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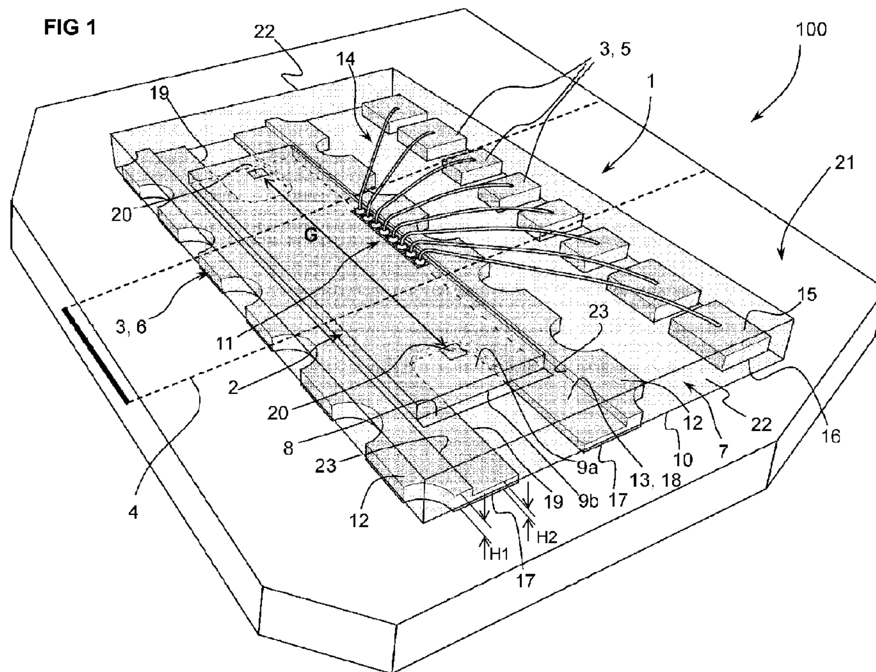

(57) **Abstract:** A magnetic field gradient transducer (1) for surface mounting on a circuit board (21), comprising - an integrated circuit (IC) chip (2) comprising an active first side (9a), a second side (9b), at least two magnetic field sensing portions (20) on the active side, and connection terminals (11) on the active side, the at least two magnetic field sensing portions (20) separated by a gap (G) configured for a magnetic field gradient measurement, - a lead frame arrangement (3) comprising a plurality of secondary conductors (5) and a shield conductor (6), the shield conductor in overlapping relation with the IC chip, - a plurality of secondary conductor bond wires (14) interconnecting two or more of the secondary conductors (5) to the connection terminals (11) of the IC chip, and - an insulating housing (7) overmolded over the IC chip, the secondary conductor bond wires, and a portion of the lead frame arrangement (3), whereby circuit board contact portions of the secondary conductors and the shield conductor are exposed and configured for surface mount connection

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to the external circuit board. The shield conductor has a non-indented portion (12) and an indented portion (13) upon which the IC chip is mounted, the indented portion having a thickness H2 less than a thickness H1 of the non-indented portion and secondary conductors.

MAGNETIC FIELD GRADIENT TRANSDUCER AND CURRENT TRANSDUCER THEREWITH

The present invention relates to an integrated circuit magnetic field gradient transducer for surface mounting on a circuit board, for current sensing applications. The present invention also relates to an open loop coreless current transducer with an integrated circuit magnetic field gradient transducer.

It is known to provide integrated circuit magnetic field gradient transducers for current sensing applications, having surface mount electrical connections for mounting on a circuit board. In many applications, there is an advantage in having a very compact and low height magnetic field transducer for measuring a current in a primary conductor on the circuit board, or in a primary conductor integrated with the magnetic field transducer, or to which the magnetic field transducer is assembled.

Such coreless magnetic field transducers may include an integrated circuit (IC) chip having an active sensing layer thereon detecting the magnetic field induced by a current to be measured flowing in a primary conductor in proximity to the magnetic field transducer, the integrated circuit chip being electrically connected to secondary contacts that supply power and allow transmission of the measurement signal to the external circuit board.

Active portions and connection interfaces on the semi-conductor substrate which, for instance a CMOS IC, are typically provided on a same single side of the IC. It is known to interconnect IC chip connections with bond wires to secondary conductors formed from a lead frame. A lead frame is a strip of sheet metal that is stamped and formed to cut out secondary contacts from the sheet metal, the contacts and integrated circuit being overmolded by an insulating polymer, connection ends of the contacts being exposed and configured for a solder or welding connection to circuit traces on the circuit board.

Magnetic field gradient sensors have two magnetic field active sensing portions separated by a gap, configured to measure a difference in the magnetic field between the two separate portions. Magnetic field gradient sensors are very compact and sensitive, and well adapted for coreless transducers, however are sensitive to external electrical fields. Also, the strength of the measurement signal of magnetic field gradient sensors for current sensing applications is strongly dependent on the distance from primary conductor.

In view of the foregoing, it is an object of the present invention to provide a magnetic field gradient transducer for surface mounting on a circuit board, for current sensing applications, that has a high measurement sensitivity.

It is advantageous to provide a magnetic field gradient transducer for surface mounting on a circuit board, for current sensing applications, that is compact and economical to manufacture.

Another object of the invention, is to provide an open loop coreless current transducer on a circuit board that is accurate, compact and economical to manufacture.

Objects of the invention have been achieved by providing a magnetic field gradient transducer according to claim 1.

Objects of the invention have been achieved by providing a current transducer according to claim 8.

Objects of the invention have been achieved by providing a method of manufacturing a magnetic field gradient transducer according to claim 9.

Disclosed herein is a magnetic field gradient transducer for surface mounting on a circuit board, comprising

- an integrated circuit (IC) chip comprising an active first side, a second side, at least two magnetic field sensing portions on the active side, and connection terminals on the active side, the at least two magnetic field sensing portions separated by a gap configured for a magnetic field gradient measurement,
- a lead frame arrangement comprising a plurality of secondary conductors and a shield conductor, the shield conductor in overlapping relation with the IC chip,
- a plurality of secondary conductor bond wires interconnecting two or more of the secondary conductors to the connection terminals of the IC chip, and
- an insulating housing overmolded over the IC chip, the secondary conductor bond wires, and a portion of the lead frame arrangement, whereby circuit board contact portions of the secondary conductors and the shield conductor are exposed and configured for surface mount connection to the external circuit board.

The shield conductor has a non-indented portion and an indented portion upon which the IC chip is mounted, the indented portion having a thickness H2 less than a thickness H1 of the non-indented portion and secondary conductors.

In an advantageous embodiment, the indented portion is bounded on at least two edges by the non-indented portions.

In an advantageous embodiment, the IC chip has a rectangular shape, a long edge of the rectangular shaped IC chip parallel to the at least two edges of the indented portion.

In an advantageous embodiment, the indented portion is substantially linear.

In an advantageous embodiment, the shield conductor indented portion extends from a first outer side of the transducer to a second opposite outer side of the transducer.

In an advantageous embodiment, the indented portion extends from the first outer side of the transducer to the second opposite outer side of the transducer.

In an advantageous embodiment, an insulating layer is positioned between the second side of the IC chip and the indented portion of the lead frame arrangement.

Also disclosed herein is an open loop coreless current transducer comprising a circuit board, a primary conductor for carrying a current to be measured formed on or in the circuit board, and a magnetic field gradient sensor according to any preceding embodiment, mounted on the circuit board over the primary conductor.

Also disclosed herein is a method of manufacturing a magnetic field gradient transducer according to any preceding embodiment, comprising forming the shield conductor as a continuous strip extending along a length of a plurality of magnetic field gradient transducers, mounting a plurality of the IC chips in the indented portion at defined intervals, wire bonding the secondary conductors to the connection terminals on the IC chips, overmolding of the overmold housing over said length of a plurality of magnetic field gradient transducers while the shield conductor remains in the form of a continuous strip, and then separating individual transducers by cutting the shield conductor strip and overmold housing at defined intervals corresponding to outer sides of the transducer.

Further objects and advantageous features of the invention will be apparent from the claims, from the detailed description, and annexed drawing, in which:

Figure 1 is a perspective view of a surface mount magnetic field gradient transducer according to an embodiment of the invention, the overmold housing portion being shown transparent.

Referring to the figure, a magnetic field gradient transducer 1 for surface mount connection on an external circuit board comprises an integrated circuit (IC) chip 2 mounted on a lead frame arrangement 3 housed within an insulating overmold housing 7.

The integrated circuit (IC) chip 2 has a first active side 9a and a second side 9b, at least the first active side 9a having active portions including electrical connection terminals 11 for connection to power and signal transmission conductors and a pair of magnetic field sensor portions 20 arranged at or close to the surface of the first active side 9a. The pair of magnetic field active sensing portions are separated by a gap, configured to measure a difference or gradient in the magnetic field between the two separate magnetic field sensing portions.

If a primary conductor 4 carrying a primary current to be measured passes substantially centrally across the gap G separating the magnetic field sensing portions, the magnetic fields at the positions of the magnetic field sensing portions are of opposite polarity.

The primary conductor 4 may be in the form of a circuit trace in a layer in or on the circuit board 21, or a separate bus bar assembled to the circuit board.

Each magnetic field sensing portion may comprise a Hall effect sensor, or a giant magneto-resistive sensor or other forms of magnetic field sensors that are *per se* well known in the art. The IC chip 2 may for instance be in the form of a CMOS chip although other types of semi-conductor integrated circuit chips with magnetic field sensing portions *per se* known in the art may be used. The semi-conductor chip does not need to be further described, such semi-conductor chips with magnetic field sensing portions and connection terminals being *per se* well known in the art.

The lead frame arrangement 3 comprises a shield conductor 6 and a plurality of secondary conductors 5. The lead frame arrangement is formed from a sheet of conductive metal, more specifically in the form of a band or strip that is stamped and formed in a stamping and forming process to cut out, bend and/or emboss the sheet metal to form the shield conductor and secondary conductors. Stamping and forming of lead frame arrangements from sheet metal are *per se* well known techniques.

The secondary conductors 5 which serve to interconnect the IC chip 2 to power and signal connections of an external circuit to which the current transducer is intended to be connected, comprise a plurality of conductors formed from the lead frame arrangement, each secondary conductor comprising a connection portion 15 on one side and a surface mount connection terminal 16 on the other side. The surface mount connection terminal 16 may be for instance arranged in a row presenting contact pads intended for surface mount solder or welding connection, as *per se* known in the art, to circuit traces of an external circuit board. The surface mount connection terminals 16 are thus positioned proximate an outer edge of the transducer overmold housing 7, the IC connection side 15 being positioned proximate the IC chip 2 allowing bond wire connections between the IC chip 2 and the IC connection side 15 of the secondary conductors. In variants, the secondary conductor terminals may have stamped and formed contact portions with various shapes and configurations, for instance that project below and outwardly from the IC chip housing lower surface 10, adapted for surface mount connection to circuit board conductive traces as *per se* known in the art.

Bond wires 14 are connected between the IC connection side 15 of each secondary conductor 5 and connection terminals 11 on the active first side 9a of the IC chip 2. It may be noted that certain secondary conductors may have no connection to the IC chip, forming a redundant secondary conductor for use with semi-conductor chips with more connection portions. In other words, the number of connections depend on the functions incorporated in the IC chip. The lead frame conductor arrangement 3 may have a constant configuration, whereas the number of wire bond interconnections between the secondary conductors and IC chip may depend on the configuration of the IC chip and desired functionalities to be incorporated in the transducer.

The may be plated with any suitable wire bondable layer in accordance with the bond wires used for the primary and secondary conductors.

The shield conductor 6 is positioned below and overlapping the IC chip 2, whereby the IC chip is mounted on the shield conductor 6. The shield conductor 6 serves as a shielding conductor for electrical shielding of the IC chip 2, and in addition may serve as a heat conductor to evacuate heat from the IC chip 2.

Similar to the secondary conductors, the shield conductor 6 comprises one or more surface mount connection terminals 17 on the bottom side. The surface mount connection terminal 17 may be for instance arranged in a row presenting contact pads intended for surface mount solder or welding connection, as *per se* known in the art, to circuit traces of an external circuit board. The surface mount connection terminals 17 are thus positioned proximate an outer

edge of the transducer overmold housing 7. In variants, the secondary conductor terminals may have stamped and formed contact portions with various shapes and configurations, for instance that project below and outwardly from the IC chip housing lower surface 10, adapted for surface mount connection to circuit board conductive traces as *per se* known in the art.

The sheet metal from which the lead frame is cut out and formed, has a thickness H1, which is thus also the thickness of the secondary conductors 5 and of a non-indented portion 12 of the shield conductor 6. The shield conductor comprises an indented portion 13 that has a thickness H2 smaller than the thickness H1 of the non-indented portion 12. The indented portion thickness H2 is preferably less than 60% of the non-indented portion thickness H1, for instance about 50% ($H2<0.6xH1$, e.g $H2 = 0.5xH1$).

The indented portion 13 may be formed by etching or other *per se* known subtractive manufacturing techniques (e.g. machining, grinding, spark erosion, ablative processes) or may be formed by stamping or rolling with a die that compresses and plastically deforms the material of the lead frame arrangement.

The indent advantageously reduces the distance between the magnetic field sensing portions 20 and the mounting side 10 of the transducer, thus reducing the distance between the magnetic field sensing portions 20 and the primary conductor 4 formed in or on the circuit board 21, or assembled to the circuit board. The indent allows to preserve the shielding quality of the IC chip 2, while ensuring greater measurement sensitivity due to the reduced distances between the magnetic field sensing portions and the magnetic field source, in the present application, the primary conductor. The indent also provides the advantage of reducing the overall thickness of the transducer, rendering it more compact than in a configuration without indent in the shield conductor.

Slots 19 may be cut out of the shield conductor to reduce eddy currents.

In an embodiment, the indented portion may be a continuous linear indent formed in the lead frame arrangement to simplify manufacturing processes for forming the indent, whereby the IC chip has a rectangular shape, with its long side arranged parallel to the linear edges of the indent. The indented portion is preferably formed within the non-indented portion bounded on at least two edges 23 by the non-indented portions. The indent may also serve to position and secure the mounting of the IC chip during the assembly process.

The ends of the shield conductor and the indented portion may extend from one outer side 22 of the housing 7 to the opposite second outer side 22.

An insulating layer 8 is positioned between the second side 9b of the IC chip and the indented
5 portion 13 of the lead frame arrangement 3. The insulating layer 8 may consist of an adhesive material to bond to the second side surface of the IC chip and a surface portion of the lead frame which is covered by the insulating layer during the assembly process of the transducer, or may comprise an insulating foil of material bonded to the lead frame and/or IC chip with an adhesive coating. The insulating layer may also be welded to the lead frame or held in an
10 assembled position between the lead frame and the IC chip by other means prior to the overmolding of the insulating housing 7.

In an advantageous manufacturing process of the magnetic field gradient transducer, the shield conductor may form a continuous strip extending along the length of a plurality of
15 transducers, the IC chips being mounted in the indents at defined intervals, the wire bonding of secondary conductors, and the overmolding of the overmold housing 7 being performed while the shield conductor 6 remains in the form of a continuous strip. Individual transducers may then be separated by cutting the shield conductor strip and overmold housing at defined intervals corresponding to the side edges 22 of the transducer.
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The IC chip assembly process on the lead frame arrangement, wire bonding process, and overmolding process is very economical by way of this process.

List of references used

- **Current transducer 100**
  - **Circuit board 21**
  - **Primary conductor 4**
  - **Magnetic field gradient transducer 1**
    - **integrated circuit (IC) chip 2**
      - **first side (active side) 9a**
        - magnetic field sensing portions 20
        - connection terminals 11
      - **second side 9b**
    - **insulating layer 8 (between IC chip and lead frame)**
    - **lead frame arrangement 3**
      - *secondary conductors 5*
      - *shield conductor 6*
    - **secondary conductors 5**
      - IC connection side 15
      - surface mount connection terminals 16
      - secondary conductor bond wires 14
    - **shield conductor 6**
      - IC mounting side 18
        - Non-indented portion 12
          - Height H1
        - Indented portion 13
          - Height H2
          - Indent edges 23
        - Slot 19
      - surface mount connection terminals 17
    - **Overmold housing 7**
      - mounting side 10
      - outer sides 22

Claims

1. A magnetic field gradient transducer (1) for surface mounting on a circuit board (21), comprising
5 - an integrated circuit (IC) chip (2) comprising an active first side (9a), a second side (9b), at least two magnetic field sensing portions (20) on the active side, and connection terminals (11) on the active side, the at least two magnetic field sensing portions (20) separated by a gap (G) configured for a magnetic field gradient measurement,
- a lead frame arrangement (3) comprising a plurality of secondary conductors (5) and a shield
10 conductor (6), the shield conductor in overlapping relation with the IC chip,
- a plurality of secondary conductor bond wires (14) interconnecting two or more of the secondary conductors (5) to the connection terminals (11) of the IC chip, and
- an insulating housing (7) overmolded over the IC chip, the secondary conductor bond wires, and a portion of the lead frame arrangement (3), whereby circuit board contact portions of the
15 secondary conductors and the shield conductor are exposed and configured for surface mount connection to the external circuit board,
characterized in that the shield conductor has a non-indented portion (12) and an indented portion (13) upon which the IC chip is mounted, the indented portion having a thickness H2 less than a thickness H1 of the non-indented portion and secondary conductors.

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2. The magnetic field gradient transducer according to the preceding claim wherein the indented portion is bounded on at least two edges (23) by the non-indented portions.

3. The magnetic field gradient transducer according to the preceding claim wherein the IC
25 chip has a rectangular shape, a long edge of the rectangular shaped IC chip parallel to the at least two edges of the indented portion.

4. The magnetic field gradient transducer according to any preceding claim wherein the indented portion is substantially linear.

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5. The magnetic field gradient transducer according to any preceding claim wherein the shield conductor indented portion extends from a first side (22) of the transducer to a second opposite side (22) of the transducer.

35 6. The magnetic field gradient transducer according to the preceding claim wherein the indented portion extends from the first side (22) of the transducer to the second opposite side (22) of the transducer.

7. The magnetic field gradient transducer according to any preceding claim wherein an insulating layer (8) is positioned between the second side (9b) of the IC chip and the indented portion (13) of the lead frame arrangement (3).

5 8. An open loop current transducer (100) comprising a circuit board (21), a primary conductor (4) for carrying a current to be measured formed on or in the circuit board, and a magnetic field gradient transducer (1) according to any preceding claim, mounted on the circuit board over the primary conductor.

10 9. A method of manufacturing a magnetic field gradient transducer according to any preceding claim 1-7, comprising forming the shield conductor as a continuous strip extending along a length of a plurality of magnetic field gradient transducers, mounting a plurality of the IC chips in the indented portion at defined intervals, wire bonding the secondary conductors to the connection terminals on the IC chips, overmolding of the overmold housing (7) over said
15 length of a plurality of magnetic field gradient transducers while the shield conductor remains in the form of a continuous strip, and then separating individual transducers by cutting the shield conductor strip and overmold housing at defined intervals corresponding to outer sides (22) of the transducer.

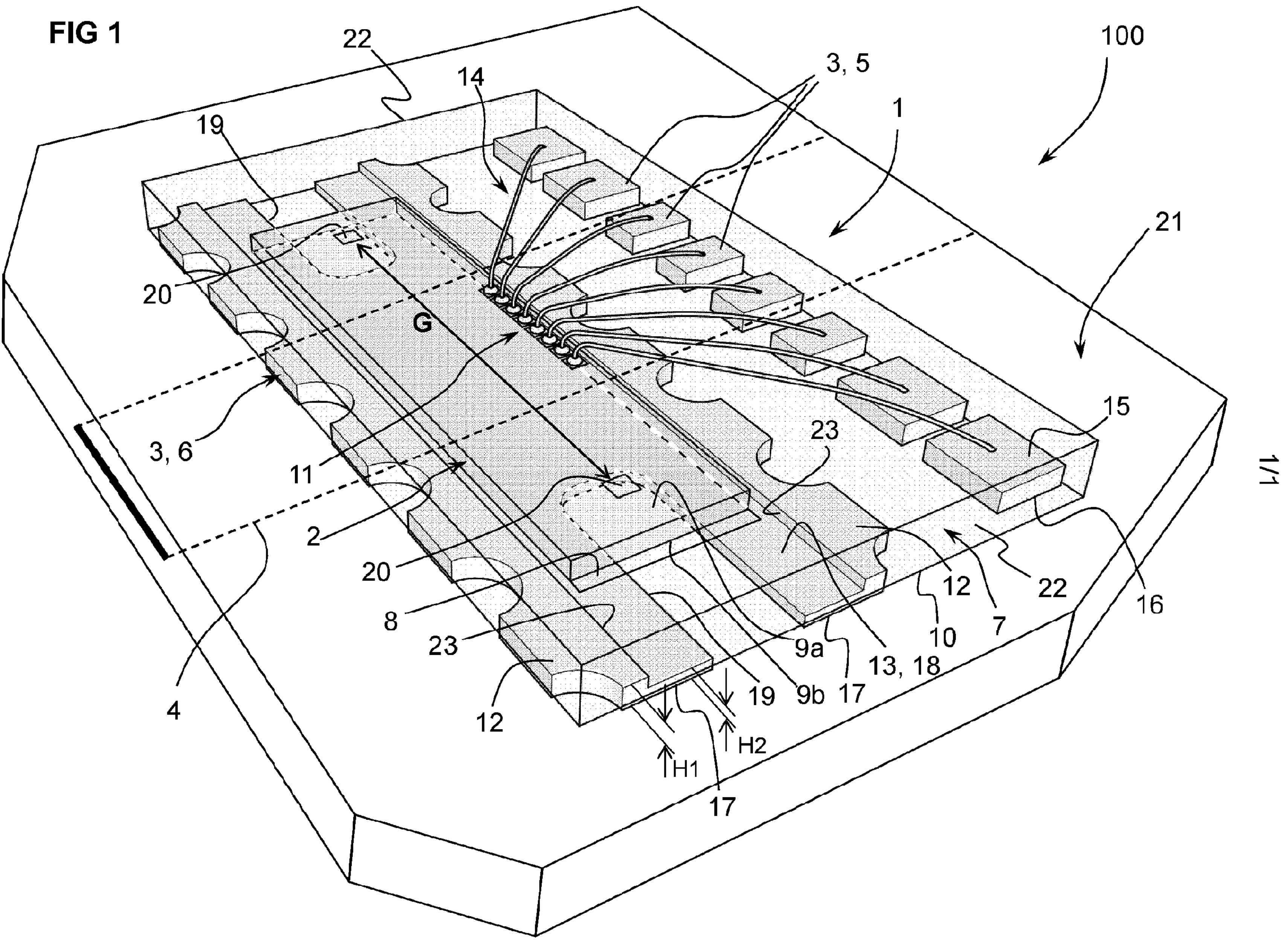

FIG 1

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R19/20 G01R15/20 G01R33/00
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)
G01R

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	paragraph [0003] - paragraph [0105]; figures 1, 1A, 2, 3	1,9

Y	US 2021/376227 A1 (LATHAM ALEXANDER [US] ET AL) 2 December 2021 (2021-12-02)	1
A	paragraph [0025] - paragraph [0055]; figures 1, 6A	2-9

A	US 2006/181263 A1 (DOOGUE MICHAEL C [US] ET AL) 17 August 2006 (2006-08-17) the whole document	1-9

A	US 2008/297138 A1 (TAYLOR WILLIAM P [US] ET AL) 4 December 2008 (2008-12-04) the whole document	1-9

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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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International application No
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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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A	paragraph [0051] - paragraph [0058]	1-8

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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