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(54) Title of the Invention: **Flexible wearable materials having electronic functionality, and articles comprising such materials**
Abstract Title: **Flexible wearable materials and articles having electronic functionality**

(57) Flexible wearable material 300 comprising one or more electrically conductive paths; a control unit comprising a processor; one or more sensors integrated into the wearable material and coupled to the processor, for providing measurement signals to the control unit; an electrical power supply for supplying electrical power to the one or more sensors by means of the one or more electrically-conductive paths; and one or more actuators coupled to and controlled by the control unit. The material may comprise knitted or woven fabric with electrically conductive yarn 10, or a flexible 3d printed material. The sensors may be chosen from pressure sensors; temperature sensors; biosensors; moisture sensors; accelerometers and inclinometers. The actuators may comprise one or more motors that can provide a massage or vibration function, or one or more heating elements. The material may be used to form an item of footwear, a sock, a tubular article for sheathing a limb, a boot, sock or pad for an animal's hoof or paw, or a vehicle seat.

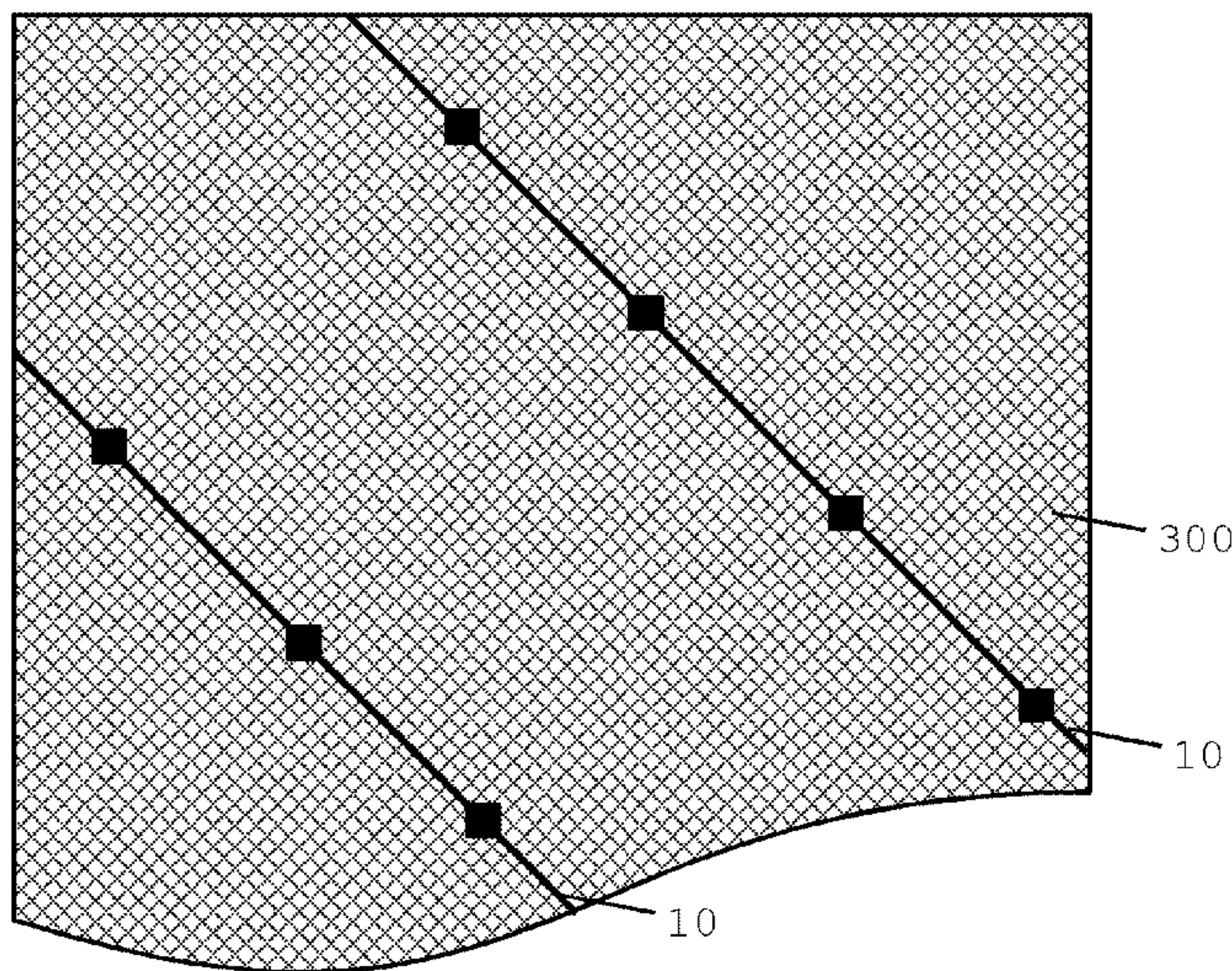


Figure 2

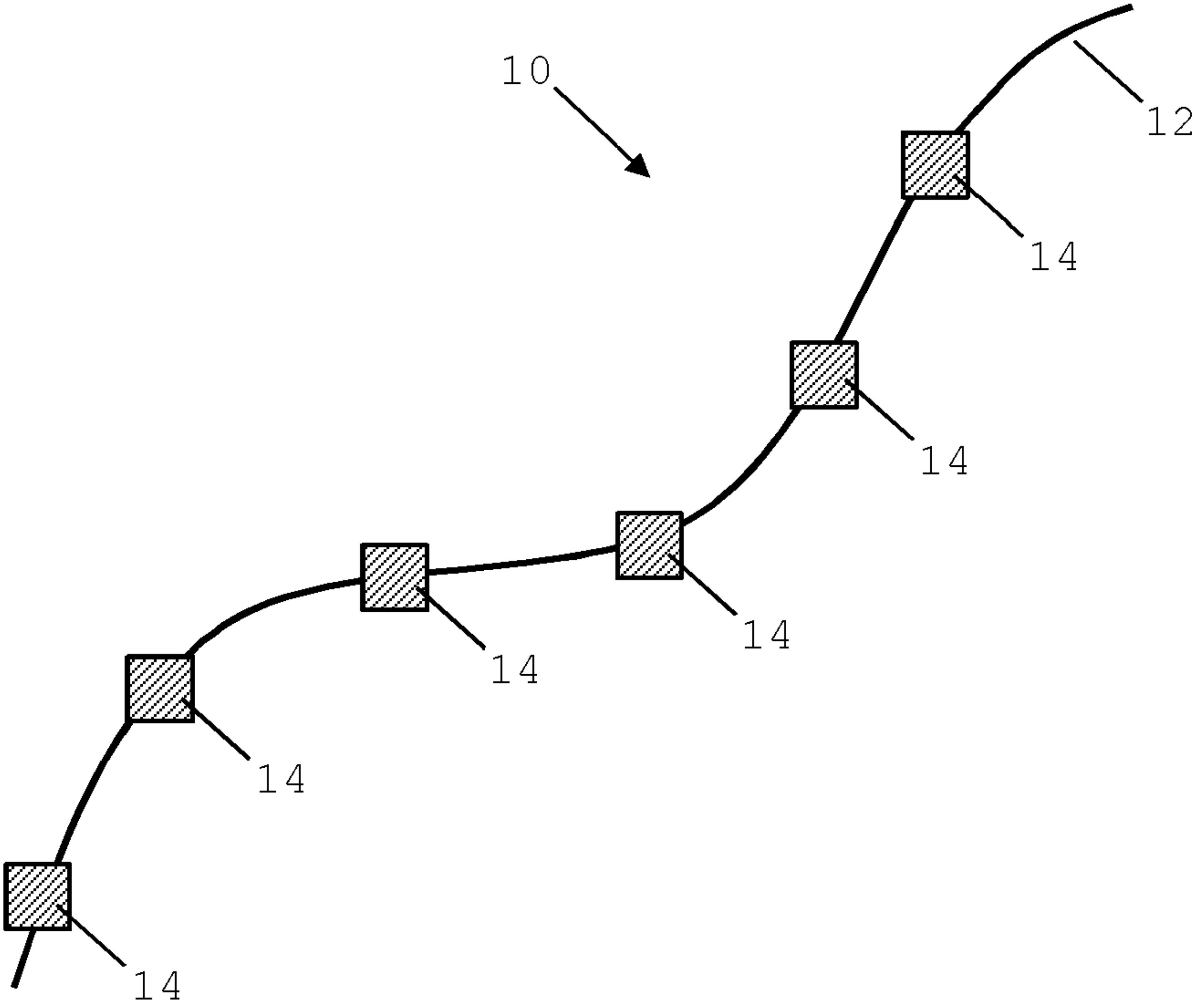


Figure 1

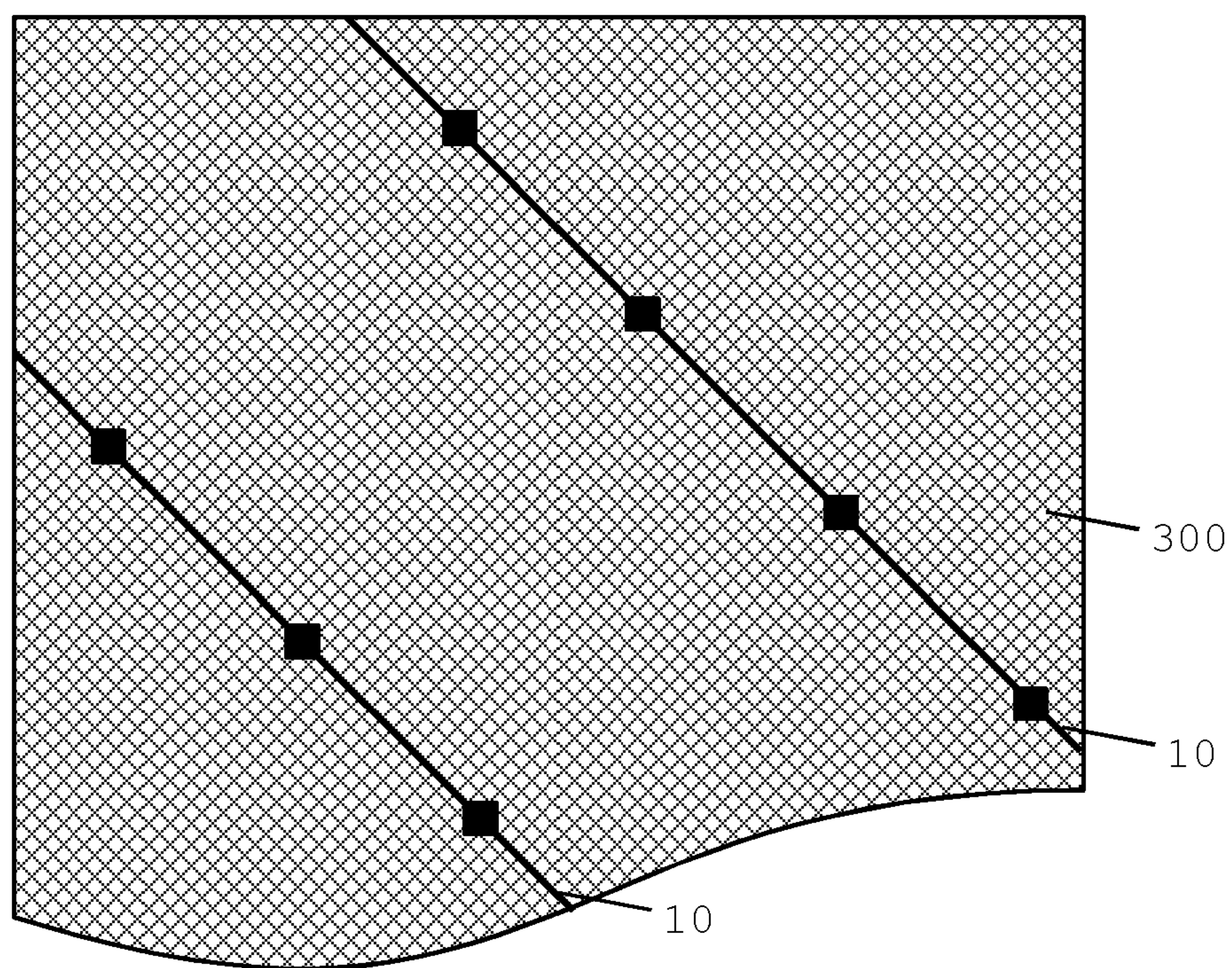


Figure 2

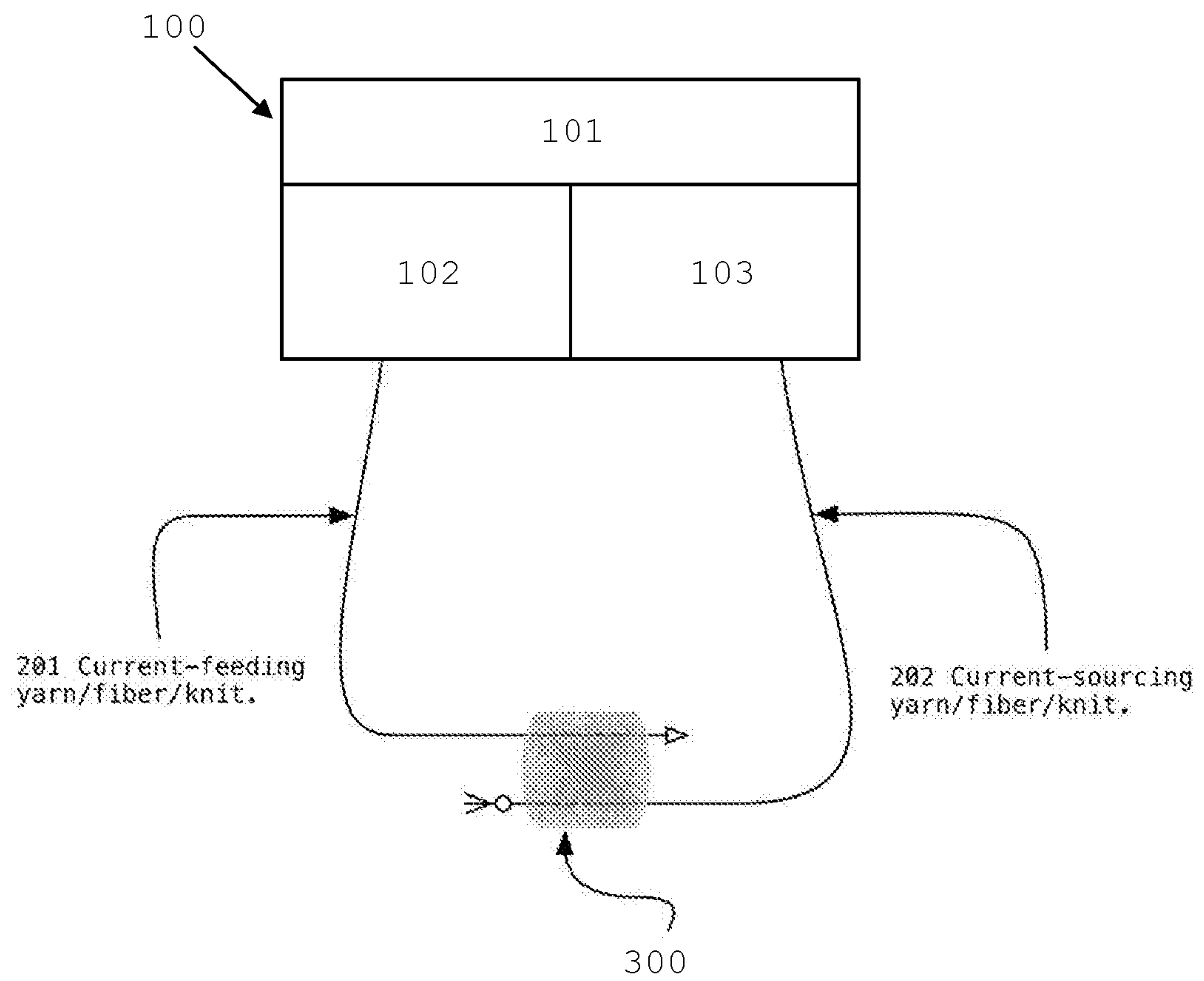


Figure 3

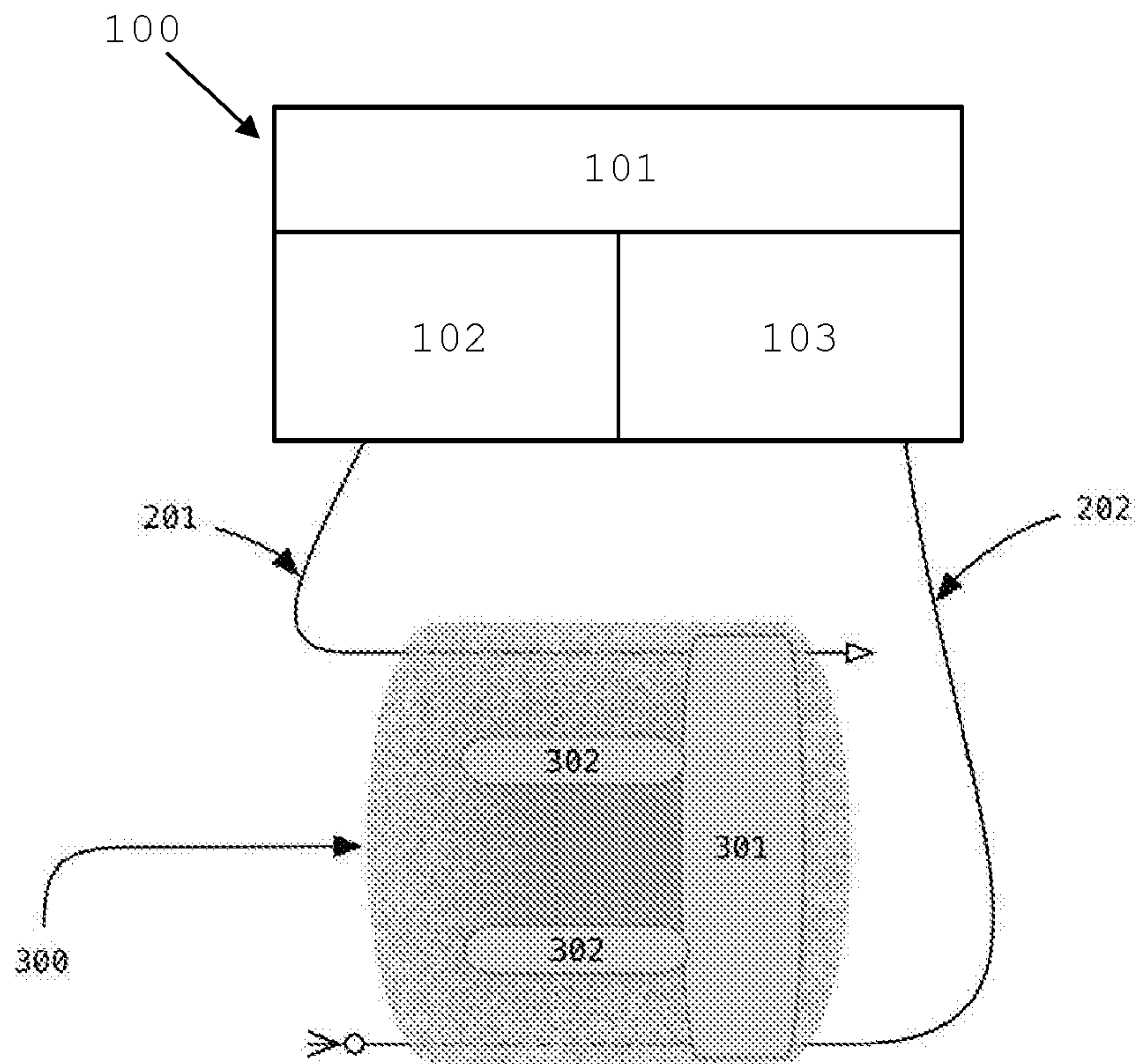


Figure 4

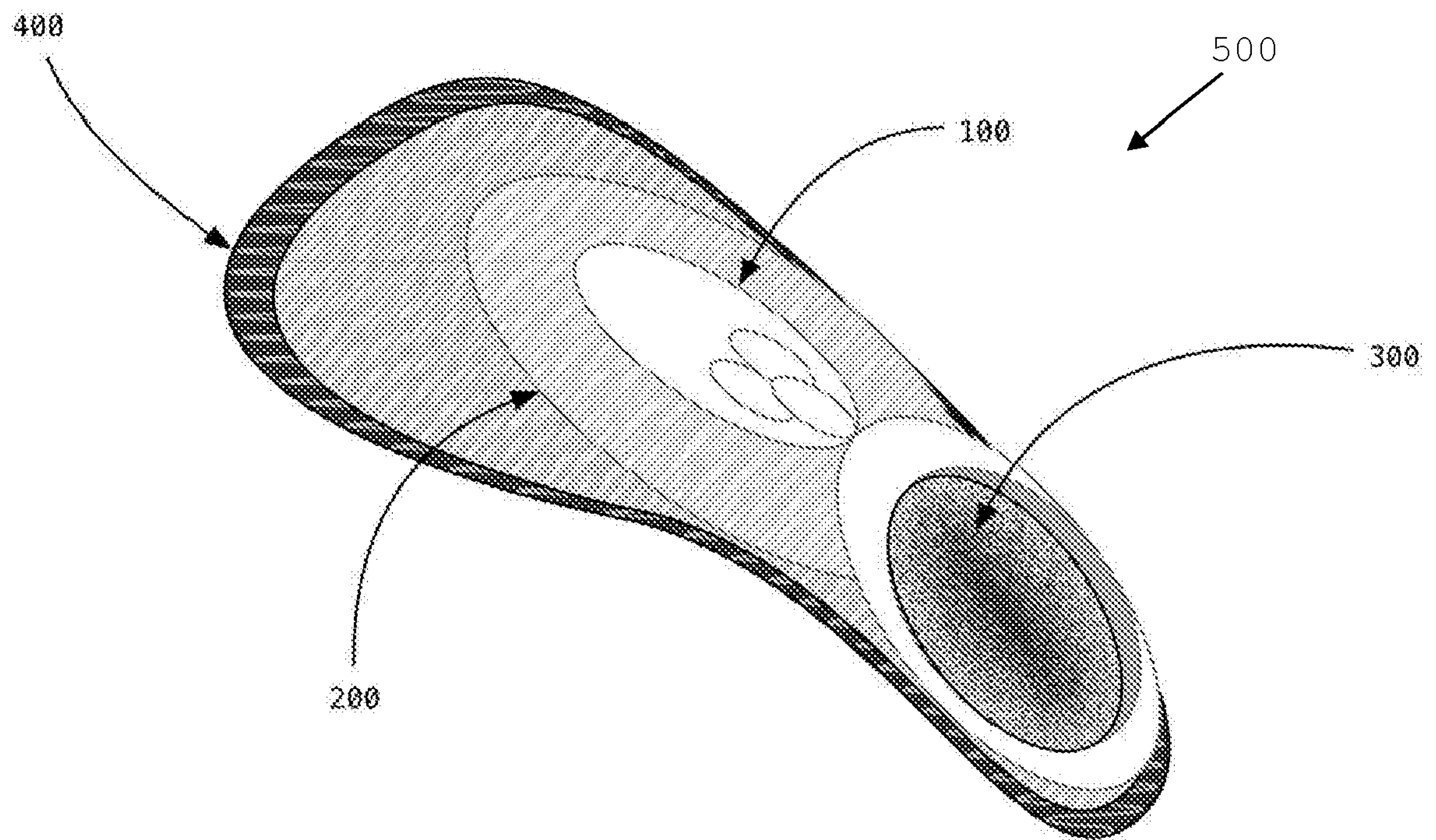


Figure 5

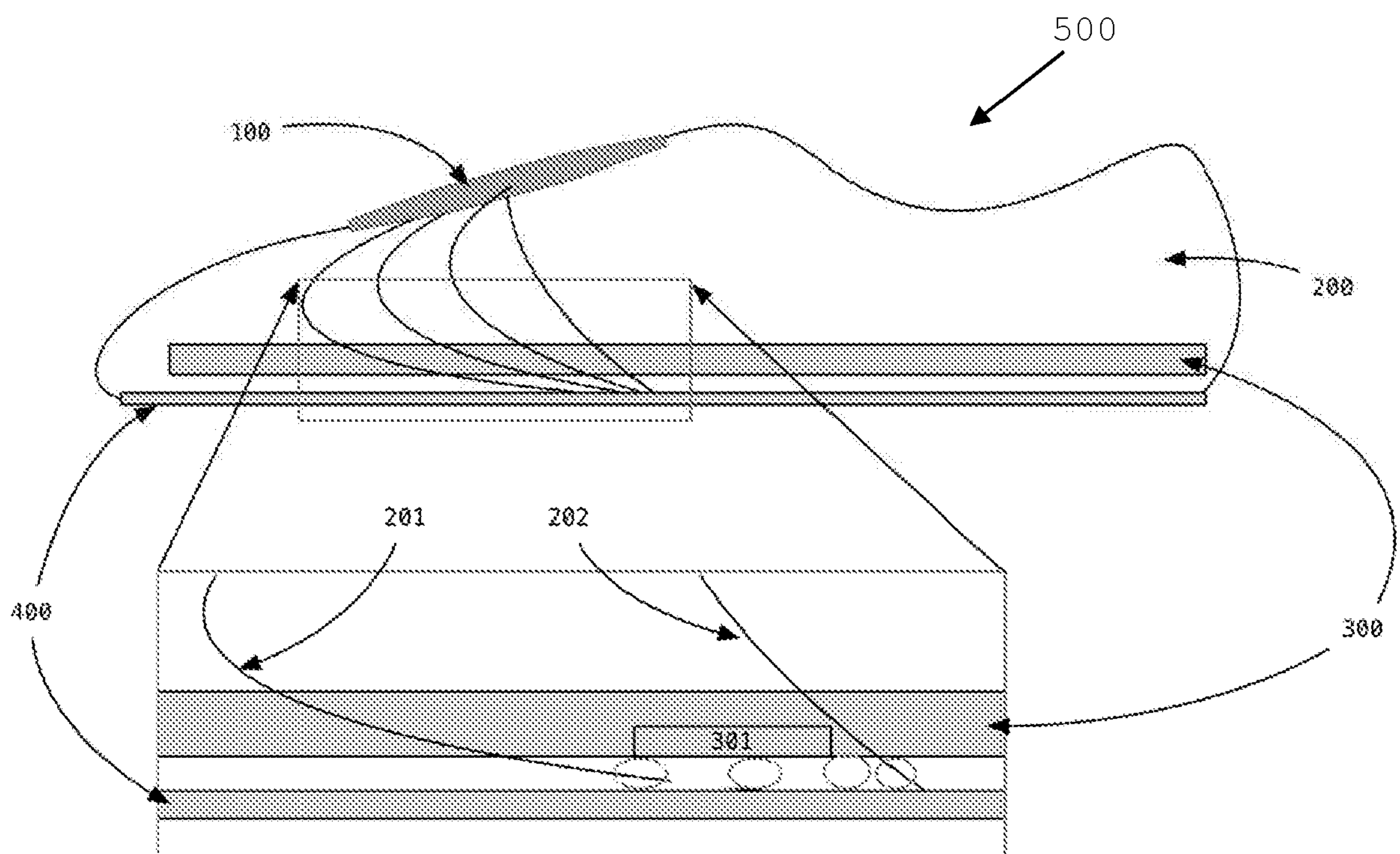


Figure 6

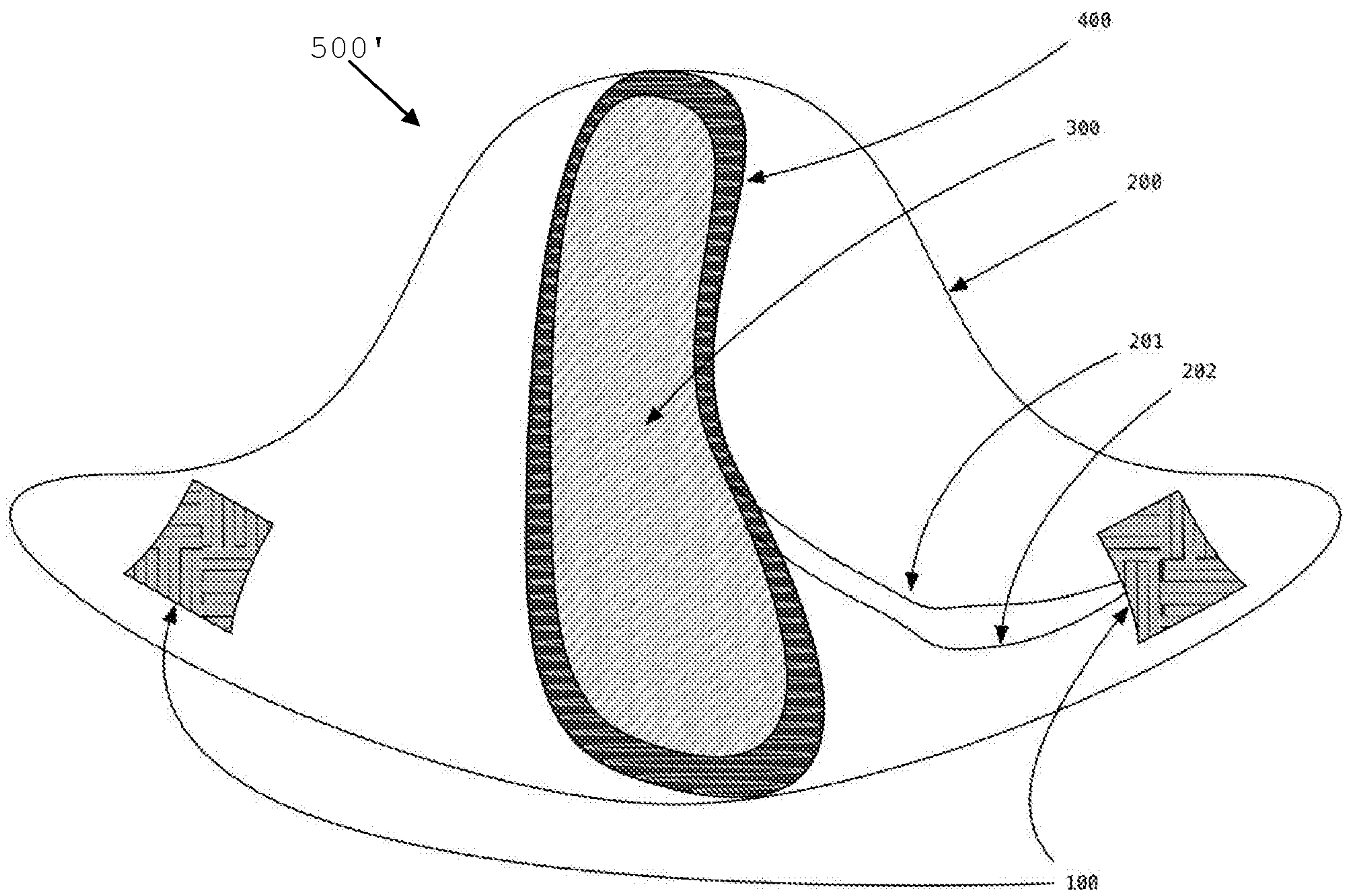


Figure 7

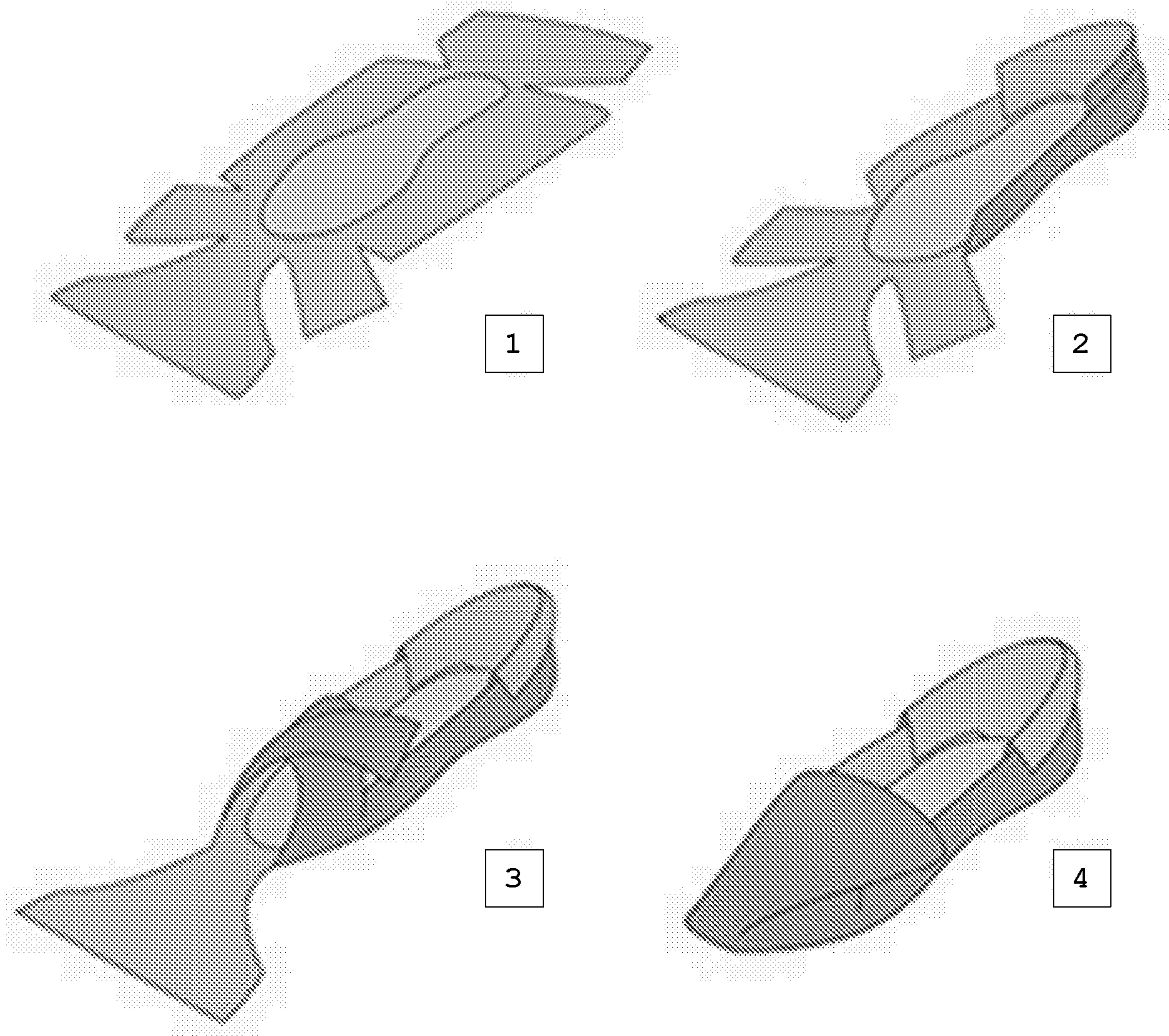


Figure 8

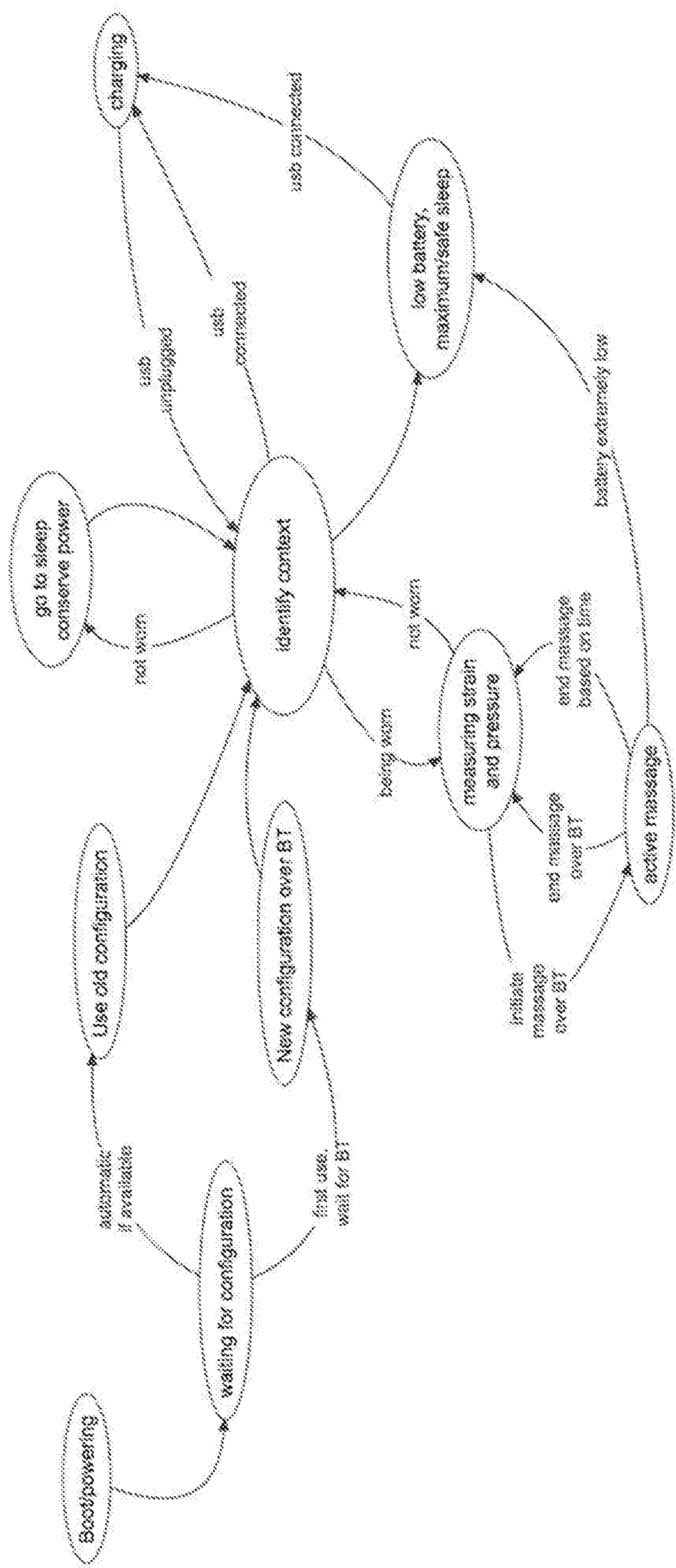


Figure 9

FLEXIBLE WEARABLE MATERIALS HAVING ELECTRONIC FUNCTIONALITY, AND ARTICLES COMPRISING SUCH MATERIALS

Field of the Invention

5 The present invention relates to flexible wearable materials having electronic functionality. It is particularly applicable, but by no means limited, for use in items of footwear.

Background to the Invention

10 Flexible wearable materials having electronic functionality are being developed. There is a desire to improve these to achieve enhanced functionality and to realise new applications.

Summary of the Invention

15 According to a first aspect of the invention there is provided flexible wearable material comprising: one or more electrically-conductive paths; a control unit comprising a processor; one or more sensors integrated into the wearable material and coupled to the processor, for providing measurement signals to the control unit; an electrical power supply for supplying electrical power to the one or more sensors by means of
20 the one or more electrically-conductive paths; and one or more actuators coupled to and controlled by the control unit.

The term “processor” as used herein should be interpreted broadly, to encompass a general purpose processor, the processor of an application specific integrated circuit,
25 a microprocessor, a digital signal processor, a controller, a microcontroller, a state machine, and so on. The term “processor” may also refer to a plurality of such processing devices in combination.

Advantageously the control unit may be configured to activate the one or more
30 actuators in response to a measurement signal received from the one or more sensors satisfying a predetermined condition.

In some embodiments the flexible wearable material may comprise knitted or woven fabric. The one or more electrically-conductive paths may be formed of electrically-

conductive yarn within the fabric. The one or more sensors may be attached to the electrically-conductive yarn.

5 In other embodiments the flexible wearable material may comprise flexible 3D-printed material.

More generally, in some embodiments the electrical power supply may comprise a battery. Alternatively, or in addition, the electrical power supply may comprise an input via which electrical power may be received from elsewhere (e.g. by means of an
10 electrical power supply cable).

The one or more sensors may be selected from a group comprising: pressure sensors, temperature sensors, biosensors, moisture sensors, accelerometers and inclinometers. Other types of sensors may also be used, as those skilled in the art
15 will appreciate.

The one or more actuators may comprise one or more motors and/or one or more heating elements. Advantageously, the one or more motors may be configured to provide a vibration/massage function. Other types of actuators may also be provided,
20 as those skilled in the art will appreciate.

According to a second aspect of the invention there is provided an article (preferably a wearable article) comprising flexible wearable material according to the first aspect of the invention.

25

In various presently-preferred embodiments the article is an item of footwear, such as a massage shoe.

In alternative embodiments the article may be a sock, a tubular article open at both
30 ends for sheathing a limb, or a tubular article open at one end for sheathing a limb.

In yet further alternative embodiments the article may be a boot, sock or pad for an animal's foot/hoof/paw.

Other embodiments and applications are also possible, as described herein, and as those skilled in the art will appreciate.

Brief Description of the Drawings

5 Embodiments of the invention will now be described, by way of example only, and with reference to the drawings in which:

Figure 1 illustrates an electrically-conductive yarn with a plurality of sensors attached;

10 Figure 2 illustrates a piece of fabric (so-called “smart material”, which may be knitted or woven, for example) incorporating a plurality of lengths of yarn as depicted in Figure 1 with sensors attached;

Figure 3 schematically illustrates apparatus comprising a piece of smart material as depicted in Figure 2, to which a control module, a power supply module and an analysis module are coupled by means of appropriate circuitry;

15 Figure 4 schematically illustrates apparatus comprising a piece of smart material as depicted in Figure 2, to which a control module, a power supply module, an analysis module and a plurality of actuators are coupled by means of appropriate circuitry;

Figure 5 illustrates a shoe incorporating apparatus as depicted in Figure 4;

20 Figure 6 illustrates a shoe layer and connection diagram in respect of the shoe as depicted in Figure 5;

Figure 7 illustrates another shoe structure incorporating smart material;

Figure 8 illustrates another possible shoe structure which may embody the invention, along with the manner of manufacture (folding sequence) of the shoe; and

25 Figure 9 illustrates an operational flow diagram relating to the use of a wearable device (e.g. a shoe) incorporating smart material with sensors, and having one or more massage-giving actuators.

In the figures, like elements are indicated by like reference numerals throughout.

Detailed Description of Preferred Embodiments

Overview

The present work provides flexible wearable material (preferably comprising knitted or woven fabric, or alternatively flexible 3D-printed material) which includes electrically
 5 conductive parts or paths (e.g. conductive yarns) and non-conductive parts or paths (e.g. non-conductive yarns), a processor, an electrical power supply (e.g. a battery, or an input via which electrical power may be received from elsewhere), one or more sensors (integrated into the fabric), and one or more actuators (e.g. to provide
 10 massage functionality or for haptic purposes). The fabric may be knitted or woven in, for example, (a) an open form, intended for wrapping around a limb; (b) a tubular form open at both ends, intended for sheathing a limb; or (c) a tubular form open at one end only, intended for sheathing a limb.

15 The fabric may have one or more conductive and non-conductive areas or paths made from different types of yarns, filaments or other suitable textile materials. The fabric may also comprise other electro-active materials and/or other electrical or electronic components.

20 The wearable material has a range of application areas, including for use in healthcare. For example, a woven or knitted structure according to an embodiment of the invention may be used for real-time analysis, and may provide connectivity to smart phones or other systems, e.g. through wireless data transfer. Artificial Intelligence may be used to interpret the readings from the sensors and to control the
 25 operation of the actuators. Embodiments may be provided for independent as well as connected behaviour.

Advantageously, the wearable material can be attached to a limb (in the form of a shoe, for example, or some other structure to be worn for ambulatory movement) in
 30 such a way that it does not inhibit the movement of the wearer, whilst providing electronic functionality (including sensing functionality and, preferably, actuation functionality).

Electrically-conductive yarn with sensors attached

Figure 1 illustrates, as identified by numeral 10, an electrically-conductive yarn 12 with a plurality of sensors 14 attached, that may be used to produce “smart material” fabric. Although, in the illustrated example, a plurality of sensors 14 are attached to the electrically-conductive yarn 12, in an alternative example a single sensor 14 may be attached to the yarn 12. Suitable electrically-conductive yarns include the so-called “Volt Smart Yarns” supplied by Supreme Corporation, 325 Spencer Road, Conover, NC 28613, USA.

10 The electrically-conductive yarn 12 is preferably copper-based, and is stretchable and flexible. The or each sensor 14 may be attached to the electrically-conductive yarn 12 using a placement machine. It is then encapsulated to seal the sensor 14 onto the yarn. The electrically-conductive yarn 12 may be provided with a non-conductive coating (e.g. a plastic coating).

15

The or each sensor 14 may be, for example, a pressure sensor, a temperature sensor or a moisture sensor, although other types of sensors are also possible, such as biosensors (e.g. to measure heart rate), accelerometers and inclinometers. The functionality and exemplary applications of different types of possible sensors are described in greater detail below.

20

As also discussed in greater detail below, the or each sensor 14 receives electrical power via the electrically-conductive yarn 12. As illustrated in Figure 1, a plurality of sensors 14 may be wired in series along the electrically-conductive yarn 12, so that they are all powered by the same length of yarn. The or each sensor 14 may also send its measurement readings (e.g. pressure measurements, temperature measurements, moisture measurements) via electrically-conductive yarn. A plurality of different types of sensors may be provided along a given length of electrically-conductive yarn.

25

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“Smart material” fabric

Figure 2 illustrates a piece of flexible knitted or woven fabric 300 (so-called “smart material” fabric) incorporating a plurality of lengths of yarn 10, each length of yarn 10 being electrically-conductive and having one or more sensors 14 attached – for

example as described above with reference to Figure 1. Although, in the illustrated example, a plurality of lengths of such yarn 10 are shown, in an alternative example a single length of yarn 10 may be incorporated in the fabric 300. Preferably, though, a plurality of lengths of such yarn 10 may be used, e.g. to produce a two-dimensional array of sensors across the fabric.

The length(s) of yarn 10 that are electrically-conductive and have one or more sensors 14 attached are knitted or woven into the fabric 300 among other non-conductive lengths of yarn. The non-conductive lengths of yarn may be, for example, wool, cotton, or a synthetic fibre.

Example implementations

Figure 3 schematically illustrates apparatus comprising a piece of smart material 300 (for example as described above with reference to Figure 2), to which a control module 101, a power supply module 102 and an analysis module 103 are coupled by means of appropriate circuitry. Together, the control module 101, power supply module 102 and analysis module 103 form a control unit 100.

The control module 101 includes a processor and is configured to control the power supply module 102 and the analysis module 103. It may also be configured to make operational decisions and to perform top-level analysis.

The power supply module 102 (which may also comprise a processor) is configured to supply electrical power to the smart material 300 (specifically, to the sensors thereof) by means of a conductive yarn/fibre/knit 201. The power supply module 102 may receive electrical power from a battery or from elsewhere, e.g. by means of an electrical power supply cable. It is expressly contemplated, for instance, that certain embodiments may draw current via a plugged-in USB cable or the like, e.g. of the order of 500 mA to 5 A.

The analysis module 103 (which may also comprise a processor) is configured to receive measurement signals from the sensor(s) of the smart material 300 by means of a conductive yarn/fibre/knit 202 and to analyse them, for example to determine quantitative measurements of e.g. pressure or temperature. However, depending on

the sensor type and the intended application, the output from a particular sensor may alternatively be qualitative or binary (e.g. in the case of a moisture sensor, is moisture present or not?). If the smart material 300 comprises a plurality of sensors, then preferably the positions of the individual sensors are known to the analysis module, so that it can determine location-specific measurements. For instance, the sensors may be addressable.

The smart material 300 may for example be an insole of a shoe, although many other applications are also possible. Advantageously, the smart material 300 may be exchangeable, and the measurement system may user-adjustable, to cater for users of different weights, different pressure configurations, different moisture levels, etc.).

Implementations based on Figure 3 may comprise any number of control units 100 and sensors, with a minimal implementation having one of each. Control unit 100 may comprise modules 101, 102 and 103, but it is not necessary for these to be separate modules. Any part of the overall apparatus may include a power supply (e.g. a battery or other electronic component, or an input to receive power from elsewhere).

As another implementation, Figure 4 schematically illustrates apparatus comprising a piece of smart material 300 (for example as described above with reference to Figure 2), to which a control module 101, a power supply module 102, an analysis module 103 and a plurality of actuators 302 are coupled by means of appropriate circuitry. The smart material 300 may for example be an insole of a shoe, although many other applications are also possible. Although, in the illustrated implementation, a plurality of actuators 302 are provided, in an alternative implementation a single actuator 302 may be provided. Together, the control module 101, power supply module 102 and analysis module 103 form a control unit 100. As illustrated, the smart material 300 also includes an optional module 301 for identifying the overall component (e.g. a specific insole of a shoe) that includes the smart material. The module 301 may (but not necessarily) include a memory and/or a processor for controlling the properties of the component (e.g. insole).

The control module 101 includes a processor and is configured to control the power supply module 102 and the analysis module 103. In the case of the overall component which includes the smart material being an insole, the control module 101 may analyse what the insole is built into, and may analyse wear and tear of the insole.

5

As described above, the power supply module 102 is configured to supply electrical power to the smart material 300 (specifically, to the sensors thereof) by means of a conductive yarn/fibre/knit 201. The power supply module 102 may receive electrical power from a battery or from elsewhere, e.g. by means of an electrical power supply cable.

10

Also as described above, the analysis module 103 (which may also comprise a processor) is configured to receive measurement signals from the sensor(s) of the smart material 300 by means of a conductive yarn/fibre/knit 202 and to analyse them, for example to determine quantitative measurements of e.g. pressure or temperature. However, depending on the sensor type and the intended application, the output from a particular sensor may alternatively be qualitative or binary (e.g. in the case of a moisture sensor, is moisture present or not?). If the smart material 300 comprises a plurality of sensors, then preferably the positions of the individual sensors are known to the analysis module, so that it can determine location-specific measurements. For instance, the sensors may be addressable.

15

20

The actuators 302 are electrically-controlled devices, such as motors (e.g. for vibration/massage purposes) or heating elements, which may be activated, under the control of the control unit 100, via the module 301. When used in an article of footwear, such motors may be positioned to coincide with key pressure points (reflexology points) on the foot, to apply vibration/massage to those specific points. The functionality and exemplary applications of different types of possible actuators are described in greater detail below.

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The control unit 100 may be configured to activate the actuators 302 (e.g. motors) in response to a measurement signal received from the sensors in the smart material 300 satisfying a predetermined condition – such as, for example, a measured pressure exceeding a predetermined threshold (e.g. indicating a relatively high level

of pressure on the foot), or a measured pressure differential across the foot exceeding a predetermined threshold (e.g. indicating a relative imbalance of the foot).

5 The actuators 302 may be encased in material (e.g. including, but not necessarily, polymers, conductive materials, alloys or combinations of such), active components, or any other devices.

Figures 5 and 6 illustrate a shoe 500 incorporating apparatus as depicted in Figure 4.

10 More particularly, the shoe 500 includes a smart material insole 300 (e.g. as described above) and an outsole 400, which may comprise any suitable material(s). The outsole 400 may also have similar “smart” characteristics and constituent features (e.g. sensors and actuators) to those of the insole 300. Numeral 200 refers to knitted or woven fabric making the shoe, which may consist of any number of
15 conductive yarns/fibres/knits 201 and 202. The shoe 500 also includes a control unit 100 as described above, and, as illustrated, may also include an optional module 301 as described above.

Figure 7 illustrates another embodiment of a shoe 500' incorporating a smart material
20 insole 300 (e.g. as described above) and an outsole 400. Numeral 200 refers to knitted or woven wrap-around fabric making the shoe, which may consist of any number of conductive yarns/fibres/knits 201 and 202. The shoe 500 also includes a control unit 100 which may contain elements 101-103 as described above. These can be split into multiple parts – in this case, provided as two separate units that come
25 together as the wrap-around fabric 200 is folded.

The shoe 500' of Figure 7 can alternatively be formed as shown in Figure 8. This shows, as stages 1-4, the sequence by which the wrap-around fabric is folded to make the shoe. The above-described smart material, with sensors and optional
30 actuators, may form any part of the illustrated material (e.g. the insole and/or the outsole).

In alternative implementations the shoe (including the sensors and conductive tracks) can be made using additive manufacturing (3D printing).

Figure 9 is an operational flow diagram relating to the use of a wearable device (e.g. a shoe) incorporating smart material with sensors, and having one or more massage-giving actuators.

5

Sensor types and exemplary applications

By way of example, the following types of sensors may be used in embodiments of the invention (for example, but not limited to, shoes):

10

- Pressure sensors (e.g. to measure pressure at different points across the underside of the wearer's foot, and/or to measure the wearer's weight).
- Temperature sensors (e.g. to measure the temperature of the underside of the wearer's foot).
- Biosensors (e.g. to measure the wearer's heart rate).
- Moisture sensors (e.g. to detect the presence of sweat, for example as a result of exercise).
- Accelerometers and inclinometers (e.g. to detect the wearer's posture, gait or speed of movement).

15

Actuator types and exemplary applications

20

By way of example, the following types of actuators may be used in embodiments of the invention (for example, but not limited to, shoes):

- Motors (e.g. to provide vibration or massage to the wearer's body (e.g. foot), or haptic feedback to the wearer).
- Heating elements (e.g. to provide heating to the wearer's body (e.g. foot)).

25

Shoe/sock implementation

One implementation of a knitted or woven shoe provides a textile bio-engineering computing platform (textile bioinformatics) incorporating a dynamic adaptive knit structure having anti-microbial and sweat wicking properties. The circuit within the knit structure may be provided with any or all of the following sensors and actuators:

30

- Knitted temperature sensors.
- Heating elements (e.g. so that the shoe heats up when it senses the wearer's feet are cold).

- Pressure sensors (e.g. to understand daily pressures on the wearer's feet with real-time information).
- Actuators (embedded in the insole) for vibration / massage therapy.
- Biometric sensing – Hydration / Biometric Impedance Analysis (e.g. to monitor the body's water intake levels and how sweat affects hydration to determine the body's water content. This information provides useful insights into the body's hydration levels (total body water) and fat percentage.)

The knitted or woven shoe is developed for healthy and quality lifestyles with functions of protection, prevention, diagnosis and treatment of disease, and for improving health.

The structure of the shoe can be customised via 3D scanning of the person's foot, for extra support and cushioning to achieve an increase in comfort of the individual foot bed.

The shoe preferably houses a rechargeable battery which can be wirelessly charged (e.g. using nano-generation / flexible super capacitors).

A Bluetooth (BT) or other short-range low-power wireless transmitter (e.g. radio frequency identification, RFID) may be incorporated in the shoe, to directly communicate / exchange information with another device (e.g. a smart phone running an app). This may use Augmented Intelligence to nudge the user's behaviour, e.g. with respect to improving their posture.

Alerts may also help to identify when to massage the wearer's feet to ease pressure on the feet (e.g. to treat peripheral neuropathy).

Massage/vibration therapy may be used as an aid to improve circulation and balance (as cold feet, typically caused by poor blood flow, can cause a loss of senses). The shoe can create better awareness of foot health (as poor blood circulation has been linked to chronic health conditions such as high blood pressure, obesity, and diabetes).

Understanding daily pressure on the wearer's feet is important to avoiding irreversible damage. The shoe may provide real-time information which allows the management of this.

- 5 By supplying biometric data from the shoe to a doctor (e.g. via a wireless cloud-based platform), the doctor can have the wearer's biometric data to hand before they visit, and can use this data to predict future illness and better treat current illness. For instance, this may potentially prevent wounds and amputations caused by diabetes.
- 10 The shoe incorporating a textile computing platform could connect the user to the Internet of Things ("IoT"). This may be used to connecting the wearer to a medical practitioner / health service. An Artificial Intelligence algorithm may be used for the advancement of holistic wellbeing and management of rehabilitation, therapy and preventative care.

15

Possible applications

- Footwear or socks, e.g. to measure foot pressure and provide massage/vibration therapy to the wearer's feet, thereby relieving stress and promoting health and wellbeing.
- 20 • Footwear or socks to massage a passenger's feet on an aeroplane, to help prevent deep vein thrombosis (such an article could be plugged-in to the aeroplane's electrical power supply, e.g. via a USB lead, or may alternatively be battery powered).
- Wearables (e.g. footwear or socks) to promote holistic wellbeing (targeting the reflex / vagus nerve to promote relaxation). The device may also incorporate one or more magnets for holistic wellbeing purposes.
- 25 • Wearables (e.g. footwear or socks) to promote context awareness.
- A learning sole that prevents fatigue.
- Footwear or socks for sportspeople, e.g.:
 - 30 - athletes (e.g. to monitor pressure across the foot when running or jumping);
 - football players (e.g. to monitor pressure across the foot when kicking a football, to determine which part of the foot is being used, and to help improve the player's technique);

- racing drivers (e.g. monitoring accelerator foot pedal / shoe interaction; feedback from the pedals);
- explorers;
- soldiers (military boots);
- 5 - water sport shoes (e.g. for surfing, diving – can incorporate safety / GPS / navigation features);
- outdoor activity shoes (e.g. for hiking, mountain climbing – can provide rest / recuperation of soles).
- 10 • Wearables for sensory touch / haptic feedback (e.g. for virtual reality applications).
- Vehicle seat fabric (e.g. to measure pressure and provide massage/vibration therapy to the driver's or passenger's back, thereby relieving stress and promoting health, wellbeing and alertness).
- 15 • As part of a platform for developers / customisation, including haptic feedback to send a message through touch (e.g. a "hug shirt" or other wearable which provides sensory touch communication or interpersonal connectivity (e.g. a hug sensation) over a distance).
- Wearables (e.g. footwear or gloves) for the elderly to assist independent living – e.g. to provide early indicators of low grip strength or decreased muscle mass, to predict a risk of falling, to monitor vital signs (e.g. dehydration or low heart rate).
- 20 • Medical applications for higher resolution health care (e.g. personalisation, adaptation, monitoring & notifications, key to future discoveries, especially where patterns of disease are invisible to infrequent clinical observation).
- 25 • Integration with care planning.
- Remote monitoring.
- Longitudinal assessment.
- Decision support.
- Early warning & intervention.
- 30 • Applications to treat Parkinson's, multiple sclerosis, diabetic neuropathy (mobility aid to aid balance and reduce falls with those with sensory deficiencies), Alzheimer's, early detection of type 1 diabetes signs (loss of sensation in toes & ball of foot), rehabilitation, cerebral palsy, artificial limbs.

- IoT in healthcare – e.g. remote monitoring to efficiently monitor health parameters. Doctors can easily track a patient's condition and determine critical insights, leading to a more advanced diagnosis process. This provides a solution to save both time and resources in hospitals, delivering real-time data to doctors. The device can send alerts to doctors' smart watches or smartphones, promoting more intensive care. Moreover the technology can be incorporated in artificial limbs and other supportive devices. Safety applications include real-time GPS tracking to detect locations efficiently, addressing women's and children's safety and aiding dementia patients.
- Boots, socks or pads for animals' feet/hooves/paws – e.g. horse shoes, dressage recovery boots, sports boots, sensory wraps for horse training, jumping, riding and eventing. A particular issue is that, with horses, the vast majority of hoof cracks are secondary to poor hoof balance. This is often due to excessive or uneven load on a certain part of the hoof wall in stance or during motion. This causes damage to the tubular horn structure within the hoof wall, causing it to weaken and split. Monitoring of the pressure exerted on a horse's hooves, using a horse boot embodiment of the present invention, can lead to fatigue/injury prevention. No horse has 100% balanced feet and we can only endeavour to gradually make changes to try and achieve balance as close as possible for the individual horse. Foot placement will give an insight into the sites of impact and the possible leveraging forces exerted on the hoof wall. Embodiments can also provide treatment of the aches, pains and strains that can occur to a horse's hooves during training and in competition, to provide prophylactic physiotherapy.

Other applications are also possible, as those skilled in the art will appreciate.

Possible modifications and alternatives

Detailed embodiments and some possible alternatives have been described above.

As those skilled in the art will appreciate, a number of modifications and further alternatives can be made to the above embodiments whilst still benefiting from the inventions embodied therein. It will therefore be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the scope of the appended claims.

For instance, in respect of the implementation described above with reference to Figure 3, in one variant the power supply module 102 may be referred to as a “current-feeding module” (CFM), and the analysis module 103 may be referred to as a “current-sensing module” or “current-sourcing module” (CSM). The CFM 102 is configured to create a current, the characteristics of which are known, and to analyse changes caused by the CSM 103. The CSM 103 is configured to source the current fed by the CFM 102 and to modify and analyse the results.

Further, in respect of the implementation described above with reference to Figure 4, in one variant (as may be applied to an insole, for instance) the power supply module 102 may be referred to as a “current-feeding module” (CFM), and the analysis module 103 may be referred to as a “current-sensing module” or “current-sourcing module” (CSM). The CFM 102 is configured to send an identifying signal to the e.g. insole, in addition to reading characteristics. The CSM 103 is configured to source the identifying signal, and to act according to CFM controls. The CSM 103 can provide electrical comparison for the CFM 102.

Summary

Amongst other things, the present work provides a knitted or woven structure, said structure comprising conductive and nonconductive parts, a computational structure, a power supplying structure, a sensing structure and an actuating structure, which may be knitted or woven as an open form intended for wrapping around a limb, or as a tubular form open at both ends intended for sheathing a limb, or as a tubular form open from one end intended for sheathing a limb, with conductive and non-conductive area or areas made with different types of yarns, filaments or other suitable textile materials, which may comprise electroactive materials or electrical or electronic components, including but not limited to microprocessors, sensors, actuators, power supplies, and batteries.

The system described in the present work is primarily intended for healthcare, with a knitted or woven structure supporting this use through a possibility for real-time analysis, and connectivity to smart phones or other systems, such as Artificial

Intelligence through wireless data transfer. The system described is capable of independent as well as connected behaviour.

5 The present work solves a problem of arranging or manufacturing computational structures to a knitted or woven structure within a casing suitable for attaching to a limb, such as but not limited to a shoe or a structure to be worn for ambulatory movement, in such a way that it does not inhibit the movement of the wearer, while providing electronic functionality within the knitted or woven structure.

CLAIMS

1. Flexible wearable material comprising:
one or more electrically-conductive paths;
5 a control unit comprising a processor;
one or more sensors integrated into the wearable material and coupled to the processor, for providing measurement signals to the control unit;
an electrical power supply for supplying electrical power to the one or more sensors by means of the one or more electrically-conductive paths; and
10 one or more actuators coupled to and controlled by the control unit.
2. Flexible wearable material according to claim 1, wherein the control unit is configured to activate the one or more actuators in response to a measurement signal received from the one or more sensors satisfying a predetermined condition.
15
3. Flexible wearable material according to claim 1 or claim 2, comprising knitted or woven fabric.
4. Flexible wearable material according to claim 3, wherein the one or more
20 electrically-conductive paths are formed of electrically-conductive yarn within the fabric.
5. Flexible wearable material according to claim 4, wherein the one or more sensors are attached to the electrically-conductive yarn.
25
6. Flexible wearable material according to claim 1 or claim 2, comprising flexible 3D-printed material.
7. Flexible wearable material according to any preceding claim, wherein the
30 electrical power supply comprises a battery.
8. Flexible wearable material according to any preceding claim, wherein the electrical power supply comprises an input via which electrical power may be received from elsewhere.

9. Flexible wearable material according to any preceding claim, wherein the one or more sensors are selected from a group comprising: pressure sensors, temperature sensors, biosensors, moisture sensors, accelerometers and
5 inclinometers.
10. Flexible wearable material according to any preceding claim, wherein the one or more actuators comprise one or more motors.
- 10 11. Flexible wearable material according to claim 10, wherein the one or more motors are configured to provide a vibration/massage function.
12. Flexible wearable material according to any preceding claim, wherein the one or more actuators comprise one or more heating elements.
15
13. An article comprising flexible wearable material according to any preceding claim.
14. An article according to claim 13, being an item of footwear.
20
15. An article according to claim 14 when dependent on claim 11, being a massage shoe.
16. An article according to claim 13, being a sock, a tubular article open at both
25 ends for sheathing a limb, or a tubular article open at one end for sheathing a limb.
17. An article according to claim 12, being a boot, sock or pad for an animal's foot/hoof/paw.



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Claims searched: 1-17

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Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1-17	WO 2014/138204 A1 (UNIV DREXEL) see paragraphs [0046], [0047], and [0082] in particular
X	1-5,7-17	WO 2006/113918 A2 (NOBLE FIBER) whole document relevant
X	1-5,7-11,13-17	US 2017/017264 A1 (VACAS) see paragraphs [0039] - [0042] and [0048] - [0049] in particular
X	1-3,7-17	DE 102009033510 A1 (SEFAR) see WPI abstract accession no. 2010-F39574
X	1-5,7-17	US 2014/070957 A1 (LIFE CORP) see figures and paragraphs [0087] - [0089] in particular
X	1-5,7-11,13-17	WO 2016/130888 A1 (APPLE) see paragraphs [0027] and [0033] in particular
X	1-5,7-9,13-17	WO 2016/198969 A1 (CONTINENTAL) see pages 35-37 in particular
X	1-9, 12-17	WO 2017/095026 A1 (FOUND OF SOONGSIL) whole document relevant
X	1-5,7,9-11,13-17	US 2016/263375 A1 (WU) see paragraphs [0016] and [0033] - [0038] in particular

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC
A43B
The following online and other databases have been used in the preparation of this search report
EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
A43B	0003/00	01/01/2006
A01K	0013/00	01/01/2006
A43B	0007/02	01/01/2006
A43B	0013/38	01/01/2006
A43B	0017/00	01/01/2006
A43B	0023/02	01/01/2006
A43B	0023/04	01/01/2006