



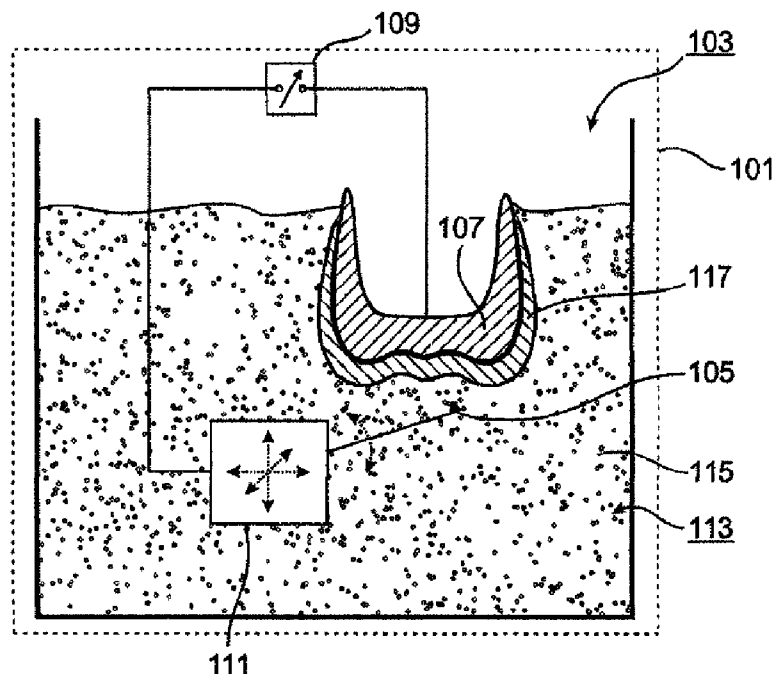
US 20090095629A1

(19) **United States**(12) **Patent Application Publication**
Wiest et al.(10) **Pub. No.: US 2009/0095629 A1**(43) **Pub. Date: Apr. 16, 2009**(54) **DEVICE AND METHOD FOR
ELECTROPHORETIC DEPOSITION WITH A
MOVABLE ELECTRODE**(76) Inventors: **Thomas Wiest**, Hunfeld (DE); **Rolf
Clasen**, St. Ingbert (DE); **Stephan
Dierkes**, Bremen (DE); **Johannes
Zeiner**, Saarbrücken (DE)Correspondence Address:
BROMBERG & SUNSTEIN LLP
125 SUMMER STREET
BOSTON, MA 02110-1618 (US)(21) Appl. No.: **12/281,796**(22) PCT Filed: **Mar. 7, 2007**(86) PCT No.: **PCT/EP07/52132**§ 371 (c)(1),
(2), (4) Date: **Dec. 18, 2008**(30) **Foreign Application Priority Data**

Mar. 7, 2006 (DE) 10 2006 010 808.6

Publication Classification(51) **Int. Cl.**
C25D 13/00 (2006.01)(52) **U.S. Cl.** 204/471; 204/623(57) **ABSTRACT**One object on which the present invention is based is to
specify an apparatus (101, 201, 301, 401, 501) for production

of a mold (117), in particular of a dental mold (117), by means of electrophoretic deposition of particles (115) from a suspension (113, 213), in which case a predetermined spatial shape can be produced deliberately in order in this way to produce the mold (117) as close as possible to its final dimensions and final contour. A further aim is to produce the mold (117) at low cost, with efficient use of resources, quickly and in as simple a manner as possible, with good reproducibility of the method being desirable in order to achieve a low scrap rate. For this purpose, an apparatus (101, 201, 301, 401, 501) is proposed having a chamber (103, 503) for holding the suspension (113, 213), a first electrode (105, 405, 905) which is associated with the chamber (103, 503), a second electrode (107, 207, 307, 407, 807, 907) which is associated with the chamber (103, 503), a mount structure (107, 219, 907), which is associated with the chamber (103, 503) and on which the particles (115) can be deposited, with the mount structure (107, 219, 907) being formed by the second electrode (107, 207, 307, 407, 807, 907) and/or by a deposition element (219) which is arranged between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), and a voltage source (109, 409) for production (52) of an electrical potential difference between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), and having a positioning element (111, 111a) for carrying out a relative movement between the first electrode (105, 405, 905) and the mount structure (107, 219, 907) along a first predetermined path (627) during the electrophoretic deposition. According to a further aspect, a corresponding system (having an apparatus (101, 201, 301, 401, 501) according to the invention and a suspension (113, 213) of particles (115) which can be deposited electrophoretically), a corresponding method, a computer program for controlling an apparatus (101, 201, 301, 401, 501) such as this and a data storage medium having a computer program such as this are intended to be specified.



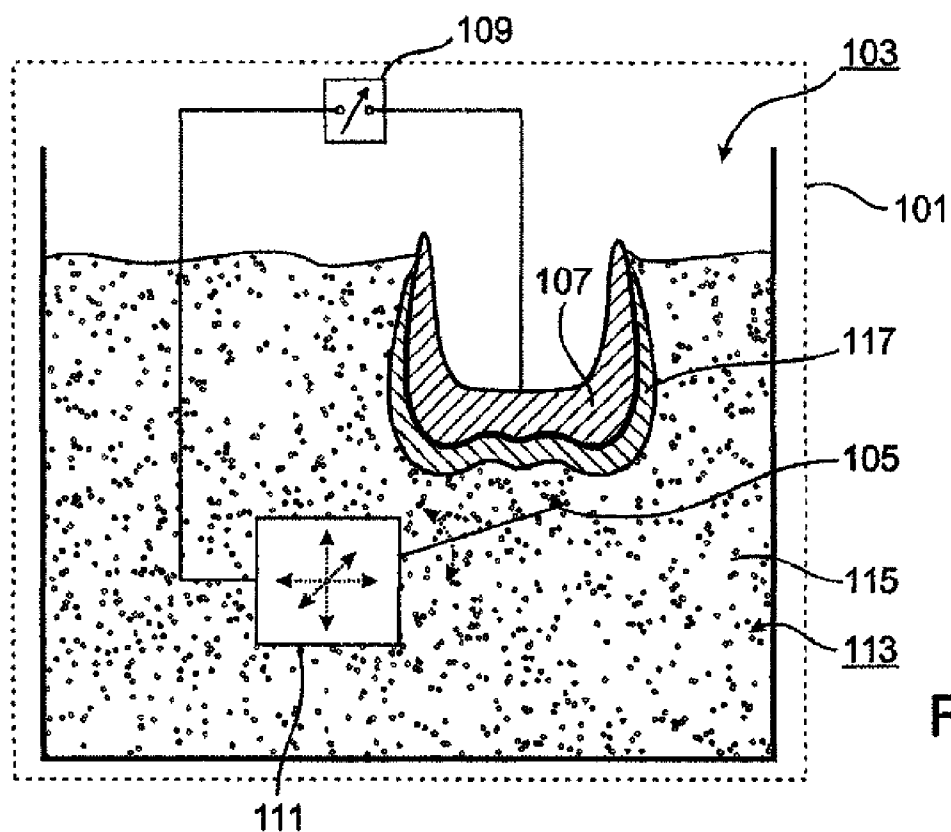


Fig. 1

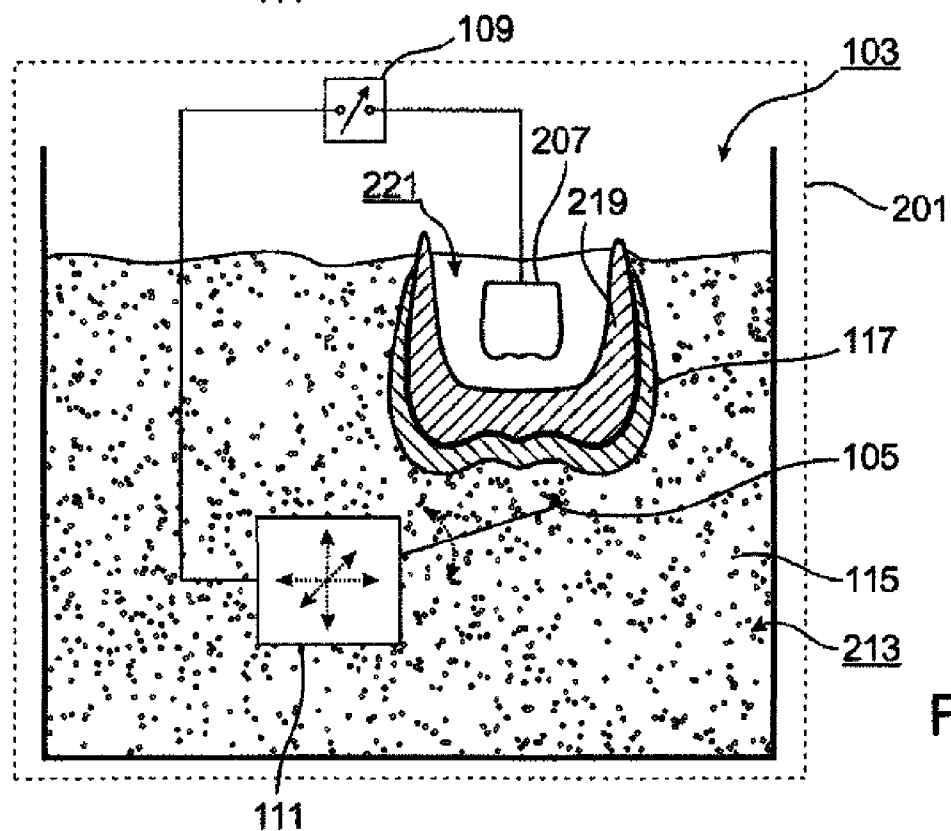


Fig. 2

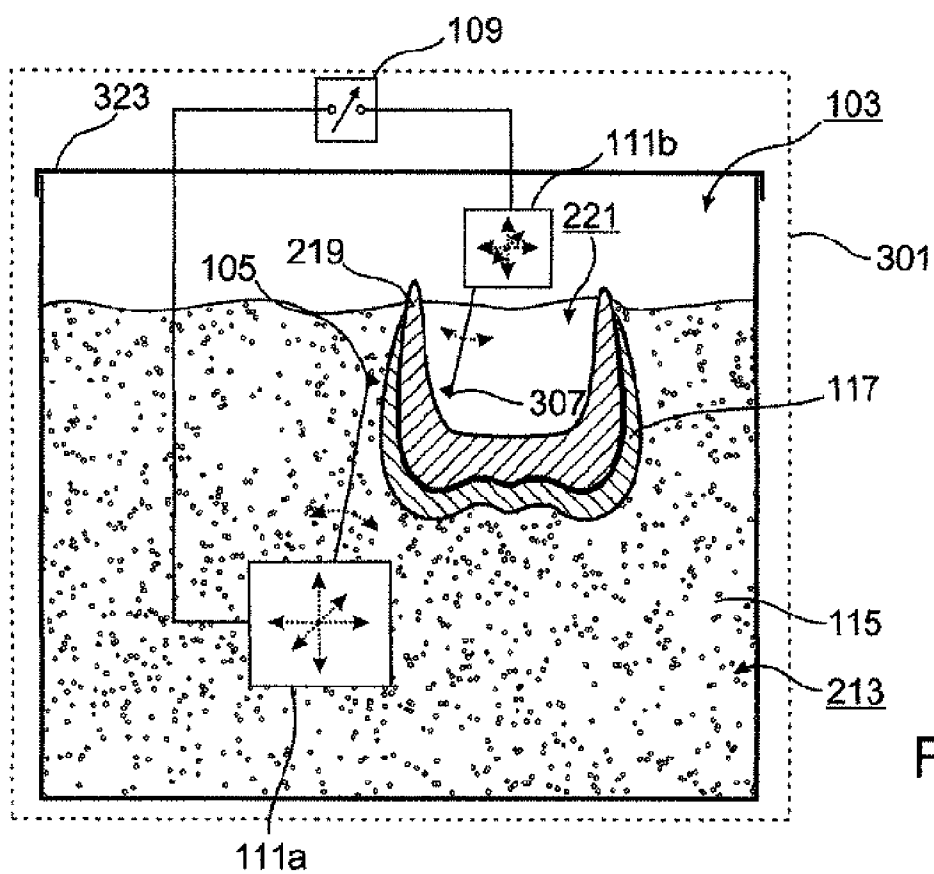


Fig.3

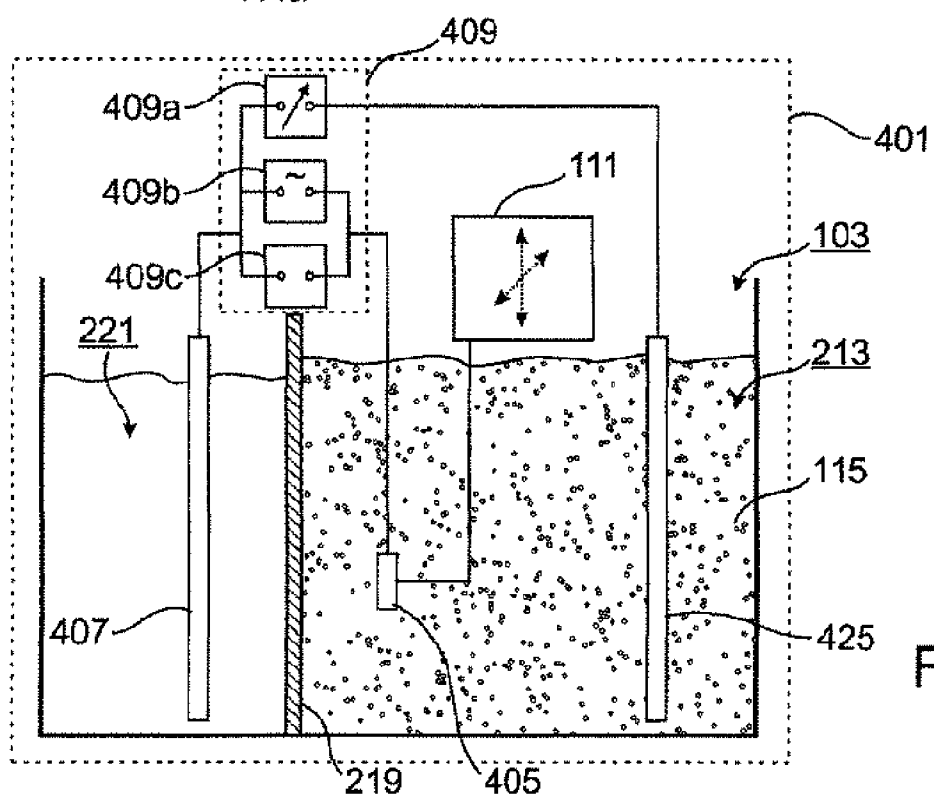
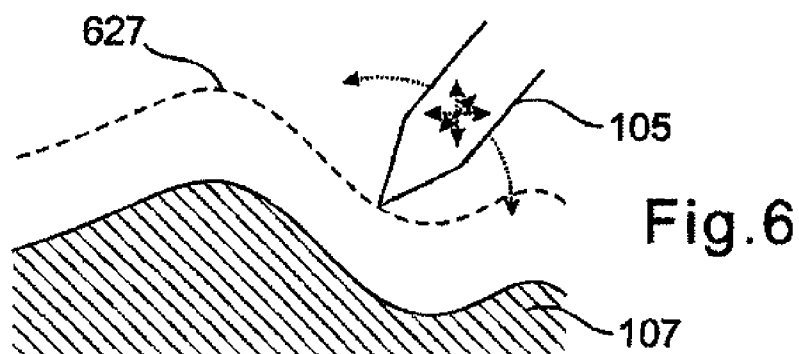
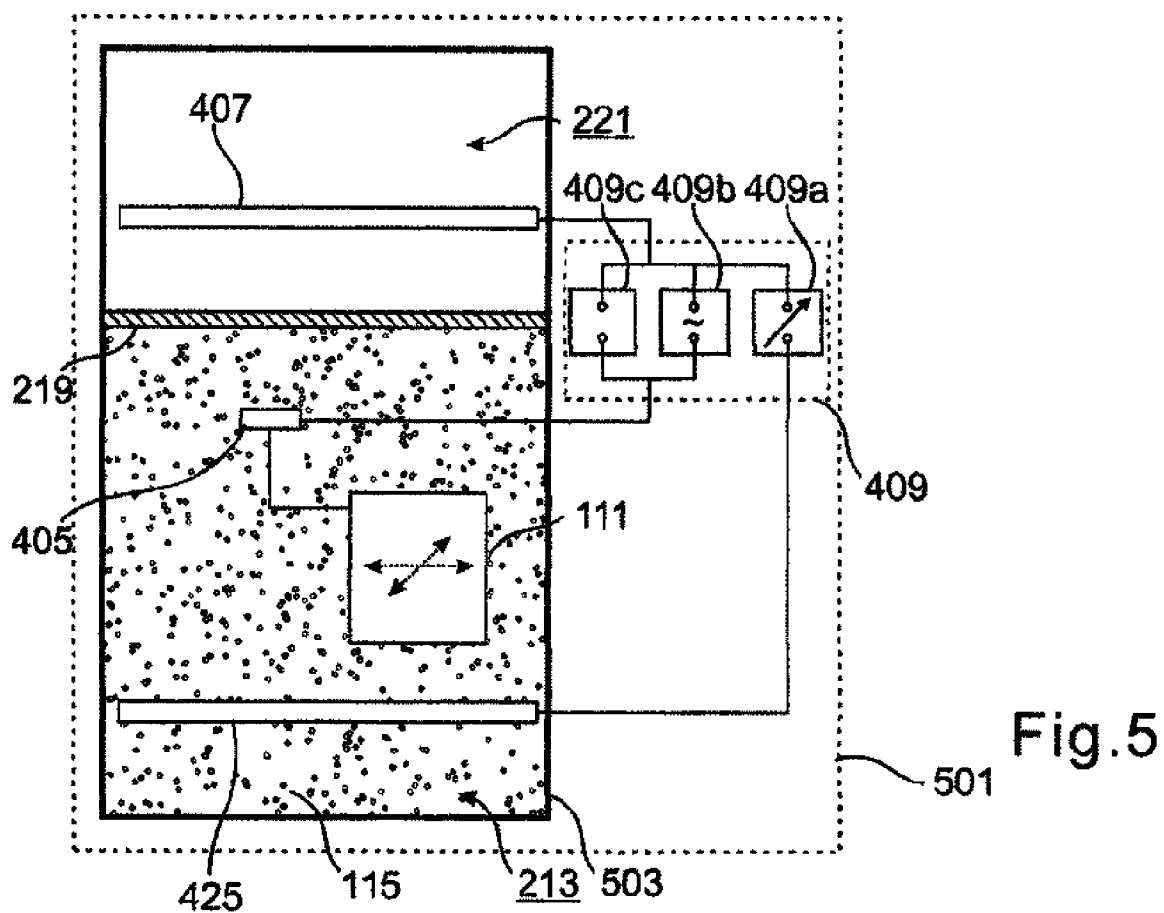
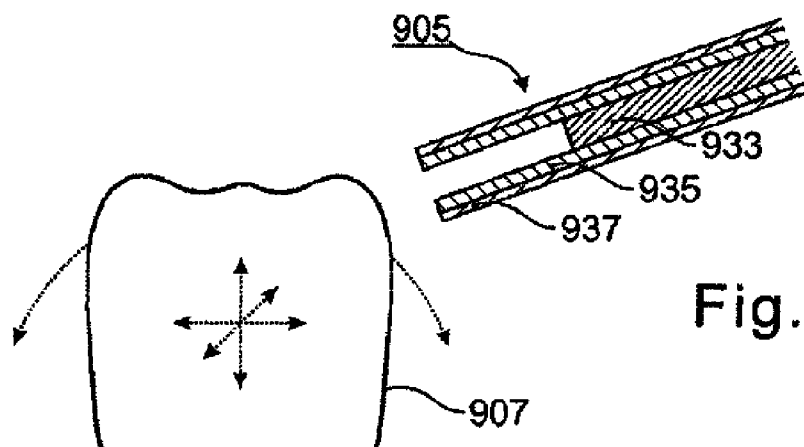
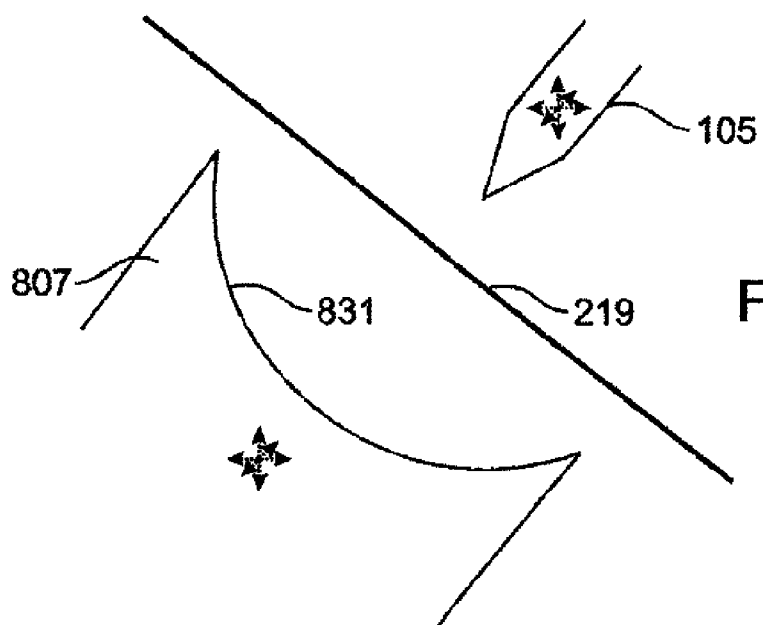
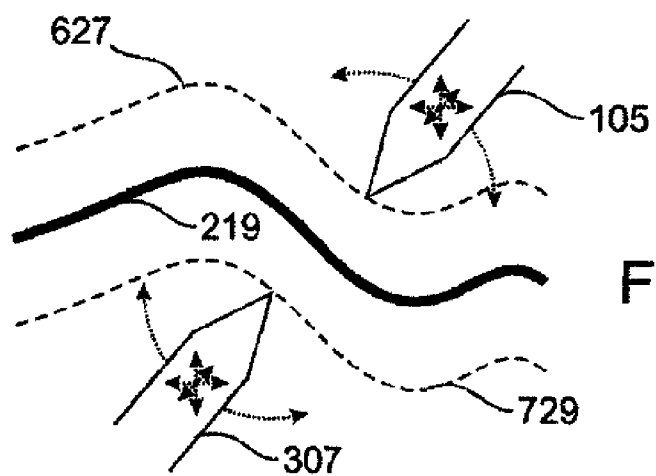


Fig.4





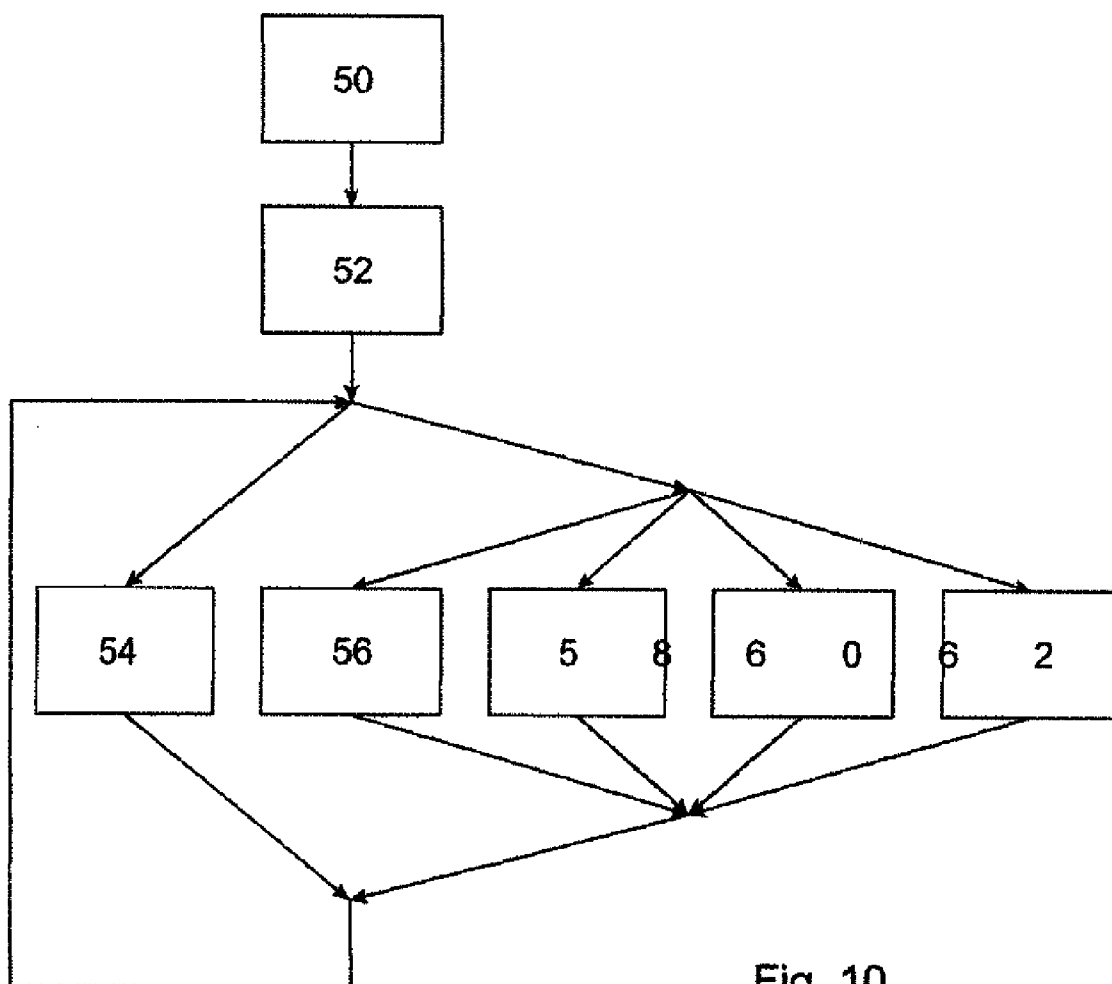


Fig. 10

DEVICE AND METHOD FOR ELECTROPHORETIC DEPOSITION WITH A MOVABLE ELECTRODE

[0001] The present invention relates to an apparatus and a method for production of a mold, in particular of a dental mold, by means of electrophoretic deposition of particles from a suspension. The invention also relates to a system having an apparatus such as this and a suspension of particles which can be deposited electrophoretically, to a computer program for controlling an apparatus such as this, and to a data storage medium having a computer program such as this.

[0002] Electrophoretic deposition of particles is a well-established method for production of ceramic, metallic or metal-ceramic parts or glass bodies. In recent years, the electrophoretic deposition of particles has been brought ever more sharply into focus for the production of ceramic parts, in particular in the field of fuel cell development and in the field of dentistry. The reason for this can be seen in the capability to produce homogeneous and dense particle packings in which, furthermore, the layer thickness can be adjusted in a defined manner.

[0003] In recent years, methods supported by a potential (methods in which an electrical field is applied in order to assist or accelerate the process) have become established for production of dental ceramics since, in contrast to dye-casting methods, these allow higher green densities and higher homogeneity. For example, the shrinkage during sintering can be minimized, thus allowing production closer to the final contours than can be achieved by dye casting. Furthermore, the sample shrinks isotropically because of the homogeneity. The suspensions on which these methods are based offer the advantage that reprocessing and thus reuse are possible after production of the mold.

[0004] Zirconium oxide, in particular, has been proven to be highly suitable for use as a material for production of dental ceramics. This has the advantage, in addition to the very high strength of the green bodies and molds, that very good translucency is also possible, which means that this material has the optical characteristics of a real tooth, or comes very close to this.

[0005] EP 0 200 242 A2 and EP 0 196 717 A1 have disclosed a method for production of a glass body in which a porous green body is formed from an aqueous suspension with a highly dispersed solid content, and this is then cleaned and sintered, with the green body being produced by separation of the phases of the suspension by means of electrophoresis.

[0006] DE 103 19 300 A1 discloses a method for production of a silica glass body. In this case, silicon dioxide particles are deposited on an electrically non-conductive membrane from an aqueous dispersion.

[0007] DE 103 20 936 A1 discloses a method for production of a completely ceramic green body, in particular for the dental field, in which ceramic particles are deposited on a porous mold from a suspension, with one electrode being arranged within the porous mold and one electrode being arranged outside it. This means that, when using water as a dispersant or suspension agent, no gas bubbles which occur as a result of electrolytic decomposition are enclosed in the green body.

[0008] DE 101 20 084 A1 discloses a method in which dental molds are produced on a model by means of electro-

phoretic deposition. The outer surface, facing away from the model, of the ceramic body which is obtained in this case is processed with ceramic material being removed.

[0009] DE 100 49 974 A1 discloses a dental ceramic being produced from at least one ceramic powder with the addition of a metallic powder, with the green body preferably being produced by electrophoretic deposition. During sintering in an oxidizing atmosphere, the metal is reduced, and this is used to compensate for the sintering shrinkage.

[0010] DE 100 49 971 A1 discloses a method in which a green body for a dental ceramic is deposited electrophoretically on an electrode, with the green body and the suspension from which it is deposited containing ceramic fibers and/or nanocrystalline particles.

[0011] "Creation and Optical Property of Microphotonic Crystals by Electrophoretic Deposition Method using Micro-counter Electrode" (J.-I. Hamagami, K. Hasegawa and K. Kanamura, Mat. Res. Soc. Symp. Proc. 797 (2004) 151-156) describes a method in which a microelectrode is arranged opposite a flat electrode in order to allow locally limited electrophoretic deposition.

[0012] The often-stated advantage of electrophoretic deposition of allowing homogeneous layers also represents a restriction, however, on the known methods. The largely uniform deposition of the particles over the entire electrode or the entire deposition element and over the deposited mold altogether means that the entire deposited mold has an essentially uniform layer thickness of deposited particles. This uniform layer thickness makes it necessary to provide for post-processing of the deposited body, for example by milling, in the case of the known methods, in order to achieve desired differences in the layer thickness in the deposited mold. Particularly in the dental field, it is frequently necessary or desirable to produce molds with a varying wall thickness, for example for crowns.

[0013] DE 102 51 369 A1 and DE 103 34 437 A1 teach the provision of an electrode which is specifically shaped and has areas of different conductivity for production of a desired three-dimensional shape of a deposited green body, that is to say for deposition of layers of different thicknesses. In this case, it has been found to be disadvantageous that the specific shape of the deposition electrode can be determined only empirically. The effect of a predetermined shape of the deposition electrode in conjunction with areas of different conductivity on the three-dimensional shape of the deposited layer can be predicted only roughly, if at all.

[0014] Rapid prototyping methods have become established for the production of small batches and for the construction of prototypes and individual structures, in the dental field as well. Their major advantage is their flexibility, since the tool is not only suitable for producing a specific geometry but also ensures shape flexibility. Most known embodiments are based on layers (or films) of ceramic powder which are fixed in layers on a position-selective basis. The excess, unfixed powders are generally thrown away.

[0015] One fixing option is selective laser sintering (SLS), in which a large amount of excess material is used. This must be processed again in complicated steps. In the case of laminated object manufacturing (LOM), in which tailor-made films with a thickness of about 130 μm are laminated to one another and are then sintered, excess material is likewise produced, and cannot be reprocessed.

[0016] EP 1 021 997 A2 discloses a method in which tooth replacement and dental accessories are produced by means of

laser sintering. In this case, a bio-compatible material is selectively irradiated, thus resulting in sintering taking place at these points.

[0017] DE 102 19 983 A1 discloses a method in which a laser beam is passed selectively over a powder accumulation composed of metallic or non-metallic powders, such that a geometry can be formed layer by layer by reduction of the already sintered or molten structure. This has the disadvantage that the geometry, in particular an existing weak point, must be post-processed mechanically.

[0018] The result of successive sintering, generally layer-by-layer, is inferior, with respect to the homogeneity of the material, than a body which is sintered as an entity and is deposited, for example, by means of electrophoresis.

[0019] The known methods in which (electrophoretic) deposition is used make it possible to define a surface of the mold to be produced sufficiently accurately, specifically the surface of the mold which rests on that surface of the mount structure on which deposition takes place. Desired variation of the thickness of the mold and thus specific adjustment of the three-dimensional shape of the mold are feasible only to a very restricted extent, and are possible only with poor reproducibility.

[0020] Known rapid prototyping methods admittedly allow a desired three-dimensional shape to be produced specifically, but the particular homogeneity of electrophoretic deposition is not achieved in the process. Furthermore, significant material losses resulting from production scrap cannot be avoided with the known methods.

[0021] One object on which the present invention is based is to specify an apparatus and a method for production of a mold, in particular of a dental mold, by means of electrophoretic deposition of particles from a suspension, in which case a predetermined three-dimensional shape can be produced deliberately in order in this way to produce a mold which is as close as possible to the final dimensions and the final contour. A further aim is to produce the molds at low cost, with efficient use of resources, quickly and as simply as possible, with good reproducibility of the method being desirable in order to achieve a low scrap rate. According to a further aspect, a corresponding system (having an apparatus according to the invention and a suspension of particles which can be deposited electrophoretically), a computer program for controlling an apparatus such as this and a data storage medium having a computer program such as this will be specified.

[0022] According to the invention, in order to achieve the object, an apparatus is proposed for production of a mold, in particular of a dental mold, by means of electrophoretic deposition of particles from a suspension, having a chamber for holding the suspension, a first electrode which is associated with the chamber, a second electrode which is associated with the chamber, a mount structure, which is associated with the chamber and on which particles can be deposited, with the mount structure being formed by the second electrode and/or by a deposition element which is arranged between the first electrode and the second electrode, and a voltage source for production of an electrical potential difference between the first electrode and the second electrode, in which case the apparatus has a positioning element for carrying out a relative movement between the first electrode and the mount structure along a first predetermined path during the electrophoretic deposition.

[0023] Furthermore, the invention relates to a method for production of a mold, in particular of a dental mold, by means of electrophoretic deposition of particles from a suspension, having the following steps: provision of a suspension of particles which can be deposited electrophoretically, production of an electrical potential difference between a first electrode and a second electrode, with one of the two electrodes being arranged at least partially in the suspension, and with the other of the two electrodes making electrical contact with the suspension, and electrophoretic deposition of particles from the suspension on a mount structure, with the mount structure being formed by the second electrode and/or by a deposition element which is arranged between the first electrode and the second electrode, in which case the first electrode and/or the mount structure are/is moved relative to one another along a predetermined path during the electrophoretic deposition.

[0024] The invention also relates to a system for production of a mold, in particular of a dental mold, by means of electrophoretic deposition of particles from a suspension, having: an apparatus for production of a mold according to the invention and a suspension of particles which can be deposited electrophoretically in the chamber of the apparatus, with the mount structure and the first or the second electrode being arranged at least partially in the suspension in the operating state, and with the other of the said electrodes at least making electrical contact with the suspension.

[0025] The invention additionally relates to a computer program which causes an apparatus to produce a mold by means of electrophoretic deposition of particles from a suspension according to the invention in order to carry out a method according to the invention when the computer program is run on the apparatus, and to a data storage medium having a computer program such as this.

[0026] The invention is based on the discovery that it is possible to retain the advantages of electrophoretic deposition and in the process to achieve a specific three-dimensional structure of the deposited layer if the electrical field which is relevant for the electrophoretic deposition is designed to be variable on the mount structure, by means of a relative movement between an electrode and the mount structure (on which particles are intended to be deposited). A mold whose geometry corresponds very largely to a predetermined intended geometry can be produced in a simple manner by a predetermined variation of the electrical field which causes the deposition, as a consequence of the relative movement between the first electrode and the mount structure. A device for positioning an electrode and/or a mount structure is admittedly known from DE 103 20 936 A1, but the corresponding apparatus differs from the apparatus according to the invention in that the mount structure is brought together with an electrode to a predetermined, defined position, with a voltage source being available only when the electrode arrangement has been fixed. DE 103 20 936 A1 does not envisage a (relative) movement of the mount structure being carried out during the electrophoresis.

[0027] The relative movement of the first electrode with respect to the mount structure is essential for the invention. It is of secondary importance which element of the apparatus is in this case moved with respect to the chamber or other elements of the entire apparatus. It is possible to move only the first electrode with respect to a mount structure which is fixed in the chamber, or else to move only the mount structure with respect to a first electrode which is fixed relative to the chamber. Furthermore, it is also possible to move both ele-

ments, the mount structure and the first electrode, relative to one another and at the same time in each case relative to the chamber.

[0028] If the mount structure is formed by a deposition element which is arranged between the first and the second electrode, for example an electrically non-conductive, ion-permeable film or membrane, then this allows suspensions based on water to be used without any gas which is created as a result of electrolysis of the water adjacent to an electrode being enclosed in the deposited layer. An apparatus according to the invention is advantageously designed such that ions which are created during electrolytic decomposition of the dispersant or suspension agent water and all the other free ions which are present in the system can pass through the deposition element and can reach the electrode located behind it. The gases which are created by recombination thus occur adjacent to the electrode and not at the deposition point (the deposition element). This means that, in one particularly advantageous embodiment of the invention, an aqueous suspension can be used because the gas bubbles are not enclosed in the deposition body, which means that no flaws are created in the deposition body or green body.

[0029] This is a very major advantage, particularly for the production of dental ceramics. The use of water as a suspension agent is particularly advantageous since the high dielectric constant of the water means that high and very high deposition rates can be achieved, thus making it possible to shorten the process duration.

[0030] However the mount structure can also be formed in a known manner by the second electrode, in which case electrically non-conductive materials can also be used as the electrode material, for example gypsum, wax or plastic, provided that adequate electrical conductivity of the electrode is achieved by a suitable coating or admixture.

[0031] The mount structure may have a flat or contoured shape. For example, a three-dimensional free-form structure can be formed on a flat mount structure. In this case, only one data record is required to control the electrode movement. In the case of a mount structure with a contoured shape, for example a duplicate of a dental master model, areas of different layer thickness can thus be achieved by controlled guidance of the relative movement along a predetermined path. The shape of the mount structure in this case in its own right predetermines the internal and external contour of the green body or mold to be produced. Conventionally, by way of example, a desired mount structure shape can be produced by modeling, molding or else a rapid prototyping method.

[0032] The material of the electrodes is preferably chemically resistant to the suspensions that are used, or is inert with respect to them. This also applies to the material of the deposition element. The electrodes are preferably composed of a material selected from the group comprising zinc, titanium, tungsten, tantalum, graphite, noble metal (in particular silver, gold, platinum), electrically conductive plastics and their mixtures. Furthermore, the electrodes may have an electrode core which is coated with the materials mentioned above. The material of the electrode core itself is not of any more importance if the electrode core is not intended to come into contact with the suspensions or liquids that are used. However, if such a contact is envisaged, the material of the electrode core should likewise be chemically resistant or inert. The electrode materials are preferably chosen such that contamination of the deposited mold is very largely avoided.

[0033] In one embodiment of the invention which has been found to be highly advantageous, the ceramic particles have a shape that is as round as possible.

[0034] Furthermore, it has been found to be advantageous to add a dispersant aid, preferably tetramethylammonium hydroxide (TMAH) or hydrochloric acid (HCl). This allows the pH value to be adjusted in a simple manner.

[0035] A suspension with an electrical conductivity value between 0.001 mS/cm and 175 mS/cm is preferable, in particular between 0.1 mS/cm and 75 mS/cm.

[0036] So-called supercritical drying is advantageous for drying the deposition body. In general, however, the deposition body can also be dried simply at room temperature. A further, special drying method is drying in a saturated atmosphere since this avoids structure inaccuracies.

[0037] It has been found to be advantageous for dental ceramics which have zirconium oxide and are produced in the inventive manner to be sintered in zone sintering ovens at temperatures between 1200° C. and 1800° C., preferably between more than 1400° C. and 1700° C. In this case, a rate of 1 to 15 mm/min, in particular 5 to 12 mm/min and preferably 8 mm/min, is maintained. Alternatively, the green body that is produced can be sintered in a vacuum sintering oven or a chamber sintering oven.

[0038] In one advantageous embodiment of the invention, the mount structure is formed by a deposition element which is arranged between the first electrode and the second electrode, with the positioning element making it possible to carry out a relative movement along a second predetermined path between the second electrode and the first electrode and/or the deposition element.

[0039] If not only a relative movement between the first electrode and the deposition element but also a further relative movement of the second electrode with respect to the first electrode and/or the deposition element are possible, additional degrees of freedom exist for the configuration of the relative movements of the electrodes and of the deposition element with respect to one another, thus resulting in greater flexibility for the configuration options. Starting from a relative movement between the first electrode and the deposition element, the apparatus is designed according to this embodiment, for example, such that the second electrode remains stationary relative to the first electrode but is moved with respect to the deposition element. Another example is relative fixing of the second electrode with respect to the deposition element during a movement of the second electrode with respect to the first electrode. The apparatus can also be designed such that it allows a movement of the second electrode relative to both the deposition element and the first electrode.

[0040] In a further preferred refinement of the invention, the deposition element has an ion-permeable membrane, in particular composed of a material selected from the group comprising gypsum, polystyrene, polymethylmethacrylate, polyethersulfone and their mixtures.

[0041] It has been found that, in addition to gypsum, the said plastics can be used in particular preferably as a material for the deposition element. The deposition element is preferably electrically non-conductive and preferably does not have semiconducting characteristics either. A pore size in the deposition element in the range of 10 nm to 10 μ m, preferably 500 nm to 1 μ m, and particularly preferably between more than 60 nm and 1 μ m is advantageous. Furthermore, it has been found to be advantageous for the deposition element to be wettable

by the suspension agent and the other liquids which are used in the electrophoresis operation. The contact angle between the deposition element and, for example, water is accordingly advantageously less than 90° , preferably less than 80° . If the criteria mentioned here are satisfied, it may be possible to use other materials as well for the deposition element. It has been found that the material of known flexible dialysis tubes is suitable for use in an apparatus according to the invention.

[0042] In a further embodiment of the apparatus according to the invention, the mount structure is formed by a deposition element which is arranged between the first electrode and the second electrode, with the chamber having at least two chamber elements which are separated by the deposition element, with the first electrode being associated with a first chamber element and with the second electrode being associated with a second chamber element, and with at least the first or the second chamber element being intended to hold the suspension.

[0043] In a corresponding refinement of the system according to the invention, the mount structure is formed by a deposition element which is arranged between the first electrode and the second electrode, with the chamber, when in the operating state, having at least two chamber elements which are separated by the deposition element, with the first electrode being associated with a first chamber element and with the second electrode being associated with a second chamber element, and with at least the first or the second chamber element containing the suspension. In particular, it is preferable for the other of the said chamber elements when in the operating state to contain an electrically conductive liquid as a compensation liquid. The values of the electrical conductivity of the suspension and of the compensation liquid are in this case advantageously each between 0.001 mS/cm and 175 mS/cm, preferably between 0.1 mS/cm and 75 mS/cm. It is additionally preferable for the ratio of the electrical conductivity of the suspension to the compensation liquid to be in the range from 0.02 to 50, in particular from 0.02 to 1. If the electrical conductivities of the suspension and compensation liquid are equal or substantially equal, this advantageously results in the same or substantially the same distribution of the electric current in the suspension and compensation liquid with the same or substantially the same current densities in the suspension and compensation liquid.

[0044] During operation, the electrical field causes the particles to migrate in a known manner in a desired or specific direction, thus achieving the electrophoretic deposition. If a deposition element is now provided according to the invention and is arranged between the first electrode and the second electrode, then the particles which can be deposited are repelled by one of the electrodes and are attracted to the other during operation, with particles striking the deposition element. Particles which are located between the attracting electrode and the deposition element move in the direction of the attracting electrode, however, and will never reach the deposition element, and they therefore cannot be deposited there, either. If the deposition element now splits the chamber into at least two chamber elements, in each of which one of the electrodes is arranged during operation, then it is sufficient according to the invention to provide for a suspension to be introduced into only one chamber element, specifically into that chamber element whose particles are repelled by the associated electrode. According to the invention, the chamber can also be split by a deposition element into chamber elements which, for example, are in the form of a cup. In this

case, one chamber element comprises the interior of the cup, and the other chamber element is formed by the area of the chamber outside the cup. One example of a split such as this can be found in DE 103 20 936 A1.

[0045] In one preferred embodiment of the invention, one or both of the electrodes is or are provided with a means for shielding and/or focusing an electrical field between the electrodes.

[0046] The shielding or focusing of the electrical field of the electrode or electrodes during operation makes it possible for the particles to be deposited in a position-selective and specific basis on the mount structure. By shielding or focusing it is possible for the field which is built up between the electrodes during operation to be restricted to a defined portion of the surface of the mount structure, and/or it is possible to reduce the field strength in areas outside this defined portion to a desired value in such a way that this field arrangement results in particles being deposited only, or essentially only, in this surface portion. According to the invention, this allows the surface of the mount structure to be covered uniformly, as if it were being painted with an "electrophoretic" brush, with the relative movement along the predetermined path, in which case the strength or thickness of the deposited layer can be adjusted, for example, by the field strength and the dwell time. In one refinement of the invention, the density of the deposited mold can be varied locally by variation of the parameters which govern the deposition, as a consequence of the local deposition conditions.

[0047] In one particularly advantageous refinement of the embodiment described above, one or both electrodes is or are formed from a line element which is surrounded by a shield, with the shield extending further than the line element in the direction of the opposite electrode.

[0048] It has been found that formation of at least one electrode with a coaxial shield makes it possible to set an electrical field which is locally narrowly limited. Up to now, it has not been possible to achieve local limiting such as this in other arrangements for electrophoretic deposition. The invention therefore allows a considerable improvement in the local deposition efficiency and variability of the local deposition conditions.

[0049] In a further preferred refinement of the invention, one or both of the electrodes has or have a pointed tip.

[0050] The electrical field of a pointed tip is localized well. Particularly when using two opposite electrodes in the form of a pointed tip, a symmetrical field can be produced, thus making it possible to simplify the control of the electrophoretic deposition.

[0051] In one advantageous embodiment of the invention, one of the electrodes has a pointed tip and the other of the electrodes has a surface with a cross section in the form of a circular arc, preferably a surface in the form of a spherical zone or a spherical cup.

[0052] An electrode arrangement such as this can be used to produce a symmetrical electrical field with a largely uniform field distribution. This makes it easier to plan the movement of the electrode in order to produce a desired deposition layer or mold with desired geometry.

[0053] In a further advantageous refinement of the invention, the surfaces of the electrodes each have mutually opposite partial surfaces with parallel surface normals.

[0054] An electrode arrangement such as this makes it possible to produce a particularly uniform electrical field as is also formed, for example, between the electrodes of a plate

capacitor. Deposition can therefore be carried out easily and in a particularly controlled manner, according to the invention.

[0055] In one advantageous refinement of the invention, the voltage source is designed to produce a constant or pulsed DC voltage or a constant or pulsed DC voltage with an AC voltage superimposed on it.

[0056] A constant or pulsed DC voltage can be produced in a particularly simple manner. Superimposition of an AC voltage on a voltage such as this is not subject to any stringent apparatus requirements either. It has been found that a DC voltage with an AC voltage superimposed on it allows an increased deposition density to be achieved in the mold. In this case, it is preferable for the result of the superimposition not to have any change in mathematical sign since, otherwise, the driving force for the electrophoretic deposition is also reversed. There is no need for the DC voltage to have a constant value in all cases throughout the entire operating time when carrying out a method according to the invention. In this context, a voltage can be regarded as being constant just if the voltage remains constant for a time period of at least 10 seconds, preferably at least 1 minute.

[0057] According to a further advantageous refinement of the invention, the apparatus has a third electrode which is associated with the chamber, with the voltage source being designed to produce a constant or pulsed DC voltage or a constant or pulsed DC voltage with an AC voltage superimposed on it, between the third electrode and the first and/or second electrode.

[0058] The electrode arrangement of the apparatus according to the invention is therefore not restricted to just two electrodes. For example, it is possible for one or more further electrodes to be associated with the chamber, in which case, during operation, the field which is formed between the first and the second electrodes has one or more further fields superimposed on it which is or are produced by the additional electrode or electrodes. This allows the electrophoretic deposition process to be controlled more variably. The above statements relating to possible and preferred refinements of the first and second electrodes also apply to a third or further electrodes.

[0059] It is particularly preferable for at least one of the possible relative movements to comprise a movement in at least two spatial directions, preferably in three spatial directions, and/or a rotation.

[0060] A particularly high degree of design freedom is achieved if the electrodes can carry out a movement on at least one plane, and better still in three dimensions, with respect to one another or if one electrode can move in such a manner with respect to the mount structure, in which case it is also possible for the elements to rotate about a dedicated axis and/or relative to another element.

[0061] In a further refinement of the invention, means are provided for arrangement of the first electrode essentially vertically above or below the second electrode.

[0062] A refinement such as this makes it possible for the particles to be deposited to move in the suspension during operation in the direction of the attraction of the earth or against the force of gravity. It has surprisingly been found that, when the particles move in the opposite direction to the earth's attraction during the deposition process, this makes it possible to achieve an increased density of the deposition body or mold. One possible explanation for this may be that relatively large accumulations of the particles can form in the

suspension, in particular in a poorly dispersed suspension, which fall downward as a consequence of the force of gravity, independently of the prevailing electrical field. If the electrophoretic deposition is carried out against the direction of the force of gravity, particles are therefore preferably deposited which have not (yet) been joined together to form accumulations. On the other hand, electrophoretic deposition in the direction of the earth's attraction makes it possible to build up the layers more quickly, if the force of gravity coincides with the electrical field.

[0063] In one refinement of the method according to the invention, the first electrode and/or the mount structure are moved relative to one another during the electrophoretic deposition such that the local deposition conditions are governed essentially by the relative movement.

[0064] In an inhomogeneous field, the field strength on the surface of the mount structure can be varied not only by global variation of the field by changing the potential difference but also in a simple manner by different positioning of the mount structure in the field. Such different positioning is carried out by means of a relative movement. Particularly in the case of a focused or shielded field, specific surface areas of the mount structure are subjected to the electrical field at different times by a relative movement of the mount structure with respect to the corresponding electrode, with (local) electrophoretic deposition of particles taking place as a consequence of the locally acting electrical field.

[0065] In one advantageous refinement of the system according to the invention, the suspension has an organic suspension agent (dispersant).

[0066] An organic suspension agent can be used particularly advantageously when the structuring capability of the material to be deposited is subject to very stringent requirements and a high deposition rate is of secondary importance. It has been found that, in the case of organic suspension agents, steeper field gradients are possible in comparison to the aqueous suspensions. The reason for this is possibly the lower electrical conductivity of organic liquids. The steeper field gradients, that is to say the use of organic dispersants, allow more specific modeling of the deposition body. By way of example, ethanol or dielectric liquids (for example hydrocarbons) can be used as organic, non-aqueous dispersants.

[0067] In one advantageous refinement of the system according to the invention the suspension has water as the suspension agent (dispersant).

[0068] The use of water as a suspension agent makes it possible to achieve very high deposition rates, supposedly because the dielectric constant is higher than that of organic suspension agents, thus shortening the process duration and increasing the throughput. Deionized water, in particular distilled water, is preferred in this case, with bidistilled water being particularly preferred.

[0069] According to the invention typical deposition rates are in the range from 0.05 mm/min to 10 mm/min, in particular in the range from 0.5 to 2 mm/min for aqueous suspensions. In general the deposition rate for organic suspension agents is less by a factor 10 to 100 than that in aqueous suspensions.

[0070] The invention will be explained in more detail in the following text using preferred exemplary embodiments and with reference to the attached figures, in which, schematically:

[0071] FIG. 1 shows an apparatus according to the invention in a system for production of a mold according to a first aspect of the invention,

[0072] FIG. 2 shows an apparatus according to the invention in a system for production of a mold according to a second aspect of the invention,

[0073] FIG. 3 shows an apparatus according to the invention in a system for production of a mold according to a third aspect of the invention,

[0074] FIG. 4 shows an apparatus according to the invention in a system for production of a mold according to a fourth aspect of the invention,

[0075] FIG. 5 shows an apparatus according to the invention in a system for production of a mold according to a fifth aspect of the invention,

[0076] FIG. 6 shows an electrode arrangement according to a sixth aspect of the invention,

[0077] FIG. 7 shows an electrode arrangement according to a seventh aspect of the invention,

[0078] FIG. 8 shows an electrode arrangement according to an eighth aspect of the invention,

[0079] FIG. 9 shows an electrode arrangement according to a ninth aspect of the invention, and

[0080] FIG. 10 shows a flowchart of one exemplary embodiment of a method according to the invention.

[0081] Mutually corresponding elements are provided with the same reference symbols in the figures, even when they are used in different exemplary embodiments.

[0082] FIG. 1 shows, schematically, an apparatus according to the invention in a system for production of a mold according to a first aspect of the invention. The apparatus 101 comprises a chamber 103 for holding a suspension of particles which can be deposited electrophoretically, a first electrode 105 which is arranged such that it can move in the chamber 103, a fixed-position second electrode 107 with is arranged in the chamber as a mount structure 107, a voltage source 109 and a positioning element 111 for the first electrode 105. The suspension 113 is located in the chamber 103 and contains the particles 115, which can be deposited electrophoretically, in an organic solvent. In the schematic illustration in FIG. 1, an electrophoretically deposited layer 117 of the particles is shown on the second electrode 107. The first and the second electrode 105, 107 are located in the suspension 113 or are immersed in it. The system illustrated in FIG. 1 comprises the apparatus 101 according to the invention and the suspension 113.

[0083] The wall of the chamber 103 is composed of a non-porous, electrically non-conductive, chemically resistant material. Plastics, preferably polycarbonate (PC) and particularly preferably polymethylmethacrylate (PMMA) are particularly suitable for use as the material for the wall of the chamber 103. Another suitable material is glass.

[0084] The controllable voltage source 109 is used to form a potential difference between the first electrode 105 and the second electrode 107. The electrical field (not shown) which is created in this case causes particles 115 in the suspension 113 to migrate in the direction of the second electrode 107, where these particles then form an electrophoretically deposited layer. The details of electrophoretic deposition itself and the background to this will not be described in any more detail here since a person skilled in the art will be sufficiently familiar with the fundamental process of electrophoretic

deposition. In addition, reference is made to the prior art cited above with regard to further details relating to electrophoretic deposition.

[0085] The voltage source is shown in this case as being controllable but it is also possible to use a DC voltage source for a constant DC voltage, or some other suitable voltage source. The polarity of the voltage source is important in this context since electrophoretic deposition is possible both in the direction of a cathode and in the direction of an anode.

[0086] The positioning element 111 is designed in order to allow and to control movement of the first electrode 105 along a predetermined path. As is indicated in FIG. 1, the first electrode 105 can be moved in the three spatial directions and can be appropriately positioned by means of the positioning element 111. Furthermore, the orientation of the electrode 105 can be changed by means of the positioning element 111. If, for example, an electrode with a pointed tip is used, then this electrode can be aligned differently in space, that is to say it may have a certain orientation. If, furthermore, a shield is used for the electrode, then the electrical field which originates from this electrode first of all passes from the electrode in a direction which is governed by the shield, as a result of which it is advantageous to match this direction to the desired conditions by variation of the orientation of the electrode. Even a flat plate can be oriented as an electrode, and its surface or its edge may, for example, face another electrode.

[0087] In FIG. 1, the positioning element is illustrated in the area of the chamber 103 and the suspension 113. However, it is also possible to provide the positioning element outside the suspension or outside the chamber, possibly with only the first electrode 105 being located or immersed in the suspension, but not the positioning element. It is also possible for the positioning element to be controlled by a separate control unit, for example a computer, via which the positioning unit and thus the movement and position of the first electrode can be controlled.

[0088] The first electrode 105 has a pointed tip which can be routed in the desired manner along that surface of the second electrode 107 which makes contact with the suspension. In this case, the positioning element 111 governs not only the relative orientation of but also the distance between the first electrode 105 and the second electrode 107. Since the second electrode is arranged in a fixed position in the chamber (fixing means not illustrated), a movement of the first electrode 105 easily results in a relative movement between the first electrode 105 and the second electrode 107, which in this case carries out the function of a mount structure. In the exemplary embodiment shown in FIG. 1, the second electrode 107 comprises a gypsum model which was prepared in a suitable manner for use as an electrode. By way of example, an electrically conductive lacquer or coating can be provided for the model or a sufficient amount of electrically conductive material can be added to the gypsum during production of the model.

[0089] If the first electrode 105 is positioned at a specific distance from and with a specific orientation with respect to the second electrode 107, then particles 115 are deposited from the suspension 113 on the second electrode 107 as a result of the electrical field which is formed between the first and the second electrode 105, 107. Because of the arrangement of the electrodes, this deposition of particles takes place only in a specific area on the second electrode 107 and a layer which has already been deposited on the second electrode 107. If the first electrode 105 is now moved, then the area in

which deposition takes place is therefore also moved over the second electrode. A large surface area of the second electrode 107 can therefore gradually be covered with a layer composed of electrophoretically deposited particles, with the layer thickness depending in particular on the deposition parameters comprising the field strength (in particular on the surface on which deposition takes place) and (electrode) dwell time or movement speed. The field strength can in this case once again be set, for example, via the voltage or via the electrode separation.

[0090] As an alternative to the embodiment illustrated in FIG. 1, it is also possible to provide for the second electrode which forms the mount structure to be moved, or for both electrodes to be moved.

[0091] FIG. 2 shows, schematically, an apparatus according to the invention in a system for production of a mold according to a second aspect of the invention. The apparatus 201 corresponds largely to the apparatus from FIG. 1 as described above. Like that, the apparatus 201 comprises a chamber 103 for holding a suspension with particles which can be deposited electrophoretically, a moving first electrode 105 which is arranged in the chamber 103, a voltage source 109 and a positioning element 111 for the first electrode 105. The suspension 213 which contains particles, 115, which can be deposited electrophoretically, with water as the suspension agent, is located in the chamber 103. The first electrode 105 is located in the suspension 213. In contrast to the apparatus described above, corresponding to a first aspect of the invention, the apparatus 201 has a deposition element 219 which is immersed in the suspension 213 and splits the chamber 103 into two chamber elements. The first chamber element contains the suspension 213 and the second chamber element contains an electrically conductive liquid 221. While the first electrode 105 is arranged in the suspension 213 and thus in the first chamber element, the fixed-position second electrode is located in the second chamber element and in the electrically conductive liquid 221. The deposition element 219 is composed of polyethersulfone and has a pore size in the range from 60 nm to 1 μ m. The schematic illustration in FIG. 2 likewise shows an electrophoretically deposited layer 117 of particles, which in this case is located on the outer surface of the deposition element 219 facing the suspension 213 and the first electrode 105. The shape of the second electrode 207 is matched to the shape of the deposition element 219, although any other desired shape may be provided for the second electrode. The system illustrated in FIG. 2 comprises the apparatus 201 according to the invention and the suspension 213 together with the electrically conductive liquid 221.

[0092] Apart from the use of water or an organic compound as the suspension agent, the difference between the systems illustrated in FIG. 1 and FIG. 2 is that the electrophoretic deposition takes place on a deposition element 219 rather than on an electrode itself. This makes it possible to prevent gases which are created during electrolytic decomposition of the suspension agent (in this case, water) being enclosed in the form of gas bubbles in the deposited layer, which could result in undesirable flaws in the layer structure.

[0093] Alternatively or additionally, it is possible to provide for the deposition element 219 not to be arranged in a fixed position as illustrated in FIG. 2 but for the deposition element to be arranged such that it can be moved, by means of a positioning element. If the deposition element is arranged such that it can move, there may be no need for the first

electrode to be able to move since a relative movement between the first electrode and the deposition element can also be achieved in this way.

[0094] FIG. 3 schematically illustrates an apparatus according to the invention in a system for production of a mold according to a third aspect of the invention. The apparatus 301 largely corresponds to the apparatus from FIG. 2 as described above. Like that, the apparatus 301 comprises a chamber 103 for holding a suspension with particles which can be deposited electrophoretically, a moving first electrode 105 which is arranged in the chamber 103, a voltage source 109 and a positioning element 111a for the first electrode 105. The suspension 213 which contains the particles 115, which can be deposited electrophoretically, with water as the suspension agent is located in the chamber 103. The first electrode 105 is located in the suspension 213. In contrast to the apparatus described above according to a first aspect of the invention and in a corresponding manner to the apparatus described above according to a second aspect of the invention, the apparatus 301 has a deposition element 219 which is immersed in the suspension 213 and splits the chamber 103 into two chamber elements. The first chamber element contains the suspension 213 and the second chamber element contains an electrically conductive liquid 221. While the first electrode 105 is arranged in the suspension 213 and therefore in the first chamber element, the second electrode 307 which, in contrast to FIG. 2, can move, is located in the second chamber element and in the electrically conductive liquid 221. In order to allow and to control the movement of the second electrode 307, the apparatus 301 has a positioning element 111b. Although the positioning elements 111a and 111b are illustrated separately, they can both be provided individually and can be combined in a single positioning element 111. The schematic illustration in FIG. 3 likewise shows an electrophoretically deposited layer 117 of particles, which in this case is located on the outer surface, facing the suspension 213 and the first electrode 105, of the deposition element 219. Furthermore the apparatus 301 comprises a cover 323 which closes the chamber 103 and therefore prevents contamination from outside the chamber 103 entering the suspension 213 or the electrically conductive liquid 221. The system shown in FIG. 3 comprises the apparatus 301 according to the invention and the suspension 213 together with the electrically conductive liquid 221. The system shown in FIG. 3 works during operation in a similar manner to that shown in FIG. 2, with the second electrode additionally being moved in the embodiment illustrated in FIG. 3.

[0095] FIG. 4 shows, schematically, an apparatus according to the invention in a system for production of a mold according to a fourth aspect of the invention. The apparatus 401 comprises a chamber 103, a deposition element 219 which is arranged in a fixed position as a mount structure, which splits the chamber 103 into a first chamber element for holding a suspension of particles which can be deposited electrophoretically and a second chamber element for holding an electrically conductive liquid, a first electrode 405 which is arranged such that it can move in the first chamber element, a fixed-position second electrode 407 which is arranged in the second chamber element, a third electrode 425 which is arranged in a fixed position in the first chamber element, a voltage source 409 and a positioning element 111 for the first electrode 405. The suspension 213 which contains particles 115, which can be deposited electrophoretically, with water as the suspension agent is located in the first

chamber element. The first electrode **405** and the third electrode **425** are respectively located in and immersed in the suspension **213**. The electrically conductive liquid **221** is located in the second chamber element. The second electrode **407** is immersed in the electrically conductive liquid **221**.

[0096] The first electrode **405** is a flat electrode in the form of a plate which can be moved by means of the positioning element **111** parallel to the deposition element **219**, which is likewise flat, and at a fixed distance from it. The first electrode **405** is located between the deposition element and the third electrode **425**, which is likewise in the form of a flat plate. The area of the third electrode **425** corresponds approximately to that of the deposition element **219**, while the area of the first electrode **405** is considerably smaller. The second electrode **407** is located on the opposite side of the deposition element **219** taken from the first electrode **405** and, like the third electrode, is in the form of a flat plate with a size that corresponds essentially to that of the deposition element **219**.

[0097] The voltage source **409** has voltage source elements **409a**, **409b** and **409c**. The voltage source element **409a** is a controllable DC voltage source and is used to produce and maintain a DC voltage between the second electrode **407** and the third electrode **425**. This DC voltage results in an electrical field between the second electrode **407** and the third electrode **425**. The voltage source element **409c** is intended to produce and to maintain a DC voltage between the first electrode **405** and the second electrode **407**. This DC voltage has an AC voltage superimposed on it during operation, with the latter being produced by the voltage source element **409b**. The electrical field which is produced by the potential difference between the first electrode **405** and the second electrode **407** has that between the third electrode **425** and the second electrode **407** superimposed on it. Corresponding to the result of this superimposition, electrophoretic deposition takes place of particles **115** from the suspension **213** on the deposition element **219**.

[0098] This deposition can be set differently at different points on the deposition element **219** by movement of the first electrode.

[0099] The system illustrated in FIG. 4 comprises the apparatus **401** according to the invention and the suspension **213** together with the electrically conductive liquid **221**.

[0100] FIG. 5 shows, schematically, an apparatus according to the invention in a system for production of a mold according to a fifth aspect of the invention. The system according to the invention shown in FIG. 5, together with the apparatus **501** according to the invention, corresponds very largely to that shown in FIG. 4. One difference is that the apparatus **501** is designed such that the chamber **503** is split by the deposition element **219** into an upper and a lower chamber element. In the present exemplary embodiment, the first electrode **405** is arranged vertically below the second electrode **407**, thus resulting during operation in electrophoretic deposition against the influence of the force of gravity of the particles **115**. Suitable measures are taken (not shown here) in order to ensure that the suspension **213** is in contact with the deposition element **219** in the desired deposition area.

[0101] In order to assist clarity, voltage sources, suspensions or positioning elements have been excluded from the following exemplary embodiments of electrode arrangements.

[0102] FIG. 6 shows, schematically, an electrode arrangement according to a sixth aspect of the invention. A first

electrode **105** is arranged such that it can move in the vicinity of a fixed-position second electrode **107** and has a pointed tip. The first electrode **105**, or its tip, can follow a predetermined path **627** which was chosen in this case such that it follows the surface contour of the second electrode **107**. Furthermore, the inclination of the first electrode **105** can be varied in such a way that, for example, it is aligned during the movement along the path **627** at right angles to the respective surface element which is closest to it of the surface of the second electrode **107**.

[0103] FIG. 7, shows, schematically, an electrode arrangement according to a seventh aspect of the invention. A first electrode **105** and a second electrode **307** are arranged such that they can move on opposite sides of a deposition element **219**. The electrodes **105**, **307** each have a pointed tip and are arranged such that they can respectively follow a first predetermined path **627** and a second predetermined path **729**. In this case, the orientations of the electrodes can be adapted such that they run along an extended line between their tips, in which case it is possible to provide for this line in each case to be at right angles to the surface of the deposition element **219**, which is in the form of a thin membrane, when passing along the paths **627** and **729**, respectively.

[0104] FIG. 8 shows, schematically, an electrode arrangement according to an eighth aspect of the invention. A flat deposition element **219** is arranged between a first electrode **105**, which is arranged such that it can move and has a pointed tip, and a second electrode **807** which is arranged such that it can move. The first electrode **105** and the second electrode **807** are coupled to one another such that they each carry out a synchronous movement. The first electrode **105** and the second electrode **807** can therefore each move relative to the deposition element **219** but in the process they remain stationary relative to the respective other electrode. The second electrode **807** has a cross section in the form of a circular arc toward the first electrode **105**, with the tip of the first electrode **105** being located at the center point of the associated circle. This allows a symmetrical field to be produced between the electrodes.

[0105] FIG. 9 shows, schematically, an electrode arrangement according to a ninth aspect of the invention. A first electrode **905** is arranged in a fixed position close to a second electrode **907**. The first electrode **905** is coaxially shielded and comprises a line element **933** which is surrounded by insulation **935**. The insulation **935** is itself surrounded by a shielding element **937**. The insulation **935** and the shielding element **937** extend further than the line element **933** in the direction of the second electrode **907**. The shielding element **937** is in this case at the same potential as the second electrode **907**. The second electrode **907** is in this case provided as a mount structure and, as its external contour, has a desired internal contour of a mold to be produced (in this case: a dental mold). The second electrode **907** is arranged such that it can move in all spatial directions and can be inclined with respect to the first electrode **905** such that the electrical field which occurs between the first electrode **905** and the second electrode **907** during operation is always at right angles to the surface of the second electrode.

[0106] FIG. 10 shows, schematically, a flowchart of one exemplary embodiment of a method according to the invention. The suspension of particles which can be deposited electrophoretically is provided first of all (step **50**), and an electrical potential difference is produced between a first electrode and a second electrode, for example in a system as

described above (step 52). Particles are then electrophoretically deposited from the suspension on a mount structure (step 54). This mount structure may be formed by the second electrode or by a deposition element which is arranged between the first electrode and the second electrode. One of the steps 56 or 62 is carried out at the same time as the electrophoretic deposition (step 54).

[0107] Step 56 comprises the first electrode and the mount structure being moved relative to one another. In this case, either the first electrode or the mount structure or both the first electrode and the mount structure can be moved. In addition to step 56, in refinements in which a deposition element is provided as a mount structure between the first electrode and the second electrode, step 58 and/or step 60 are carried out at the same time as step 56.

[0108] Step 58 comprises the first electrode and the second electrode being moved relative to one another. In this case, either the first electrode or the second electrode or both the first electrode and the second electrode can be moved.

[0109] Step 60 comprises the second electrode and the deposition element being moved relative to one another. In this case, either the second electrode or the deposition element or both the second electrode and the deposition element can be moved.

[0110] The steps 56 to 60 cover all the relative movement options in which a relative movement takes place between the first electrode and the mount structure. The case of a relative movement between the mount structure and the second electrode without any relative movement between the mount structure and the first electrode is only apparently not covered by this since, in a situation such as this, the designations of the first electrode and the second electrode must be interchanged.

[0111] Step 62 comprises the relative positions of the first electrode and mount structure being maintained.

[0112] The illustrated exemplary embodiment of the method according to the invention comprises step 56 being carried out at least once.

[0113] Step 54 and 56 or 62 may be followed by a repetition of these steps (54-62) until the electrophoretic deposition has been completed.

[0114] In addition, it is possible for further steps to be carried out in parallel with the electrophoretic deposition, for example in which a third electrode is moved.

[0115] Further (summarizing) explanatory notes and exemplary embodiments:

[0116] As has been described above and will be described in the following text, the invention relates to a method for production of structured ceramic, metallic or metal-ceramic molds or green bodies, which can be used, after suitable sintering, for example, in the dental field. Ceramic or metallic particles are, according to the invention, locally deposited by means of electrophoresis (EPD) from a suspension with the aid of an electrode or electrodes which can move (relative to the deposition surface), in which case a local build-up can be set by shielding/focusing of the electrical field (for example by means of the electrode diameter, the electrode separation and a coaxial shield). The guidance of the electrode or the electrodes along a mount structure (for example a porous film/membrane of the opposing electrode) is subject to control by data which represents the desired configuration of the mold. An electrophoretic method is therefore available for position-resolved production of ceramic and/or metallic molds or green bodies.

[0117] According to the invention, the molds or green bodies are formed by electrophoretic deposition of dispersed ceramic and/or metal powders from suspensions onto a mount. This may relate to an electrically conductive base body, or a base body which has been made conductive, or else to an ion-permeable membrane which is arranged between the electrodes. However, according to the invention, the shape and the locally applied layer thickness of the deposited green body can also be determined by means of the structure of the mounts by means of the electrodes, which are arranged such that they can move in three dimensions, as a function of the locally effective electrical field. The local electrical field results from the electrical voltage applied to the electrodes, the electrode geometries (diameter, separation), the coaxial shielding (and the focusing) and the dielectric characteristics of the suspension. In one simple refinement of the invention, a DC voltage is applied between the electrodes. In advantageous embodiments of the invention, the DC voltage may be pulsed or an AC voltage, U_{AC} ($U_{DC} > U_{AC}$), may be superimposed on the applied DC voltage U_{DC} .

[0118] Once the mold has been formed, it can be dried and then sintered. In this case, the mount structure can be separated before, during or after the drying. A sintered-on or dense-sintered body can be produced by the sintering process. Furthermore the mold can be infiltrated with glass, plastic or metal in order to reduce the porosity and thus also to increase the strength of the mold.

[0119] The electrode or the electrodes can be guided three-dimensionally along the mount structure, during which process the applied electrical voltage can be varied. This can be controlled by means of data which allows the desired configuration of the mold close to the final dimensions.

[0120] While only layers over an area whose layer thickness cannot be influenced deliberately are produced during traditional electrophoretic deposition, the guidance (preferably three-dimensionally) of an electrode or electrodes and its or their shielded/focused/directed electrical field can be used to form not only locally different layer thicknesses but also three-dimensional molds (similarly to a rapid prototyping method) on a flat surface.

[0121] These electrode configurations can be used for non-aqueous, organic suspensions. These are advantageously used instead of water in particular when the structuring capability is subject to very stringent requirements and the high deposition rate is secondary.

[0122] The deposition of the mold on a membrane as a deposition element which is physically separate from the electrodes also makes it possible to use aqueous suspensions without any need to be concerned about the possibility of gas formation. The decomposition of water into oxygen and hydrogen adjacent to the electrodes for $U_{DC} > 1.23$ V (decomposition voltage of water) has no influence on the formation of the ceramic or metallic mold on the membrane. Aqueous suspensions are highly advantageous since they can be handled easily and allow high deposition rates because of the high dielectric constant of water.

[0123] Further exemplary embodiments will be specified in the following text:

EXAMPLE 1

[0124] 54.72 g of bidistilled water was placed in a 300 ml plastic cup. 5.28 g of tetramethylammonium hydroxide (TMAH) was added. 140 g of zirconium oxide (Tosoh Zirconia Powder TZ-8Y) was stirred in using a commercially avail-

able dissolver. The suspension produced in this way accordingly had a solid content of 70.0% by weight. The pH value of the suspension produced in this way was 12.0, with a conductivity of 4.08 mS/cm.

[0125] The suspension produced in this way was used for electrophoretic deposition, in accordance with the invention. Bidistilled water was used as the conductive liquid, with 0.96 g of TMAH added. A double-shielded cable with an internal diameter of 100 μm was used for each of the electrodes, in which the inner wire was shorter than the shield. Polyether-sulfone (PES) was used in membrane form, as the material for the deposition element. The applied electrical DC voltage from the DC voltage source was 150 V, with an electrode separation of 1.6 cm, applied for a duration of 10 minutes.

[0126] Within this time, the electrodes were controlled by a CAM system (FANUC Robot, LR Mate 200 iB) in such a way that a deposition body was formed, in the form of a cap on the membrane.

[0127] After the deposition process, the green body was removed from the deposition element and was dried at room temperature for 48 hours. The density of the green body produced in this way was determined using the Archimedes principle, and was 4.76 g/cm³. The green body produced in this way was sintered at a temperature of 1600° C. in a zone sintering oven with a feed rate of 0.8 cm/min. After this, the structure had a density of 6.27 g/cm³.

EXAMPLE 2

[0128] 32.57 g of bidistilled water was added to a 250 ml plastic cup. 7.43 g of tetramethylammonium hydroxide (TMAH) was added. 160 g of Tosoh Zirconia Powder TZ-8Y was stirred in using a commercially available dissolver. The suspension produced in this way accordingly had a solid content of 80.0% by weight. The pH value of the suspension produced in this way was 11.8, and the conductivity was 5.17 mS/cm.

[0129] The apparatus used is illustrated schematically in FIG. 5. Bidistilled water was used as the conductive liquid, with 1.43 g TMAH added to it. Single-shielded cables with an internal diameter of 100 μm were used as electrodes. Polymethylmethacrylate (PMMA) was used as the material for the deposition element.

[0130] The applied electrical DC voltage from the DC voltage source was 150 V, with the electrodes 2 initially separated by 1.2 cm. The movement of the electrodes was once again controlled by a CAM system (FANUC Robot, LR Mate 200 iB). The molds produced in this way were two caps which were formed on a membrane. In this case, separation between the electrodes was increased successively from initially 1.2 cm to 2.1 cm as the thickness of the mold increased.

[0131] After the deposition process, the green body was removed from the porous mold and was dried at room temperature for 72 h. The density of the green body produced in this way was determined using the Archimedes principle, and was 4.92 g/cm³. The green body produced in this way was finally sintered at a temperature of 1650° C. in a zone sintering oven at a speed of 0.8 cm/min. The structure then had a density of 6.15 g/cm³.

EXAMPLE 3

[0132] 52.80 g of pure ethanol was added to a 300 ml plastic cup. 7.2 g of citric acid was added as a stabilizer. 140 g of Tosoh Zirconia Powder TZ-8Y was stirred in using a com-

mercially available dissolver. The suspension produced in this way accordingly had a solid component of 70.0% by weight and a conductivity of 24.97 $\mu\text{S/cm}$.

[0133] The suspension produced in this way was used in a first chamber element in an apparatus according to the invention. The other chamber element was filled with bidistilled water, with 1.43 g of citric acid added. Double-shielded cables with an internal diameter of 100 μm were used as electrodes. A commercially available flexible dialysis tube, impregnated with bidistilled water, was used as a porous mold as material for the deposition element.

[0134] The applied electrical DC voltage from the DC voltage source was 100 V, with the electrodes initially separated by 1.75 cm. The movement of the electrodes, controlled by a CAM system (FANUC Robot, LR Mate 200 iB), was carried out at a speed of 5 mm/s until a mold thickness of 3 mm was reached, and then at a speed of 3.5 mm/s. A cap composed of zirconium oxide was thus produced.

[0135] After the deposition, the green body was dried on the porous mold at room temperature for 24 hours. The density of the green body produced in this way was determined using the Archimedes principle, and was 4.94 g/cm³. The green body produced in this way was finally sintered at a temperature of 1600° C. in a zone sintering oven at a feed rate of 0.8 mm/min. The structure then had a density of 6.1 g/cm³.

EXAMPLE 4

[0136] A slip composed of glycerin and gold particles is produced and added to a container. This slip is stabilized with uric acid. The positive imprint (working model) of a tooth stump is used as the deposition electrode. The stump material is a phosphate-bonded compound. The surface is made conductive using graphite conductive lacquer. For this purpose, the surface is first of all coated uniformly with a conductive lacquer by means of a brush, and is then dried at 170° C.

[0137] This conductive model has contact made with it and is placed in the container filled with slip. Both a large-area opposing electrode and a controllable/moveable opposing electrode are located in this container. This is a double-shielded cable with an internal diameter of 100 μm . A DC voltage of 10 V is applied between the deposition electrode and the opposing electrode, as well as between the deposition electrode and the moveable opposing electrode. The controllable electrode is moved during the two-minute deposition time. This resulted in the formation of thicker layers or anatomical molds, in a defined manner.

[0138] The carcass produced in this way is sintered together with the model in the oven at 900° C. for two hours. During the process, the carcass is sintered together on the model, and the pores disappear. After sintering, the model is removed from the carcass using nitric acid.

1. Apparatus (101, 201, 301, 401, 501) for production of a mold (117), in particular of a dental mold (117), by means of electrophoretic deposition of particles (115) from a suspension (113, 213), having:

- a chamber (103, 503) for holding the suspension (113, 213),
- a first electrode (105, 405, 905) which is associated with the chamber (103, 503),
- a second electrode (107, 207, 307, 407, 807, 907) which is associated with the chamber (103, 503),
- a mount structure (107, 219, 907), which is associated with the chamber (103, 503) and on which particles (115) can be deposited, with the mount structure (107, 219, 907)

being formed by the second electrode (107, 207, 307, 407, 807, 907) and/or by a deposition element (219) which is arranged between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), and

a voltage source (109, 409) for production of an electrical potential difference between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907),

characterized by a positioning element (111, 111a) for carrying out a relative movement between the first electrode (105, 405, 905) and the mount structure (107, 219, 907) along a first predetermined path (627) during the electrophoretic deposition.

2. Apparatus (101, 201, 301, 401, 501) according to claim 1,

with the mount structure (107, 219, 907) being formed by a deposition element (219) which is arranged between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), and with the positioning element (111, 111a) making it possible to carry out a relative movement along a second predetermined path (729) between the second electrode (107, 207, 307, 407, 807, 907) and the first electrode (105, 405, 905) and/or the deposition element (219).

3. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with the deposition element (219) having an ion-permeable membrane, in particular composed of a material selected from the group comprising gypsum, polystyrene, polymethylmethacrylate, polyethersulfone and their mixtures.

4. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with the mount structure (107, 219, 907) being formed by a deposition element (219) which is arranged between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), with the chamber (103, 503) having at least two chamber elements which are separated by the deposition element (219), with the first electrode (105, 405, 905) being associated with a first chamber element and with the second electrode (107, 207, 307, 407, 807, 907) being associated with a second chamber element, and with at least the first or the second chamber element being intended to hold the suspension (113, 213).

5. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with one or both of the electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) being provided with a means (935, 937) for shielding and/or focusing an electrical field between the electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907).

6. Apparatus (101, 201, 301, 401, 501) according to claim 5,

with one or both electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) being formed from a line element (933) which is surrounded by a shield (935, 937), with the shield (935, 937) extending further than the line element (933) in the direction of the opposite electrode.

7. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with one or both of the electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) having a pointed tip.

8. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with one of the electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) having a pointed tip and the other of the electrodes

(105, 405, 905, 107, 207, 307, 407, 807, 907) having a surface (831) with a cross section in the form of a circular arc, preferably a surface (831) in the form of a spherical zone or a spherical cup.

9. Apparatus (101, 201, 301, 401, 501) according to one of claims 1 to 6,

with the surfaces of the electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) each having mutually opposite partial surfaces with parallel surface normals.

10. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with the voltage source (109, 409) being designed to produce a constant or pulsed DC voltage or a constant or pulsed DC voltage with an AC voltage superimposed on it.

11. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with the apparatus (101, 201, 301, 401, 501) having a third electrode (425) which is associated with the chamber (103, 503), and with the voltage source (109, 409) being designed to produce a constant or pulsed DC voltage or a constant or pulsed DC voltage with an AC voltage superimposed on it, between the third electrode (425) and the first and/or second electrode (105, 405, 905, 107, 207, 307, 407, 807, 907).

12. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with at least one relative movement (627, 729) comprising a movement in at least two spatial directions, preferably in three spatial directions, and/or a rotation.

13. Apparatus (101, 201, 301, 401, 501) according to one of the preceding claims,

with means being provided for arrangement of the first electrode (105, 405, 905) essentially vertically above or below the second electrode (107, 207, 307, 407, 807, 907).

14. Method for production of a mold (117), in particular of a dental mold (117), by means of electrophoretic deposition of particles (115) from a suspension (113, 213), having the following steps:

provision (50) of a suspension (113, 213) of particles (115) which can be deposited electrophoretically,

production (52) of an electrical potential difference between a first electrode (105, 405, 905) and a second electrode (107, 207, 307, 407, 807, 907), with one of the two electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) being arranged at least partially in the suspension (113, 213), and with the other of the two electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) making electrical contact with the suspension (113, 213), and

electrophoretic deposition (54) of particles (115) from the suspension (113, 213) on a mount structure (107, 219, 907), with the mount structure (107, 219, 907) being formed by the second electrode (107, 207, 307, 407, 807, 907) and/or by a deposition element (219) which is arranged between the first electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907),

characterized in that the first electrode (105, 405, 905) and/or the mount structure (107, 219, 907) are/is moved relative to one another (56, 58, 60) along a predetermined path (627) during the electrophoretic deposition (54).

15. Method according to claim 14,

with the first electrode (105, 405, 905) and/or the mount structure (107, 219, 907) being moved (56, 58, 60) relative to one another during the electrophoretic deposition (54) such that the local deposition conditions are governed essentially by the relative movement.

16. System for production of a mold (117), in particular of a dental mold (117), by means of electrophoretic deposition of particles (115) from a suspension (113, 213), having:

an apparatus (101, 201, 301, 401, 501) for production of a mold (117) according to one of claims 1 to 13 and a suspension (113, 213) of particles (115) which can be deposited electrophoretically in the chamber (103, 503) of the apparatus (101, 201, 301, 401, 501),

with the mount structure (107, 219, 907) and the first or the second electrode (105, 405, 905, 107, 207, 307, 407, 807, 907) being arranged at least partially in the suspension (113, 213) in the operating state, and with the other of the said electrodes (105, 405, 905, 107, 207, 307, 407, 807, 907) at least making electrical contact with the suspension (113, 213).

17. System according to claim 16, with the suspension (113) having an organic suspension agent.

18. System according to claim 16, with the suspension (213) having water as the suspension agent.

19. System according to one of claims 16 to 18, with the mount structure (107, 219, 907) being formed by a deposition element (219) which is arranged between the first

electrode (105, 405, 905) and the second electrode (107, 207, 307, 407, 807, 907), with the chamber (103, 503) having at least two chamber elements, which are separated by the deposition element (219), in the operating state, with the first electrode (105, 405, 905) being associated with a first chamber element and with the second electrode (107, 207, 307, 407, 807, 907) being associated with a second chamber element, and with at least the first or the second chamber element containing the suspension (113, 213).

20. System according to claim 19, with another of the chamber elements containing an electrically conductive liquid (221) in the operating state.

21. Computer program which causes an apparatus (101, 201, 301, 401, 501) to produce a mold (117) by means of electrophoretic deposition of particles (115) from a suspension (113, 213) according to one of claims 1 to 13 in order to carry out a method according to claim 14 or 15 when the computer program is run on the apparatus (101, 201, 301, 401, 501).

22. Data storage medium having a computer program according to claim 21.

* * * * *