METHOD FOR DEPOSITION OF A SENSOR ON A CONDUCTIVE SUBSTRATE

The process comprises the step of deposition of a sensor and of a part or of the entirety of a treatment unit on a not necessarily planar conductive surface by a soft lithography technique.
Method for deposition of a sensor on a conductive substrate

The present invention concerns a method for the deposition of a sensor with part of or an entire signal treatment unit on a conductive substrate by using thin layer deposition techniques.

More specifically, the present invention is concerned with the measurement of the free end of a deformable body (for example a tubular body) and a method for manufacturing this sensor. Strain gauges are deposited on the substrate by means of a soft lithography method (for example micro contact printing). These gauges, combined with a downstream system of signal treatment allow the determination of the curvature of the substrate for each segment by measuring the surface stress. In the case of a tubular substrate, it is then possible to determine the spatial position of one extremity of this substrate by knowing the position of its other extremity.

An extension of the invention is to deposit on the tubular substrate an encoding means for determining its longitudinal position and its rotation around its axis relative to its guide. It is then possible to determine, for example, the spatial position of a tubular object, for example a biopsy needle, cannula or a Kirschner wire.

State of the art

Different methods exist for measuring the surface stress of a deformable body by means of gauges.

The traditional method is to glue on the deformable body strain gauges manufactured on a support. However, this method presents several problems. In this embodiment, the support of the gauge as well as the glue ensures the attachment to the deformable body and the transmission of the deformation.
Unfortunately, notwithstanding the progress made in the field of polymer chemistry, the glues present temperature limitations beyond which they are responsible for important flow and hysteresis and they age quickly. In addition, considering the gluing process, it is difficult to obtain a uniform layer of glue entirely free of air micro bubbles which create interference to stress transmission. When considering tubes of a small diameter (biopsy needles), the reduced space on which one may insert the measuring element makes such a solution impossible to realise.

In order to solve these problems, it is possible to replace the glue with a more or less thin layer of ceramic on which a gauge element carried by a planar deformable body is deposited using the same thin layer technique (such as disclosed for example in patents US 4,104,605 and US 4,221,649). Hence, the uniformity of the intermediate layer is ensured, its resistance to heat is extended and the entire component with a reduced thickness has a better response in sensitivity and time.

This other method for measuring surface stress of deformable bodies is difficult to transpose directly on tubular substrates because the photolithographic technique of resistive patterns of the gauge is not adapted. Nevertheless, US patent 6,531,861 proposes a solution for measuring the bending of a tubular substrate by depositing a sensitive element (electrode) by non-planar lithography. The electrodes produce a signal with amplitude giving an indication of the stress where they are placed. The use of three or more electrodes placed on the circumference of a tubular substrate allows the determination of the direction and amplitude of its bending.

Non-planar lithography on a tubular substrate (patent US 5,106,455) is a technique allowing the deposition of these electrodes. The tubular substrate, covered with an electro sensitive resin, is maintained inside a vacuum chamber. An electron beam is directed onto the substrate. In order to reach the entire substrate surface, the latter is displaced through two actuators (displacement
along two degrees of freedom: a rotation of the substrate around its principal symmetric axis and a translation in the direction of the same axis). After this operation, the resin is developed and the metal chemically engraved. This solution presents the downsides of necessitating expensive infrastructures, generating a high manufacturing cost, working under vacuum, a time-consuming manufacturing process as well as posing biocompatibility problems.

In medical applications, and more specifically in the field of biopsies, the surgeon/radiologist must insert a needle into the region where the sample of tissue is to be taken. At present, this procedure is made in two distinctive ways: either the surgeon uses an intra-operative imaging device (for example a scanner or an ultrasonic probe) in order to follow the trajectory of the needle and validate the proper positioning of the instrument when taking the sample, or he is helped by a mechanical guide and/or a surgical navigation system when imaging is not possible. This latter approach allows him to realize a planned procedure on the patient based on the pre-operative planning. The procedure is made in blind manner, meaning it is based on pre-operative data with no feedback during the actual procedure. It is possible that the collected sample is not situated in the planned region if the patient's organs move between the pre-operative imaging and the collecting of the sample, or if the needle is deformed (for example by deflection on the skull as it enters the brain). The present invention allows the surgeon, for example, to know the deformations and the position of the needle by an auxiliary means that is cheaper and less invasive than presently available alternatives.

**Summary of the invention**

The present invention concerns a measurement method of the position of the free extremity of a deformable body (substrate) and more particularly of tubular deformable bodies and the method for manufacturing said sensor. Strain gauges may be deposited either on a planar substrate or on a tubular substrate
through the use of a soft lithography method. This expression defined in an article "Soft Lithography" of Younan Xia and George M. Whitesides, published in "Angewandte Chemie International Edition" in 1998 (http://www3.interscience.wiley.com/cgi-bin/abstract/10004598/ABSTRACT?CRETRY=1&SRETRY=0), designates "a non-photolithographic micro fabrication method that would complement photolithography. These techniques would ideally circumvent the diffraction limits of photolithography, provide access to three-dimensional structures, tolerate a wide range of materials and surface chemistries, and be inexpensive, experimentally convenient, and accessible to molecular scientists."

Two examples of soft lithography are micro contact printing (R. J. Jackman, J. L. Wilbur, G. M. Whitesides, "Fabrication of Submicrometer Features on Curved Substrates by Microcontact Printing", Science, vol. 269, pp. 664-666, 1995) and hot embossing (W. M. Choi, O. O. Park, "The Fabrication of Submicron Patterns on Curved Substrates Using a Polydimethylsiloxane Film Mould", Nanotechnology, vol. 15, pp. 1767-1770, 2004) which are simple to use and need a not too expensive infrastructure.

The strain gauges and the downstream signal treatment system, which as we will see can partially or totally be deposited using the same technique, allow us to determine by segment the radius of curvature of the substrate by measuring the surface stress. In the case of a tubular substrate, it is then possible to determine the spatial position of one extremity of this substrate by knowing the position of its other extremity.

The present invention will be better understood by the description of several exemplary embodiments and of the accompanying drawings, in which:

Figure 1 shows a first embodiment of a tubular substrate;

Figure 2 shows a resistive pattern according to the invention;
Figure 3 shows an example of a longitudinal encoding means;

Figures 4 and 5 show a first application of the invention;

Figures 6 and 7 show a second application of the invention;

Figures 8 and 9 show a third application of the invention;

Figure 10 shows another embodiment of the invention and

Figure 11 shows a further embodiment of the invention.

The manufacturing process according to the invention will be described first with reference to figure 1 and to the embodiment illustrated. Accordingly, one manufactures a thin layer strain gage by depositing a first layer of an isolating material 1.1 such as SiO2 on a thickness of about 1 micron on a surface of the deformable body 1.2, for example a tubular body, of which one wishes to measure the surface stress.

One then deposits a metallic layer 1.3 on the isolating layer 1.1 in order to form a resistive pattern 2.4 (see figure 2), conductors 2.5 allowing the current to be carried to the resistive patterns and the connectors 2.6. This layer has a thickness of 0.2 micron to 1 micron depending on the desired resistive value. This layer is created by transfer of a pattern by rolling the substrate on a stamp made of polydimethylsiloxane (PDMS) covered with a layer of ink (alkanethiol) then by chemically engraving the metal not protected by the ink.

A protective biocompatible layer 1.7 is finally deposited on the resistive patterns 2.4 and also on a part of the conductors 2.5.
The tubular substrate is subdivided in several segments. One extremity 2.8 (see figure 2) of the substrate is built-in material of which the position and the spatial orientation is known (reference extremity), whereas the other extremity 2.9 is free. Each segment comprises four strain gauges deposited at 90° one from each other around the circumference of the substrate and centred with respect to the segment. In case of bending, the pairs of strain gauges facing each other are subjected to the same stress amplitude but with an inverse sign. Indeed, one strain gauge is under compression whereas the other is under tension. One measures these stresses by inserting the pairs of gauges in a Wheatstone bridge with two complement resistances (half-bridge measurement). By geometrical interpretation calculated by a treatment unit, one obtains the radius of curvature of each segment in two orthogonal planes through the two pairs of gauges of each segment. From this information and by knowing the length of each segment, the treatment unit determines the spatial position of all the points of the tubular substrate by interpolation, even when the substrate is deformed by bending. The number of segments determines the resolution with which the measurement can be carried out.

A variant of the invention is to deposit on the tubular substrate an encoding means for encoding its longitudinal position and its rotation around its axis relative to its guide. For example, a structure such as the one illustrated in figure 3 is deposited in parallel (reference 1.10 in figure 1) to the deposition of the strain gauges of figure 2. In the guide of the tubular substrate, a series of magnetic sensors (sliders) are deposited on the internal surface of the guide and this on a part of or the entire circumference. It is thus possible to determine the position and the rotation of the tubular substrate relative to its guide. The encoding technique used may be the one named "enductosyn"™ (see GB 801 516) or another equivalent.

Biopsies of cerebral tissue are one of the most complicated trocar biopsies to realise. It implies the insertion of a needle into the cortex without the aid of an intra-operative imaging device. One of the major difficulties of this procedure is
to avoid contact of the needle with a hard surface such as the skull which could cause the needle to bend and deflect its extremity. Since current supports such as stereotactic frames (see Figure 4) or navigation systems (see Figure 5) used to assist biopsies make the assumption of a rigid needle, the invention described previously can warn the surgeon of a possible deflection of the needle and to inform him of its new trajectory. If, in addition, the needle is manufactured with a position and orientation encoder as illustrated in figure 3, it is moreover possible to know the spatial position of its extremity with respect to its guide. Since the latter is rigidly attached with respect to the stereotactic frame 4.1.1 (see figure 4) or to the Mayfield head rest, it is thus possible to calculate the coordinates of the needle in the pre-operative scanner slices after registration. This computerised surgical navigation support system may have an interface similar to the device illustrated in figure 5.

Another application linked to the present invention is in the insertion of transarticular screws in cervical vertebrae C1-C2, such as illustrated in Figure 6. This procedure consists in the fixing together of the two first cervical vertebrae with a flexible wire tipped with a screw thread that is commonly called a "Kirschner wire" in order to lock them together. This wire is inserted via a special drill. Once screwed in and the position of the wire validated by a pre-operative imaging device, this wire is used as a guide for the insertion of canulated screws illustrated in Figure 7. The Kirschner wire being of a small diameter, it has a tendency to bend which poses serious problems for the calculation of trajectories when inserting it. As for biopsy needle, the invention allows us on the one hand to detect the bending of the wire and on the other hand to know through a navigating system the new trajectory followed by the wire. The validation of the wire insertion by an intra-operative imaging device is thus obsolete.

A third application linked to the present invention is osteotomy. This intervention corrects a deformation of a bone following a trauma, an improper bone growth or even in the treatment of certain arthritis. This procedure is carried out by
cutting the bone and consists in a rectification in position or alignment and in the holding of this correction. It is hence a controlled fracture which necessitates waiting for bone consolidation obtained by the creation of a bone callus. Practically, the surgeon will use an osteotomy plate which he will bend in order to adapt it to the anatomy of the patient, as illustrated in Figure 8. The deformation parameters of the plates are realised thanks to the pre-operative data then adjusted during the surgical intervention by specific tools as for example represented in figure 9. The major difficulty is to correctly bend the plate and to limit the number of readjustments during the attachment of the implant. By the present invention, it is possible to deposit a gauge system on the osteotomy plates as described above in order to allow assistance during the manufacturing of the plate. In this case, the plate is connected during adjustment to a small electronic adaptor itself connected to a computerised pre-operative planning system. This system allows feedback to the surgeon on the conformity of the deformation that is checked automatically against the planned shape. Once the adjustment has been effected the electronic device is disconnected and the osteotomy plate is implanted.

In the domain of bone osteotomy, it is also possible to integrate strain gauges, cables for the electronic devices, a power module charged by electromagnetic waves and an antenna by soft lithography: the electronic portion being assembled later and protected either in an impermeable compartment or by a biocompatible deposition on the components.

After the implantation of the plate, this device allows the surgeon to measure the force/stress applied to the plate during the recovery of the patient in order to choose the best moment to extract the osteosynthesis material. Figure 10 shows an example of such a device.

More specifically, Figure 10 shows the possible technology opportunities of the presented invention. On a not necessarily flat surface (this includes for example round / cylindrical surfaces) the above pattern can be printed in a single step.
Sensor elements 10.1 like strain gauges, temperature sensors etc. can directly be connected by wires 10.2 to a signal processing unit. The signal processing unit can be composed of one or several integrated circuits 10.3 which are placed directly on the surface and connected via bonding wires 10.5 to printed bonding pads 10.4. Traditional surface mounted devices 10.7 like resistors; capacitors etc. needed for the electronic circuit are directly connected by soldering or other methods to printed pads 10.6.

For wireless communication and powering of the sensor unit; antennas with or without integrated inductive power link 10.9 are also directly printed in the same step. Other sensors or electrical elements like finger-style capacitors 10.8 are, again, realized in a single step.

The whole signal processing part can finally be protected and hermetically sealed with a (biocompatible) epoxy drop.

The presented application has several very important advantages compared to state of the art processes:

- No interconnections need to be added between the sensor and signal processing unit. Interconnections are often the weakest link and the most expensive component.

- The sensor elements and the processing unit can be placed directly on the element to be measured. This reduces size and helps to keep a very low signal to noise level.

- If no traditional components need to be soldered, the whole sensor does not need any solder connections resulting in enhanced reliability and biocompatibility.

An improvement of the presented invention is the possibility of creating multiple electrical layers to reduce deposition space in order to realize a multi-layer Printed Circuit Board (PCB). By using "several evaporation - micro contact printing - wet edging" steps, electrical connection can be realized on multiple layers. In the example of figure 11, a first isolating layer 11.2 is deposited on the
(metal) substrate 1.1. On this insulator, a first metal layer 1.5 is evaporated. This metal layer is then structured by a first "micro contact printing - wet edging" step. Over this first electrical layer, a second isolating layer 1.3 is deposited. Then, again, by evaporating metal and "micro contact printing - wet edging" the second electrical layer is created. Horizontal connections 1.6 between layers are created to electrically interconnect the layers. These connections are either created during the second metal evaporation step (by the means of preliminary fabricated holes in the insulating layer 3) or later, after the evaporation step by other means like bonding, galvanic metal deposition etc.

A fourth application is to deposit a temperature sensor at the tip of a drill bit and a connector at its other end by means of soft lithography. Electrical tracks are made along the length of the drill bit in order to connect the sensor to the connector. An electro-mechanic protective layer is of course deposited over this first deposition.

A layer of electromagnetic protection is of course deposited over this first deposition. The drill mandrel comprises a complementary connector and electronic means to analyse the temperature of the drill bit which allows the user to modify the behaviour of the drill during use (for example to stop it when the temperature of the drill bit has reached a certain threshold.

A fifth application of the invention consists in depositing a device similar to the one of figure 10 on a metallic structure (such as concrete reinforcing bars or anchors) on architecture or civil engineering projects. Through a telemetry system, it is thus possible to analyse, over the course of time, the evolution of the forces interacting inside the structure by measuring the deformation of the internal metallic structures without seeing them.

The examples given above are not a limiting list of possible applications based on the present invention.
CLAIMS

1. A process comprising the deposition of a sensor and of a part or of the entirety of a treatment unit on a non-planar conductive surface by a soft lithography technique.

2. The process as defined in claim 1, comprising one or more of the following steps:
   a. Deposition of the sensor,
   b. Deposition of an electronic wiring (having the function of a PCB)
   c. Deposition of all or part of electronic components,
   d. Deposition of one or more telecommunication antennas, for example telemetry, and/or for the powering of the system by electronic waves, for example by induction.

3. The process of claim 1, wherein the sensor is a temperature sensor.

4. The process of claim 1, wherein the sensor is a force or bending sensor.

5. The process of claim 1, wherein the sensor is a position sensor.

6. The process of one of claims 1 to 5 in which the technology of micro contact printing is used to realise the deposition.

7. The process of one of claims 1 to 6 in which an insulating layer such as silicon dioxide, polyimide or parylene is deposited on the substrate before the resistive patterns in order to ensure an electric isolation of the resistive patterns.

8. The process of one of claims 1 to 6 in which a protective layer such as silicon dioxide, polyimide or parylene is deposited on the substrate and the
resistive patterns in order to ensure an electric isolation, a mechanical protection and a biocompatibility of the sensor.

9. A measurement device comprising:
   a. A substrate segment on which forces are applied, said segment having a reference extremity and a measured extremity,
   b. A position sensor comprising strain gauges deposited on the substrate segment by soft lithography the measured value of which allows one to determine the surface stress of the substrate,

   wherein the signal treatment unit being coupled to the strain gauges and configured to determine the spatial position of the measured end of the segment from the signals received from the strain gauges.

10. The device as defined in claim 9, wherein the strain gauges are deposited along the segment on each side of the substrate (180°) in order to determine the spatial position of the measured end of the segment through a differential measurement.

11. The device as defined in claim 9, wherein the strain gauges are deposited along the segment at an angle of 120° from each other in order to determine the spatial displacement of the measured end of the segment along two orthogonal directions.

12. The device as defined in claim 9, wherein the strain gauges are deposited along the substrate at 90° from each other in order to determine the spatial displacement of the measured end of the segment along two orthogonal directions.

13. The device as defined in claims 9 to 12, wherein the substrate has a circular section.
14. The device as defined in claims 9 to 13, wherein the substrate is made of several adjacent segments in which the reference extremity of the next segment is merged with the measured extremity of the preceding segment in order to determine the spatial position of the measured end of the last segment (measured end of the substrate).

15. The device as defined in one of claims 9 to 15, wherein the gauges are strain measurement gauges.

16. The device as defined in one of claims 9 to 15 in which the entire treatment unit or at least a part of it is integrated in the substrate.

17. A system for the measurement of a position according to the direction of the principal symmetry axis of the substrate relative to a guide comprising:
   a. An encoding system deposited on the substrate,
   b. Sliders placed in the guide of the substrate allowing a position decoding,
   c. A signal treatment unit coupled to the sliders and configured to determine the relative position of the substrate with respect to the guide.

18. A system as defined in claim 17, wherein the substrate has a circular section and several sliders are placed around the circumference of the guide in order to determine the rotation of the substrate around its principal axis.

19. The system of claims 17 and 18, wherein the encoding and decoding technique is inductosyn™.