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(54) THREAD WITH A FUNCTIONAL LAYERED STRUCTURE

(57) The invention concerns a device (1) comprising a thread (2) and a layered structure (3), wherein the layered structure (3) is arranged on a surface (4) of the thread (2).

The invention further concerns a method for producing a device (1) comprising a thread (2) and a layered structure (3) arranged on a surface (4) of the thread (2), wherein the method comprises the steps of:

a) providing the thread;
b) positioning the thread in order to allow for a deposition of a layer;
c) depositing the layer on the surface of the thread;
d) optionally repeating steps b) and c) to assemble further the layered structure;
e) optionally applying a coating on the thread at least in a region where the layered structure is deposited.

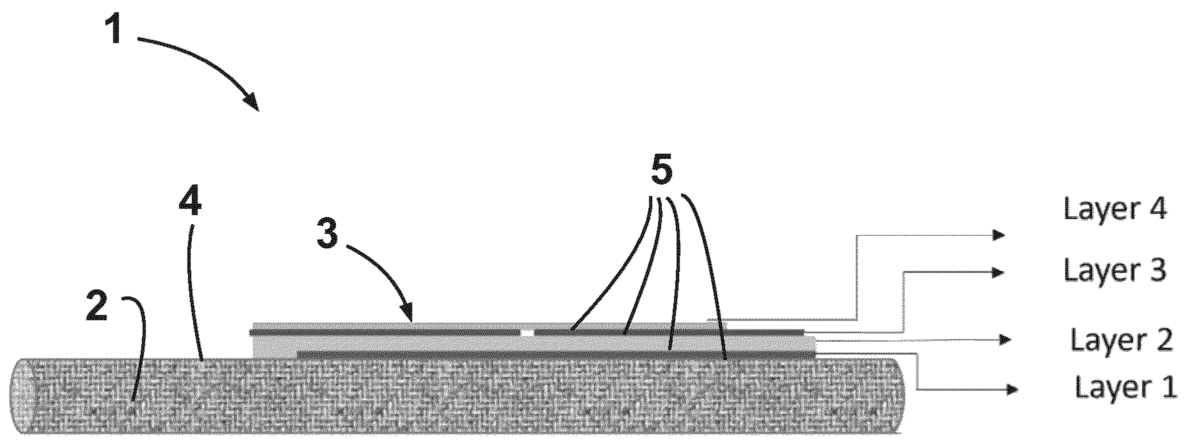

Fig. 1

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Description

[0001] The invention concerns a device comprising a thread and a layered structure.

[0002] Moreover, the invention concerns a method for producing a device comprising a thread and a layered structure.

[0003] Generally, miniaturized electronics-based systems are gaining significant interest in wearable electronics and computing. In this connection, smart textiles are of specific interest for wearables as such smart textiles which can be integrated seamlessly into everyday clothing. Nevertheless, the textile and standard electronics production technologies have very different characteristics (Malmivaara, M. (2009), 1 - The emergence of wearable computing, in McCann J. & Bryson D. (eds.), Smart Clothes and Wearable Technology pp. 3-24, Woodhead Publishing). However, the latter demands a cleanroom processing environment, precision process control, high vacuum conditions and high temperature manufacturing processes compatible with crystalline semiconductor wafers. On the other hand, textile production processes are generally compatible with large volume production and less stringent in dimensional precision at a lower cost of production. Moreover, in such processes highly rough and wavy substrates having low melting points are employed. These fundamental differences in production facilities and production processes are a major impeding force for smart textile concepts to be translated into a larger volume (Islam Molla, M. T. (2017), A scalable manufacturing method for garment-integrated technologies).

[0004] The concept of smart textiles emerged in the 1990s and includes textiles that are able to sense stimuli from the environment as well as to react and adapt to such stimuli by the integration of functionalities in the textile structure. A common method for developing smart textiles employs weaving, embroidery or knitting of conductive threads into a textile (Lee, J., Jeon, S., Seo, H., Lee, J. T., Park, S. (2021), Fiber-Based Sensors and Energy Systems for Wearable Electronics. Applied Sciences, 11 (2), 531; Stoppa, M., Chiolerio, A. (2014); Wearable electronics and smart textiles: a critical review, Sensors, 14 (7), 11957-11992, doi:10.3390/s140711957).

[0005] The capabilities of existing smart textiles are rather basic, due to limits of both the functionalities provided by these conductive threads/wires and structural features that can be formed by integration by above-mentioned methods, for example embroidery, knitting or weaving. In order to simplify a process and to enhance functionality, attempts have been directed to develop dip-coated thread-based sensors. A cotton thread based PEDOT:PSSS sensor for gas detection and a polyaniline-based pH sensor for wound monitoring are some examples (Zhang, Y., & Cui, Y. (2017), Cotton-based wearable PEDOT:PSS electronic sensor for detecting acetone vapor, Flexible and Printed Electronics, 2 (4), 042001. doi:10.1088/2058-8585/aa9a27; Lyu, B., Punjiya, M., Matharu, Z., Sonkusale, S. (2018, 27-30 May 2018), An improved pH mapping bandage with thread-based sensors for chronic wound monitoring, Paper presented at the 2018 IEEE International Symposium on Circuits and Systems [ISCAS]). A reel-to-reel fabrication strain sensor has also been reported wherein the sensor was applied for an insole fabrication (Alaimo, F., Sadeqi, A., Rezaei Nejad, H., Jiang, Y., Wang, W., Demarchi, D., Sonkusale, S. (2020), Reel-to-reel fabrication of strain sensing threads and realization of smart insole, Sensors and Actuators A: Physical, 301, 111741, doi:https://doi.org/10.1016/j.sna.2019.111741).

[0006] In order to produce conductive and functional threads, wet-spinning techniques can be applied, too. For example, Zhang et al. prepared highly stretchable and sensitive strain sensors wherein controlled distribution of conductive particles helped to achieve a better sensor sensitivity (Zhang, S., He, Z., Zhou, G., Jung, B.-M., Kim, T.-H., Park, B.-J., Byun, J.-H., Chou, T.-W., High conductive free-written thermoplastic polyurethane composite fibers utilized as weight-strain sensors, Compos. Sci. Technol. (2020), 189, 108011). However, wet-spinning or dip-coating material deposition methods are inherently limited by lower sensor integration density and a lack of patterning freedom. For this reason, Kumar et al. worked towards a fabrication of an active channel area for thread-based transistors and used a 3D-flexible 'stencil' for the material. However, this method is limited in terms of patterning freedom and production volume (Kumar, T., Owyeung, R. E., Sonkusale, S. R. (2021), Rapid cleanroom-free fabrication of thread based transistors using three-dimensional stencil-based patterning. Flexible and Printed Electronics, 6(1), 015007, doi:10.1088/2058-8585/abe459). Major limitations of these methods relate to the availability of functional materials, a complex patterning process, a limited thicknesses of the printed materials and an ineffective interface charge transport between layers.

[0007] More recently, the introduction of printed electronics on textiles enhanced the prospects for smart textile devices by adding in a layer-by-layer fashion the functional materials, i.e., printing electronics directly onto textile substrates. However, such on-textile-printed electronics face new challenges, for instance, from the surface roughness or the friction induced internal stress acting between individual threads. This often causes sensing layers to delaminate or crack and/or causes a destruction of the functionality, which, in turn, leads to short lifetimes. In addition, electronics printed on textiles often fail to conform to required 3D shapes. Furthermore, a relatively large area of the electronic components abates the textile texture and properties, making such components less appealing and exciting for wearable applications. Despite that, a strong trend toward higher integration exists as shown in the recent developments such as a so-called E-thread, in which RFID communication is realized within a thread by integrating a silicon chip and its antenna (made up of conductive strands) into a thread

(Benouakta, S., Hutu, F. D., Duroc, Y. (2021), Stretchable Textile Yarn Based on UHF RFID Helical Tag, Textiles, 1(3), 547-557).

[0008] Existing smart textile manufacturing methods are basically either based on the (i) integration of conductive threads into textiles or on (ii) printing electronic components across textile substrates. The capabilities of smart textiles based on the integration of conductive threads are rather basic. Limitations are due to both the functionalities provided by these threads and the structural features that can be formed by the integration methods such as embroidery, knitting or weaving. The introduction of printed electronics on smart textiles widened the possibilities for thin film textile devices and sensors by adding the functional materials in a layer-by-layer fashion, i.e., printing electronics directly onto textile substrates. However, these printed devices and manufacturing methods on textiles face new challenges, for instance, from the surface roughness, waviness in surface topography, or the friction-induced internal stress acting between the threads carrying a printed device. This often causes the sensing layers to delaminate or crack. In particular, the intended functionality may be lost, leading to short lifetimes of the printed devices. Most importantly, the directly printed electronics or microfabricated electronics systems integrated in wearables fail to preserve the physical properties expected from a textile, making the use of such smart textile modalities cumbersome for the end-users.

[0009] An object of the invention is to provide a device which eliminates or at least reduces the problems associated with prior art devices. In particular, it is an object of the invention to provide a device including a thread, which device is robust and durable and comprises at least one functional unit like a sensor.

[0010] Another object of the invention is to provide a method for producing a device comprising a thread, which method allows an efficient production of a device according to the invention.

[0011] In one aspect, the invention provides a device comprising a thread and a layered structure, wherein the layered structure is arranged on a surface of the thread.

[0012] A device according to the invention addresses several shortcomings of prior art functional components arranged on woven fabrics. It can be viewed as a new approach for smart textiles. A layered structure can be printed on a single thread, enabling the miniaturization of electronics. Hence, the device consists of a single thread carrying a layered structure. In particular, the layered structure can be or is a functional unit. Moreover, several layered structures, each comprising a functionality, can be arranged on the same thread. Although several functional layered structures can be arranged on several individual threads, if applicable being connected functionally with each other (for example by electrical contacts or any other type of connection allowing the functionalities to cooperate with each other), an arrangement of several layered structures on a single thread avoids any inter-thread connections. Thereby high robustness and durability can be provided, even when the layered structures and, hence, the functional units are at least partly connected to each other. At the same time, standard textile processing methods like stitching, sewing or other methods can be used to incorporate a device according to the invention in a textile or woven fabric.

[0013] A layer of the layered structure may fully cover a certain area of a thread. However, a thread with a layer deposited on its surface may comprise defined regions which are left blank. For example, a layer can be deposited in a certain pattern (e.g., a pattern consisting of periodically arranged squares or a non-coherent layer) so that a certain area of a thread is only partly covered by the layer. This also holds for multi-layer structures and a structural unit as such.

[0014] If connections are necessary and/or provided, the connections are preferably printed, although generally every type of connection can be used.

[0015] As the invention is miniaturized on a single thread, the device itself is more robust and durable due to lesser stress when compared with an arrangement of a functionality on several adjoining threads. Moreover, incorporation of a single thread with functionality into a woven fabric also allows a much more directed localization of the functionality provided by the layered structure on the thread. For instance, the thread and hence the device itself can be incorporated into a woven fabric such that a temperature measurement can be made at a certain point of a body, for example in the region of a body wound.

[0016] Another advantage of the invention is that the device itself is sustainable and resource efficient as less material is needed in comparison with state-of-the-art-coverings which cover larger surface areas across multiple threads. The latter also leads to the fact that such prior art coverings need much more material than a device according to the invention which only needs material for a localized arrangement of the layered structure on a certain position of the surface of a thread.

[0017] As the device according to the invention comprises a thread which carries at least one functional unit in form of a layered structure on its surface, the invention also copes with usual problems of prior art devices like a tendency of sensing layers to delaminate or crack so that a proper functionality is lost. These problems are mainly due to the problems associated with manufacturing methods stemming from surface roughness, waviness in surface topography or the friction-induced internal stresses acting between adjoining single threads.

[0018] In addition, miniaturization of printed sensor, actuator or other functional units into a tiny form on threads and filaments can be a giant leap for printed electronics leading to many applications. A fully printed sensor on a thread can address at least some of the key challenges in the existing smart textile technology such as comprehensiveness of the smart textile, mass volume producibility, durability and end user convenience. This also provides more functionalities, as more sensors and actuators or other functional units can be integrated onto a small area so that more features can be realized. Additionally, a more specific selection to certain locations is possible. This can be beneficial, for instance, in case of sensors on a surgical wound dressing embedding the sensor on a thread to allow for monitoring post-surgical inflammations or infections and biochemical and physical changes at a specific location.

[0019] A thread with a functional unit according to the invention is not limited to sensors but can also be extended to power sources and actuators (for example micro-heaters and lighting) enabling a full stack solution on a thread. A corresponding fabrication process of a final textile is simplified as the process can be independent of the final application (e.g., the device with the thread can be incorporated into any textile or woven fabric, respectively) and is capable of volume production that is compatible with textile manufacturing in contrast to conventional micro- or nanofabrication.

[0020] Preferably, the layered structure is printed on the surface of the thread. Printing of a layered structure provides several advantages: First, a printing process has a high enough resolution so that a functional unit like a sensor can be printed on a thin single thread. Second, printing techniques also allow to deposit a single layer of a larger structure with good quality on the surface of a single thread even when this surface is bend. Third, a printing process allows to provide a single thread comprising several functional units like different sensors. Fourth, a printing process in connection with a single thread carrying a functional unit allows to optimize the material resources needed for producing a functional unit on a thread.

[0021] Beside to deposition from fluid precursor solutions or suspensions, other possible deposition techniques for depositing at least one or more or all layers of the layered structure comprise gas phase deposition techniques, for example chemical vapor deposition. Also, other methods like stamping or soft lithography including rubber stamping can be used within the scope of the invention. In one embodiment, a combination of such methods may be used for depositing a layer structure comprising several layers being in contact with each other.

[0022] The layered structure is usually a functional unit. A functional unit can be any arrangement allowing to generate a signal in response to its surrounding and/or allowing to change its surrounding by receiving a signal. For example, a sensor would be the functional unit allowing to provide a signal of its surrounding, for instance a body temperature. A heating element which receives a signal input and then changes its surrounding by heating is a functional unit changing its surrounding by receiving a signal or input. Other examples are functional units relating to energy harvesting and/or energy storage.

[0023] Generally, any suitable printing method can be used for patterning a layered structure on the thread, in particular, any conventional or digital printing method like inkjet printing. Also, any additional components like connections between functional units or between a couple of devices may be deposited on a thread by a printing process. In this way, a wide range of applications is opened for woven fabrics comprising an inventive device, for example health monitoring wearables, smart structures for surgical implants, textiles including sweat monitoring, smart bandages to monitor wound healing or point-off-care diagnostic textiles as well as engineered tissue constructs.

[0024] In a device according to the invention, the thread has preferably a diameter of less than 1500 μm, preferably 10 μm to 1200 μm, in particular 20 μm to 1000 μm, for example 25 μm to 300 μm. In particular when the layered structure is printed on the surface of a thread, the thread can be comparably fine, still allowing to carry the deposited functional unit or several functional units. The functional units can be positioned along a length axis of a thread, but also on top of each other. Depending on the application, it is also possible to arrange functional units along a thread as well as on top of each other.

[0025] Preferably, the layered structure arranged on the thread comprises at least two layers abutting on each other, in particular stacked on each other, wherein at least one of the layers is arranged on the surface of the thread. If an upper layer is stacked on a below other layer, the upper layer can cover the below layer completely or partially. Generally, the layered structure can be a layer with a certain thickness, consisting of several regions of different materials thus generating a functional unit. For example, such a single thickness layer could comprise connected stripes of different oxides like CuO and Zno which are coated with nanoparticles for sensing certain gases. However, it is preferred that the functional unit as such is not just a single layer having a certain thickness, but comprises several layers which are abutting against each other and/or are stacked on each other when viewed in cross section along the thread or normal to the thread's length axis. For such structures, it is possible to use sequential printing steps to build up a functional unit without the need of manipulating single layers.

[0026] The layered structure usually has a thickness of 10 nm to 10 μm, preferably 50 nm to 3 μm, in particular 100 nm to 1,5 μm. A thickness of the layered structure is measured perpendicular to the surface of the thread on which the layered structure is arranged. A certain thickness depends on the functional unit which is deposited as a layered structure. Usually, the thickness of the layered structure is constant. However, in some embodiments, the thickness of the layered structure may vary. The same holds for individual layers which build up a multi-layer layered structure.

[0027] The layered structure is preferably a printed electronic and/or a sensor. The layered structure is a functional unit arranged on a surface of the thread.

[0028] For the functional unit, the thread can comprise electrical contacts, wherein the electrical contacts are connected to the layered structure. With the electrical contacts, the functional unit or layered structure can be contacted so that a voltage or current can be applied in or between individual layers. Moreover, contacts for the layered structure can be provided in order to transport and/or receive signals if needed. Still further, the device can comprise connections to a data sending and receiving unit. Such a data receiving and sending unit is usually positioned distanced from the functional unit or layered structure so that a connection can be necessary in order to finally send and receive data recorded by the functional unit or to operating the latter. In one embodiment, the data receiving and sending unit is incorporated within or onto the thread carrying the functional unit.

[0029] The thread may comprise two or more functional units and hence more than one layered structure. The number of functional units depends on the tasks to be fulfilled by the device. For example, if several types of data have to be recorded and sent via a data receiving and sending unit, several functional units can be required on a single thread.

[0030] The device may comprise at least one microchip, wherein the at least one microchip is arranged on or within the thread and wherein the at least one microchip is electrically connected to the layered structure. In this way, data can be processed already on the thread itself. The microchip can be arranged on the surface of the thread as the functional unit or layered structure. However, it is also possible for the microchip to be incorporated within the thread. The microchip can further be connected to a data receiving and sending unit. As mentioned, the data receiving and sending unit does not necessarily need to be positioned on or within the single thread on which the layered structure is deposited.

[0031] The thread can be made of a plastic material, in particular a polyester. Any suited plastic material usually used for woven fabrics may be the base for the thread. For example, threads made of polyacrylonitrile or polyamides may be used, too. Threads of cotton or wool can be used, too. The choice of a suited thread material depends on the prerequisites for the layered structure and the intended use. For some applications, a plastic material is preferred due to a lower surface roughness. For other applications and integration into a final application, cotton or wool can be a preferred choice for the thread material. In essence, any suited thread may be used with the scope of the invention, including both, natural and synthetic yarns, monofilament yarns, multifilament yarns and/or staple yarns.

[0032] The thread can be a monofilament yarn. In this case, the thread consists essentially of one single filament of preferably a plastic fiber, for example made of polyester. Such threads can be produced by spinning. Alternatively, it is also possible that the thread is a multifilament yarn. In particular, the thread can be comprised of several filaments building up the multifilament yarn.

[0033] The layered structure is preferably elastically deformable. With this property, the layered structure and, hence, the functional unit can be stretched together with the thread without the risk of losing its functionality.

[0034] The device can comprise a cover or a cover layer. The cover or cover layer protects the functional unit(s). The cover or cover layer may be formed by a plastomer. If a functional unit requires a contact to its surrounding in order to function proper, selected areas may be recessed from the cover or cover layer. In a very simple example, the cover or cover layer is produced by dip-coating.

[0035] According to the advantages outlined above, the invention comprises in a further aspect a woven fabric or a wearable device comprising at least one thread according to the invention.

[0036] In a further aspect, the invention provides a method for producing a device comprising a thread and a layered structure arranged on a surface of the thread, in particular a device according to the invention, the method comprising the steps of:

a) providing the thread;
b) positioning the thread in order to allow for a deposition of a layer;
c) depositing the layer on the surface of the thread;
d) repeating steps b) and c) to assemble the layered structure;
e) optionally applying a coating on the thread at least in a region where the layered structure is deposited.

[0037] A method according to the invention allows to produce a device in the form of a thread with a functional unit provided by a layered structure in a flexible and resources minimizing way. In particular, a method according to the invention allows the production of a device according to the invention thereby providing a product with the advantages discussed in the foregoing. During the deposition of one or more layers to build up a layered structure and, hence, functional unit on the thread, the latter can be held in a fixed position when a layer is deposited. However, a movement of the thread relative to a deposition device like a printer during a deposition step is also possible. In any case the thread should be positioned during a deposition process to allow depositing of a layer having a constant layer thickness and preferably a homogenous inner structure if this is desired.

[0038] It is preferred that at least one layer is deposited by printing, in particular roll-to-roll printing. A printing process can be a static printing process or a continuous printing process. In one embodiment, all layers of the layered structure are printed. If the thread comprises several functional units like sensors or the like, the layers of each functional unit can comprise printed layers only. This also hold for connection and optionally further components.

[0039] Further features and advantages will be recognizable from the examples described in the following. The drawings relating to the examples show:

Fig. 1 an example of a device according to the invention;

Fig. 2 a schematic example of a process of printing a layered structure on a thread;

Fig. 3 an illustration of a thread comprising several functional units deposited on a surface of the thread;

Fig. 4 a schematic illustration of a large-scale process comprising several deposition steps;

Fig. 5 photographs of threads with layered structures printed thereon;

Fig. 6 details and photographs of layered structures deposited on threads;

Fig. 7 photographs of several examples of functional units deposited on threads;

Fig. 8a a device comprising a thread with a piezoresistive element printed thereon;

Fig. 8b a diagram relating to stretching properties of the device according to Fig. 8a;

Fig. 9a a thread with a temperature sensor deposited thereon;

Fig. 9b a diagram showing a dependency of a resistance of the sensor according to Fig. 9a in relation to temperature;

Fig. 10a a thread with a pH sensor deposited thereon;

Fig. 10b a diagram concerning a pH measurement with the sensor shown in Fig. 10a;

Fig. 11a a thread with a humidity sensor deposited on its surface;

Fig. 11b a response of the humidity sensor of Fig. 11a in dependence of a humidity;

Fig. 12a a temperature response of a microheater;

Fig. 12b an image showing a temperature distribution for a microheater;

Fig. 13 a diagram showing a drying process.

General Concept

[0040] Smart textiles conventional concepts are based on functional thread knitting, weaving or the like are very much limited due to the complexity to form multilayer devices, inadequate capacity for interface engineering, and also restricted by the features of the functional threads. Printed electronics directly applied on textile fabrics have already shown many advantages to simplify the process and to produce multilayer thin film devices. However, it has some drawbacks, which are important to address, including the bulkiness and sensing layers to delaminate or crack, destroying the functionality, and short lifetimes due to the waviness and frictional stress on the printed layers. The inventive integrative production process is relatively inexpensive and compatible with mass volume production in a normal inline textile production facility. This new type of electronics on threads and filaments ensures the preservation of the natural textile while providing a wide range of functionalities to smart textiles, which can apply to consumer electronics, health monitoring, sports performance assessment and many more.

[0041] An inventive device 1 comprises a layered structure 3 printed onto a surface 4 of a thread 2 as shown in an example in Fig.1. The number of layers 5 (1 to n) depends on the applications requirements, the functionality of the device, and its design. The materials of the individual layers 5 can be anything that ranges from conductive to semiconductive and dielectric materials and these layers can be deposited in any arbitrary shapes. Any suitable printing method can be used for the patterning. In particular, conventional or digital printing methods can be chosen for the individual layers 5. However, principally other deposition methods like vapor deposition or sputtering techniques can also be applied.

[0042] With the invention, a next generation of wearable systems is provided wherein electronic components are integrated onto a single thread 2. In particular, wires, sensors, power source, transistors, connections to the cloud, and so on can all be included on a thread 2. This will enable, e.g., a digital wearable micro-total analysis system (μTAS) for medical and consumer electronics applications on a single thread 2.

[0043] As such, the invention provides a new paradigm for smart textiles. The invention envisions next generation textile electronics with numerous functionalities and high degrees of miniaturization and robustness. This approach opens the door for a wide range of new smart textiles with features that cannot be achieved with the current solutions. It will also be possible to incorporate several different sensors or actuators directly on a single thread 2, thereby creating multi-functional threads 2. By avoiding cross-overs between threads 2 and by benefiting from scaled down dimensions, the robustness of the functional units on the threads 2 will be increased, leading to more reliable textile products with longer lifetimes and more functionalities. Moreover, the devices comprising threads 2 and functional units thereon can be developed independent of the actual textiles in which the devices will be used for. Therefore, such devices can serve a wide range of different products through incorporating them into textiles, for instance, by embroidery.

[0044] In terms of possible functionalities integrated onto such threads 2 in connection with the invention, the entire broad range of printed electronics is available. This includes temperature, moisture strain, potentiometric chemical sensors (for example pH or pathogens) or biopotential sensors, to name a few. The invention also allows to realize actuators like microheaters (for localized thermal management), optical elements (like electroluminescence for phototherapy of wounds) or supercapacitors and thermoelectric generators for energy management. The inventive devices 1 can eventually find a wide range of applications, such as health monitoring wearables, smart sutures for surgical implants, sweat monitoring, smart bandages to monitor wound healing, point-of-care diagnostics, engineered tissue constructs for organ-on-a-chip platforms, and other consumer electronics segments. The applications are not limited to the above list. The inventive devices 1 extend to the miniaturization of all printed sensors and functionalities in current use.

Aerosol jet printing (resolution down to ~10 μm), inkjet printing (resolution down to ~30 μm) and screen printing (resolution down to ~25 to 50 μm) are capable of high-resolution patterning. For the sake of demonstration, several structures are shown in the following, which should be considered as examples exhibiting some of the possible functionalities. The examples are made on threads in the range of 300 μm to 1000 μm. Due to the maturation of master preparation for industrial roll-to-roll printing processes such as screen printing/gravure printing/flexographic printing, these technologies enable a commercial translation of the devices1 by using efficient roll-to-roll functional thread printing as described below.

[0045] As mentioned, a structure according to Fig. 1 can be printed on a thread 2 by using printing methods like ink-jet printing. This is exemplary shown in Fig. 2. A thread 2 is suitably fixed in or on a base so that an exact printing of a desired functional unit is possible.

[0046] Fig. 3 shows a device 1 according to the invention, wherein the device comprises a couple of functional units deposited on the surface 4 of a thread 2.

[0047] Fig. 4 depicts a possible industrial scale production of an inventive device 1. An industrial scall roll-to-roll process is used. The process setup comprises two rolls, preferably positioned on a process start and a process end. A first roll provides a thread material whereas the second roll picks up the thread material after the process steps. A thread 2 is guided through a process line with the help of the rolls. Depending on the processes used, the thread 2 is moved continuously or with interruptions and holding times at certain positions. As shown in Fig. 4, one or several printing processes ranging from modern jet deposition (ink jet, aerosol jet or the like) to conventional printing techniques such as offset printing, flexographic printing, gravure printing, and screen printing can be used.

[0048] Similarly, one or more curing processes, for example UV, laser or heat curing, can be employed. The choice for the specific printing and curing processes depends on the applications and requirements of the functional units to be deposited. In general, a process line like those shown in Fig. 4 enables a realization of a simple as well as multilateral and multi-layered structures and provides flexibility in the attainable range of layer thicknesses (ranging from some tens of nanometers to micrometers). Such a process also offers the capabilities to accommodate a broad set of viscosities, surface tensions and functional properties of the inks. The process line can be tailored to print on several sides of the thread 2, wherein the printing process can be arranged in a specific manner. For example, the flexography/gravure and jet printing units give the possibilities to print from both sides of the thread 2. Another option is to use angle bars (turn bars) to rotate the thread 2 in the printing area printing on different sides of the thread 2. An offset printing unit configuration called blanket to blanket printing could enable the simultaneous printing on both sides of the thread 2. The described process line could also comprise one of several curing methods such as thermal, UV polymerization or laser sintering, depending on the curing of different functional materials. Localized curing methods like laser sintering will enable high temperature sintering without damaging the thread. Chip integration (if required) on the thread 2 is another aspect, which can be accommodated by such process line. In such cases, an antenna and required interconnection can be fabricated within the process line by applying a suitable printing method. Web guides in the printing area can assist the precise lateral print registration and act as enabler towards the simultaneous multithread printing (parallel printing). This means the lateral movement of the thread 2 will be spatially confined with appropriate guide limits.

[0049] All features explained in the foregoing general concepts are in line with the invention and may be combined with the general teaching of the invention.

Specific Examples

Deposition of functional units

[0050] Fig. 5 shows some devices 1 according to the invention. In order to obtain such devices, screen printing and inkjet printing were applied. For the screen-printing, polyester monofilament-based screens with a mesh count of 150 per inch and a thread diameter of 59 μm were used. Printing was carried out with a semiautomatic flatbed screen printer.

[0051] The inkjet printing was carried out with a Suss LP 50 printer based on Pixdro technology and a Spectra S class print head was used. Multiple conductive and non-conductive inks were applied such as the Loctite ECI 1006 Silver paste, Saralon GMBHs Saral 700A carbon-based ink, Clevious PH1000 PEDOT: PSS, CHT Alpaprint clear NG insulative ink and Dycoatec DM-CAP-4511S. The printed samples were cured below 100 °C in a box oven. However, the curing condition mostly depend on the materials used for the thread 2 and ink.

[0052] Fig. 6 depicts multilayer printing examples on threads. Different patterns and sandwich structures are feasible. This creates the opportunities to build complex devices such as energy harvesters, energy storage, logic and light emitting devices. As an example, a chemical sensor can be encapsulated with a stretchable rubber coating layer acting as a protection layer to the printed chemical sensors, by optionally printing (patterning) of the coating layer according to desired sensing architecture and leaving a defined area (typically few hundred micrometer square) of the chemical sensor (sensing area) left open to environment, to fulfill its function.

[0053] Similarly, additional multilayer design strategies and adaptations can be adopted to fulfill end-application requirements. For example, a key challenge with smart textiles is the requirement for textile re-use and related resistance to washing cycles. In particular, threads 2 such as those made from cotton are prone to fiber swelling and expansion which may lead to cracks in the printed structure following a washing cycle. It will be clear to the skilled in the art that by selecting the right combination of multilayer printing and functional formulations, the desired property can be achieved. In the case of washing the right end encapsulation formulation needs to be selected for fiber, application process and textile washing compatibility. An example of suitable formulations is available from CHT Group with TUBICOAT MP-D or TUBIGUARD 30-F. Fig. 7 depicts examples of different materials printed on threads 2. Different patterns are feasible. This creates the opportunities to print materials with different functions (insulating, protecting, conducting, piezoelectric, magnetic etc.).

[0054] The printed structures on threads can also be stretchable. An example is shown in Fig. 8a, showing a conductor being printed using Dycoatec DM-CAP-4511S carbon paste and insulated by spray coating with a stretchable transparent coating. Fig. 8b shows the reversible piezoresistive response upon stretching to 15%.

Example 1 - Temperature Sensor

[0055] A temperature sensor was realized on a thread 2 with the help of screen-printing Saralon carbon paste cured at 100° C. The structure of the sensor realized on the thread 2 is as shown in Fig. 9a. A sensor testing was been carried out in a climate chamber at 30% relative humidity wherein the temperature was varied and the corresponding resistance change was monitored. As shown in the diagram in Fig. 9b, a resistance of the temperature sensor responds to a temperature change.

Example 2 - pH Sensor

[0056] A pH sensor has been realized on a thread 2 by printing Dycoatec DM-CAP-4511S carbon paste as a working electrode and Ag/AgCl paste as a reference electrode (shown in Fig. 10a). This working electrode was functionalized by drop casting of a conductive polymer solution on it. This conductive polymer was prepared from Polyaniline (mw 20000g/mol) dissolved in dimethyl sulfoxide (DMSO), resulting a 0.4 wt% PANI-DMSO ink. The realized sensor used electrochemical potentiometric measurements whereby the working electrode potential against the reference electrode was recorded. The conductive electrodes were coated with polymer ink, Alpa print clear NG (CHT group) to insulate certain areas of the electrode from the pH buffer. The sensor was tested against the pH buffer ranging from pH 4 to pH 9 as shown in Fig. 10b. The sensor exhibited a sensitivity of approximately 30 mV per pH unit of 1.

Example 3 - Humidity Sensor

[0057] A resistive humidity sensor was fabricated on threads 2 with the help of screen-printing carbon paste. The sensor was tested in a climate chamber for a relative humidity (RH) range from 15% to 90% at 20 °C (shown in Fig. 11b). The sensor has demonstrated a sensitivity of 0.3% resistance change per unit RH.

Example 4 - Microheater

[0058] Microheaters were prepared with the help of printing silver and carbon paste on a thread 2. The microheaters consist of high-resistive carbon, which is contacted by low-resistive silver electrodes. To this end, the silver electrodes were first printed leaving a gap of a few millimeters between the electrodes. The gap was filled by printing carbon paste, acting as microheater with a width of less than 700 μm. The microheaters showed excellent heating behavior (Fig. 12a and Fig. 12b) and a positive temperature coefficient. The heating is uniform and it is adequate for thermal sensing applications in transient measurements. The microheaters can be applied for moisture sensing applications, where the sensor is set to transient heating of few hundred milliseconds and used for the measurement. This concept is shown, as an example, in Fig. 12a, where the changes in the thermal effusivity of the surrounding environment leads to changes in the transient heating behavior of the sensor. The thermal principle-based sensor can be beneficial for wearable sensors such as wound monitoring, where the sensor can effectively measure the wound exudate volume without any cross sensitivity. Such a microheaters can also be used for drying processes as shown in Fig. 13.

Claims

1. A device (1) comprising a thread (2) and a layered structure (3), wherein the layered structure (3) is arranged on a surface (4) of the thread (2).

2. The device (1) according to claim 1, wherein the layered structure (3) is printed on the surface (4) of the thread (2).

3. The device (1) according to claim 1 or 2, wherein the thread (2) has a diameter of less than 1500 μm, preferably 10 μm to 1200 μm, in particular 20 μm to 1000 μm, for example 25 μm to 300 μm.

4. The device (1) according to any one of claims 1 to 3, wherein the layered structure (3) comprises at least two layers (5) abutting on each other, in particular stacked on each other, wherein at least one of the layers (5) is arranged on the surface (4) of the thread (2).

5. The device (1) according to any one of claims 1 to 4, wherein a layer (5) of the layered structure (3) has a thickness of 10 nm to 10 μm, preferably 50 nm to 3 μm, in particular 100 nm to 1,5 μm.

6. The device (1) according to any one of claims 1 to 5, wherein the layered structure (3) has a thickness of about 100 nm to 10 μm, preferably 150 nm to 5 μm, in particular 150 nm to 2 μm.

7. The device (1) according to any one of claims 1 to 6, wherein the layered structure (3) is a printed electronic and/or a sensor.

8. The device (1) according to any one of claims 1 to 7, wherein the thread (2) comprises electrical contacts, wherein the electrical contacts are connected to the layered structure (3).

9. The device (1) according to any one of claims 1 to 8, wherein the thread (2) comprises at least two layered structures (3).

10. The device (1) according to any one of claims 1 to 9, wherein the device (1) comprises at least one microchip, wherein the at least one microchip is arranged on or within the thread (2) and wherein the at least one microchip is electrically connected to the layered structure (3).

11. The device (1) according to any one of claims 1 to 10, wherein the thread (2) is made of a plastic material, in particular a polyester, and/or wherein the thread (2) is a monofilament yarn.

12. The device (1) according to any one of claims 1 to 11, wherein the layered structure (3) is elastically deformable.

13. A woven fabric or a wearable device comprising at least one thread according to any one of claims 1 to 12.

14. A method for producing a device (1) comprising a thread (2) and a layered structure (3) arranged on a surface (4) of the thread (2), in particular a device (1) according to one of claims 1, the method comprising the steps of:

a) providing the thread (2);
b) positioning the thread (2) in order to allow for a deposition of a layer (5);
c) depositing the layer (5) on the surface (4) of the thread (2);
d) optionally repeating steps b) and c) to assemble further the layered structure (3);
e) optionally applying a coating on the thread (2) at least in a region where the layered structure (3) is deposited.

15. The method according to claim 14, wherein at least one layer (5) is deposited by printing, in particular roll-to-roll printing.

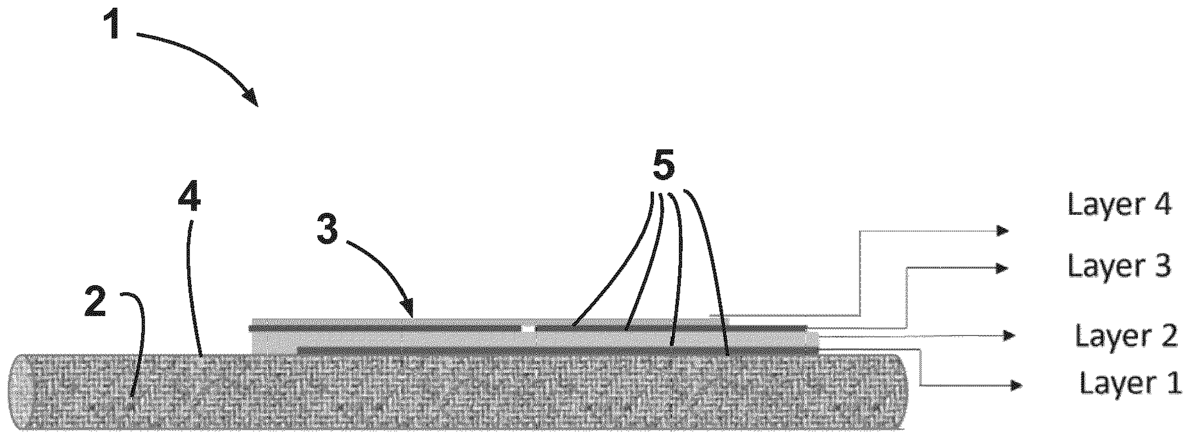

Fig. 1

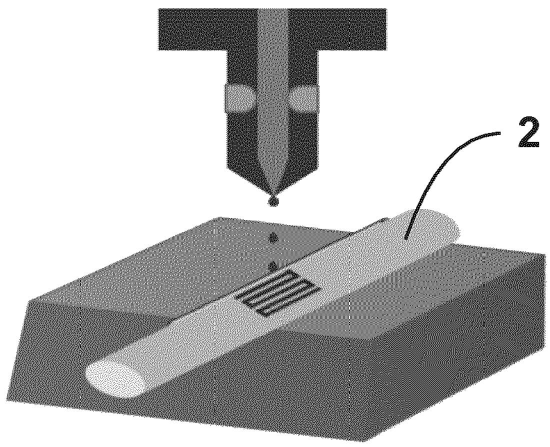

Fig. 2

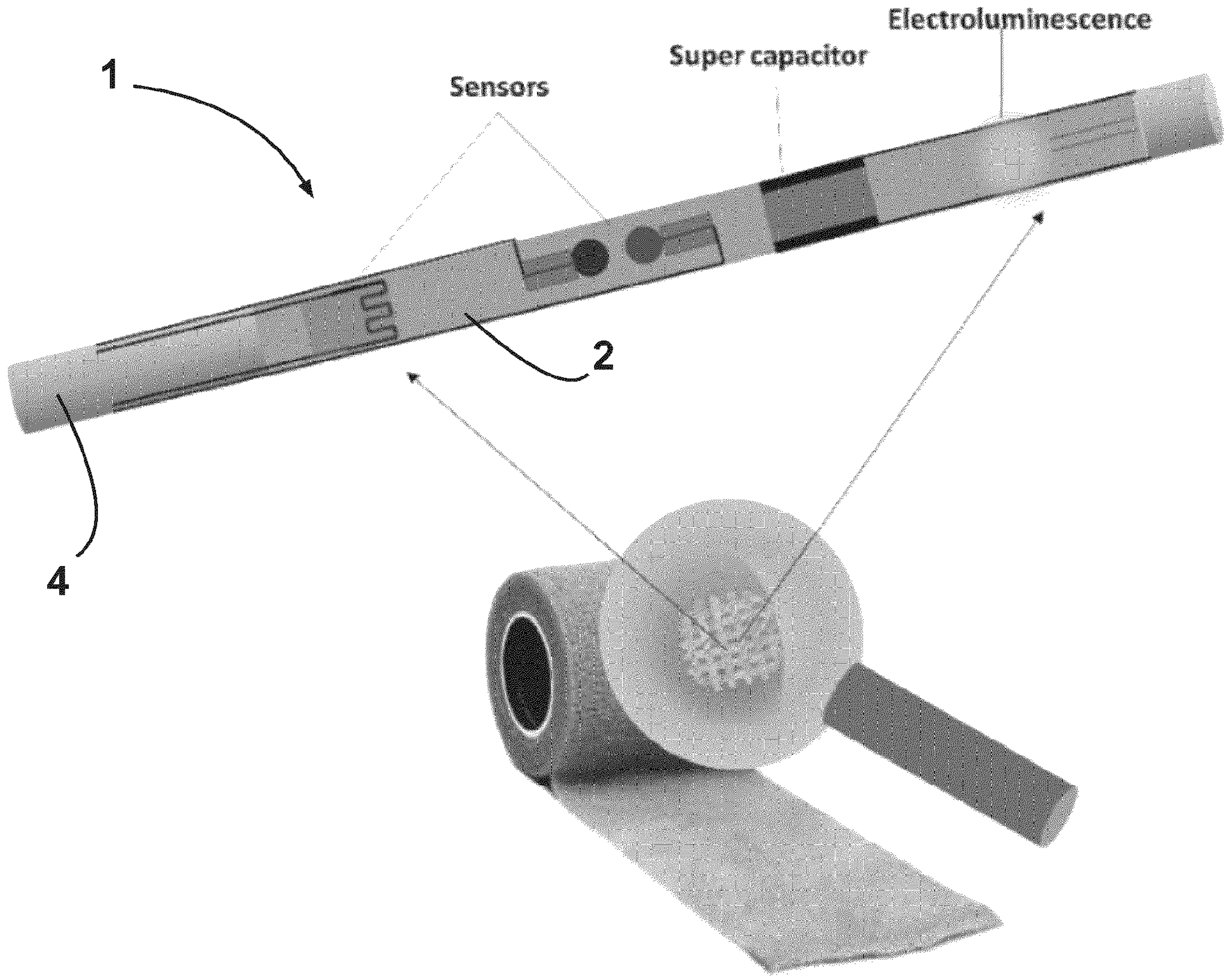

Fig. 3

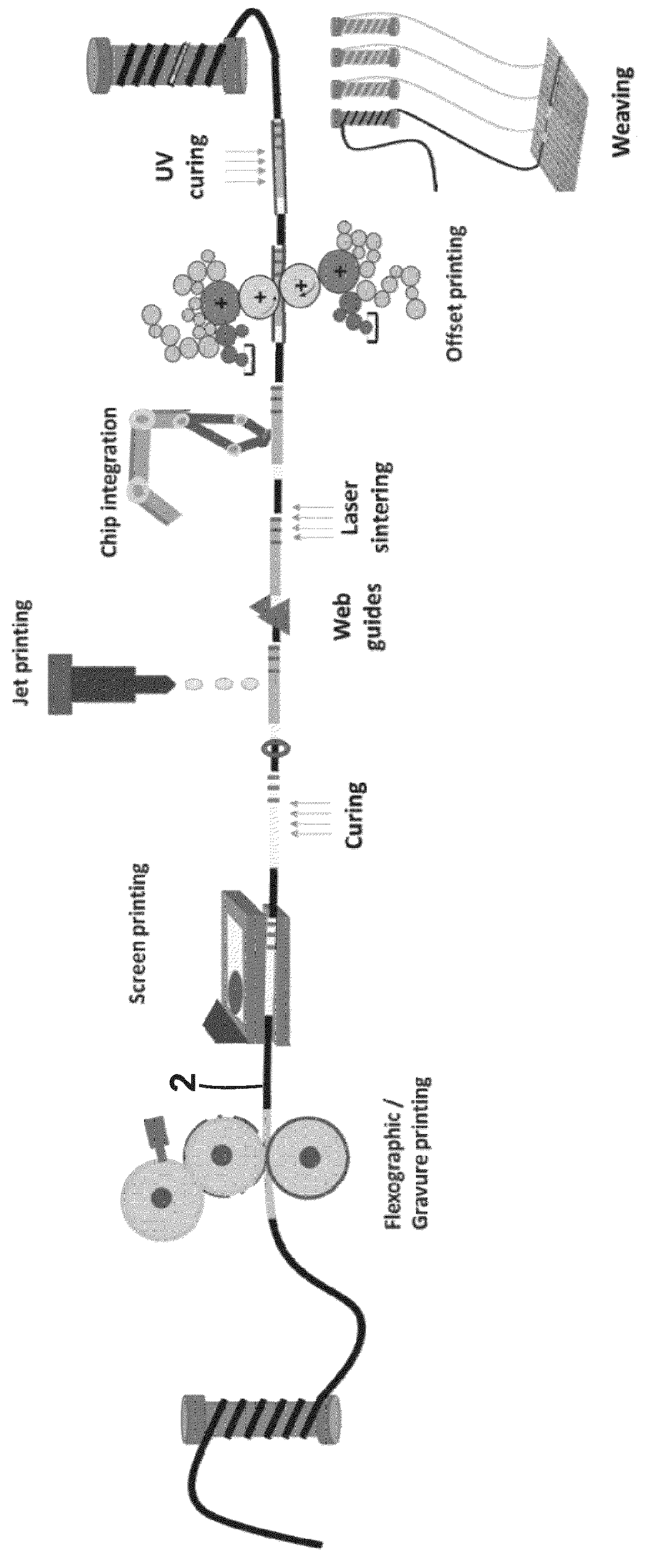
Flexographic / Gravure printing
2
Screen printing
Curing
Jet printing
Web guides
Chip integration
Laser sintering
Offset printing
UV curing
Weaving

Fig. 4

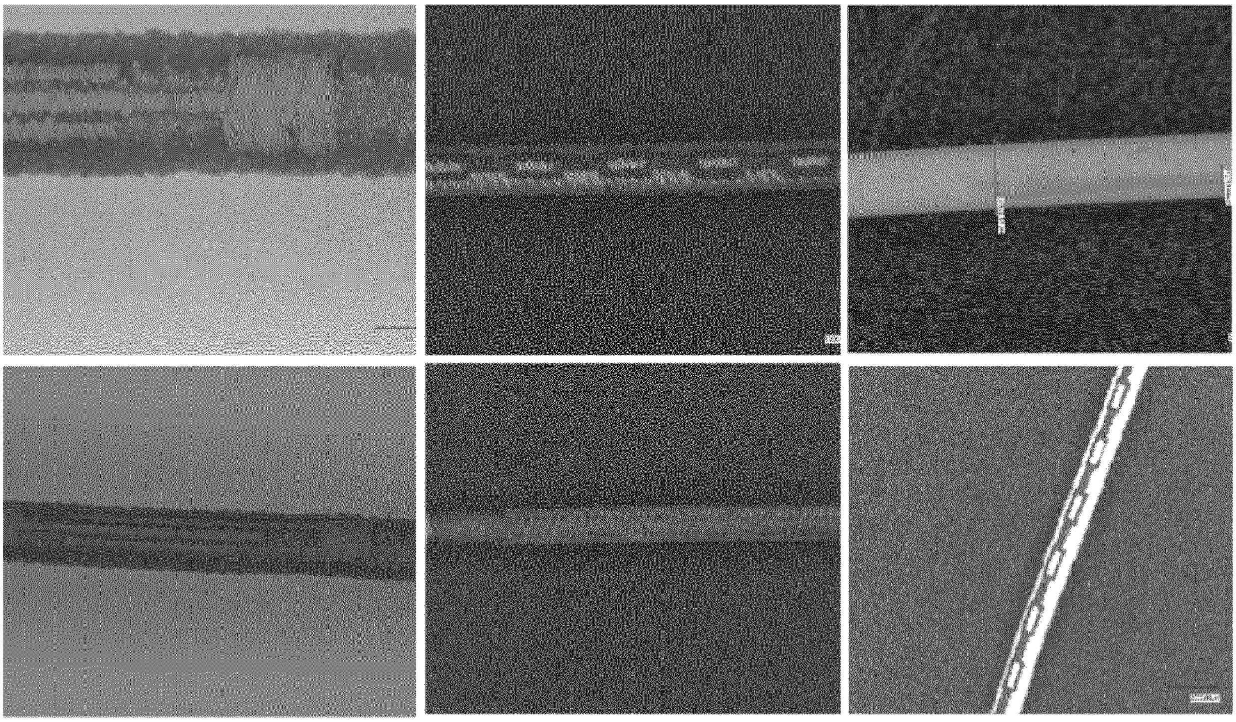

Fig. 5

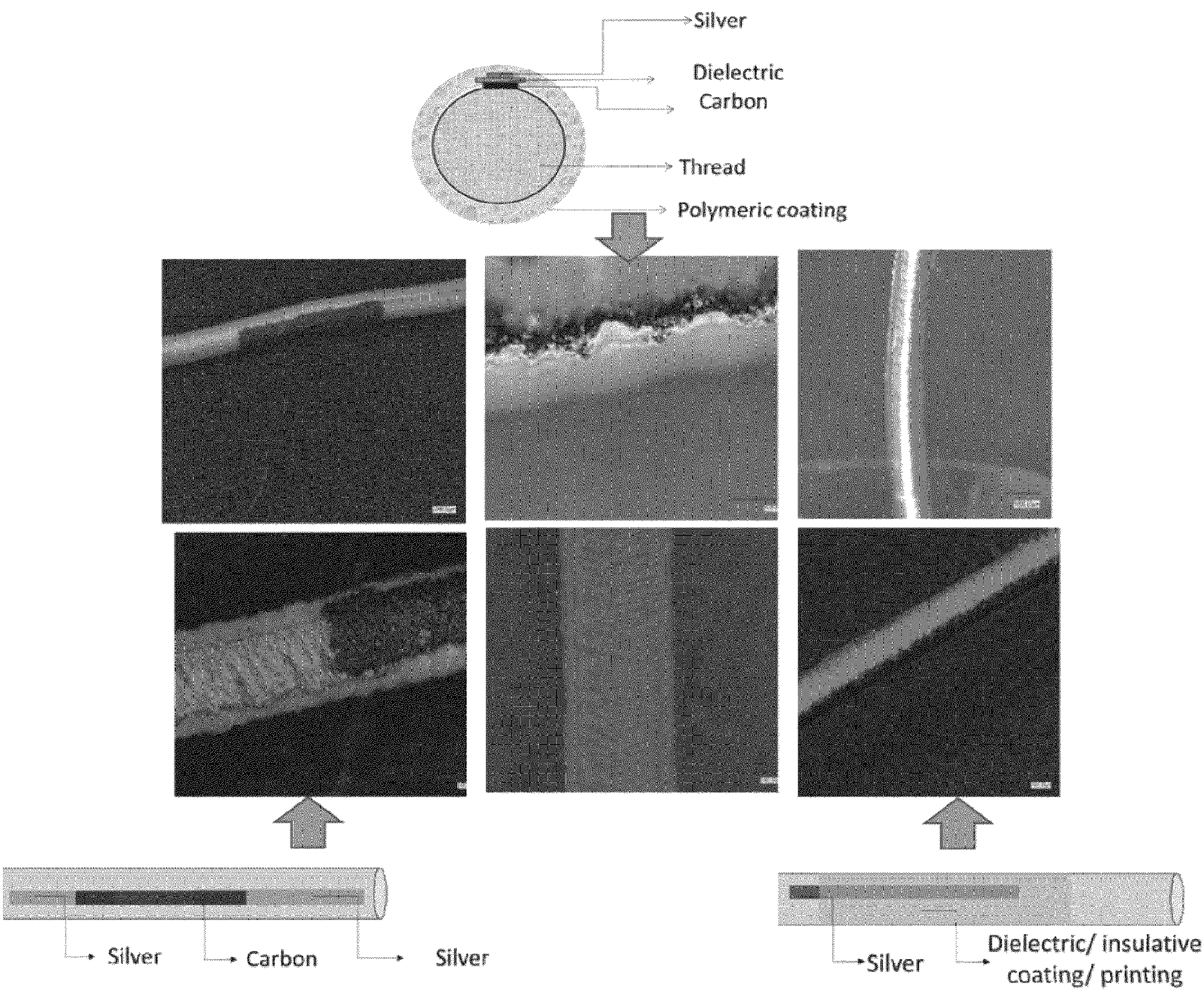
Silver
Dielectric
Carbon
Thread
Polymeric coating
Silver
Carbon
Silver
Silver
Dielectric/ insulative coating/ printing

Fig. 6

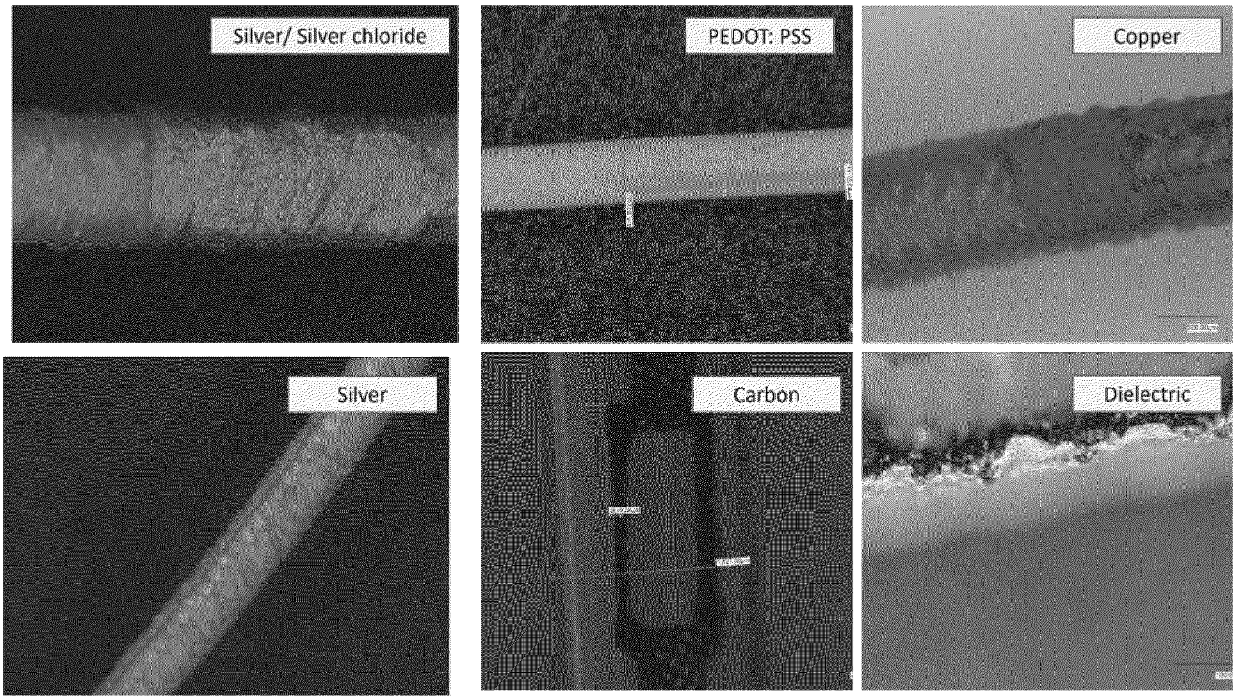
Silver/ Silver chloride
PEDOT: PSS
Copper
Silver
Carbon
Dielectric

Fig. 7

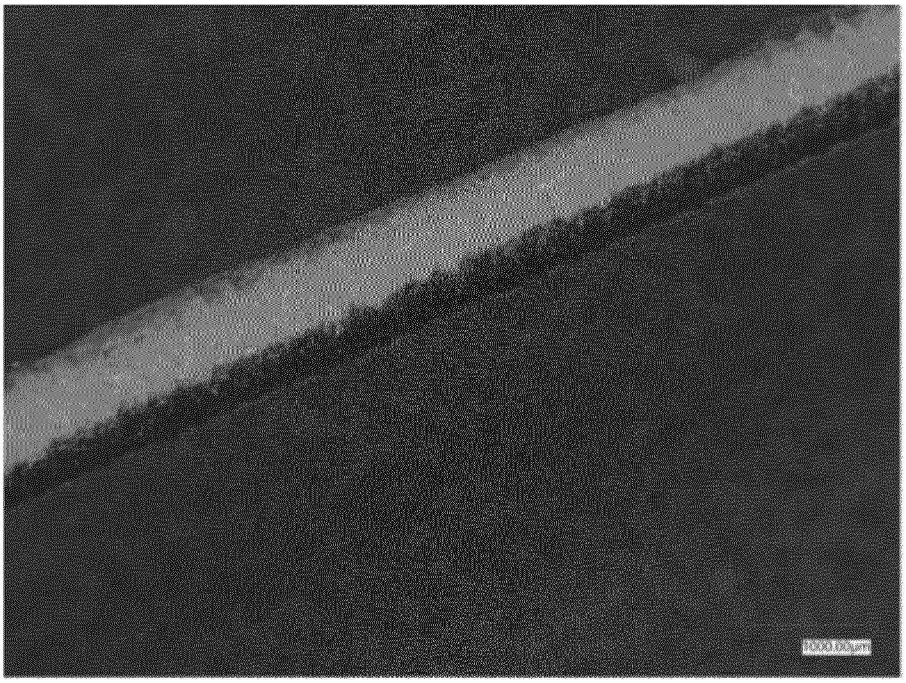
1000.00µm

Fig. 8a

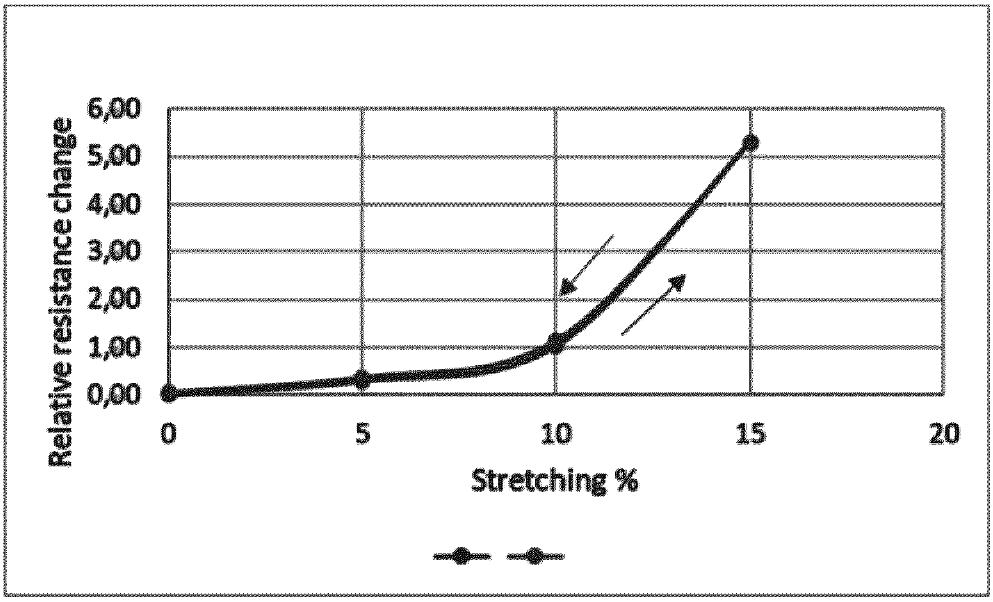
Relative resistance change
6,00
5,00
4,00
3,00
2,00
1,00
0,00
0
5
10
15
20
Stretching %

Fig. 8b

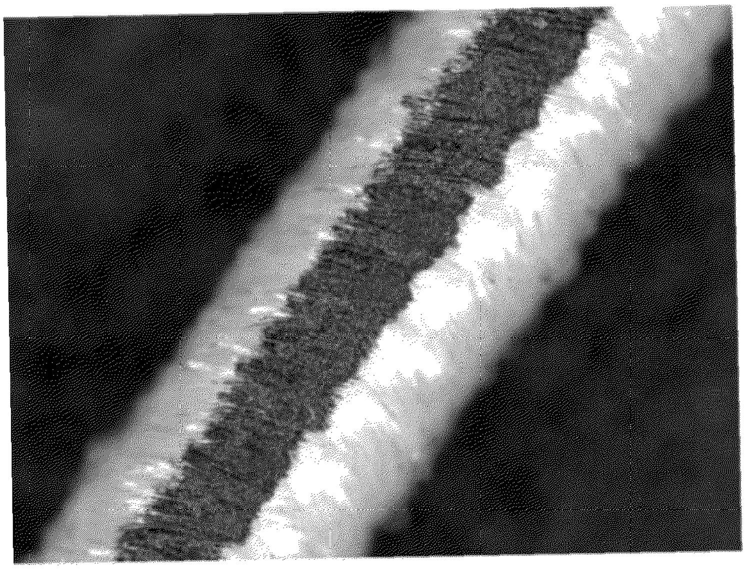

Fig. 9a

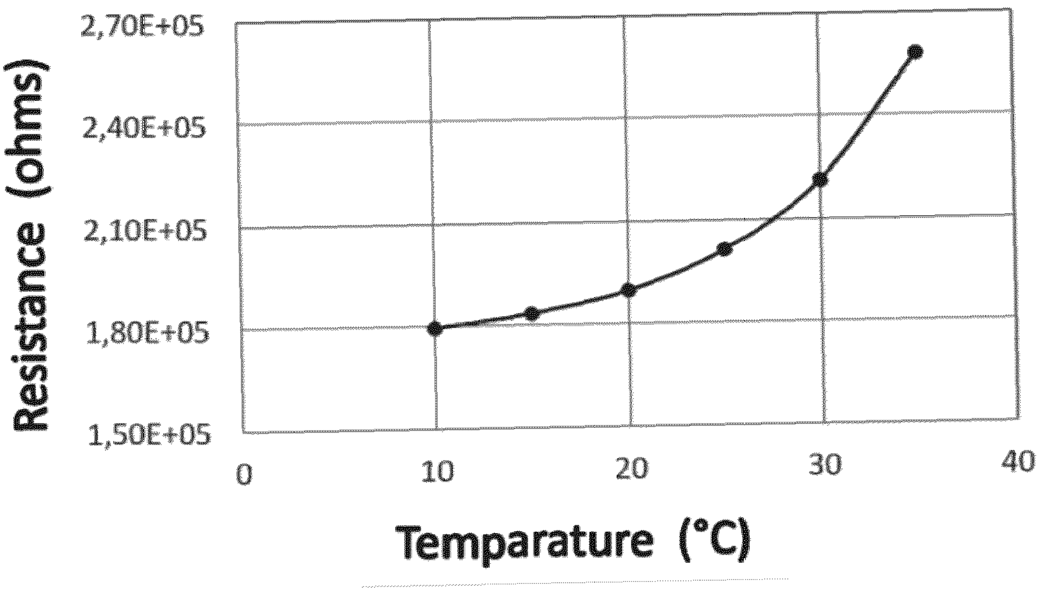
2,70E+05
2,40E+05
2,10E+05
1,80E+05
1,50E+05
Resistance (ohms)
0
10
20
30
40
Temparature (°C)

Fig. 9b

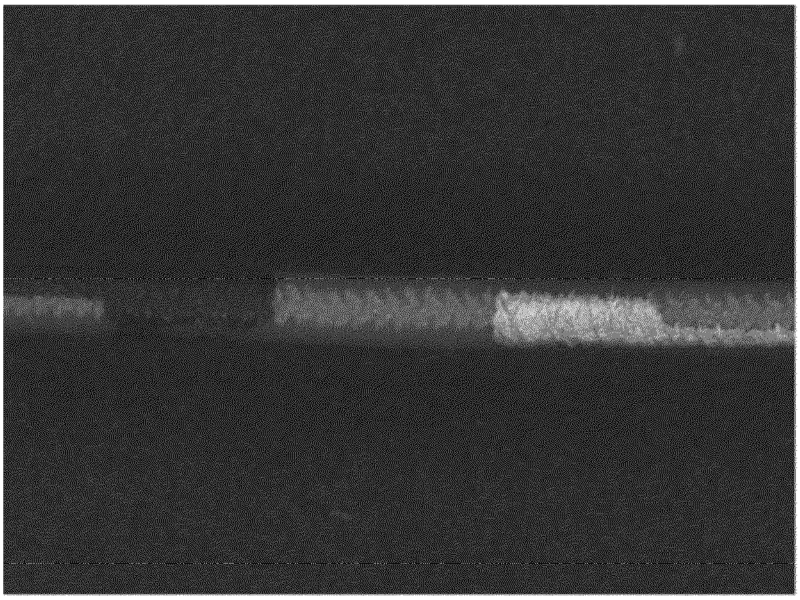

Fig. 10a

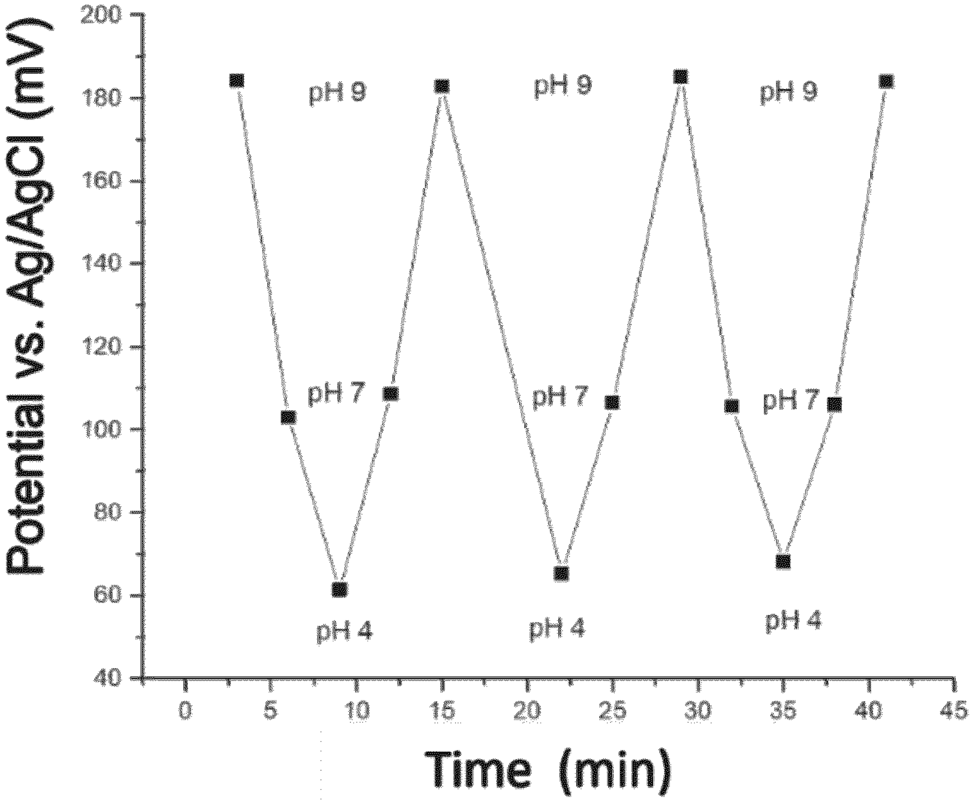

Fig. 10b

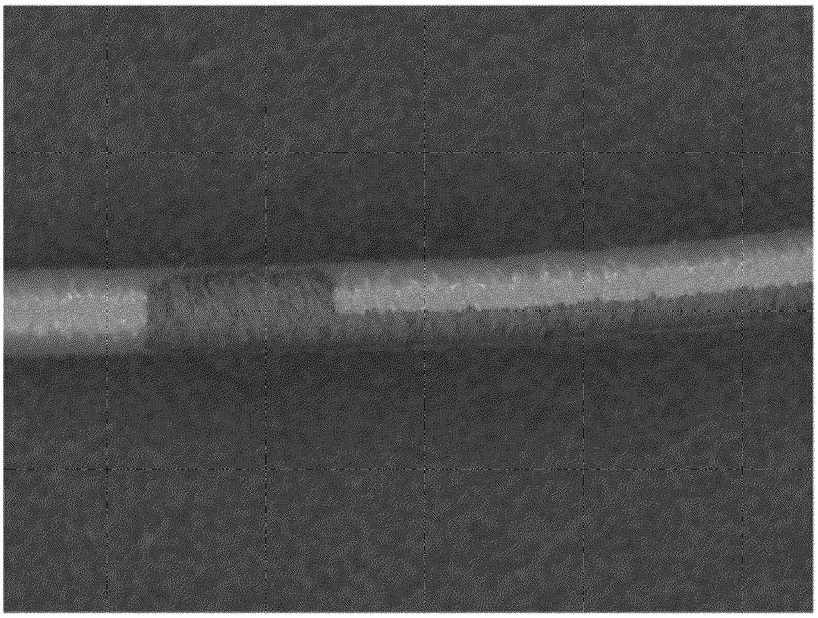

Fig. 11a

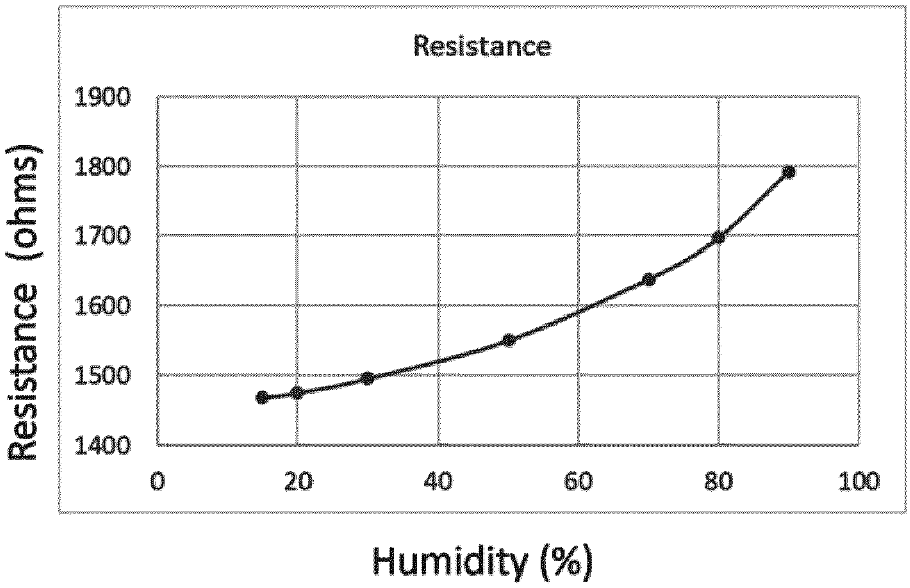

Fig. 11b

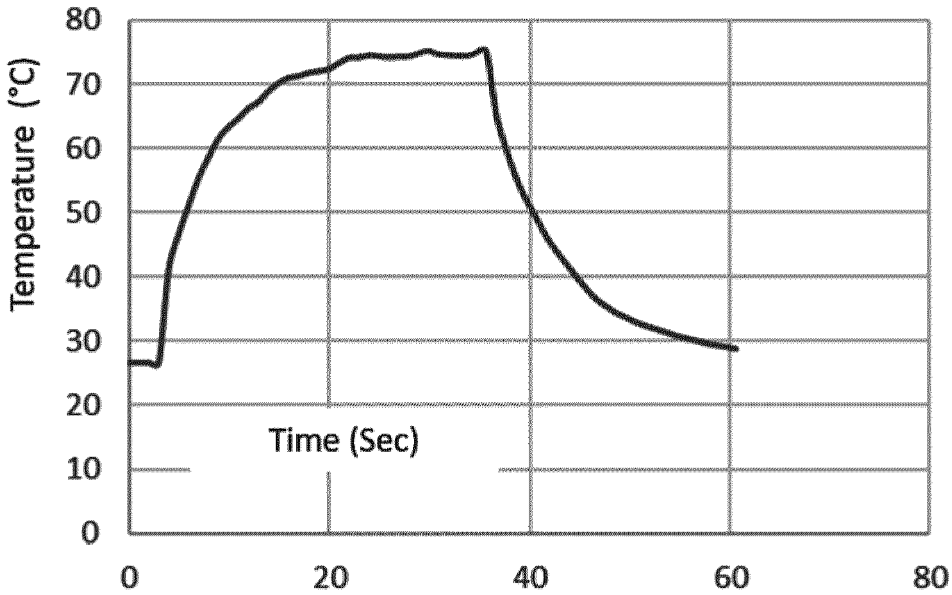

Fig. 12a

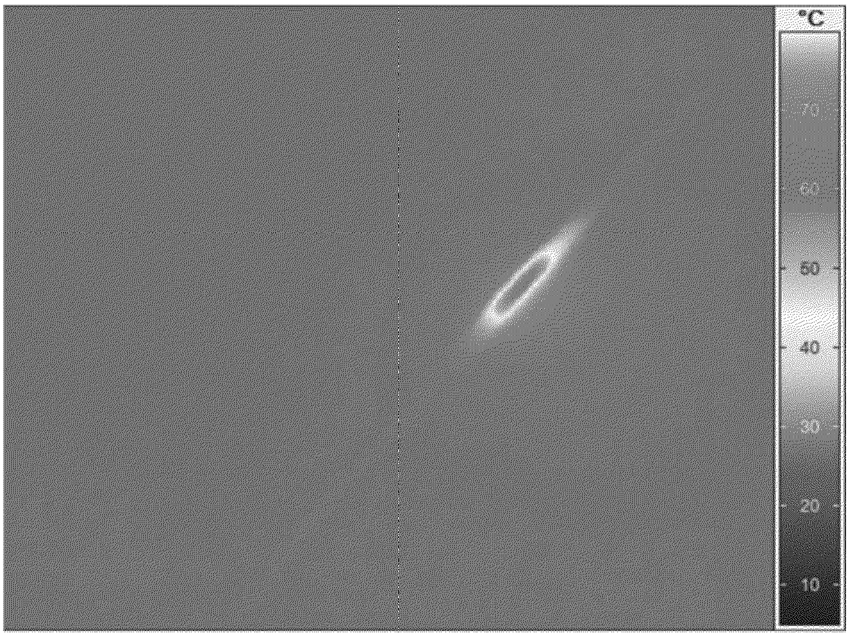

Fig. 12b

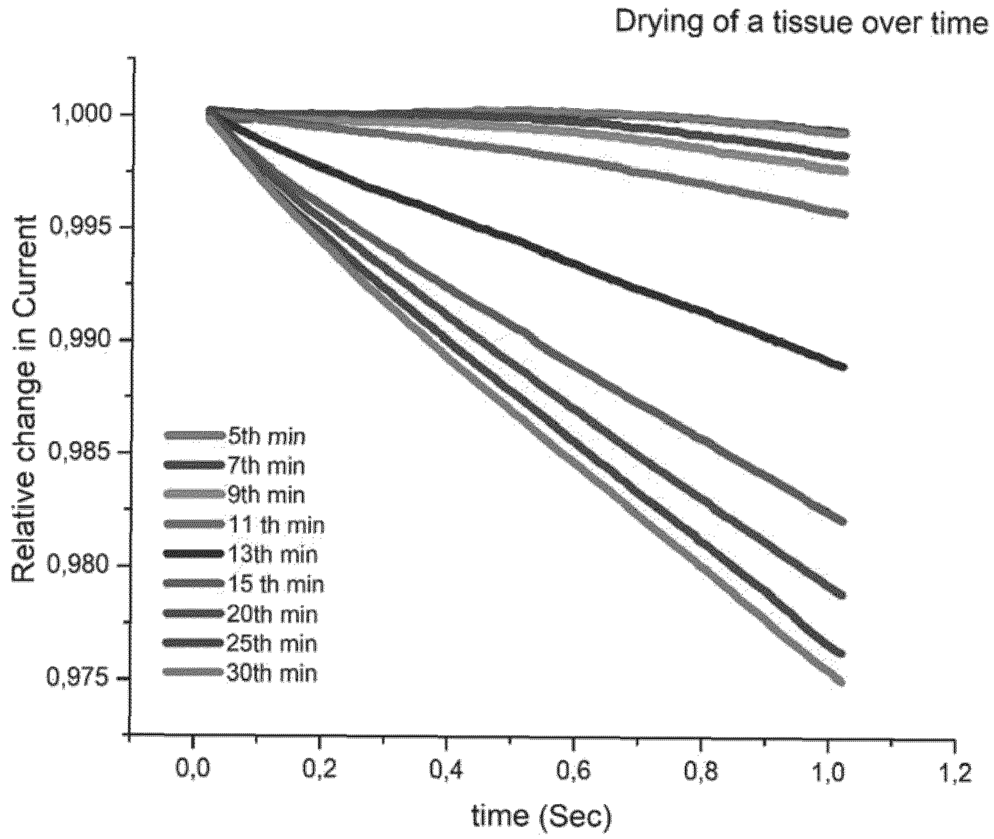
Drying of a tissue over time
Relative change in Current
1,000
0,995
0,990
0,985
0,980
0,975
0,0
0,2
0,4
0,6
0,8
1,0
1,2
time (Sec)
5th min
7th min
9th min
11 th min
13th min
15 th min
20th min
25th min
30th min

Fig. 13

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 6238

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2011/308077 A1 (SHTEIN MAX [US] ET AL) 22 December 2011 (2011-12-22) * paragraph [0003] * * paragraph [0006] * * paragraph [0039] - paragraph [0051]; figures 1-2,6 * * paragraph [0052] - paragraph [0059]; figure 8 * -----	1,3-9, 11-14	INV. D02G3/40 D02G3/44
X	US 2014/160628 A1 (DOYLE BRIAN S [US] ET AL) 12 June 2014 (2014-06-12) * paragraph [0002] * * paragraph [0023] - paragraph [0024]; figures 1-2 * * paragraph [0029]; figure 6 * * paragraph [0032]; figures 8-9 * * paragraph [0042]; figure 20 * -----	1,3-9, 11-14	
X	US 2019/024268 A1 (HWANG SUNBIN [KR] ET AL) 24 January 2019 (2019-01-24) * paragraph [0001] * * paragraph [0007] - paragraph [0016] * * paragraph [0078] - paragraph [0099]; figures 3-4 * * paragraph [0139] - paragraph [0142]; figure 8; example 1 * -----	1-9, 11-14	TECHNICAL FIELDS SEARCHED (IPC) D02G D03D B41J D06P
X	US 2020/141034 A1 (JACKSON WARREN [US] ET AL) 7 May 2020 (2020-05-07) * paragraph [0001] * * paragraph [0025]; figure 1 * * paragraph [0053] - paragraph [0056]; figure 6a * * paragraph [0059] - paragraph [0061]; figure 8 * ----- -/--	1,2,7-9, 12-15	

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	7 August 2023	Pollet, Didier

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EUROPEAN SEARCH REPORT

Application Number
EP 23 15 6238

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2004/009729 A1 (HILL IAN GREGORY [US] ET AL) 15 January 2004 (2004-01-15) * paragraph [0002] * * paragraph [0022] - paragraph [0025]; figures 1-2 * * paragraph [0070] - paragraph [0074]; figure 10 * -----	1-4,7-14	

TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	7 August 2023	Pollet, Didier

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X : particularly relevant if taken alone
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A : technological background
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T : theory or principle underlying the invention
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L : document cited for other reasons
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07-08-2023

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011308077 A1	22-12-2011	NONE	
US 2014160628 A1	12-06-2014	CN 104781897 A	15-07-2015
		CN 107968117 A	27-04-2018
		JP 2016501440 A	18-01-2016
		KR 20150056855 A	27-05-2015
		TW 201432105 A	16-08-2014
		US 2014160628 A1	12-06-2014
		US 2017316880 A1	02-11-2017
		WO 2014092785 A1	19-06-2014
US 2019024268 A1	24-01-2019	CN 109273438 A	25-01-2019
		US 2019024268 A1	24-01-2019
US 2020141034 A1	07-05-2020	US 2020141034 A1	07-05-2020
		US 2022074089 A1	10-03-2022
US 2004009729 A1	15-01-2004	AU 2003251292 A1	11-11-2003
		CN 1649539 A	03-08-2005
		EP 1503665 A1	09-02-2005
		JP 2005524783 A	18-08-2005
		KR 20050008707 A	21-01-2005
		US 2004009729 A1	15-01-2004
		US 2005081944 A1	21-04-2005
		WO 03094719 A1	20-11-2003

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REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- 1 - The emergence of wearable computing. **MALMIVAARA, M.** Smart Clothes and Wearable Technology. Woodhead Publishing, 2009, 3-24 **[0003]**
- **ISLAM MOLLA, M. T.** *A scalable manufacturing method for garment-integrated technologies,* 2017 **[0003]**
- **LEE, J. ; JEON, S. ; SEO, H. ; LEE, J. T. ; PARK, S.** Fiber-Based Sensors and Energy Systems for Wearable Electronics. *Applied Sciences,* 2021, vol. 11 (2), 531 **[0004]**
- **STOPPA, M. ; CHIOLERIO, A.** Wearable electronics and smart textiles: a critical review. *Sensors,* 2014, vol. 14 (7), 11957-11992 **[0004]**
- **ZHANG, Y. ; CUI, Y.** Cotton-based wearable PEDOT:PSS electronic sensor for detecting acetone vapor. *Flexible and Printed Electronics,* 2017, vol. 2 (4), 042001 **[0005]**
- **LYU, B. ; PUNJIYA, M. ; MATHARU, Z. ; SONKUSALE, S.** An improved pH mapping bandage with thread-based sensors for chronic wound monitoring. *the 2018 IEEE International Symposium on Circuits and Systems [ISCAS,* 27 May 2018 **[0005]**
- **ALAIMO, F. ; SADEQI, A. ; REZAEI NEJAD, H. ; JIANG, Y. ; WANG, W. ; DEMARCHI, D. ; SONKUSALE, S.** Reel-to-reel fabrication of strain sensing threads and realization of smart insole. *Sensors and Actuators A: Physical,* 2020, vol. 301, 111741 **[0005]**
- **ZHANG, S. ; HE, Z. ; ZHOU, G. ; JUNG, B.-M. ; KIM, T.-H. ; PARK, B.-J. ; BYUN, J.-H. ; CHOU, T.-W.** High conductive free-written thermoplastic polyurethane composite fibers utilized as weight-strain sensors. *Compos. Sci. Technol.,* 2020, vol. 189, 108011 **[0006]**
- **KUMAR, T. ; OWYEUNG, R. E. ; SONKUSALE, S. R.** Rapid cleanroom-free fabrication of thread based transistors using three-dimensional stencil-based patterning. *Flexible and Printed Electronics,* 2021, vol. 6 (1), 015007 **[0006]**
- **BENOUAKTA, S. ; HUTU, F. D. ; DUROC, Y.** Stretchable Textile Yarn Based on UHF RFID Helical Tag. *Textiles,* 2021, vol. 1 (3), 547-557 **[0007]**