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(54) Title: NERVE STIMULATING AND MONITORING DEVICE

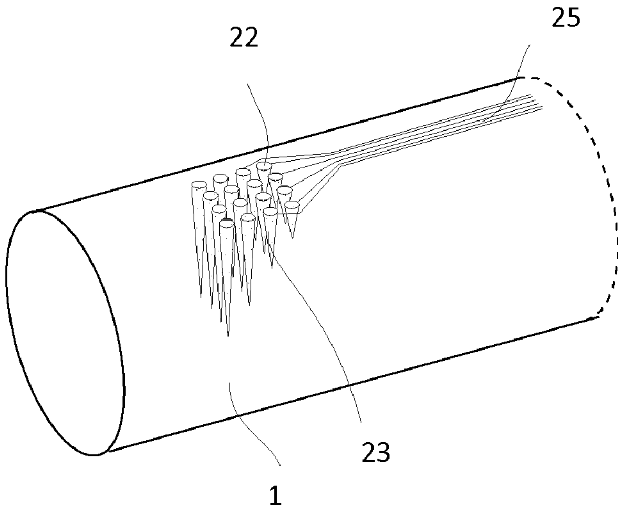

Figure 3

(57) Abstract: A device for detecting impulses within a nerve, the device comprising a support for securing to the epineurium of the nerve, at least one spike extending from said support, arranged to penetrate the perineurium and at least one chemical sensor arranged on a surface of the at least one spike.

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Nerve stimulating and monitoring device

Field of the invention

This invention relates to the field of nerve monitoring devices and nerve stimulating devices, more specifically but not restricted to, nerve cuffs and intraneural electrodes.

Background to the invention

Figure 1 illustrates a cross section of a nerve (1). The nerve contains a plurality of fascicles (2). Each fascicle forms a bundle of axons which can carry electrochemical signals toward organs. Each fascicle is surrounded by a layer of tissue called a perineurium (3). An interfascicular space (4) is provided between the fascicles and the nerve is surrounded by a layer of connective tissue called epineurium (5).

Some nerves can carry signals from sensory neurons to the central nervous system and those nerves are referred to as afferent nerves. Other nerves can carry signals from the central nervous system to muscles and organs and those nerves are referred to as efferent nerves. A third type of nerve can contain both afferent and efferent axons.

An electrochemical signal travelling along an axon is also referred to as an action potential. As the action potential travels down an axon, the electric potential difference across the cell membranes of the axon changes. The changes are caused by the opening and closing of Na^+ and K^+ gated ion channels. At an initial stage of the action potential, Na^+ channels open and Na^+ moves into the axon, causing depolarization. At a later stage of the action potential, the K^+ channels open and K^+ moves out of the axon, causing repolarization.

Summary of the invention

In accordance with an aspect of the invention, there is provided a device for detecting impulses within a nerve, the device comprising a support for securing to the epineurium of the nerve, at least one spike extending from said support and arranged to penetrate the perineurium, and at least one chemical sensor arranged on a surface of the at least one spike.

The spike may further be arranged to carry an electric signal for stimulating at least part of the nerve. The dimensions of the chemical sensor may be chosen to correspond to the dimensions of a fascicle within the nerve and the position of the chemical sensor may be chosen such that the chemical sensor is in direct contact with the fascicle when the spike is entered in to the nerve. The device may comprise a plurality of chemical sensors attached to the at least one spike for interfacing a corresponding plurality of fascicles and may further comprise a reference chemical sensor attached to a part of the device remote from the at least one spike.

The device may further comprise a reference electrode. The chemical sensors may be sensitive to one of: K^+, Na^+, Cl^- and H^+. The device may comprise a plurality of spikes arranged along a helical path or arranged along a linear path parallel to the longitudinal axis of the nerve. The support may be a nerve cuff and may a flexible material for wrapping the nerve cuff around the nerve. Alternatively, the cuff may comprise two substantially rigid sections connected to each other by a hinge.

The device may further comprise a processor connected to the at least one chemical sensor which is arranged to process the chemical signal. The processor may further be arranged to send a signal to the spike and the signal may be arranged to be sent to the spike depending on the measured chemical signal in a closed-loop control system.

Brief description of the drawings

Some preferred embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 illustrates a cross section of a nerve;

Figure 2 shows a perspective view of a nerve with a nerve cuff;

Figure 3 shows a perspective view of a nerve with a detail of a nerve cuff;

Figures 4 a) and b) show a perspective view of two spikes;

Figure 5 shows a perspective view of a nerve with a nerve cuff;

Figure 6 shows a perspective view of an open nerve cuff with spikes;

Figure 7 shows a perspective view of a nerve cuff with spikes in an open state and

Figure 7a) shows the nerve cuff in a closed state.

Detailed description of certain embodiments

Herein disclosed is a means for both stimulating a nerve and detecting activity of the nerve. The stimulation may be carried out in response to a detected activity of the nerve or the stimulation may be carried out without first detecting a signal. Detection of an activity of a nerve may be carried out by a means for detecting an action potential travelling along an axon. One way of detecting an action potential is detecting a change in concentration of Na^+ and K^+ ions in a portion of the nerve. A second way of detecting an action potential is detecting electrical activity with an electrode, whereby the electrode is arranged to estimate the potential difference between the inside and the outside of the axons. The stimulation may be carried out by a means for applying a voltage difference to a portion of the nerve or injecting current into a portion of the nerve.

A first embodiment is illustrated in Figs. 2 and 3. A substantially cylindrical nerve cuff 21 partially or completely surrounds a portion of the length of the nerve 1. The parts of the nerve corresponding to the parts of the nerve shown in Fig. 1 are indicated with the same reference numerals. In radial direction of the nerve, the cuff follows the perimeter of the nerve such that there is a direct contact between the cuff and the nerve. The cuff may be made of a flexible material such that the cuff can be wrapped around a nerve when putting the cuff in place. A plurality of arrays of pointed spikes 22, 23 are provided on the inside 24 of the cuff and extend from the cuff into the nerve.

An array of spikes is illustrated in more detail on Fig. 3. The arrays are connected to contacts 25 which can carry an electrical signal to or from the spikes. The spikes have different lengths and thereby extend to different parts of the nerve. A particular spike may penetrate one or more fascicles and the interfascicular space.

Fig. 2 illustrates that nerve electrical monitoring electrodes may be provided as a band 26 or as pads 27 distributed around the inside of the nerve cuff.

Two embodiments of spikes 23 are illustrated in Figures 4 a) and b). The end of a spike which is connected to the cuff is larger than the opposite end of the spike, which has a sharp tip for entering the spike into nerve tissue. The embodiments illustrated in Figs. 4 a) and b) have a conical shape. The spikes are, for example, between 0.1 and 3mm in length, depending upon the size of the nerve. The size is selected depending on the nerve to minimise damage to the nerve. The sensing area may be along substantially the whole surface of the spike, as illustrated in Fig. 4 a) as portion 27, or consisting of one or more sensing areas 27 which cover only a small part of the total spike surface and which are distributed along the spike surface as illustrated in Fig. 4 b). Examples of dimensions of the sensing areas are in the order of tens of micrometers, such as 30x30μm. The sensing areas are connected to contacts 25 for carrying signals to and from the sensing areas.

The sensing membrane 27 is a membrane deposited on the surface of a metal contact on the spike. These can be ISFET-type, capacitive-type or direct open circuit potential membranes. Two types of electrochemical sensors may be used: potentiostatic, which control a DC bias and measuring current, or potentiometric, which passively measure the potential- without forcing a bias potential or current. Potentiometric sensors are well suited for in-vivo sensing.

One specific example of a sensor 27 is an Ion-Selective Field Effect Transistor (ISFET). ISFETs may be used for pH measurements but can also be made sensitive to specific ions by the deposition of an appropriate ionophore into a polymer membrane. If the ISFETs are sensitive to specific ions they are referred to as ChemFETs. The ionophore facilitates selective ion transfer. A further option is an extendable planar version of an ISFET which has a separate sensing area and a coupled transistor. In this way, the sensing area is not restricted by the size of the transistor and can be made smaller. The transistor gate is then coupled to this in external recording circuitry. Applying the above examples of sensing structure based on ISFETs or ChemFETs to neural interfacing electrodes avoids any of the possible problems associated with interfacing a complementary metal–oxide–semiconductor (CMOS) silicon structure directly with tissue.

For measurements of pH within the nerve the inventors have appreciated that there are the following options for membranes including, but not limited to Iridium Oxide, Silicon Oxide, Silicon Nitride and Aluminium Oxide. Several other membranes may be attached, including ionic conductive polymers, plasticized polyvinyl chloride (PVC), ion-conductive inorganic crystals, biological ionophores, and enzymes. Most of these membranes can be manufactured using one of several technologies including thin-film deposition, electrochemical processes and dip-coating.

A spike as illustrated in Fig. 4b) provides sufficient spatial and temporal resolution to detect action potentials in individual fascicles. A particular sensing membrane 27 may be positioned on the spike such that it can be interfaced with a particular fascicle. The spike can be used to send an electronic signal into the nerve. When chemical sensors are used on the spike, the electrical stimulation and chemical sensing may be carried out simultaneously because electrical signal would not interfere with the chemical sensing membrane.

For calibration purposes, a platinum reference electrode may be provided within the cuff or an additional chemical sensor may be provided outside the cuff. The calibration measurements from the reference electrode or external chemical sensor can be compared with the measurements from the chemical sensors on the spike before or after amplification of the signals.

Figs. 5 and 6 illustrate an alternative arrangement of spike electrodes wherein the spikes (23) are distributed around the cuff such that, when wrapped around a nerve, rows of spikes are arranged along a helical path. As shown in Fig. 6, when the cuff is not wrapped around a nerve and laid out flat, the spikes are arranged in multiple substantially linear rows. The inventors have appreciated that this allows for an easier insertion into the nerve when the cuff is wrapped around the nerve.

Figs. 7 and 7a illustrate another embodiment of a cuff, wherein the spikes 23 are embedded in a semi-rigid cuff surface 21. The cuff illustrated in Figs. 7 and 7a consists of two halves forming a cylinder when joined together. The cylinder is opened up along its longitudinal axis and one or more hinges 28 allows the opening and closing of the cuff. Spikes can be placed in any convenient arrangement to minimize damage to the nerve. The arrangement shown in Fig. 7a is a substantially linear row of spikes along the longitudinal axis of the cylinder.

A further embodiment (not illustrated) is where the spikes are supported by a structure which does not form a cylinder when attached to the nerve. For example, the spikes may be supported by a substantially flat surface connected to a means for attaching the surface to the nerve, for example one or more rings.

Although the invention has been described in terms of preferred embodiments as set forth above, it should be understood that these embodiments are illustrative only and that the claims are not limited to those embodiments. Those skilled in the art will be able to make modifications and alternatives in view of the disclosure which are contemplated as falling within the scope of the appended claims. Each feature disclosed or illustrated in the present specification may be incorporated in the invention, whether alone or in any appropriate combination with any other feature disclosed or illustrated herein.

CLAIMS:

1. A device for detecting impulses within a nerve, the device comprising:

a support for securing to the epineurium of the nerve;

at least one spike extending from said support and arranged to penetrate the perineurium;

at least one chemical sensor arranged on a surface of the at least one spike.

2. The device according to claim 1, wherein the spike is further arranged to carry an electric signal for stimulating at least part of the nerve.

3. The device according to claim 1 or 2, wherein the dimensions of the chemical sensor are chosen to correspond to the dimensions of a fascicle within the nerve and wherein the position of the chemical sensor is chosen such that the chemical sensor is in direct contact with the fascicle when the spike is entered in to the nerve.

4. The device according to any one of the preceding claims, wherein the device comprises a plurality of chemical sensors attached to the at least one spike for interfacing a corresponding plurality of fascicles.

5. The device according to any one of the preceding claims, further comprising a reference chemical sensor attached to a part of the device remote from the at least one spike.

6. The device according to any one of the preceding claims, further comprising a reference electrode.

7. The device according to any one of the preceding claims, wherein the chemical sensors are sensitive to one of: K^+, Na^+, Cl^- and H^+.

8. The device according to any one of the preceding claims, comprising a plurality of spikes arranged along a helical path.

9. The device according to any one of claims 1 to 8, comprising a plurality of spikes arranged along a linear path parallel to the longitudinal axis of the nerve.

10. The device according to any one of the preceding claims, wherein the support is a nerve cuff.

11. The device according to any one of the preceding claims, wherein the support is a nerve cuff comprising a flexible material for wrapping the nerve cuff around the nerve.

12. The device according to any one of claims 1 to 10, wherein the support is a nerve cuff comprising two substantially rigid sections connected to each other by a hinge.

13. The device according to any one of the preceding claims, further comprising a processor connected to the at least one chemical sensor and arranged to process the chemical signal.

14. The device according to claim 13, wherein the processor is further arranged to send a signal to the spike.

15. The device according to claim 14, wherein the signal is arranged to be sent to the spike depending on the measured chemical signal in a closed-loop control system.

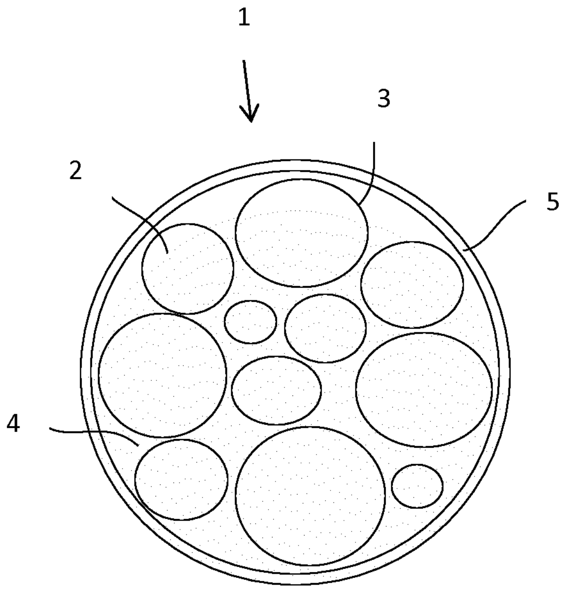

Figure 1

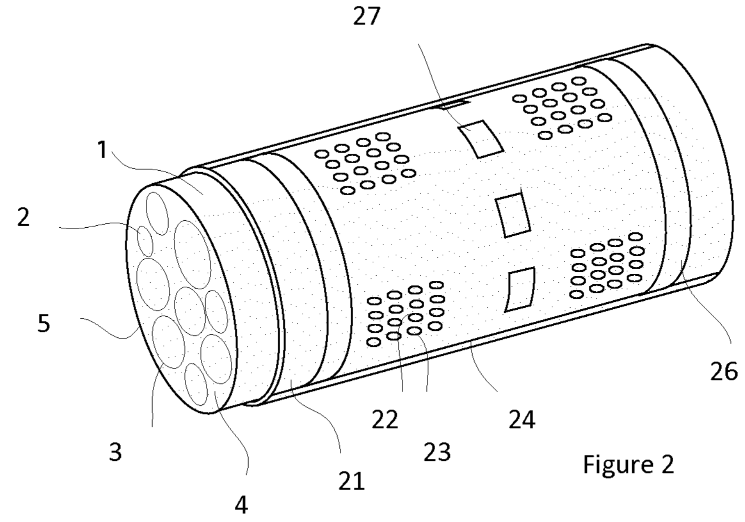

Figure 2

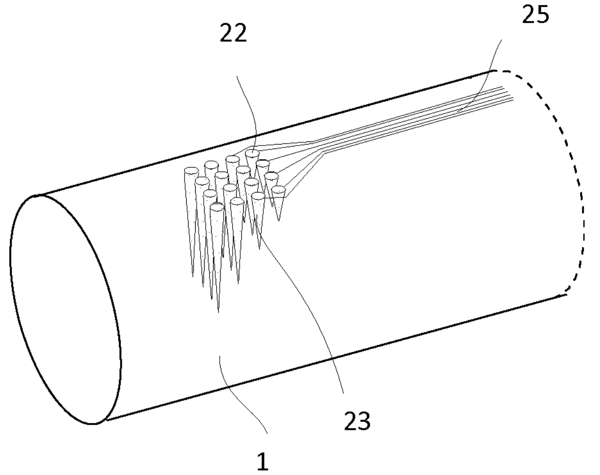

Figure 3

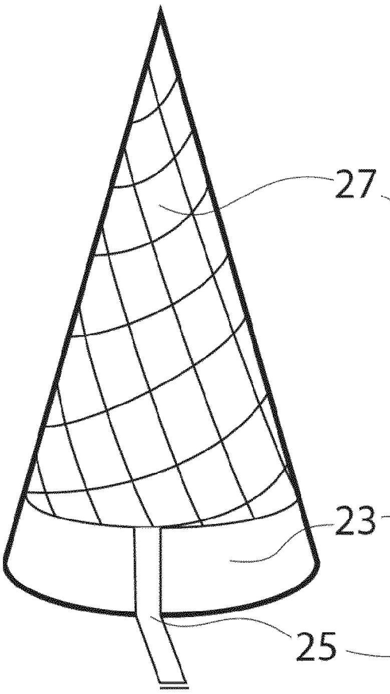

Fig. 4a

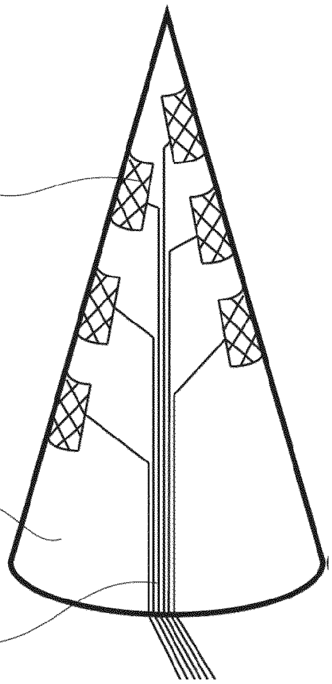

Fig. 4b

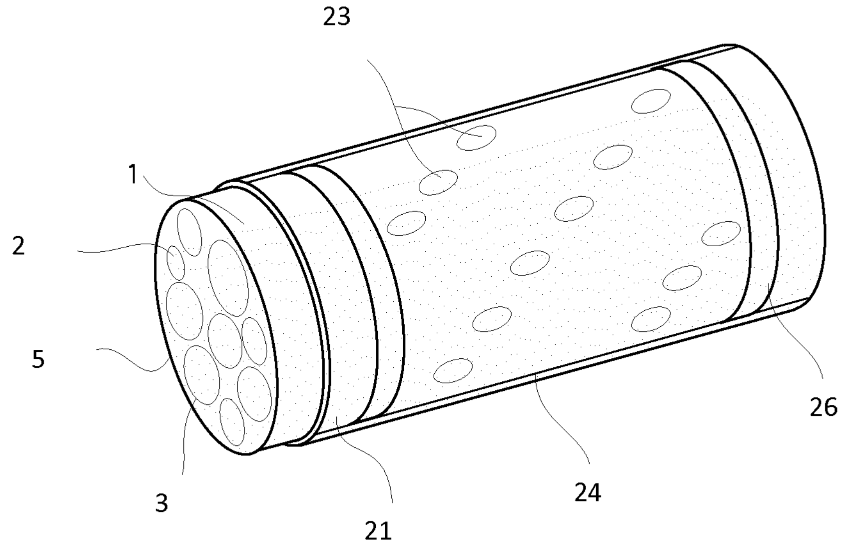

Figure 5

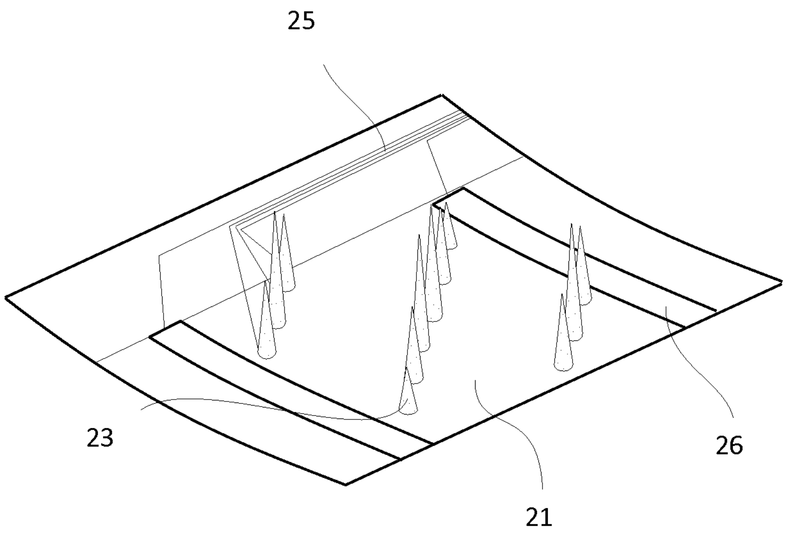

Figure 6

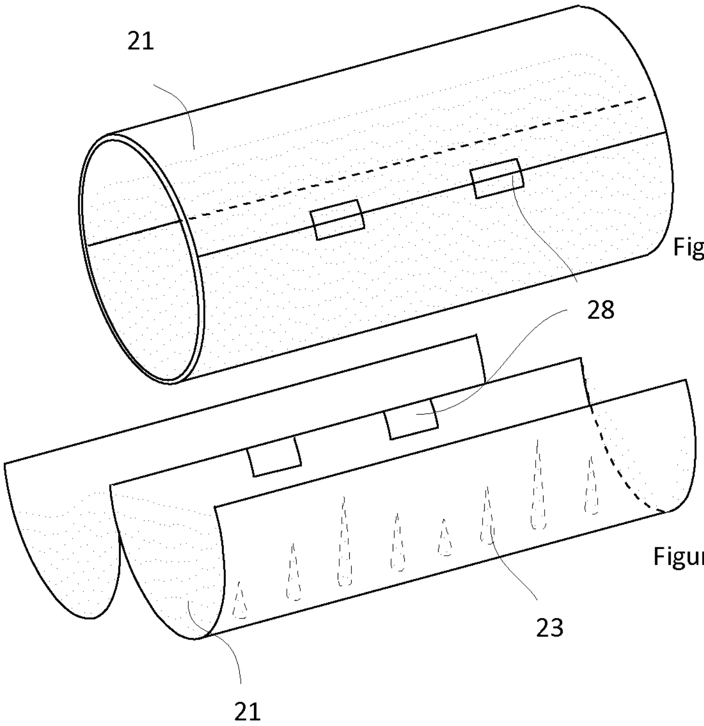

Figure 7

Figure 7a

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/065511

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/05 A61B5/04 A61B5/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61N A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	WO 2008/007065 A2 (IMP INNOVATIONS LTD [GB]; TRIANTIS IASONAS [GB]; TOUMAZOU CHRISTOFER [) 17 January 2008 (2008-01-17) abstract; figures 1-6 pages 1-9	1-15
A	US 4 969 468 A (BYERS CHARLES L [US] ET AL) 13 November 1990 (1990-11-13) abstract; figures 1-15 column 6, line 21 - column 14, line 34	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
2 October 2015	14/10/2015

Name and mailing address of the ISA/	Authorized officer
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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/065511

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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