde, chloral hydrate), CNS depressants, antidepressant therapeutic agents, antipsychotic and antimanic agents, norepinephrine inhibitors, monoamine oxidase inhibitors, selective serotonin-reuptake inhibitors, benodiazepine sedative-antianxiety agents, serotonin 5-HT_{1A}-receptor partial agonists, buspirone, agents that block D_2-dopamine receptors, agents that reduce dopamine neurotransmission in forebrain, tricyclic phenothiazines, thioxanthenes, dibenzepines, butyrophenones and congeners,

heterocyclics, benzamides, agents that interact with D_1- and D_4- dopaminergic, 5-HT_{2A}- and 5-HT_{2C}-serotonergic, and α-adrenergic receptors, clozapine, olanzapine, quetiapine, risperidone, fluphenazine, haloperidol, chlorpromazine, lithium, lithium carbonate, lithium citrate, sedative-anticonvulsant benzodiazepines, sodium divalproex, carbamazepine, antiseizure drugs that promote an inactivated state of voltage-activated Na+ channels, antiseizure drugs that enhance gamma-aminobutyric acid (GABA)-mediated synaptic inhibition, antiseizure drugs that enhance gamma-aminobutyric acid (GABA)-mediated synaptic inhibition by an action presynaptically, antiseizure drugs that enhance gamma-aminobutyric acid (GABA)-mediated synaptic inhibition by an action postsynapically, cholinergic agents, levodopa, dopamine-receptor agonists, catechol-O-methyltransferase (COMT) inhibitors, acetylcholinesterase (AChE) inhibitors, NMDA-receptor antagonists, and opioid analgesics.

In a patient having a condition, such as injury or inflammation, causing a physiological or pathophysiological response to the condition or whose treatment requires agent or agents that have a therapeutic effect on the physiological or pathophysiological response to injury or inflammation, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: histamine and histamine antagonists, bradykinin and bradykinin antagonists, 5-hydroxytryptamine (serotonin), lipid substances that are generated by biotransformation of the products of the selective hydrolysis of membrane phospholipids, eicosanoids, prostaglandins, thromboxanes, leukotrienes, aspirin, nonsteriodal anti-inflammatory agents, analgesic-antipyretic agents, agents that inhibit the synthesis of prostaglandins and thromboxanes, selective inhibitors of the inducible cyclooxygenase, selective inhibitors of the inducible cyclooxygenase-2, autacoids, paracrine hormones, somatostatin, gastrin, cytokines that mediate interactions involved in humoral and cellular immune responses, lipid-derived autacoids, eciosanoids, β-adrenergic agonists, ipratropium, glucocorticoids, methylxanthines, and leukotriene inhibitors.

In a patient diagnosed with a disorder affecting renal and/or cardiovascular function or whose treatment requires agent or agents that have a therapeutic effect on the renal and/or cardiovascular function, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: diuretics, vasopressin, agents affecting the renal conservation of water, rennin, angiotensin, agents useful in the treatment of myocardial ischemia, anthihypertensive agents, angiotensin converting enzyme inhibitors,

β-andrenergic receptor antagonists, agents for the treatment of hypercholesterolemia, and agents for the treatment of dyslipidemia.

In a patient diagnosed with a disorder in the gastrointestinal system and/or function or whose treatment requires agent or agents that have a therapeutic effect on the gastrointestinal system or function, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: agents used for control of gastric acidity, agents for the treatment of peptic ulcers, agents for the treatment of gastroesophageal reflux disease, prokinetic agents, antiemetics, agents used in irritable bowel syndrome, agents used for diarrhea, agents used for constipation, agents used for inflammatory bowel disease, agents used for biliary disease, agents used for pancreatic disease.

In a patient diagnosed with a disorder requiring chemotherapy of a parasitic infection or whose treatment requires agent or agents that have a chemotherapeutic effect on an infection in the patient, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: drugs used to treat protozoal infections, drugs used to treat Malaria, Amebiasis, Giardiasis, Trichomoniasis, Trypanosomiasis, and/or Leishmaniasis, and/or drugs used in the chemotherapy of helminthiasis.

In a patient diagnosed with a disorder requiring chemotherapy of neoplastic diseases or whose treatment requires agent or agents that have a chemotherapeutic effect on a neoplastic disease or infection in the patient, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: antineoplastic agents.

In a patient diagnosed with a disorder requiring chemotherapy of microbial diseases or whose treatment requires agent or agents that have a chemotherapeutic effect on microbial diseases or infections in the patient, the agent (or agents in a co-treatment embodiment) dispensed by the pump may include by way of illustration and not limitation: antimicrobial agents, sulfonamides, trimethoprim-sulfamethoxazole quinolones, and agents for urinary tract infections, penicillins, cephalosporins, and other, *β*-Lactam antibiotics, an agent comprising an aminoglycoside, protein synthesis inhibitors, drugs used in the chemotherapy of tuberculosis, *mycobacterium avium* complex disease, and leprosy, antifungal agents, antiviral agents including nonretroviral agents and antiretroviral agents. Additional disorders requiring chemotherapy or whose treatment requires agent or agents that have a chemotherapeutic effect in the patient are described in the Handbook of Chemotherapy (Sixth

Edition), Roland T. Skeel, M.D. Editor, Physicians Cancer Chemotherapy Drug Manual 2003 by Edward Chu, Vincent T. DeVita, Lippincott's Cancer Chemotherapy Handbook by Delia C. Baquiran, Jean Gallagher, each of which is incorporated herein by reference in their entirely and for all purposes.

In addition, agents may include drugs used for immunomodulation, such as immunomodulators, immunosuppressive agents, tolerogens, and immunostimulants.

In addition, agents may include drugs acting on the blood and the blood-forming organs, hematopoietic agents, growth factors, minerals, and vitamins, anticoagulant, thrombolytic, and antiplatelet drugs.

In addition, agents may include hormones and hormone antagonists, pituitary hormones and their hypothalamic releasing factors, thyroid and antithyroid drugs, estrogens and progestins, androgens, adrenocorticotropic hormone; adrenocortical steroids and their synthetic analogs; inhibitors of the synthesis and actions of adrenocortical hormones, insulin, oral hypoglycemic agents, and the pharmacology of the endocrine pancreas, agents affecting calcification and bone turnover: calcium, phosphate, parathyroid hormone, vitamin D, calcitonin, and other compounds.

In addition, agents may include vitamins such as water-soluble vitamins, vitamin B complex, ascorbic acid, fat-soluble vitamins, vitamins A, K, and E. In addition, agents may include drugs suited to dermatological pharmacology and ocular pharmacology.

Additional disorders and their treatments may be found in Goodman and Gilman's "The Pharmacological Basis of Therapeutics" Tenth Edition edited by Hardman, Limbird and Gilman or the Physician's Desk Reference, both of which are incorporated herein by reference in their entirety. It is to be appreciated therefore that the embodiments of the present invention are not limited merely to the agent, agents or disorders listed above but that embodiments of the present invention may be used to advantage for the delivery of agents, including diagnostic and testing agents for the purpose of detecting, treating, managing, or diagnosing any of the above listed disorders as well as those disorders mentioned in Goodman and Gilman's "The Pharmacological Basis of Therapeutics" Tenth Edition edited by Hardman, Limbird and Gilman or mentioned in the Physician's Desk Reference.

Agents may be used alone or in formulations comprising a pharmaceutically acceptable carrier. The formulation may also comprise a solvent. The agent may be a biological molecule or a pharmaceutical drug, DNA, RNA or a protein.

It is to be appreciated that the EK functionality of pumps of the present invention do not provide any perceptible indication of operation. As used herein, perceptible indication of

operation refers to a any outward sign that the pump is operating. For example, conventional piezoelectric pumps have a distinct buzz resulting from the vibration of the piezoelectric elements. Conventional mechanical and peristaltic pumps have distinct mechanical noises that indicate the pump is operating. Such perceptible indications, especially noises, are undesirable for pump systems worn on the person or to be operated in public, for example, to dispense insulin prior or during a meal. Embodiments of the present invention are capable of dispensing or administering an agent without a perceptible indication of pump operation. For example, embodiments of the present invention may operate and generate noise levels below 20 db, or in some embodiments below 10 db or in still other embodiments generate noise inaudible or barely audible to a human being.

The pump and pumping systems described herein are useful in methods for the treatment of animal subjects. The term "animal subject" as used herein includes humans as well as other mammals. The methods generally involve the administration of one or more agents for the treatment of one or more diseases. Combinations of agents can be used to treat one disease or multiple diseases or to modulate the side-effects of one or more agents in the combination.

The term "treating" and its grammatical equivalents as used herein includes achieving a therapeutic benefit and/or a prophylactic benefit. By therapeutic benefit is meant eradication or amelioration of the underlying disorder being treated. For example, in a cancer patient, therapeutic benefit includes eradication or amelioration of the underlying cancer. Also, a therapeutic benefit is achieved with the eradication or amelioration of one or more of the physiological symptoms associated with the underlying disorder such that an improvement is observed in the patient, notwithstanding that the patient may still be afflicted with the underlying disorder. For example, administration of a chemotherapeutic agent to a patient suffering from cancer provides therapeutic benefit not only when the patient's tumor marker level is decreased, but also when an improvement is observed in the patient with respect to other complications that accompany the cancer like pain and psychiatric disorders. For prophylactic benefit, the combination of phosphate binder and gastric pH modulator may be administered to a patient at risk of developing a particular disease, like cancer, or to a patient reporting one or more of the physiological symptoms of a disease, even though a diagnosis of this disease may not have been made.

In some of the embodiments of the present invention the agent is a drug. Drugs are any compounds of any degree of complexity that perturb a biological state, whether by known or unknown mechanisms and whether or not they are used therapeutically. Drugs thus

include: typical small molecules of research or therapeutic interest; naturally-occurring factors, such as endocrine, paracrine, or autocrine factors or factors interacting with cell receptors of all types; intracellular factors, such as elements of intracellular signaling pathways; factors isolated from other natural sources; pesticides; herbicides; and insecticides. The biological effect of a drug may be a consequence of, inter alia, drug-mediated changes in the rate of transcription or degradation of one or more species of RNA, the rate or extent of translation or post-translational processing of one or more polypeptides, the rate or extent of the degradation of one or more proteins, the inhibition or stimulation of the action or activity of one or more proteins, and so forth. In fact, most drugs exert their affects by interacting with a protein. Drugs that increase rates or stimulate activities or levels of a cellular constituent are called herein "activating drugs", while drugs that decrease rates or inhibit activities or levels of cellular constituents are called herein "inhibiting drugs".

The agents used in the pumps described herein may be used alone or in combination with one or more pharmaceutically acceptable carrier. Examples of suitable carriers are known in the art, for example, see Remington: The Science and Practice of Pharmacy by A.R. Gennaro (Editor), 20th Edition, 2000. Preferably the carrier improves the delivery of the agent to the subject. It is also preferable that the carrier does not hinder the delivery of the agent. In some of the embodiments, the carrier has sufficient ionic properties to support the electro-osmotic functioning of the pump.

In some embodiments, the pump is used to detect the presence of one or more markers of a disease. If a marker of a disease is detected as being present, the pump is used to deliver one or more agents to treat the disease. The term marker as used herein is intended to encompass biological markers and also measurable phenotypic characteristics like temperature, pressure, etc., Examples of biological markers include, but are not limited to, DNA, RNA, proteins, enzymes, hormones, cells, portions of cells, tissues, or organs, subcellular organelles like mitochondria, nucleus, Golgi complex, lysosome, endoplasmic reticulum, and ribosome, chemically reactive molecules like H^+, superoxides, and ATP. Examples of markers include, but are not limited to, prostate specific antigen for prostate cancer, glucose and/or insulin levels for diabetes, and blood pressure measurements for hypertension.

While preferred embodiments of the present invention have been shown and described herein, it will be obvious to one skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. For example, the

systems of the invention may comprise for example any of the features of conventional drug delivery or analyte monitoring devices including for example alarms or other indicators for notifying a user of when drug delivery is complete. In yet another example, various retention members and the like may be coupled to the various device and systems in aid in the portability of the various devices and system. In addition, the intended uses of the present invention include a variety of medical applications as well as other applications where highly precise, compact devices for fluid transport are needed. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

WHAT IS CLAIMED IS:

1. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir at a pump fluid flow rate substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the third reservoir and through a pump outlet at a dispensed fluid flow rate as the pump fluid moves from the first reservoir into the second reservoir, the dispensed fluid flow rate being between about .1 times and 10 times the pump fluid flow rate.

2. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid, the electrokinetic pump having a volume no greater than 250% of an initial volume of dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir.

3. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a syringe containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the syringe and into a patient as the pump fluid moves from the first reservoir into the second reservoir.

4. The method of claim 3 further comprising adding dispensed fluid to the syringe prior to the moving step.

5. A method of pumping fluid comprising:

providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump;

moving dispensed fluid out of the third reservoir and through a first electrokinetic pump pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir;

providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid, a second reservoir, a third reservoir and a dispensed fluid disposed in the third reservoir;

connecting the electrodes of the second electrokinetic pump to a power source; and

moving dispensed fluid out of the third reservoir and through a second electrokinetic pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump.

6. The method of claim 5 wherein the step of moving dispensed fluid from the first electrokinetic pump is performed at a first rate and the step of moving dispensed fluid from the second electrokinetic pump is performed at a second rate different than the first rate.

7. The method of claim 5 wherein the dispensed fluid of the first electrokinetic pump and the dispensed fluid of the second electrokinetic pump are the same kind of fluid.

8. The method of claim 5 wherein the dispensed fluid of the first electrokinetic pump and the dispensed fluid of the second electrokinetic pump are different kinds of fluid.

9. A method of pumping fluid comprising:

providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power

source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump;

moving dispensed fluid out of the third reservoir and through a pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir;

providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid, a second reservoir, a third reservoir and a dispensed fluid disposed in the third reservoir;

connecting the electrodes of the second electrokinetic pump to a power source; and

moving dispensed fluid out of the second electrokinetic pump third reservoir and through the pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump.

10. The method of claim 9 wherein the step of moving dispensed fluid from the first electrokinetic pump is performed at a first rate and the step of moving dispensed fluid from the second electrokinetic pump is performed at a second rate different than the first rate.

11. The method of claim 9 wherein the dispensed fluid of the first electrokinetic pump and the dispensed fluid of the second electrokinetic pump are the same kind of fluid.

12. The method of claim 9 wherein the dispensed fluid of the first electrokinetic pump and the dispensed fluid of the second electrokinetic pump are different kinds of fluid.

13. A method of pumping fluid comprising:

providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump;

moving dispensed fluid out of the third reservoir and through a pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir;

providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir of pump fluid and a second reservoir;

connecting the electrodes of the second electrokinetic pump to a power source; and

moving dispensed fluid out of the third reservoir and through the pump outlet into the patient as pump fluid of the second electrokinetic pump moves from the first reservoir into the second reservoir of the second electrokinetic pump substantially without the occurrence of Faradaic processes in the second pump.

14. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

determining a patient's need for a dispensed fluid;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the third reservoir and through a pump outlet into the patient as the pump fluid moves from the first reservoir into the second reservoir in response to the determined need.

15. The method of claim 14 wherein the dispensed fluid comprises insulin and the determining step comprises determining the patient's blood glucose concentration, the moving step comprising injecting a quantity of insulin into the patient in response to the determined blood glucose concentration.

16. The method of claim 15 wherein the moving step comprises automatically injecting a quantity of insulin into the patient in response to the determined blood glucose concentration.

17. The method of claim 14 wherein the determining step comprises sampling a fluid taken from the patient with a second electrokinetic pump.

18. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump;

moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

monitoring a parameter related to an amount of dispensed fluid moved out of the third reservoir during the moving step.

19. The method of claim 18 further comprising using the monitored parameter to provide feedback control of the moving step.

20. The method of claim 19 wherein the monitored parameter is flow rate.

21. The method of claim 19 wherein the monitored parameter is position of a third reservoir pump element.

22. The method of claim 18 further comprising using the monitored parameter to provide an indication related to the dispensed fluid.

23. The method of claim 18 further comprising using the monitored parameter to calculate a desired amount of dispensed fluid to be dispensed.

24. The method of claim 22 wherein the step of using the monitored parameter comprises using the monitored parameter to indicate the presence of an occlusion in the pump outlet.

25. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the third reservoir and through a pump outlet for a fixed time interval to dispense a fixed volume of dispensed fluid as the pump fluid moves from the first reservoir into the second reservoir.

26. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power

source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump;

moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

adjusting an amount of dispensed fluid moved out of the third reservoir.

27. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes, a first reservoir containing pump fluid, a second reservoir, and a third reservoir containing a dispensed fluid;

connecting the electrodes to a power source;

loading a dispensed fluid into the third reservoir;

treating the electrokinetic pump to alter a characteristic of the dispensed fluid;

moving pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump; and

moving dispensed fluid out of the third reservoir and through a pump outlet as the pump fluid moves from the first reservoir into the second reservoir.

28. The method of claim 27 wherein the treating step comprises irradiating the electrokinetic pump.

29. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source; and

moving substantially all of the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a flow rate of less than about 1 microliter/minute and with a steady state flow rate error of no more than about 5% over the entire method step.

30. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source;

generating a pump fluid pressure between about 1 and about 1000 psi; and

moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

31. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid, a power source connectable to the electrodes and a housing containing the electrodes, dielectric material, reservoir and power source, the electrokinetic pump having a volume of at most about 11 cm^3;

connecting the electrodes to a power source; and

moving at least about 0.2 milliliters of pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

32. The method of claim 31 wherein the moving step comprises moving the pump fluid at a rate of less than about 10 nanoliters/min.

33. The method of claim 32 wherein the moving step comprises moving the pump fluid substantially continuously for about 30 days.

34. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

supporting the electrokinetic pump on a patient;

connecting the electrodes to a power source; and

moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

35. The method of claim 34 further comprising implanting the electrokinetic pump in a patient.

36. The method of claim 34 wherein the electrokinetic pump has a shape, the implanting step comprising placing the electrokinetic pump adjacent to an anatomical feature of the patient having a shape complementary to the electrokinetic pump shape.

37. A method of pumping fluid comprising:

providing a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source;

moving pump fluid out of the reservoir at a first rate into a patient substantially without the occurrence of Faradaic processes in the first pump;

providing a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir of a pump fluid;

connecting the electrodes of the second electrokinetic pump to a power source; and

moving pump fluid out of the second electrokinetic pump reservoir at a second rate into the patient substantially without the occurrence of Faradaic processes in the second pump.

38. The method of claim 37 wherein the pump fluid of the first electrokinetic pump and the pump fluid of the second electrokinetic pump are the same kind of fluid.

39. The method of claim 37 wherein the pump fluid of the first electrokinetic pump and the pump fluid of the second electrokinetic pump are different kinds of fluid.

40. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source in a time modulated manner; and

moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

41. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power

source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source by alternating the power source between an on state and an off state; and

moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

42. A method of pumping fluid comprising:

providing an electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2 and being connectable to a power source, a porous dielectric material disposed between the electrodes and a reservoir containing pump fluid;

connecting the electrodes to a power source by alternating the power source between a normally off state and a periodic on state in response to a computer program; and

moving pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump.

43. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a controller adapted to control delivery of power from the power source to the electrodes to move a fixed volume of dispensed fluid out of the third reservoir.

44. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a controller adapted to control delivery of power from the power source to the electrodes to move dispensed fluid for a fixed period of time.

45. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a controller adapted to control delivery of power from the power source to the electrodes to move dispensed fluid out of the third reservoir at a fixed time interval.

46. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move

the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a controller adapted to control delivery of power from the power source to the electrodes to move an amount dispensed fluid out of the third reservoir in response to a user input.

47. An electrokinetic pump system comprising:

a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a first pump outlet; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the first pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; and

a second electrokinetic pump comprising a second pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the second pair of electrodes, a fourth reservoir containing pump fluid, a second reservoir and a sixth reservoir containing a dispensed fluid, and a second pump outlet, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the second electrokinetic pump dispensed fluid through the second pump outlet into the patient when the second electrokinetic pump electrodes are connected to a power source without the occurrence of Faradaic processes in the second pump,

the system further comprising a controller adapted to control the first and second electrokinetic pumps.

48. The electrokinetic pump system of claim 47 wherein the first electrokinetic pump is further adapted move dispensed fluid at a first rate and the second electrokinetic pump is further adapted to move dispensed fluid at a second rate different than the first rate.

49. An electrokinetic pump system comprising:

a first electrokinetic pump comprising a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2; a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; and a power source connected to the

electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; and

a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the electrodes, a fourth reservoir containing pump fluid, a fifth reservoir and a sixth reservoir containing a dispensed fluid, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the second electrokinetic pump dispensed fluid through the pump outlet into the patient when the second electrokinetic pump electrodes are connected to a power source substantially without the occurrence of Faradaic processes in the second pump.

50. The electrokinetic pump system of claim 49 wherein the first electrokinetic pump is further adapted move dispensed fluid at a first rate and the second electrokinetic pump is further adapted to move dispensed fluid at a second rate different than the first rate.

51. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a first electrokinetic pump comprising a porous dielectric material disposed between the electrodes; a first reservoir containing pump fluid; a second reservoir; a third reservoir containing dispensed fluid and a pump outlet; and a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet into a patient as the pump fluid moves from the first reservoir into the second reservoir; and

a second electrokinetic pump comprising a pair of double-layer capacitive electrodes connectable to a power source, a porous dielectric disposed between the electrodes, a fourth reservoir containing pump fluid and a fifth reservoir, the second electrokinetic pump electrodes and dielectric material being adapted to move the second electrokinetic pump fluid out of the fourth reservoir into the fifth reservoir to move the dispensed fluid through the pump outlet into the patient when the second electrokinetic pump electrodes are connected to

a power source substantially without the occurrence of Faradaic processes in the second pump.

52. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and a movable member comprising a hydraulic amplifier disposed between the second reservoir and the third reservoir adapted to move as pump fluid moves from the first reservoir into the second reservoir to move the dispensed fluid out of the third reservoir.

53. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a sensor adapted to determine a patient's need for the dispensed fluid.

54. The electrokinetic pump system of claim 53 further comprising a controller adapted to control delivery of power from the power source to the electrodes in response to a signal from the sensor.

55. The electrokinetic pump system of claim 53 wherein the sensor comprises an electrokinetic pump adapted to sample a fluid from the patient.

56. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

an external port communicating with the third reservoir;

a movable member disposed between the second reservoir and the third reservoir adapted to change an effective volume of the third reservoir as an effective volume of the second reservoir changes;

a power source connected to the electrodes;

the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a laminated housing, the electrokinetic pump system having a volume no greater than 250% of the largest effective volume of the third reservoir.

57. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a first reservoir containing pump fluid;

a second reservoir;

a third reservoir containing dispensed fluid and a pump outlet;

an external port communicating with the third reservoir;

a movable member disposed between the second reservoir and the third reservoir adapted to change an effective volume of the third reservoir as an effective volume of the second reservoir changes;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the first reservoir into the second reservoir substantially without the occurrence of Faradaic processes in the pump and to move

the dispensed fluid out of the pump outlet as the pump fluid moves from the first reservoir into the second reservoir; and

a sensor adapted to monitor a parameter related to an amount of fluid dispensed from the third reservoir.

58. The electrokinetic pump system of claim 57 further comprising a feedback control element adapted to control power delivered to the electrodes by the power source in response to a signal from the sensor.

59. The electrokinetic pump system of claim 57 wherein the parameter is flow rate of fluid dispensed from the third reservoir.

60. The electrokinetic pump system of claim 57 wherein the third reservoir comprises a syringe, the sensor being adapted to monitor a position of the syringe.

61. The electrokinetic pump system of claim 60 wherein the syringe comprises a plunger and a magnet, the sensor comprising a magnetostrictive sensor adapted to detect a position of the magnet.

62. The electrokinetic pump system of claim 60 further comprising a controller adapted to control application of power from the power source to the electrodes in response to a sensor output signal.

63. The electrokinetic pump system of claim 57 further comprising an indicator adapted to provide an indication related to fluid dispensed from the third reservoir.

64. The electrokinetic pump system of claim 63 wherein the indication comprises an occlusion of the external port.

65. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid; and

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a flow rate of less than about 1 microliter/minute and with a steady state flow rate error of no more than about 5%.

66. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid; and

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump at a pump fluid pressure between about 1 and about 1000 psi.

67. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

a housing having a volume of at most about 11 cm^3 and wherein the electrodes, dielectric material and power source are further adapted to move at least about 0.2 milliliters of pump fluid from the reservoir.

68. The electrokinetic pump system of claim 67 wherein the electrodes, dielectric material and power source are further adapted to move pump fluid from the reservoir at a rate of less than 10 nanoliters/min.

69. The electrokinetic pump system of claim 68 wherein the electrodes, dielectric material and power source are further adapted to move pump fluid from the reservoir from the reservoir substantially continuously for about 30 days.

70. The electrokinetic pump system of claim 67 wherein the housing comprises a laminated housing.

71. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid; and

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump;

wherein the electrodes, dielectric material and power source are further adapted to be implanted in a patient.

72. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

an indicator adapted to indicate an amount of pump fluid present in the reservoir.

73. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

a controller adapted to provide power from the power source to the electrodes in a time modulated manner.

74. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

a controller adapted to alternate the power source between an on state and an off state.

75. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

a controller adapted to alternate the power source between a normally off state and a periodic on state in response to a computer program.

76. An electrokinetic pump system comprising:

a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2;

a porous dielectric material disposed between the electrodes;

a reservoir containing pump fluid;

a power source connected to the electrodes; the electrodes, dielectric material and power source being adapted to move the pump fluid out of the reservoir substantially without the occurrence of Faradaic processes in the pump; and

a housing containing the electrodes, reservoir, dielectric material and power source, the housing being adapted to be worn on a human or animal body.

77. A displacement pump comprising:

a dispensed fluid reservoir;

a pump outlet;

a displacement mechanism;

a power source adapted to operate the displacement mechanism; and

a housing containing the reservoir, pump outlet, power source and displacement mechanism, the housing having a volume no more than 250% of the volume of the dispensed fluid reservoir;

the displacement mechanism and power source being further adapted to dispense substantially all of dispensed fluid from the reservoir through the pump outlet at a flow rate no more than 1 microliter/minute with a steady state flow rate error of no more than about 5%.

78. The pump of claim 77 wherein the displacement mechanism comprises a movable member.

79. The pump of claim 78 wherein the displacement mechanism further comprises an electrokinetic assembly comprising a pair of electrodes connectable to the power source, a porous dielectric material disposed between the electrodes; and pump fluid in contact with the electrodes.

80. The pump of claim 79 wherein the electrodes comprise double-layer capacitive electrodes.

81. A pump comprising:

a reservoir of pump fluid;

a pump mechanism operable on the pump fluid;

a pump outlet;

a power source connectable to the pump mechanism to move pump fluid from the reservoir through the pump outlet at a flow rate no more than 1 microliter/minute with a steady state flow rate error of no more than about 5%; and

a housing containing the reservoir, electrodes, pump outlet and power source, the housing having a volume no more than 150% of the volume of the reservoir.

82. The pump of claim 81 wherein the pump mechanism comprises a pair of double-layer capacitive electrodes having a capacitance of at least 10^{-2} Farads/cm^2.

FIG. 1

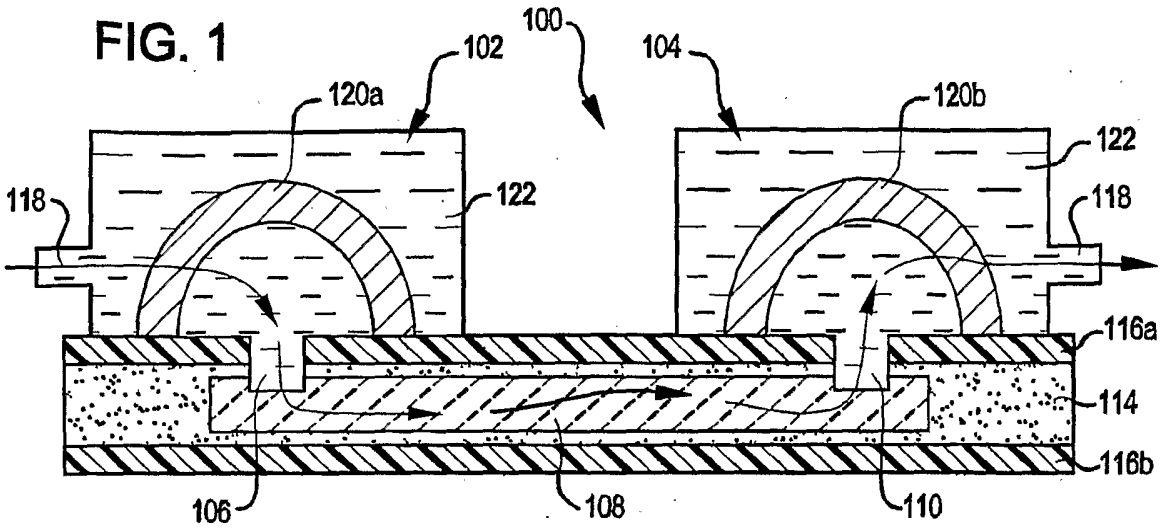


FIG. 2

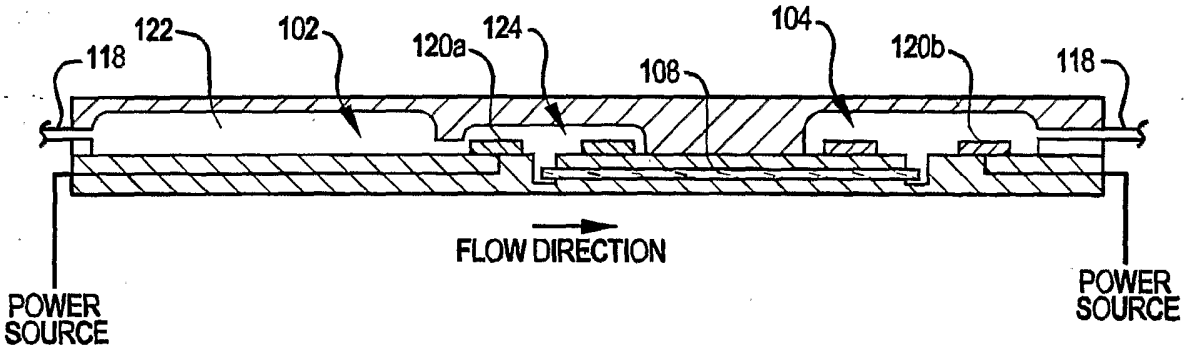


FIG. 3

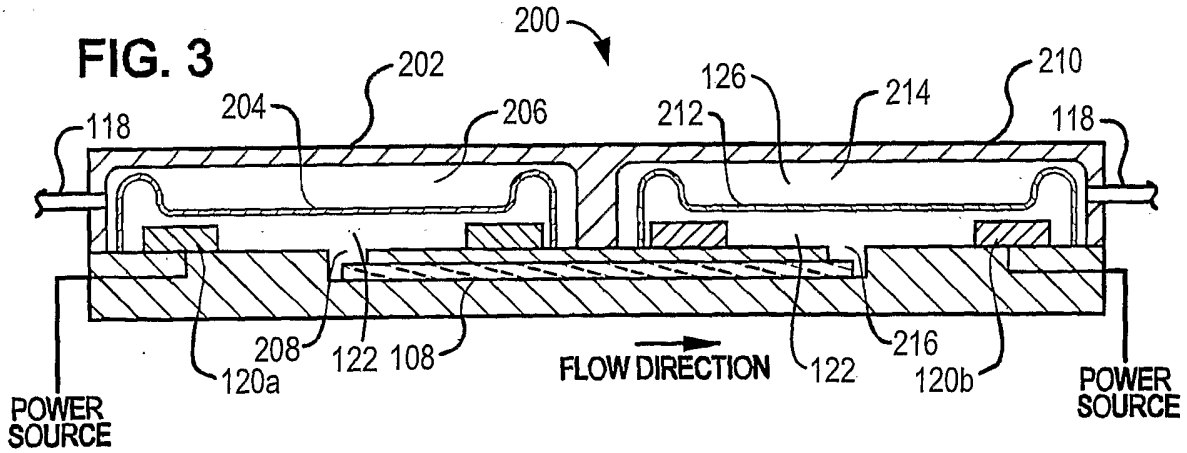


FIG. 4a
START

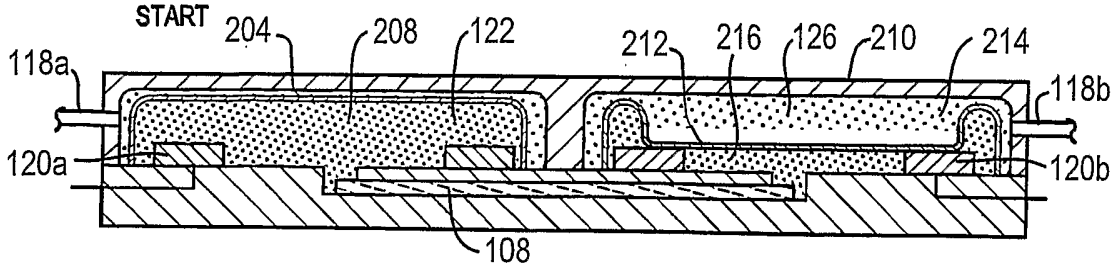


FIG. 4b
MIDPOINT

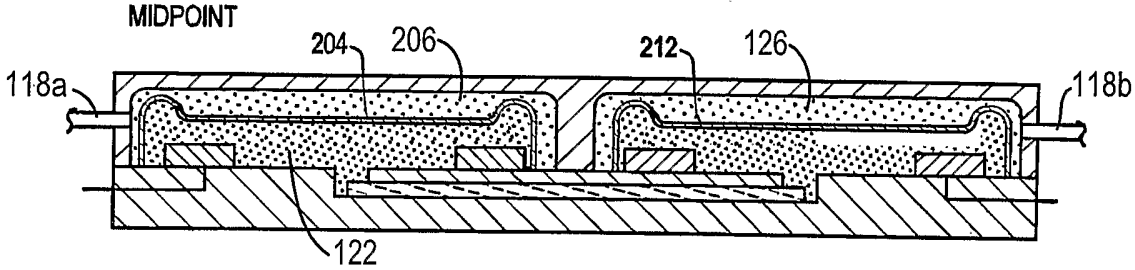


FIG. 4c
END OF DELIVERY

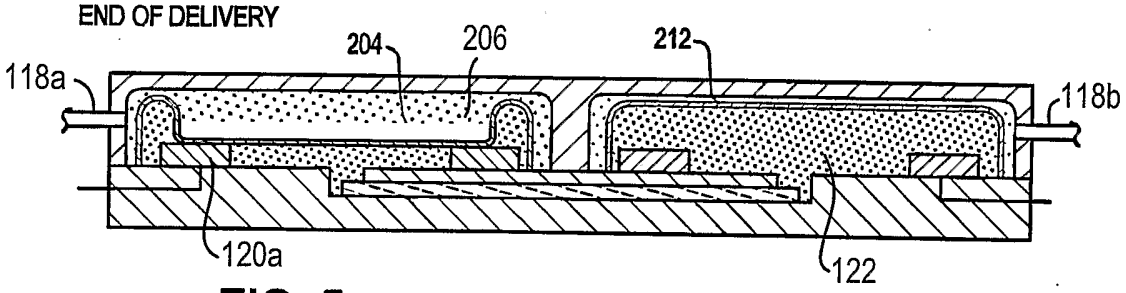


FIG. 5a

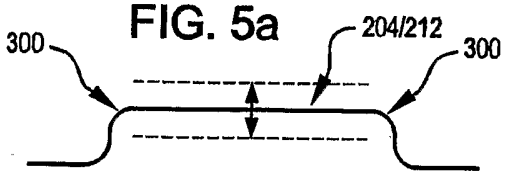


FIG. 5b

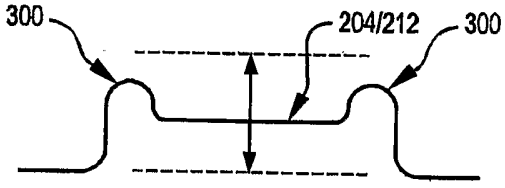


FIG. 5c

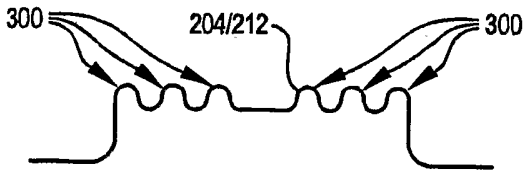


FIG. 6

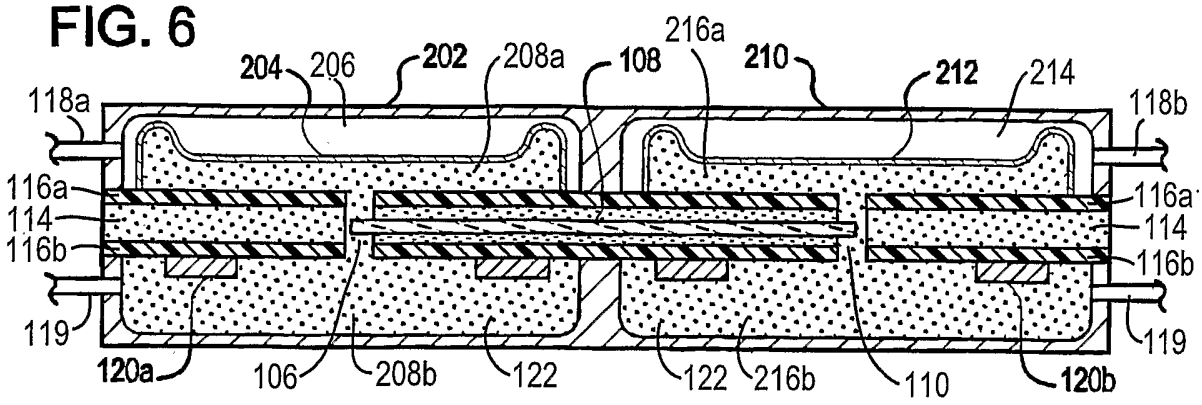


FIG. 7

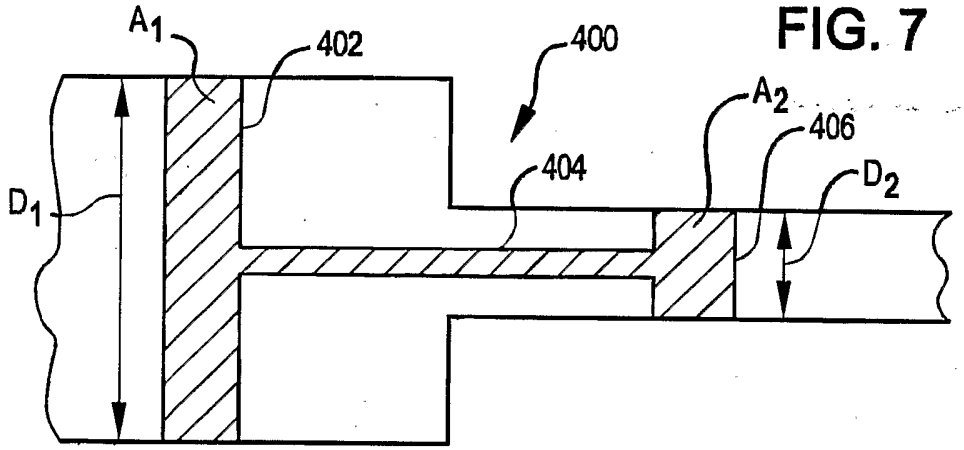


FIG. 8

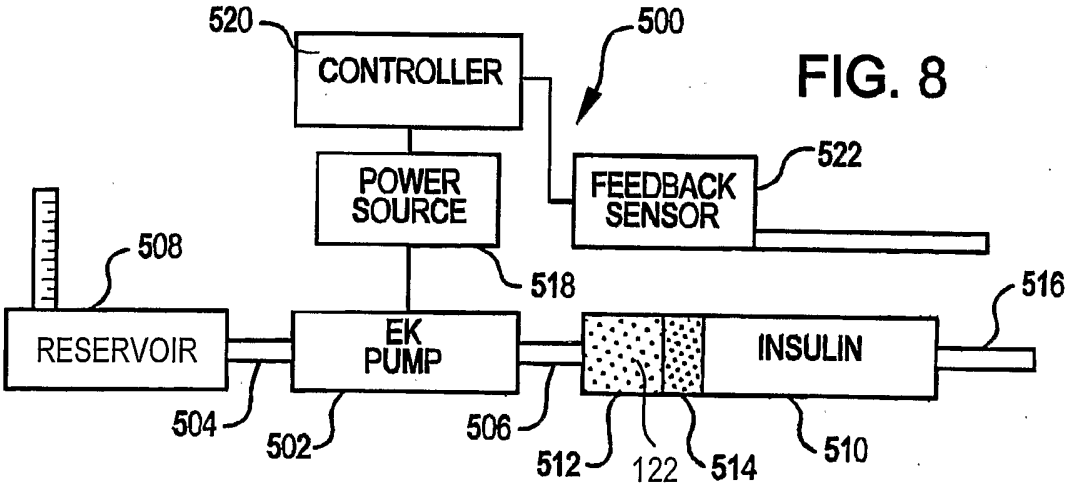


FIG. 9

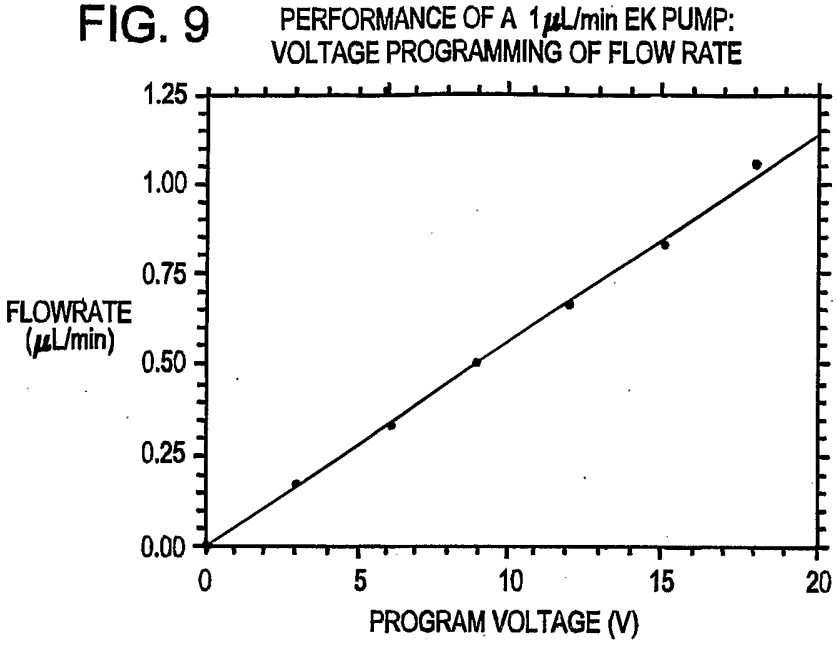


FIG. 10

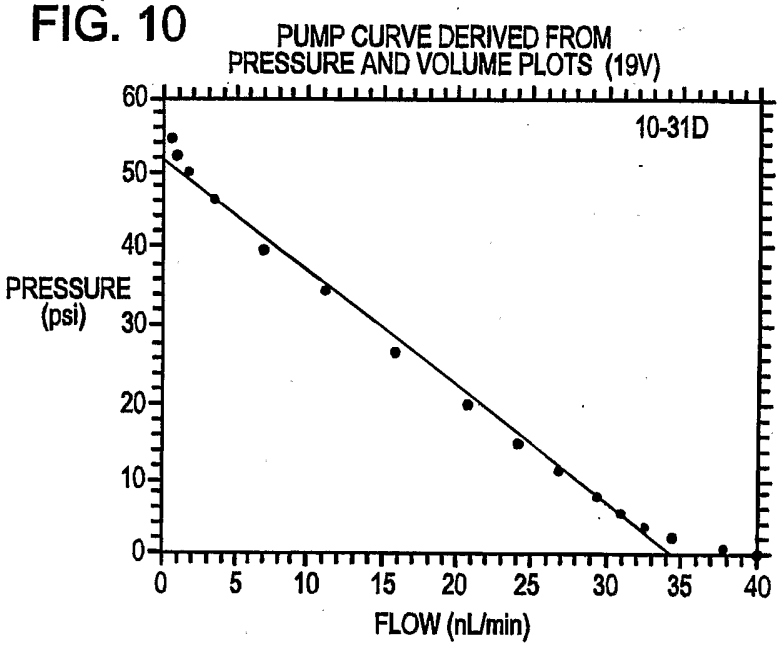


FIG. 11a

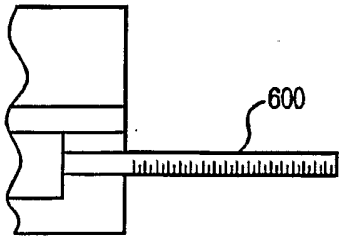


FIG. 11b

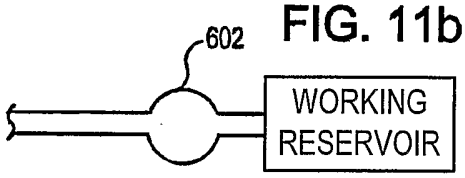


FIG. 12a

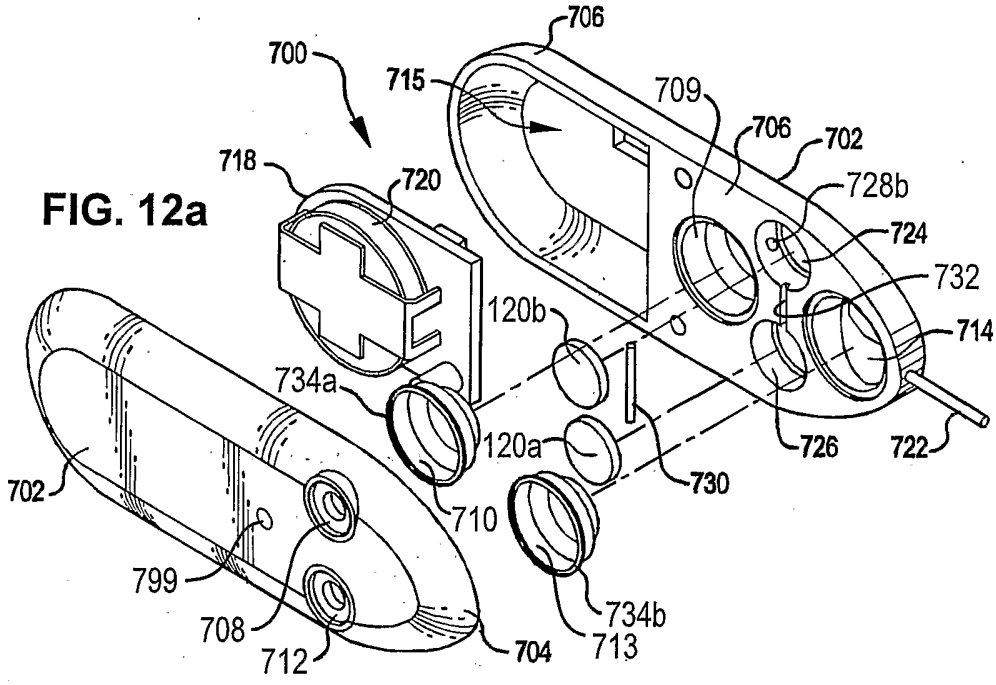
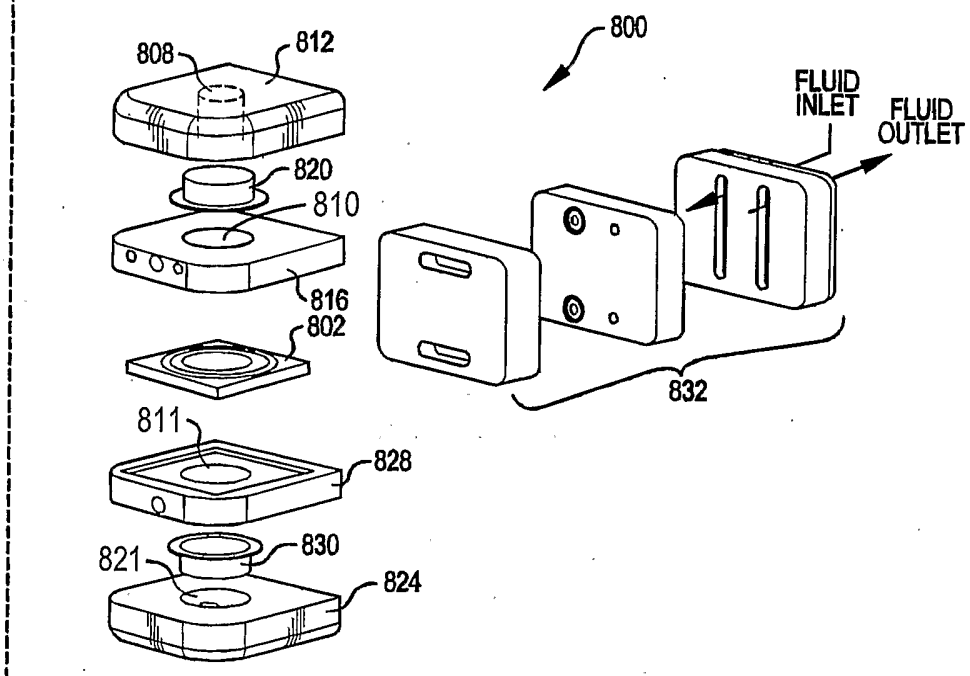


FIG. 13a



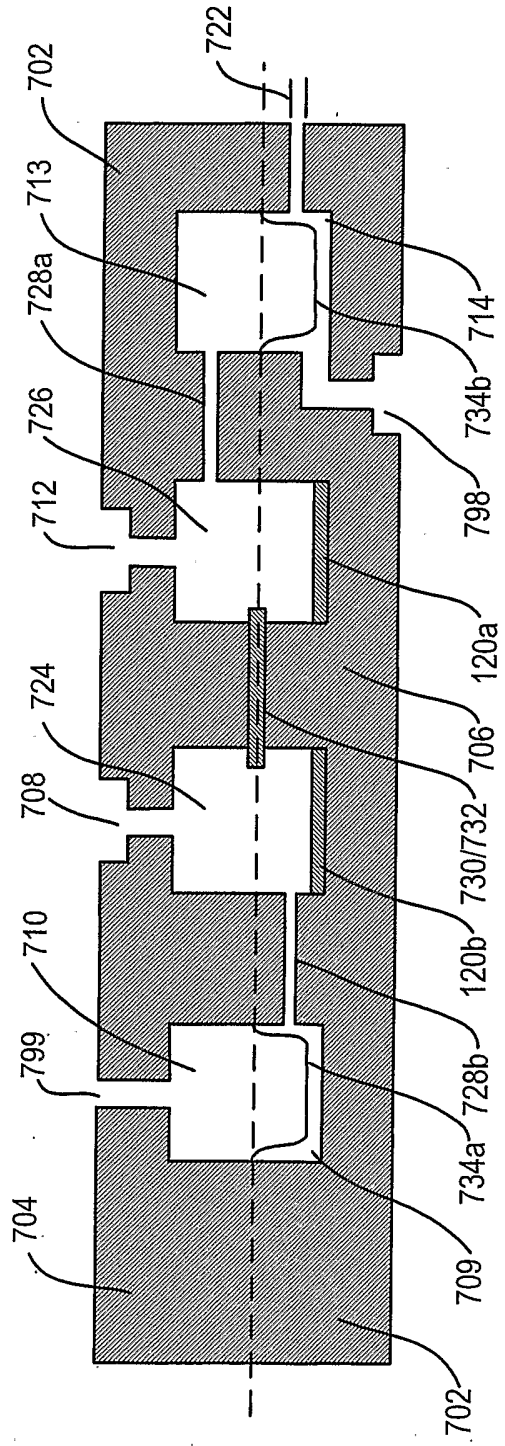

722
702
713
728a
726
712
724
708
710
799
704
714
734b
798
120a
706
730/732
120b
728b
734a
709
702

FIG. 12b

FIG. 13b

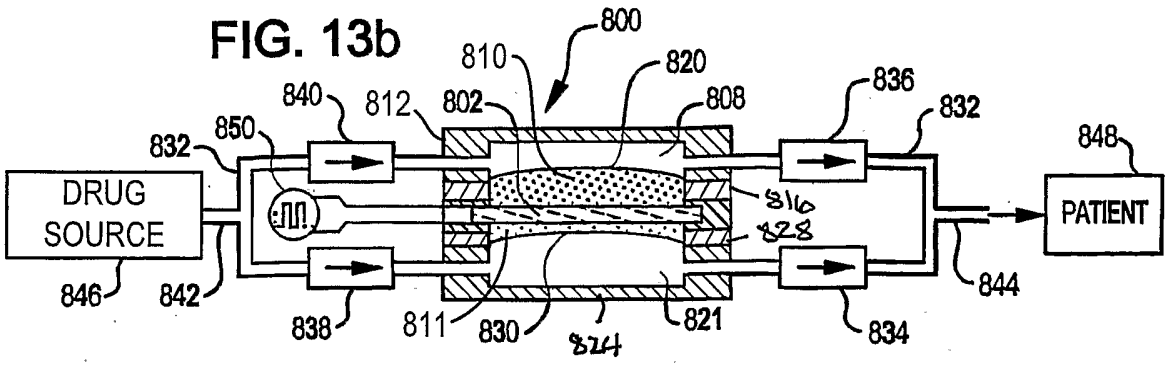


FIG. 14

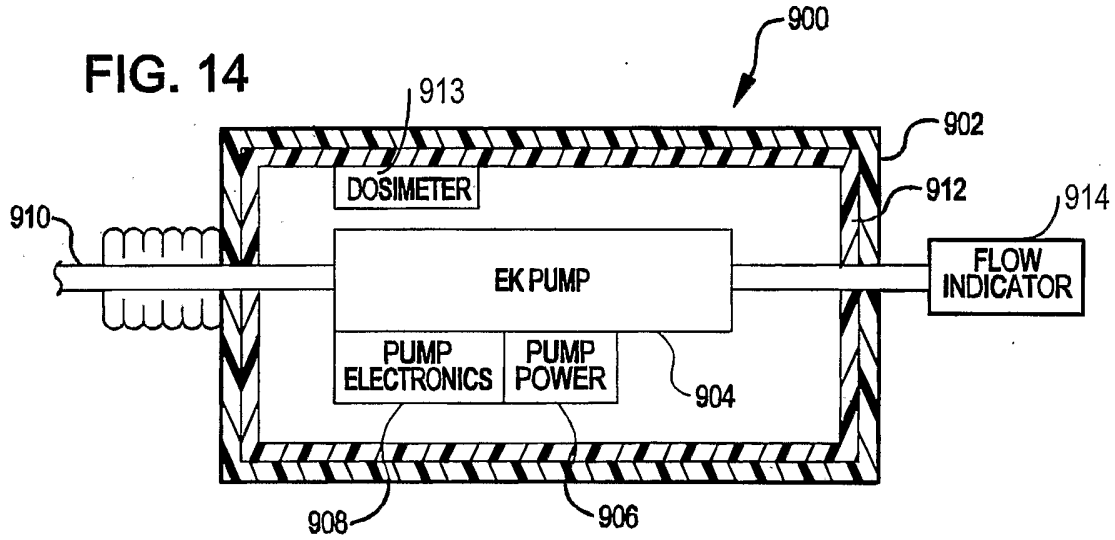
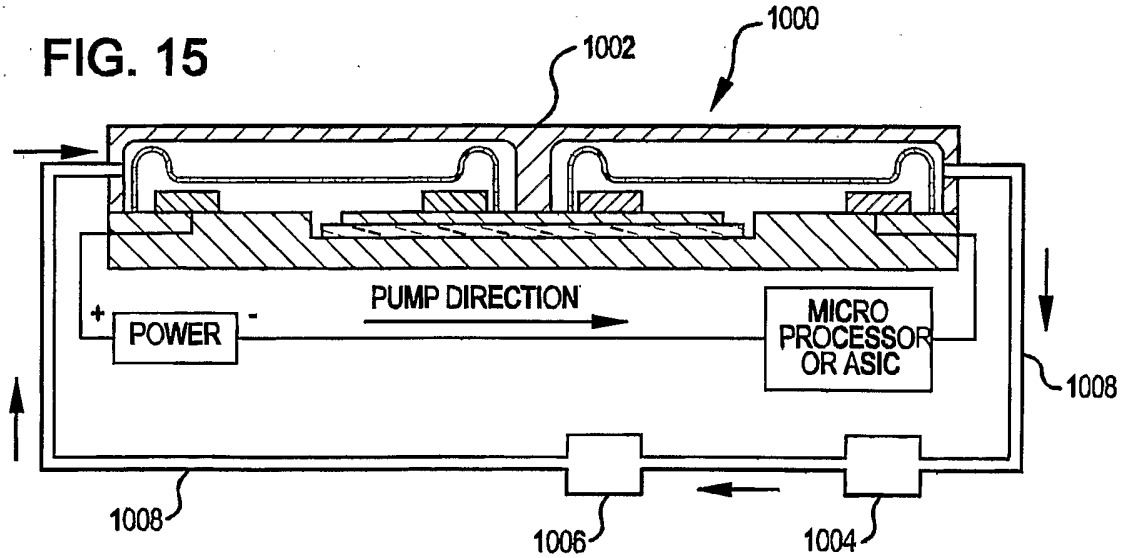


FIG. 15



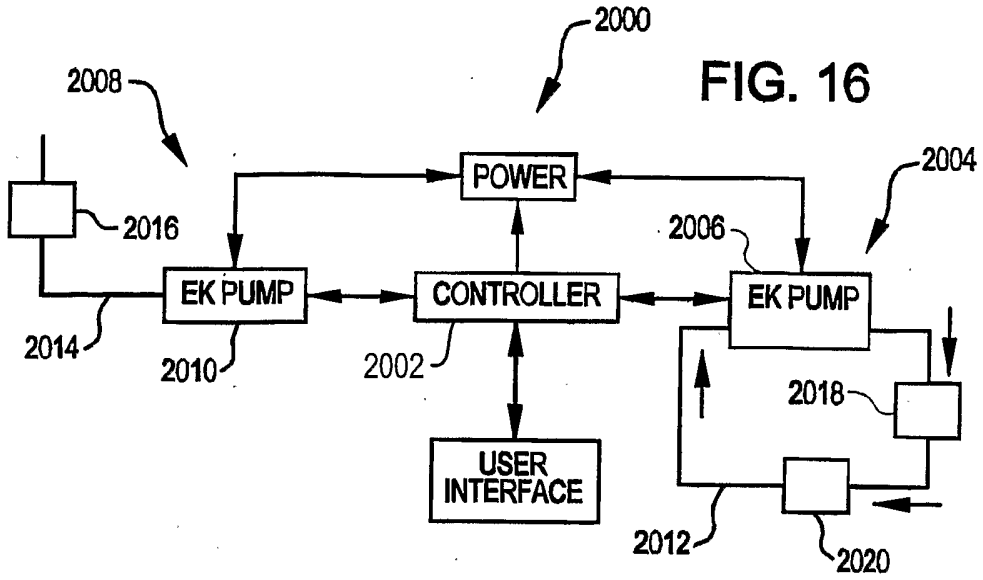

2000
2008
POWER
2004
2016
2006
EK PUMP
CONTROLLER
EK PUMP
2014
2010
2002
2018
USER INTERFACE
2012
2020

FIG. 16

FIG. 17

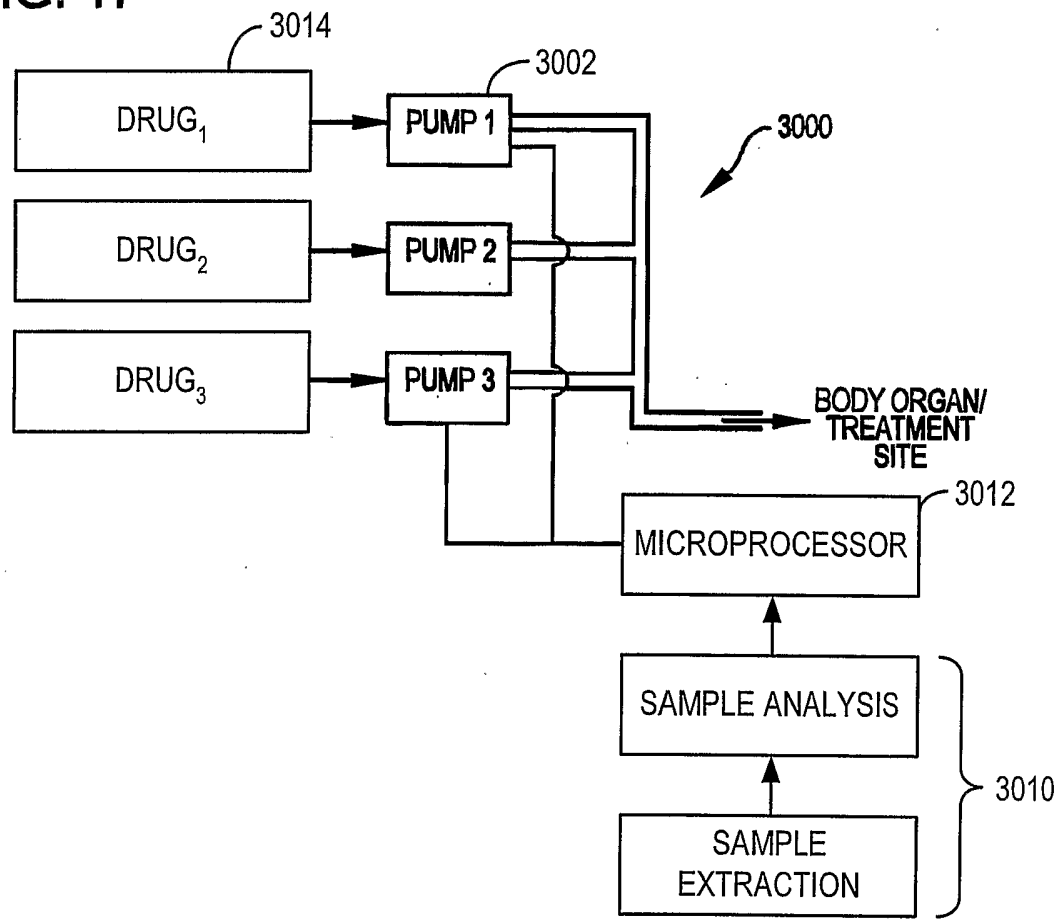

3014
3002
DRUG1
PUMP 1
3000
DRUG2
PUMP 2
DRUG3
PUMP 3
BODY ORGAN/ TREATMENT SITE
3012
MICROPROCESSOR
SAMPLE ANALYSIS
3010
SAMPLE EXTRACTION

FIG. 18

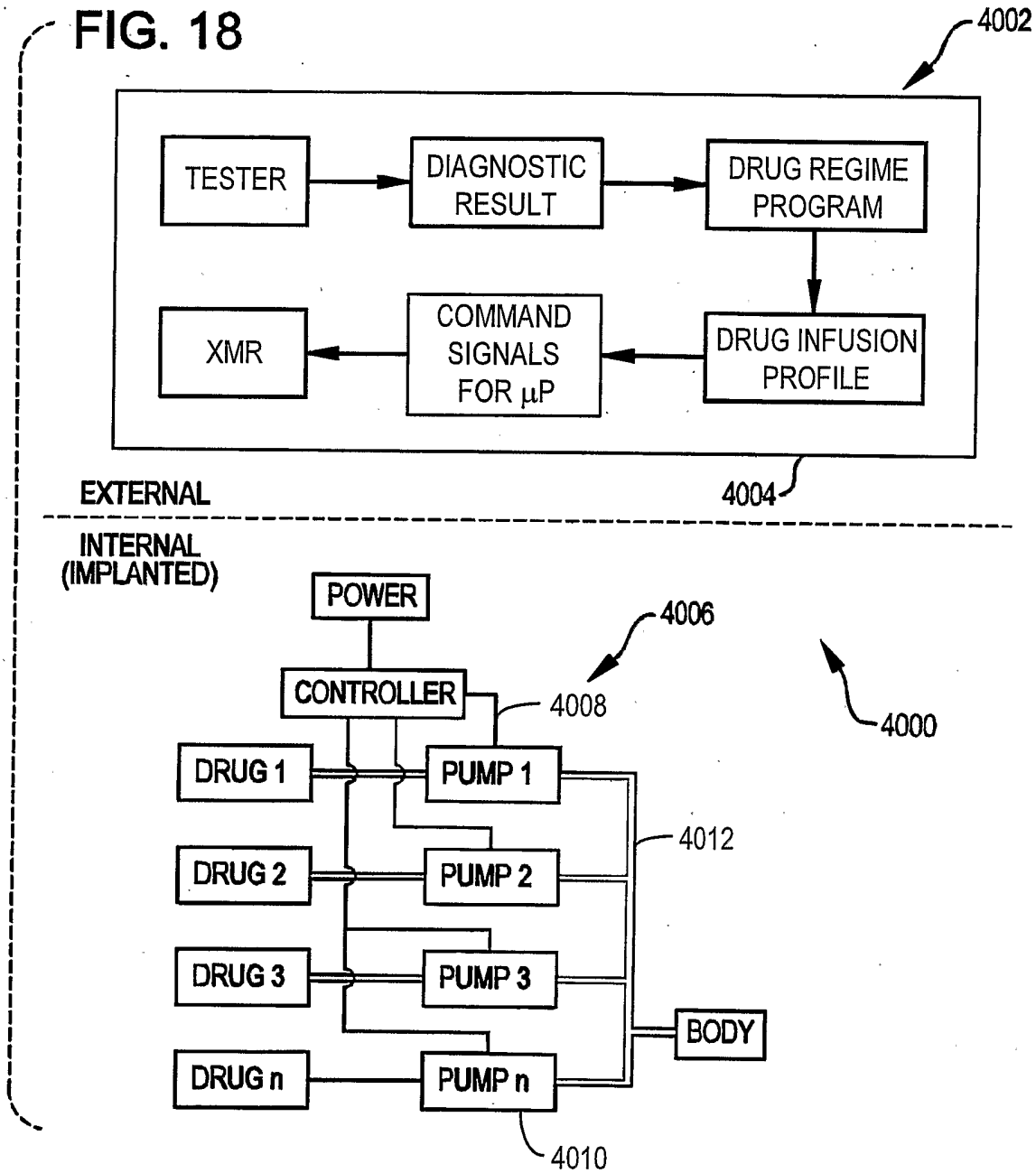

4002
TESTER
DIAGNOSTIC RESULT
DRUG REGIME PROGRAM
XMR
COMMAND SIGNALS FOR μP
DRUG INFUSION PROFILE
4004
EXTERNAL
INTERNAL (IMPLANTED)
POWER
4006
CONTROLLER
4008
4000
DRUG 1
PUMP 1
4012
DRUG 2
PUMP 2
DRUG 3
PUMP 3
BODY
DRUG n
PUMP n
4010

FIG. 19

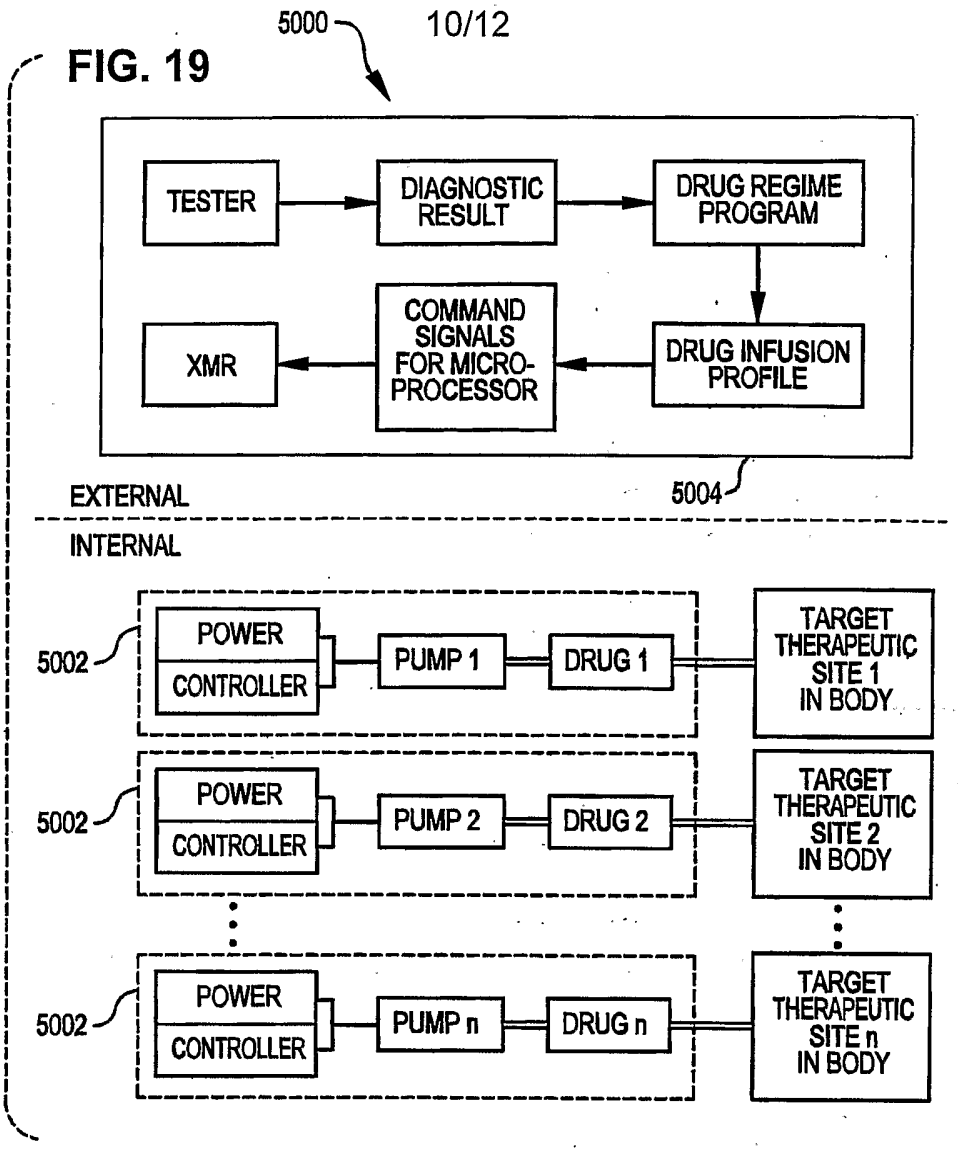

5000
TESTER
DIAGNOSTIC RESULT
DRUG REGIME PROGRAM
XMR
COMMAND SIGNALS FOR MICRO-PROCESSOR
DRUG INFUSION PROFILE
5004
EXTERNAL
INTERNAL
5002
POWER CONTROLLER
PUMP 1
DRUG 1
TARGET THERAPEUTIC SITE 1 IN BODY
5002
POWER CONTROLLER
PUMP 2
DRUG 2
TARGET THERAPEUTIC SITE 2 IN BODY
5002
POWER CONTROLLER
PUMP n
DRUG n
TARGET THERAPEUTIC SITE n IN BODY

FIG. 20

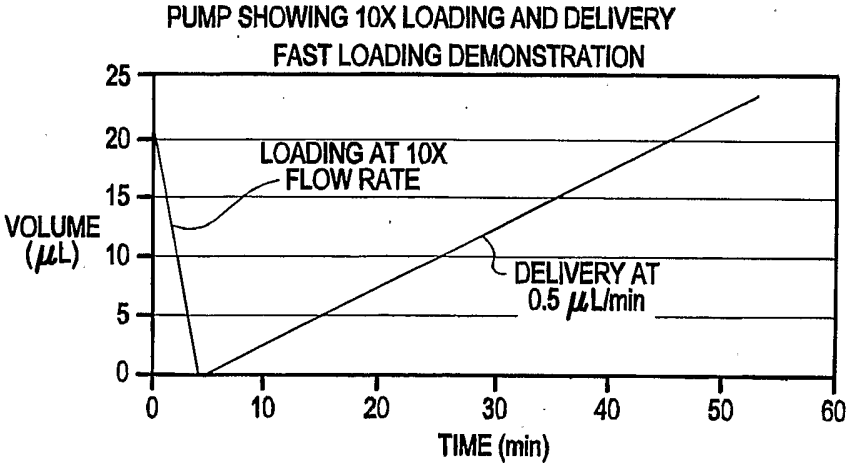

PUMP SHOWING 10X LOADING AND DELIVERY
FAST LOADING DEMONSTRATION
LOADING AT 10X FLOW RATE
DELIVERY AT 0.5 μL/min
VOLUME (μL)
TIME (min)
0
5
10
15
20
25
0
10
20
30
40
50
60

FIG. 21

0.51 μL/min AT 24 VOLTS, 33 μL DELIVERED, LESS THAN 0.3% ERROR IN TOTAL VOLUME DELIVERED, INDIRECT PUMP (DELIVERY FLUID ISOLATED), PUMP SIZE: 1" x 0.6" x 0.5"

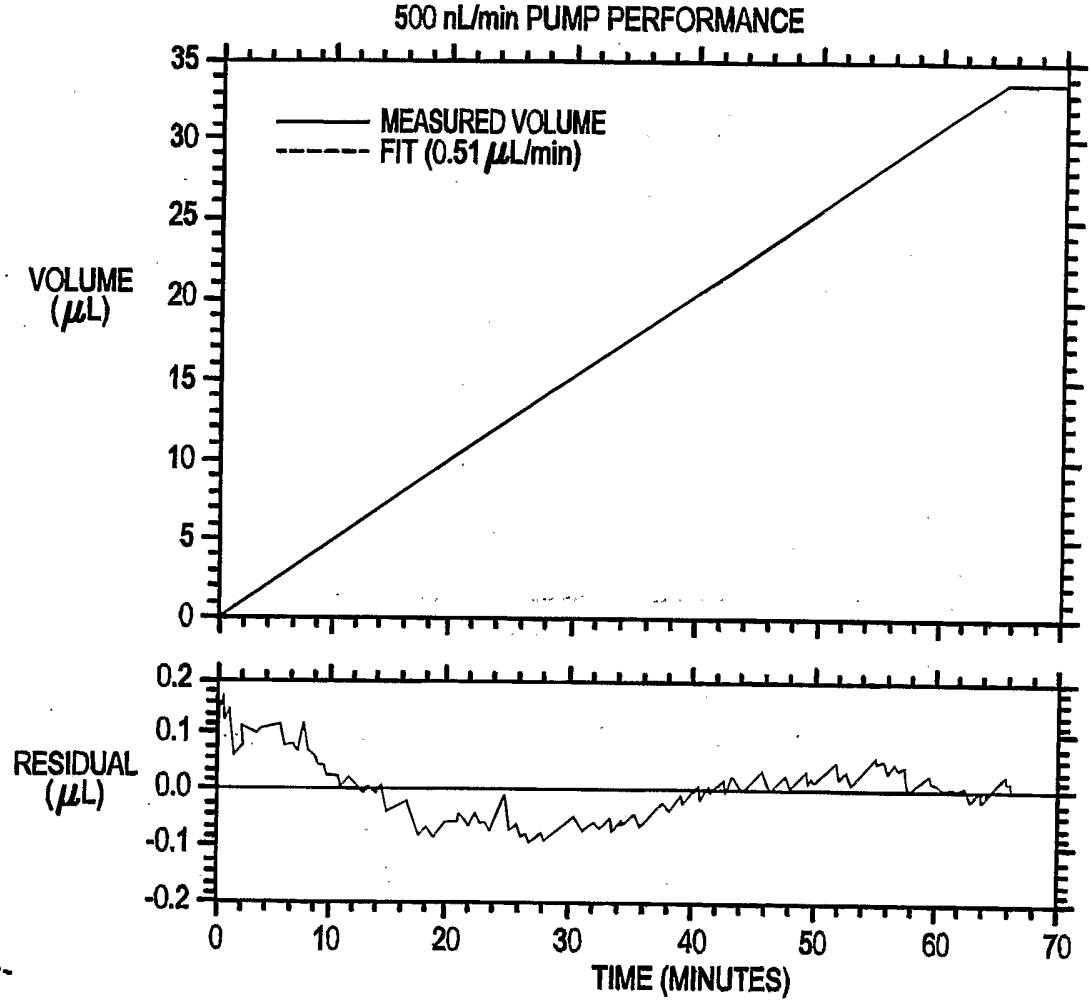


FIG. 22

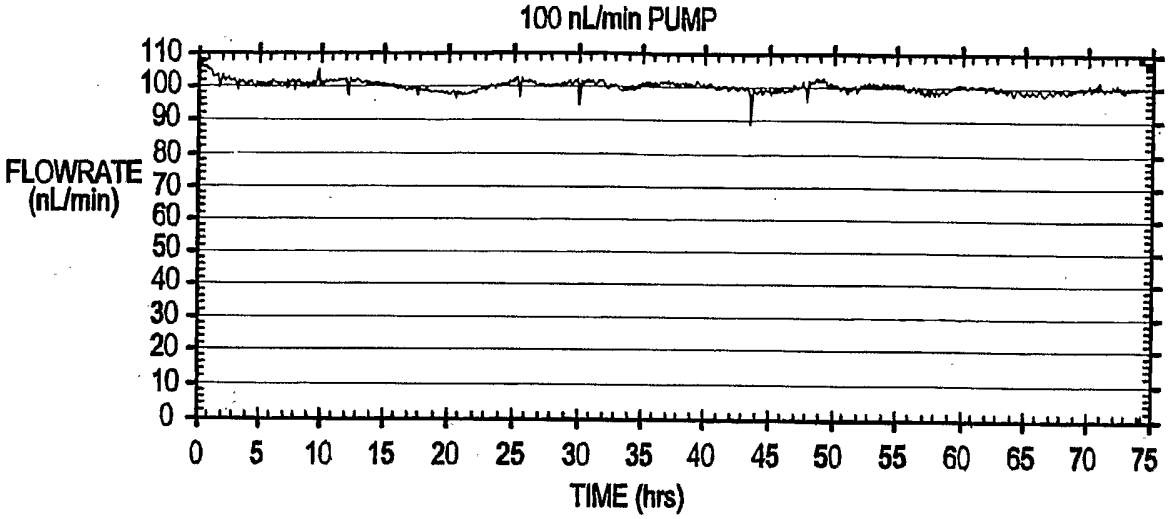
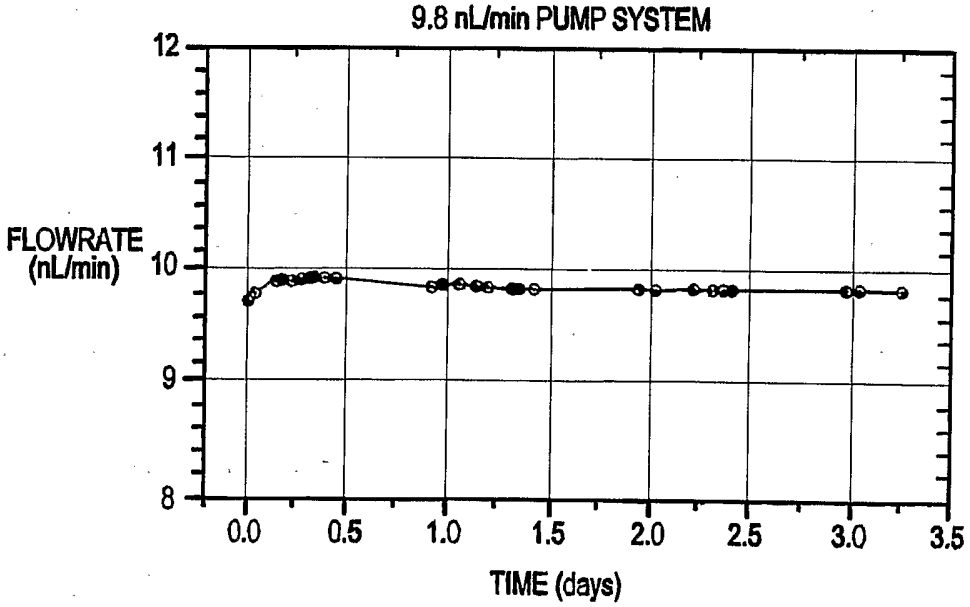

100 nL/min PUMP
FLOWRATE (nL/min)
110
100
90
80
70
60
50
40
30
20
10
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
TIME (hrs)

FIG. 23


9.8 nL/min PUMP SYSTEM
FLOWRATE (nL/min)
12
11
10
9
8
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
TIME (days)