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(54) Title: A DEVICE AND METHOD FOR POWERING AN IMPLANTABLE MEDICAL DEVICE

(57) Abstract: Disclosed herein is a device (106) and method for powering an implantable medical device (IMD) (102). The device (106) comprises a polymeric platform (108) made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate. On the polymeric platform (108), a multi-modal energy harvester comprising a plurality of photovoltaic cells (110) and a piezoelectric harvesting system (112) is integrated. A pattern printed metal plate (114) is also integrated on the polymeric platform (108) to transform the harvested energy into mid-field energy for powering the IMD (102) either directly or by charging a flexible printed battery (104) integrated with the IMD (102).

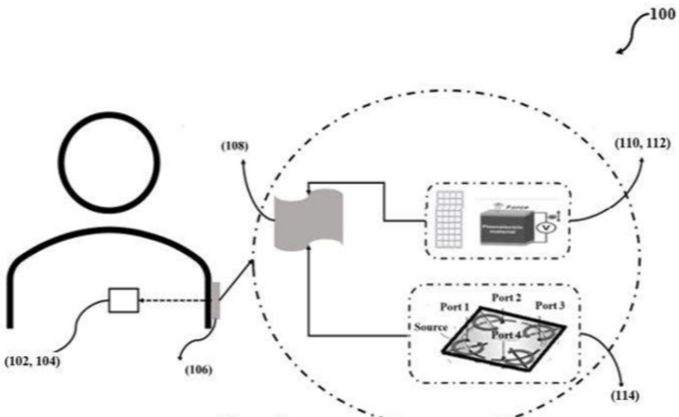

Figure 1

FORM 2

THE PATENTS ACT 1970
(39 OF 1970)
&
The Patent Rules, 2003
Complete Specification
(See Section 10 and Rule 13)

1. TITLE OF THE INVENTION

A DEVICE AND METHOD FOR POWERING AN IMPLANTABLE MEDICAL DEVICE

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3. PREAMBLE TO THE DESCRIPTION

COMPLETE

The following specification describes the invention and the manner in which it is to be performed

DESCRIPTION

TECHNICAL FIELD

[001] The present invention generally relates to the field of Implantable Medical Devices (IMDs) and more particularly, to providing a device and a method to power IMDs with the help of Mid-Field propagating mode mechanism, and using printed rechargeable flexible batteries charged via multimodal energy harvesting mechanism.

BACKGROUND OF INVENTION

[002] The following description includes information that may be useful in understanding the present invention. It is not an admission that any of the information provided herein is prior art or relevant to the presently claimed invention, or that any publication specifically or implicitly referenced is prior art.

[003] Implantable medical devices (IMDs) are surgically or medically inserted inside the body cavity of a subject (e.g. patient) for performing different functionalities such as rebuilding body functions, achieving a better quality of life, or expanding longevity depending upon the type and purpose of the IMD. Over the years IMD development has faced challenges in various areas such as materials, battery power, functionality, electrical power consumption, size shrinkage, system delivery, and wireless communication. One of the major issues faced with the IMDs of the present day is the fact that they are battery powered and therefore, the subject needs to undergo a surgical procedure for battery replacement and it is well-known that surgical procedures, however minor they may be, pose certain risks. Further, over the years IMDs have been used for specific purposes within the body such as a pacemaker and electro-stimulators for heart, cochlear implants and blood pressure sensing implants. These IMDs have in-built batteries that require large device dimensions for appropriate energy storage and therefore, cannot be scaled down. However, with the advances in science and technology, miniaturization is a key feature being aimed to achieve for IMDs that since being small in size (~mm dimensions) can be used for implantation for various types of disorders such as cardiac, orthodontic, gastric and neurological.

[004] There is, therefore, a need for a device that eliminates the need of unnecessary surgery for replacing the batteries of an IMD implanted inside the subject and wirelessly powers the IMD either by recharging its battery or by directly powering it. Further, there is also a need for a device that can be scaled down to smaller dimensions without compromising its energy storage capability. Furthermore, there is also a need for a method that develops such a device by using techniques that are sustainable and helps in attaining an eco-friendly device for powering the IMD.

SUMMARY OF INVENTION

[005] The present disclosure overcomes one or more shortcomings of the prior art and provides additional advantages discussed throughout the present disclosure. Additional features and advantages are realized through the techniques of the present disclosure. Other embodiments and aspects of the disclosure are described in detail herein and are considered a part of the claimed disclosure.

[006] In one non-limiting embodiment of the present disclosure, a device for powering an implantable medical device (IMD) implanted inside body of a subject is disclosed. The device comprises a polymeric platform made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate. The device further comprises a plurality of photovoltaic cells and a piezoelectric harvesting system integrated upon the polymeric platform. The device further comprises a pattern printed metal plate integrated on the polymeric platform, wherein the combination of the plurality of photovoltaic cells and the piezoelectric harvesting system forms a multi-modal energy harvester. Further, an energy harvested by at least one of the plurality of photovoltaic cells and the piezoelectric harvesting system is converted into electric energy that is further transformed into mid-field energy through the pattern printed metal plate.

[007] In one non-limiting embodiment of the present disclosure, a method for powering an implantable medical device (IMD) implanted inside body of a subject is disclosed. The method comprises developing a device for facilitating multi-modal energy harvesting. The developing of the device comprises synthesizing a polymeric platform made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate, integrating a plurality of photovoltaic cells and a piezoelectric harvesting system upon the polymeric platform, and integrating a pattern printed metal plate on the polymeric platform, wherein the combination of the plurality of photovoltaic cells and the piezoelectric harvesting system forms a multi-modal energy harvester. Further, an energy harvested by at least one of the plurality of photovoltaic cells and the piezoelectric harvesting system is converted into electric energy that is further transformed into mid-field energy through the pattern printed metal plate.

[008] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF DRAWINGS

[009] The embodiments of the disclosure itself, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings. One or more embodiments are now described, by way of example only, with reference to the accompanying drawings in which:

[0010] Figure 1 illustrates an exemplary environment **100** depicting a device for powering an implantable medical device (IMD) implanted in a body of a subject in accordance with an embodiment of the present disclosure;

[0011] Figure 2 illustrates an electro-stimulator **200** in accordance with an embodiment of the present disclosure; and

[0012] Figure 3 depicts a flowchart illustrating a method **300** for powering an implantable medical device (IMD) implanted in a body of a subject in accordance with an embodiment of the present disclosure.

[0013] The figures depict embodiments of the disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the disclosure described herein.

DETAILED DESCRIPTION

[0014] The foregoing has broadly outlined the features and technical advantages of the present disclosure in order that the detailed description of the disclosure that follows may be better understood. It should be appreciated by those skilled in the art that the conception and specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure.

[0015] The novel features which are believed to be characteristic of the disclosure, both as to its organization and method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying Figures. It is to be expressly understood, however, that each of the Figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

[0016] Disclosed herein is a device and method for powering an implantable medical device. Implantable medical devices (IMDs) are surgically or medically inserted inside the body cavity of a subject, for example a patient, for performing different functionalities such as rebuilding body functions, achieving a better quality of life, or expanding longevity depending upon the type and purpose of the IMD. However, one of the major issues faced with the IMDs of the present day is the fact that they are battery powered and therefore, the subject needs to undergo a surgical procedure when the IMD runs out of battery and requires replacement. It is well-known that surgical procedures, however minor they may be, pose certain risks. Over the years, IMDs have been used for specific purposes within the body such as a pacemaker for heart, cochlear implants and blood pressure sensing implants. These IMDs have in-built batteries that require large device dimensions for appropriate energy storage and therefore, cannot be scaled down. However, with the advances in science and technology, miniaturization is a key feature being aimed to achieve for IMDs that since being small in size (~mm dimensions) can be used for implantation for various types of disorders such as cardiac, orthodontic, gastric and neurological. Further, the commonly used batteries for IMDs, especially pacemakers use either Ni-Cd (Nickel-Cadmium) batteries, Li-ion (Lithium-ion) batteries, Li-I (Lithium-iodide) batteries or Li-polymer batteries. However, these batteries generally face the issues of leakage which can prove to be hazardous to the subject since the chemicals of the battery would leak inside the body of the subject, are costly and also have a low efficiency.

[0017] The present disclosure understands this need and provides a device that eliminates the need of unnecessary surgery for replacing the batteries of an IMD implanted inside the subject and wirelessly powers the IMD either by recharging its battery or by directly powering it. Further, the device of the present disclosure is scaled down to smaller dimensions without compromising its energy storage capability. Furthermore, the present disclosure also proposes a flexible printed battery that overcomes the disadvantages of the conventional batteries as described above. The detailed description of the device is described in the subsequent paragraphs.

[0018] **Figure 1** illustrates an exemplary environment **100** depicting a device for powering an implantable medical device (IMD) implanted in a body of a subject in accordance with an embodiment of the present disclosure.

[0019] In the exemplary embodiment **100** as depicted in Figure 1, the device **106** for powering the IMD **104** is such that it can be adhesively placed on the skin surface of the subject and hence can be operated at any location on the body of the subject. The device **106** comprises a polymeric platform **108** developed by a suitable physical method or a chemical method or a combination of both. The doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate. In accordance with an embodiment of the present disclosure, the doped polymer film comprises a TiO_2 (titanium dioxide)-graphene-polyaniline conducting polymeric film and the bio-compatible antibacterial adsorber comprises either a fibroin protein or an agarose antibacterial adsorber. Further, in accordance with an embodiment of the present disclosure, the polymeric platform **108** is developed by employing electrospinning method while the graphene that needs to be incorporated in the polymeric platform **108** is synthesized by hydrothermal method using bio-wastes. However, it may be noted that other suitable techniques may be employed to develop the polymeric platform **108** including but not limited to photopolymerization technique and electrodeposition technique. Furthermore, in accordance with an embodiment of the present disclosure, the polymeric platform **108** is developed to have dimensions between 0.5-1 micron.

[0020] On the polymeric platform **108**, various electronic components are integrated in order to form a multi-modal energy harvesting structure. The first part of electronic components comprises a plurality of photovoltaic cells **110** and a piezoelectric harvesting system **112**. The piezoelectric harvesting system **112** comprises a piezoelectric material connected to an electric circuit such that when a force is applied on the piezoelectric material, the mechanical energy is converted into electrical energy by means of the electric circuit. In a similar fashion, the photovoltaic cells **110** convert solar energy into electrical energy. Therefore, the plurality of photovoltaic cells **110** and a piezoelectric harvesting system **112** forms a multi-modal energy harvester.

[0021] The second part of electronic components comprises a pattern printed metal plate **114** integrated on the polymeric platform **108** to transform the generated electrical energy into mid-field energy. In one embodiment, the metallic pattern plate **114** is developed by printing copper ink patterns on the polymeric platform **108**. Using the pattern printed metal plate **114** on the polymeric platform **108** placed on the skin surface, the output mid-field can be focused to dimensions much smaller than the vacuum wavelength, creating a high energy density region within which the multi-modal energy harvesting structure can be made extremely small. In other words, the device **106** is scaled down to smaller size without compromising its energy harvesting capability.

[0022] Further, in accordance with an embodiment of the present disclosure, a flexible printed battery **104** integrated with the IMD **102** is described. The flexible printed battery **104** comprises an electrode assembly, an electrolyte contained within a sealed housing, and a plurality of electrical contacts configured to supply the electric current from the flexible printed battery **104** to the IMD **102**. In accordance with an embodiment of the present disclosure, the electrode assembly is printed by using a printable ink made of an eco-friendly substance such as soya bean oils.

[0023] The device **106** adhesively placed on the skin surface of the subject may either power the IMD **102** directly or may charge the flexible printed battery **104** integrated with the IMD **102**. The powering of the IMD **102** by either charging of the flexible printed battery **104** or directly is accomplished by mid-field power transfer that allows the propagation of the mid-field energy, through the biological tissues of the subject without posing any harm to the subject. The mid-field energy is received by the IMD **102** through an electro-stimulator **200** (of Fig. 2) that acts as an antenna. In one embodiment, the IMD **102** comprises electrodes that are connected to the flexible printed battery **104** in order to recharge it.

[0024] Further, with the flexible printed battery **104** being integrated with the IMD **102** allows the IMD **102** to be scaled down to smaller sizes and therefore, allows the possibility to devise IMDs for various disorders concerning cardiac, orthodontic, gastric and neurological domains. Furthermore, as can be seen from Figure 2, the electro-stimulator **200** (acting as an antenna for the IMD **102**) has dimensions as small as 5 mm which helps in further reducing overall size of the IMD **102**.

[0025] Figure 3 depicts a method **300** for powering an implantable medical device (IMD) implanted inside body of a subject, in accordance with an embodiment of the present disclosure.

[0026] The order in which the method **300** is described is not intended to be construed as a limitation, and any number of the described method blocks may be combined in any order to implement the method. Additionally, individual blocks may be deleted from the methods without departing from the spirit and scope of the subject matter described.

[0027] At block **302**, the method **300** may include developing a device **106** for facilitating multi-modal energy harvesting. To develop the device **106**, the method **300** executes blocks **302A**-**302C**.

[0028] At block **302A**, the method **300** may include synthesizing a polymeric platform **108** made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate.

[0029] At block **302B**, the method **300** may include integrating a plurality of photovoltaic cells **110** and a piezoelectric harvesting system **112** upon the polymeric platform **108**.

[0030] At block **302C**, the method **300** may include integrating a pattern printed metal plate **114** on the polymeric platform **108**.

[0031] At block **304**, the method **300** may include adhesively placing the device **106** on a skin surface of the subject.

[0032] At block **306**, the method **300** may include powering the IMD **102** directly or charging a flexible printed battery **104** integrated with the IMD **102** by using mid-field energy, propagating through the body of the subject and received by the IMD **102** through an electro-stimulator **200** as depicted in Figure 2 that acts as an antenna.

[0033] A description of an embodiment with several components in communication with each other does not imply that all such components are required. On the contrary, a variety of optional components are described to illustrate the wide variety of possible embodiments of the disclosure.

[0034] When a single device or article is described herein, it will be clear that more than one device/article (whether they cooperate) may be used in place of a single device/article. Similarly, where more than one device or article is described herein (whether they cooperate), it will be clear that a single device/article may be used in place of the more than one device or article or a different number of devices/articles may be used instead of the shown number of devices or programs. The functionality and/or the features of a device may be alternatively embodied by one or more other devices which are not explicitly described as having such functionality/features. Thus, other embodiments of the disclosure need not include the device itself.

[0035] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the disclosure be limited not by this detailed description, but rather by any claims that issue on an application based here on. Accordingly, the embodiments of the present disclosure are intended to be illustrative, but not limiting, of the scope of the disclosure, which is set forth in the following claims.

[0036] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

<u>We Claim</u>:

1. A device (106) for powering an implantable medical device (IMD) (102) implanted inside body of a subject, the device (106) comprising:

   a polymeric platform (108) made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate;

   a plurality of photovoltaic cells (110) and a piezoelectric harvesting system (112) integrated upon the polymeric platform (108); and

   a pattern printed metal plate (114) integrated on the polymeric platform (108);

   wherein the combination of the plurality of photovoltaic cells (110) and the piezoelectric harvesting system (112) forms a multi-modal energy harvester, and wherein an energy harvested by at least one of the plurality of photovoltaic cells (110) and the piezoelectric harvesting system (112) is converted into electric energy that is further transformed into mid-field energy through the pattern printed metal plate (114).

2. The device as claimed in claim 1, wherein the device (106) either powers the IMD (102) directly or charges a flexible printed battery (104) integrated with the IMD (102) by using the mid-field energy, propagating through the body of the subject and received by the IMD (102) through an electro-stimulator (200) that acts as an antenna.

3. The device as claimed in claim 1, wherein:

   the doped polymeric film comprises a TiO_2-graphene-polyaniline conducting polymeric film;

   the biocompatible antibacterial adsorber comprises either a fibroin protein or an agarose antibacterial adsorber; and

   the polymeric platform (108) is developed by either a physical method, a chemical method or a combination thereof.

4. The device as claimed in claim 1 is capable of adhesion on a skin surface of the subject.

5. The device as claimed in claim 1, wherein the flexible printed battery (104) comprises:

   an electrode assembly, wherein the electrode assembly is printed by using a printable ink made of an eco-friendly substance;

   an electrolyte contained within a sealed housing; and a plurality of electrical contacts configured to supply an electric current from the flexible printed battery (104) to the IMD (102).

6. A method for powering an implantable medical device (IMD) (102) implanted inside body of a subject, the method comprising:

developing a device (106) for facilitating multi-modal energy harvesting, wherein developing the device (106) comprises:

synthesizing a polymeric platform (108) made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate;

integrating a plurality of photovoltaic cells (110) and a piezoelectric harvesting system (112) upon the polymeric platform (108); and

integrating a pattern printed metal plate (114) on the polymeric platform (108);

wherein the combination of the plurality of photovoltaic cells (110) and the piezoelectric harvesting system (112) forms a multi-modal energy harvester, and wherein an energy harvested by at least one of the plurality of photovoltaic cells (110) and the piezoelectric harvesting system (112) is converted into electric energy that is further transformed into mid-field energy through the pattern printed metal plate (114).

7. The method as claimed in claim 6, further comprising powering the IMD (102) directly or charging a flexible printed battery (104) integrated with the IMD (102) by using the mid-field energy, propagating through the body of the subject and received by the IMD (102) through an electro-stimulator (200) that acts as an antenna.

8. The method as claimed in claim 6, wherein:

the doped polymeric film comprises a TiO_2-graphene-polyaniline conducting polymeric film;

the biocompatible antibacterial adsorber comprises either a fibroin protein or an agarose antibacterial adsorber; and

the polymeric platform (108) is developed by either a physical method, a chemical method or a combination thereof.

9. The method claimed in claim 6, comprising adhesively placing the device (106) on a skin surface of the subject.

10. The method as claimed in claim 6, wherein the flexible battery (104) comprises:

an electrode assembly, wherein the electrode assembly is printed by using a printable ink made of an eco-friendly substance;

an electrolyte contained within a sealed housing; and

a plurality of electrical contacts configured to supply an electric current from the flexible printed battery (104) to the IMD (102).

Dated this 12th day of April 2022

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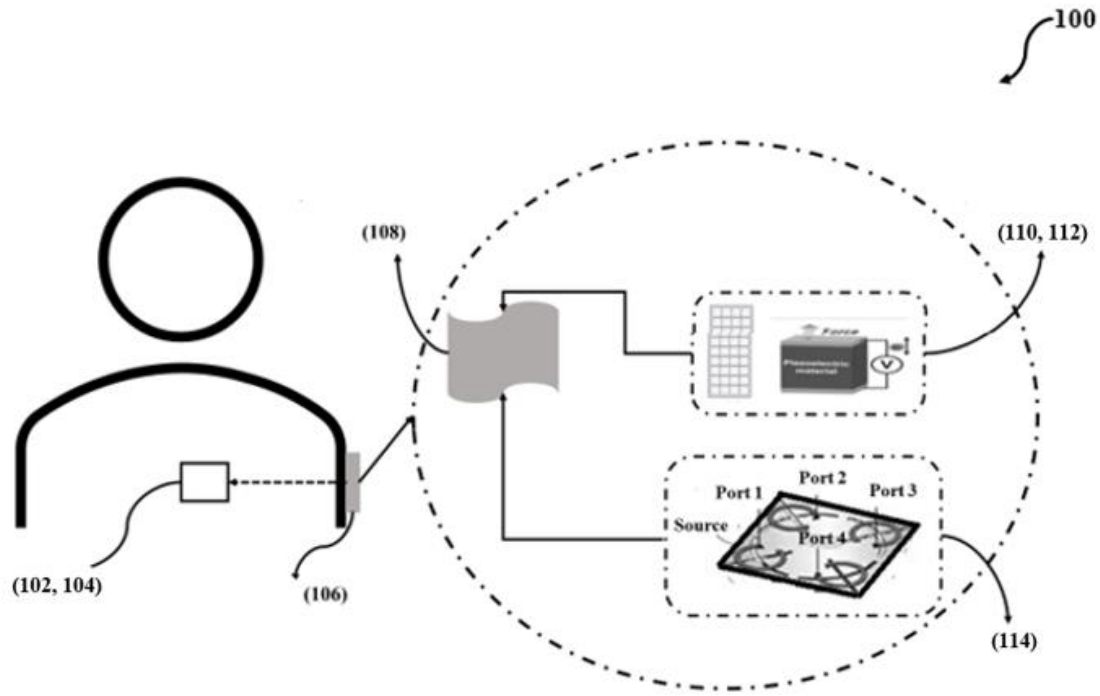
ABSTRACT

A DEVICE AND METHOD FOR POWERING AN IMPLANTABLE MEDICAL DEVICE

Disclosed herein is a device **(106)** and method for powering an implantable medical device (IMD) **(102)**. The device **(106)** comprises a polymeric platform **(108)** made up of a doped polymer film embedded within a biocompatible antibacterial adsorber on a flexible substrate. On the polymeric platform **(108)**, a multi-modal energy harvester comprising a plurality of photovoltaic cells **(110)** and a piezoelectric harvesting system **(112)** is integrated. A pattern printed metal plate **(114)** is also integrated on the polymeric platform **(108)** to transform the harvested energy into mid-field energy for powering the IMD **(102)** either directly or by charging a flexible printed battery **(104)** integrated with the IMD **(102)**.



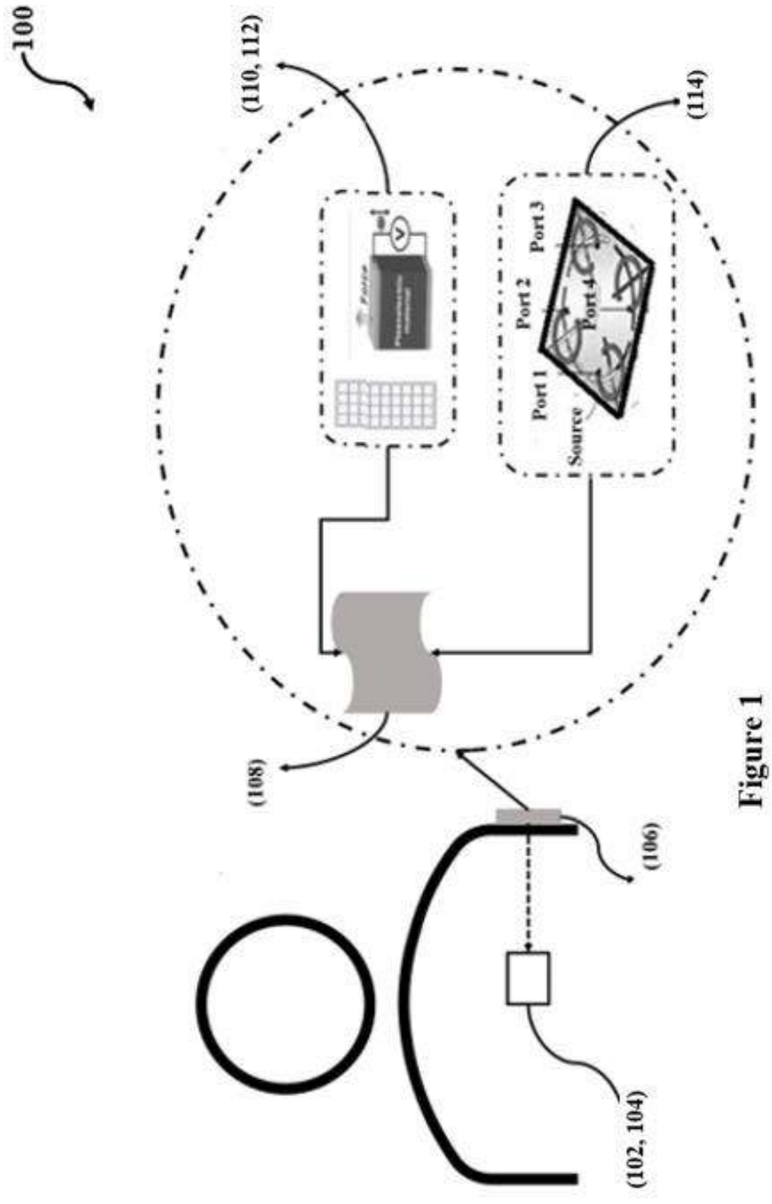


Figure 1

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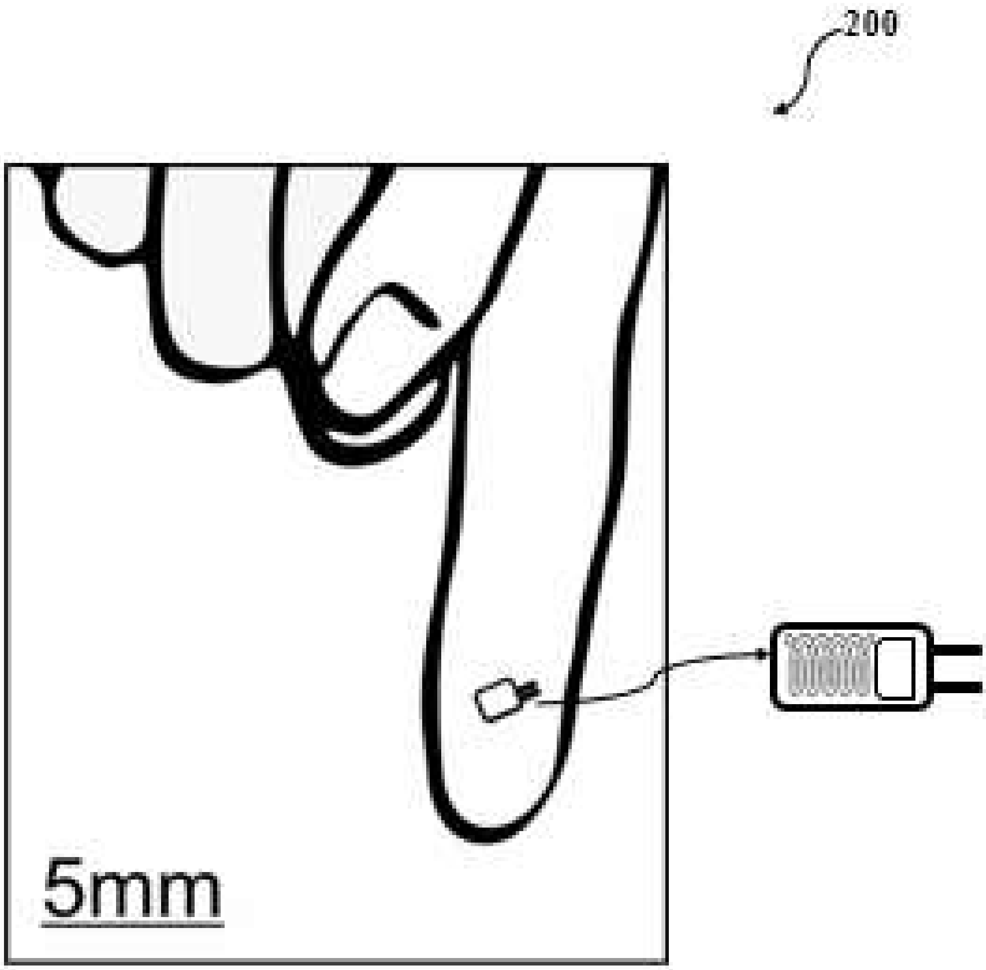

Figure 2

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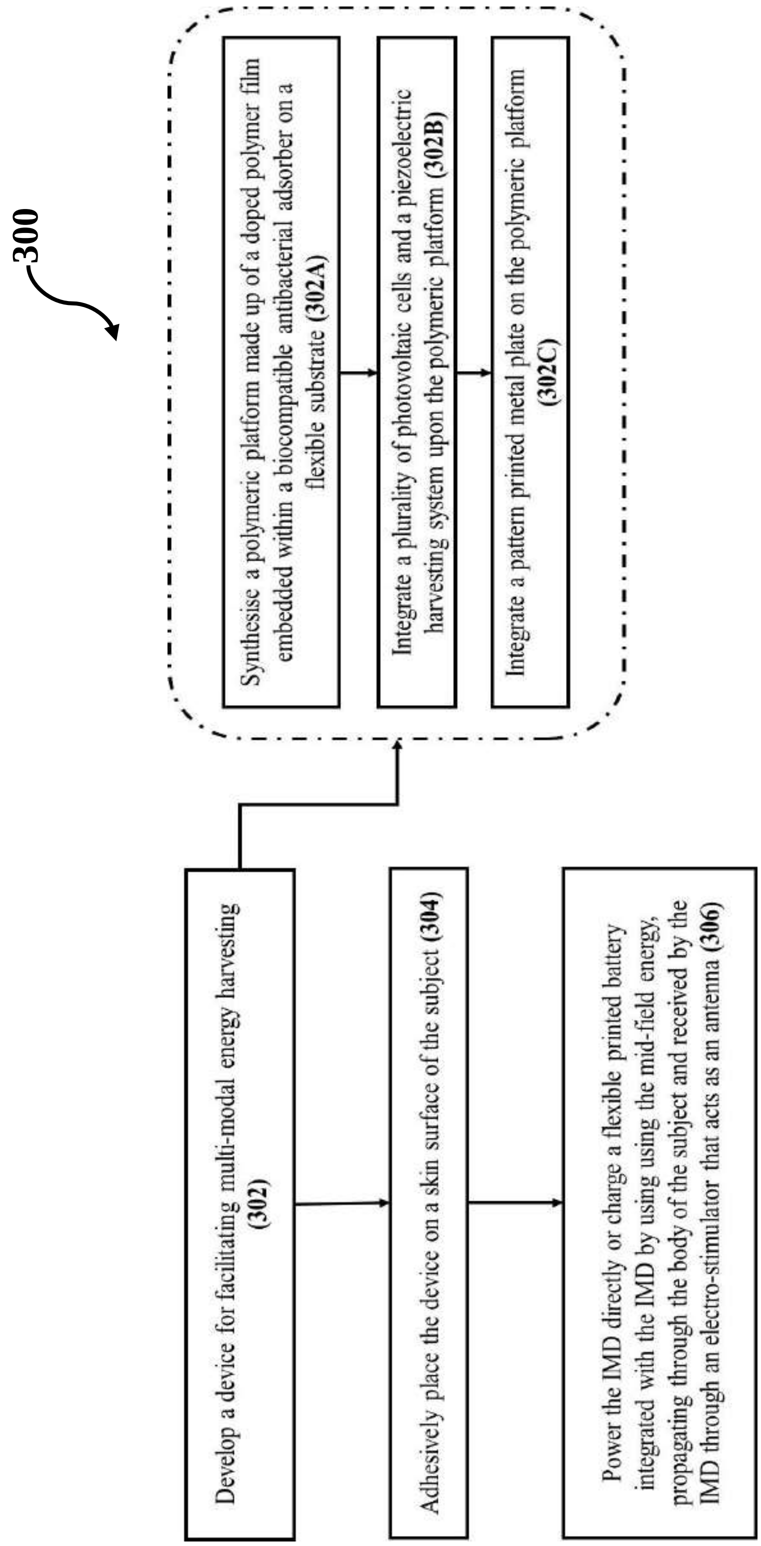

Figure 3

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