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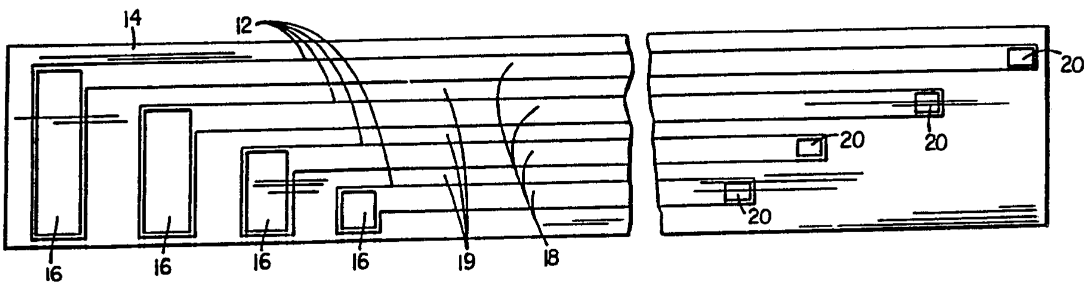
(54) Title: FLEXIBLE MEASUREMENT PROBES



(57) Abstract

Flexible measurement probes are described for the determination of oxygen partial pressure; temperature and perfusion; and combined measurement of oxygen partial pressure, temperature, and perfusion. The probes are fabricated by patterning a metal coated substrate to form a conductive pattern of ribbon leads (12), insulating the conductive ribbon leads except for contact openings (20), and then attaching sensors to the conductive ribbon leads through noble metal plated open contacts. The plated contacts may be used directly to measure oxygen partial pressure.

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FLEXIBLE MEASUREMENT PROBES

Background

This invention is in the field of measurement probes.

Accurate, multi-point measurement of oxygen partial pressure, temperature, and perfusion in tumors and tissues is important clinically. Patients with malignancies not susceptible to surgery, radiation or chemotherapy are often responsive to elevated tumor temperatures resulting from the local application of heat. In precisely selected volumes of tissue that make up the malignancy, specific, well-characterized temperature elevations must be produced, maintained and monitored to be effective. Numerous devices exist to provide for the measurement of temperature, oxygen partial pressure (pO_2) and blood perfusion in living tissue. For example, a rigid probe designed to measure pO_2 and temperature in body tissue utilizes discrete thermistors, individually placed on the probe substrate. An integrated thin film array on a rigid substrate incorporates temperature sensitive resistors and oxygen sensors. A linear array of diodes on silicon islands supported by a flexible polyimide substrate is used for temperature profile measurement.

Summary of the Invention

The invention features in one aspect an apparatus for measuring the partial pressure of oxygen which includes a flexible substrate, an electrical conductor which is photolithographically patterned on the substrate, insulation covering the conductor except for a small, exposed contact area, and metal plating on the exposed contact area, in which electrical current flowing through the electrical conductor is correlated with oxygen partial pressure at the metal plating.

In a second aspect the invention features an apparatus for measuring temperature and perfusion which includes two lead assemblies, each lead assembly including a flexible substrate, an electrical conductor photolithographically patterned on the substrate, insulation covering the conductor except for a small, exposed contact area, and a thermal sensor bonded between the small contact areas on the two lead assemblies, in which a voltage drop across the thermal sensor is correlated with temperature and, in which the rate of heat dissipation from the thermal sensor is correlated with perfusion.

In a third aspect the invention features an apparatus for measuring temperature, perfusion, and the partial pressure of oxygen which includes two lead assemblies, each lead assembly including a flexible substrate, an electrical conductor photolithographically patterned on the substrate, and insulation covering the conductor except for a small, exposed contact area; a thermal sensor bonded between the small, exposed contact areas on the two lead assemblies; an additional exposed contact area provided, on one of the lead assemblies, on the side of the flexible substrate opposite the thermal sensor; and metal plating on the additional exposed contact area, in which electrical current flowing through the electrical conductor attached to the metal plating is correlated with oxygen partial pressure at the metal plating, in which a voltage drop across the thermal sensor is correlated with temperature, and in which the rate of heat dissipation from the thermal sensor is correlated with perfusion.

In preferred embodiments of the invention the flexible substrate is polyimide, the electrical conductor is copper, the thermal sensor is thermistor, and the metal plating is gold. The apparatus includes a plurality of small, exposed contact areas and electrical conductors. The two lead assemblies included in the apparatus for measuring temperature and perfusion or for measuring temperature, perfusion and oxygen partial pressure can be attached.

Flexible measurement probes are inexpensive, disposable, and simple to manufacture. Electrical conductors deposited photolithographically are not susceptible to the stresses imposed by use in living tissue. The measurement probe can be used for oxygen sensing directly after manufacture with no requirement of additional assembly. Using the probe for temperature sensing requires the attachment of one part, a thermistor. This step is easily accomplished at the provision of contact areas surrounded by insulation permits assembly without precise alignment of the thermistor with the contact.

Other features and advantages will be apparent from the following description of the preferred embodiment thereof, and from the claims.

Description of the Preferred Embodiments

We first briefly describe the drawings.

Drawings

Fig. 1 is a view of measurement probe ribbon leads patterned on polymer sheets;

Fig. 2 is a detail view, not to scale, of the connector and contact ends of ribbon leads;

Fig. 3 is a view, not to scale, of an oxygen sensor;

Fig. 4 is a view, not to scale, of a thermistor assembly for a temperature and perfusion sensor;

Fig. 5 is a view, not to scale, of a thermistor assembly and oxygen sensor for a combined oxygen, temperature, and perfusion sensor.

The flexible measurement probes can be divided into three groups: oxygen sensors, temperature and perfusion sensors, and oxygen, perfusion and temperature sensors. The probes are fabricated by patterning a metal coated substrate to form a conductive ribbon leads except for contact openings, and then attaching sensors to the conductive ribbon leads through noble metal plated open contacts. Final insulation of the sensors may be required to complete assembly.

Referring to Figs. 1 and 2, individual measurement probe ribbon leads 12 are laid down in a serpentine pattern 10 on 3mm wide x 30mm long x 25 μm thick flexible polymeric substrate 14 such as Kapton™ (a Dupont material made primarily of polyimide) by first bonding a 25μm coating of copper or other suitable conductive material to one side of the substrate with an epoxy of other suitable adhesive. Next, the copper film is patterned using a standard photolithographic technique such as coating the film with photoresist, selectively exposing the photoresist using ultraviolet light illumination through a pre-patterned glass mask, developing the transferred image, and then chemically etching the exposed copper. The copper pattern is then cleaned of photoresist, and re-coated with another photosensitive polymer. This second coating is then patterned as above and left in place to form an insulation barrier and to define contact openings. The resulting ribbon leads 12 have 1mm wide edge connectors 16 attached to 75μm wide (with 100μm spacing) conductor ribbons 18 which are insulated except for small 50μm x 100μm contact areas 20 for plating for oxygen sensing or for the attachment of temperature sensors or other connectors. Depending on the exact nature of assembly and intended use, the patterns may be cut into specific configurations and the openings may be plated with gold, nickel, platinum, or other suitable material.

Referring also to Fig. 3, an oxygen sensor 30 is made from one ribbon lead 12 cut from pattern 10. The sensor contains a connector 16, conductor ribbon 18, and contact area 20, over which is plated a noble metal, for example, gold or platinum.

Referring also to Fig. 4, a temperature/perfusion sensor 40 is assembled by attaching a thermal measurement device 42, such as a thermistor, a diode, or an integrated circuit temperature sensor, between contact areas 20 of two ribbon leads 12 cut from pattern 10, by using a variety of techniques such as soldering, gluing with conductive epoxy or some other suitable conductive adhesive, or thermosonically bonding with gold or other die attach material. The sensor is insulated with epoxy or some other insulating adhesive filling in the space 44 between the ribbon leads. Alternatively, the ribbon leads could be left attached when cut from the pattern and then wrapped around the thermistor.

Referring also to Fig. 5, a composite temperature/perfusion sensor 50 is fashioned by modifying a temperature/perfusion sensor 40 made as described above, so as to open a backside contact through the polymer substrate to one conductor 52 or to the thermal measurement device metal contact surface 54, and then plating gold 46 or other suitable material onto this contact area. Alternately, a ribbon lead 12 is prepared with double sided patterning to produce an oxygen contact opening on the back side of the polymer lead pattern before the temperature sensor is assembled, or a third ribbon lead is attached back with one of the other two, to the same effect.

<u>Use</u>

Embedded in living tissue, for example, a tumor, the measurement probes can be used to monitor hyperthermia treatment for malignancies which have failed to respond to surgery, radiation, and/or chemotherapy. (See co-pending application U.S.S.N. 859,453.)

In an oxygen sensor, either the independent or combined probe, oxygen reacts with the metal plating over the electrical conductor to generate an electrical current which is proportional to oxygen partial pressure.

In a temperature sensor, the thermal sensor has a temperature sensitive resistor which exhibits resistance as a function of temperature. The voltage drop across the resistor is then correlated with temperature.

Perfusion measurements are determined by correlating the rate of heat dissipation from the thermal sensor with blood flow.

The measurement probe can also be used for profiling temperature, perfusion, and oxygen partial pressure in other applications such as food processing and air exchange system.

Other embodiments are within the following claims. For example, other suitable substrate materials may be teflon or mylar, and other conductive materials may be nickel or platinum.

Claims

1. Apparatus for measuring the partial pressure of oxygen comprising

a flexible substrate,

an electrical conductor photolithographically patterned on said substrate,

insulation covering said conductor except for a small, exposed contact area, and

metal plating on said exposed contact area,

wherein electrical current flowing through said electrical conductor is correlated with oxygen partial pressure at said metal plating.

2. Apparatus for measuring temperature and perfusion comprising

two lead assemblies, each lead assembly comprising

a flexible substrate,

an electrical conductor photolithographically patterned on said substrate, and

insulation covering said conductor except for a small, exposed contact area, and

a thermal sensor bonded between said small contact areas on said two lead assemblies,

wherein a voltage drop across said thermal sensor is correlated with temperature, and

wherein the rate of heat dissipation from said thermal sensor is correleated with perfusion.

3. Apparatus for measuring temperature, perfusion, and the partial pressure of oxygen comprising

two lead assemblies, each lead assembly comprising

a flexible substrate,

an electrical conductor photolithographically patterned on said substrate, and insulation covering said conductor except for a small, exposed contact area;

a thermal sensor bonded between said small, exposed contact areas on said two lead assemblies,

an additional exposed contact area provided, on one of said lead assemblies, on the side of said flexible substrate opposite said thermal sensor; and

metal plating on said additional exposed contact area,

wherein electrical current flowing through said electrical conductor attached to said metal plating is correlated with oxygen partial pressure at said metal plating,

wherein a voltage drop across said thermal sensor is correlated with temperature, and

wherein the rate of heat dissipation from said thermal sensor is correlated with perfusion.

4. The apparatus of claim 2 or 3 wherein said two lead assemblies are attached.

5. The apparatus of any one of claims 1-3 wherein said electrical conductor comprises a plurality of said small, exposed contact areas.

6. The apparatus of any one of claims 1-3 comprising a plurality of said electrical conductors.

7. The apparatus of any one of claims 1-3 wherein said flexible substrate is polyimide.

8. The apparatus of any one of claims 1-3 wherein said electrical conductor is copper.

9. The apparatus of claim 2 or 3 wherein said thermal sensor is a thermistor.

10. The apparatus of claim 1 or 3 wherein said metal plating on said exposed contact area comprises gold.

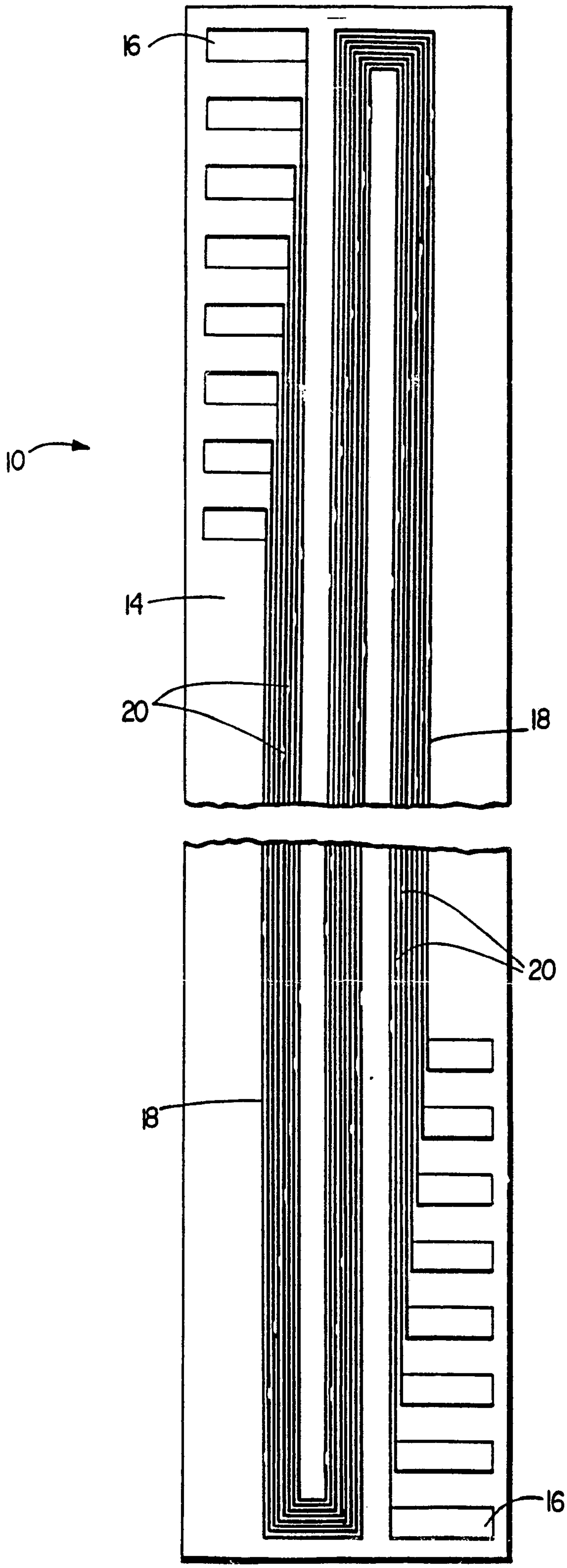

FIG.1

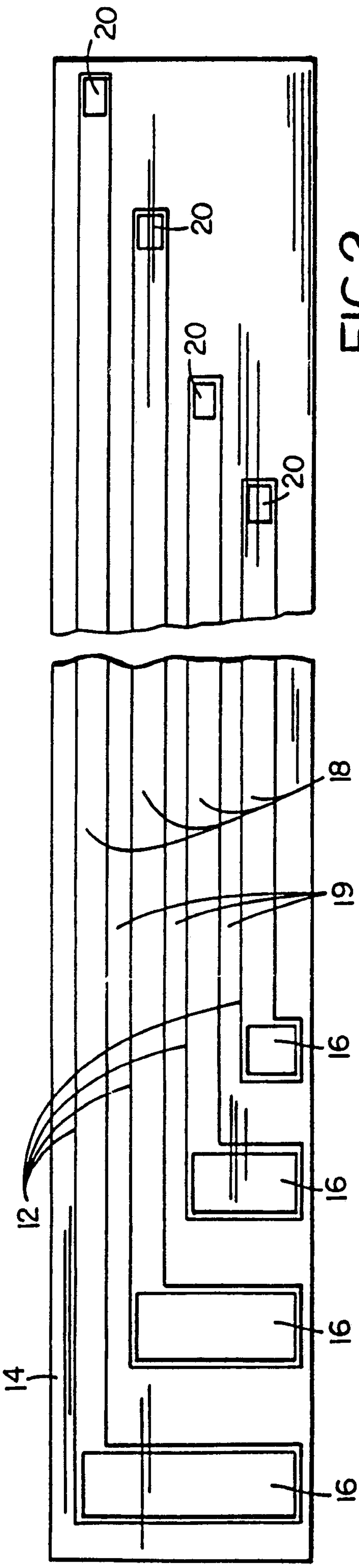

FIG.2

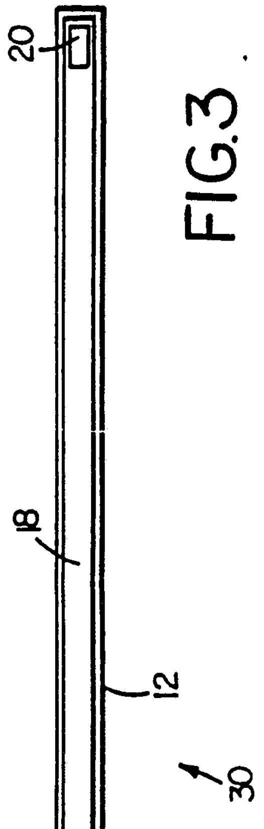

FIG.3

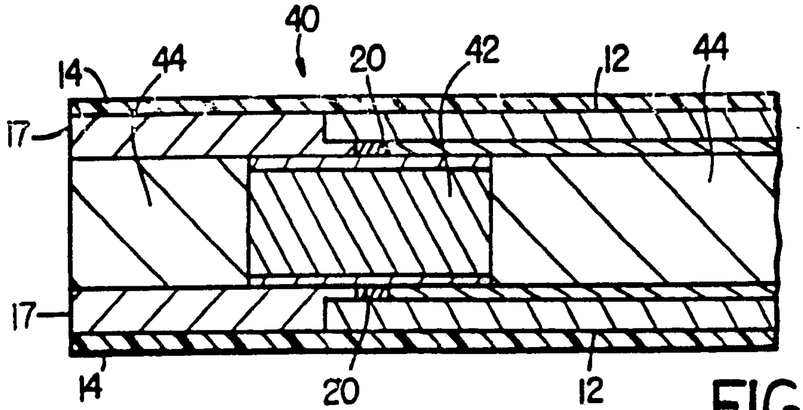
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FIG.4

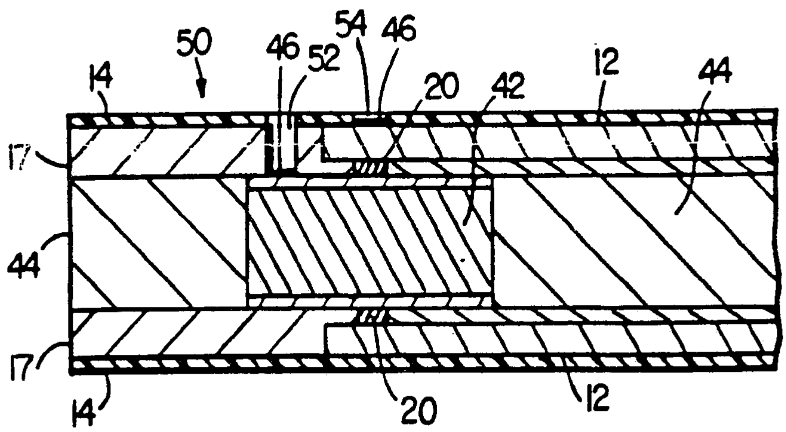
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FIG.5

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US89/05619

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5) A61B 5/00

U.S. cl. 128/635;128/736;204/403;204/408

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	128/635,642,736 374/178 204/403,408

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X Y	US,A, 4,461,304 (KUPERSTEIN) 24 July 1984, See entire document.	1,5,6 1,5-8
A	US,A, 4,534,356 (PAPADAKIS) 13 August 1985, See entire document.	1-10
A	US,A, 4,741,343 (BOWMAN) 03 May 1988, See entire document.	1-10
Y	US,A, 4,781,798 (GOUGH) 01 November 1988, See entire document.	1,5-8
A	JP,A, 139,589 (SANGYO) 30 October 1979, See entire document.	2-10
A	JP,A, 109,313 (MATSUSHITA) 22 August 1980, See entire document.	2-10
Y	Medical and Biological Engineering, issued 1974, J. Butler, "A Multicathode Oxygen Sensor Fabricated using Integrated Circuit Techniques", see pages 5.2a-5.2b.	1,5-8
Y	Medical and Biological Engineering and Computing, Vol. 17, issued March 1979, R.S. Pickard, "Flexible printed-circuit probe for electrophysiology", see pages 261-267.	1,5-8

* Special categories of cited documents: [10]

"A" document defining the general state of the art which is not considered to be of particular relevance

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
23 January 1990	22 MAR 1990
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