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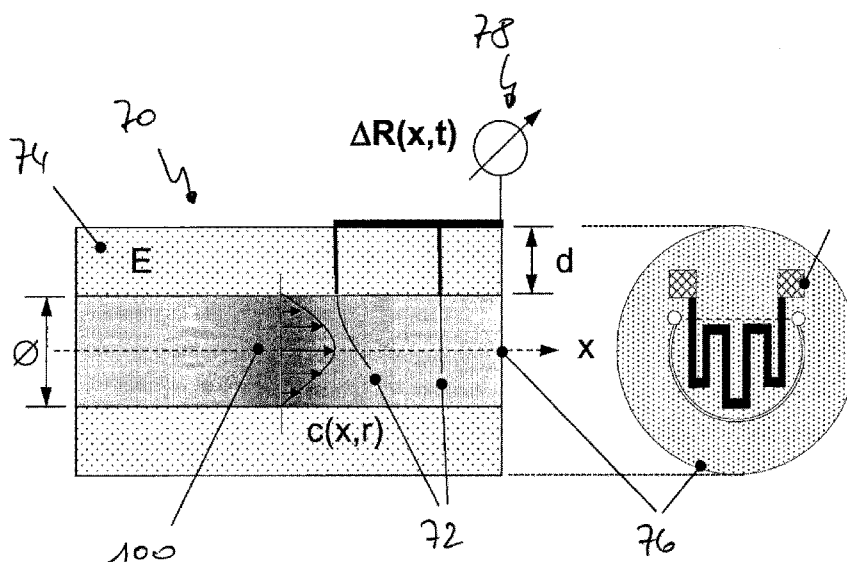
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(54) Title: FLOW SENSOR BASED ON THIN-FILM STRAIN-GAUGE MATERIAL

**Fig. 8**

(57) **Abstract:** A flow sensor comprises small strain-gauge-like bending sensitive filaments or foil-based flaps to be attached to the object at which a mass flow is to be analyzed. The filament / flap is provided with a thin Ni-C layer which changes its electrical resistance under mechanical stress. The mass flow will deform the filament or flap structure which creates an electrical signal proportional to the strength of the current. Due to the tiny sensor geometry the transient mass flow will not be distorted and the pressure difference between both sides of the sensor substrate is negligible. The bending of the sensor is then driven by the flow resistance of the sensor, i.e. by the consumption of kinetic energy.

Flow Sensor based on Thin-Film Strain-Gauge Material

Technical field

[0001] The present invention generally relates to the field of quantitative characterization of static or transient flow rates in industrial engineering. The present invention more particularly relates to flow sensor devices for the quantification of bulk fluid movement.

Background Art

[0002] Flow can be measured in a variety of ways. Positive-displacement flow meters accumulate a fixed volume of fluid and then count the number of times the volume is filled to measure flow. Other flow measurement methods rely on forces produced by the flowing stream as it overcomes a known constriction, to indirectly calculate flow.

[0003] In general, volumetric and mass flow meters are comparatively large measuring devices when compared with typical dimensions of the object the current is passing through (e.g. within tube cross sections) or is flowing against (e.g. mock-up of cars, buildings, planes etc.). Thus, such measurement devices cannot be used to monitor local, i.e. position dependent changes of flow parameters, transient changes between laminar and turbulent flow conditions and boundary layer effects. Especially in case of small object dimensions a quantitative characterization of fluid dynamical processes is hardly possible without disturbing the effect of interest which needs to be investigated.

Technical problem

[0004] It is an object of the present invention to provide an improved flow sensor device, which is suitable for a quantitative characterization of fluid dynamical processes. This object is achieved by the invention as claimed in claim 1.

General Description of the Invention

[0005] A flow sensor device for detecting at least one parameter of a mass flow in accordance with an important aspect of the invention comprises at least one bending sensitive sensor element to be arranged so as to extend into a mass flow to be analyzed, said bending sensitive sensor element having at least one

property which is indicative of a deformation of said bending sensitive sensor element. The flow sensor device further comprises a detection unit operatively coupled to the bending sensitive sensor element for detecting a variation of at least one property and/or for quantifying said at least one property.

[0006] The measuring principle of the flow sensor device according to the present invention relies on the detection of a deformation of a bending sensitive sensor element. Such a bending sensitive sensor element may be provided with very small dimensions and accordingly may be configured so as to not substantially disturb the mass flow may be analyzed.

[0007] The at least one bending sensitive sensor element may for instance comprise a flexible carrier element and a strain sensitive material applied to said flexible carrier element, said strain sensitive material having at least one property which is indicative of mechanical stress induced in the material and being electrically connected between at least one pair of terminals of said at least one bending sensitive sensor element. If the terminals are connected to the detection unit, the detection unit may detect a change of a the property of the strain sensitive material or may quantify said property so that the mechanical strain caused by bending of the sensor element may be determined.

[0008] The strain sensitive material preferably comprises a layer of metal containing carbon material, preferably a layer of nickel containing hydrogenated amorphous carbon (Ni:a-C:H). Metal containing carbon thin films can be prepared to exhibit piezoresistive properties with a high sensitivity to mechanical strain and with a temperature independent resistance. This advantageous combination of properties predisposes these films to be used as strain sensitive material for the flow sensors. Nickel containing carbon films (often termed as Ni containing hydrogenated amorphous carbon, shortly Ni:a-C:H) for instance yield a strain sensitivity (gauge factor) of approx. 20 together with a temperature coefficient of resistivity (TCR) below ± 50 ppm/K in the wide temperature range of 100 K to 400 K.

[0009] In one embodiment said flexible carrier element comprises a flap made of a flexible polymer film and preferably a flap made of a polyimide film. The flap is preferably an integral part of a sheet of said polymer film and formed from said

polymer sheet by cutting out a contour of said flap such a way that said flap comprises a bending end, at which said flap forms an integral part of said sheet and at which said flap is bendable with respect to a plane of said sheet, and an opposing free end, at which said flap is separated from said sheet. The flap is configured to be exposed to the mass flow to be analyzed and to be deformed or bent by the mass flow impacting on said flap. The contour and/or the form of the flap may be easily adapted to the specific application and use of the flow sensor device. The flap may e.g. have a generally quadratic form or a generally rectangular form with a longitudinal extension between said bending end and said free end being substantially larger than the transverse extension along the bending end or bending line. Alternatively the flap may have a generally rectangular form with a transverse extension along the bending end or bending line being substantially larger than the longitudinal extension between said bending end and said free end. In yet another embodiment specifically adapted to quantify the mass flow through a tube having a circular cross section, the flap may have a generally disc shaped form or the form of a segment of a disc.

[0010] It will be noted, that the flap may extend essentially in the plane of said sheet. Alternatively the flap may be bent at said bending end so as to extend at a certain angle α ($\alpha \neq 0$) with respect to said plane of said sheet. The flap may e.g. bend so as to extend perpendicularly to the sheet plane. The specific embodiment may be chosen depending on the application for which the flow sensor will be used and on the mounting arrangement of the carrier sheet with respect to the mass flow to be analyzed.

[0011] In one specific embodiment suitable for detecting a mass flow directed perpendicularly to a cross section of a conduit, the flap extends essentially in the plane of said sheet and the carrier sheet is arranged in a plane normal to said mass flow. The strain sensitive material is then preferably applied to said flap in a pattern which extends over a substantial part of a longitudinal extension of said flap between said bending end and said opposing free end. In operation, the flap is then deviated from its normal orientation by the mass flow and thereby subjected to a mechanical stress. The amount of mechanical stress resp. the amount of bending can be determined by the stress induced in the strain sensitive material.

The configuration of the pattern extending from the bending end to the free end thereby ensures a very high dynamic response from the sensor element.

[0012] In order to further enhance the dynamic response to the bending, i.e. the sensitivity of the sensing element, the strain sensitive material is preferably applied to said flap in a meandering pattern between electrical contact lines, said electrical contact lines for electrically connecting said strain sensitive material to said two terminals of said at least one bending sensitive sensor element. Such a configuration maximizes the length of the sensing path and thus the dynamic response of the sensor to the bending action.

[0013] In a different embodiment, the size of the flap may be reduced in view of a minimal perturbation of the mass flow. The flap may e.g. have a longitudinal extension which is substantially smaller than the transverse extension along the bending end. The flap is preferably bent so as to extend perpendicularly to the sheet plane. Such a sensing element may be mounted on a surface at which a mass flow is directed substantially in parallel to the surface. The carrier sheet may for instance be mounted flat on the surface of interest so that the flap or flaps extend substantially normally to a boundary layer of said mass flow.

[0014] With such an arrangement, the deformation or bending of the flap itself is substantially reduced due to the small longitudinal extension of the flap. In this embodiment, said strain sensitive material is therefore preferably applied to said flap substantially in the region of said bending end. In operation, the flap dissipates kinetic energy from the mass flow and is deviated from its original orientation. The bending end of the flap is accordingly subjected to mechanical stress which may be detected by means of the strain sensitive material arranged along the bending end.

[0015] It will be noted that irrespective of the above described embodiments, a plurality of flaps may be formed in or from a single sheet of said polymer film. It is thus possible to produce a sensing unit having a plurality of bending sensitive sensing elements in a single unit. The strain sensitive material pattern applied onto the different flaps may then be connected to individual terminals on the carrier sheet by means of conducting lines made of a suitable conductive material, such as silver or copper or the like. Alternatively the different pattern may be suitably

interconnected, e.g. in parallel or in series, between a single pair of terminals by means of common conducting lines applied or printed onto the carrier sheet. It remains to be noted that the individual flaps may be arranged in any suitable configuration, such as one behind the other in a direction of the mass flow or in a direction transverse to the mass flow, or in a staggered arrangement.

[0016] In another embodiment, the flexible carrier element comprises a fiber made of a flexible material, preferably a glass fiber and/or a polymer fiber. The fiber comprises a mounting end and a free end, said mounting end for mounting said fiber on a suitable support so that, in operation, said free end extends into the mass flow to be analyzed. The mounting end may e.g. be mounted on a support film to be arranged on a surface at which a parallel mass flow is to be analyzed. The arrangement may be such that the fiber extends substantially perpendicularly to the mass flow to be analyzed or at an angle different from 90°. It will be noted that due to the very small dimension of a flexible glass fiber, the embodiment as fiber or filament is especially suited for minimizing a distortion of a mass flow to be analyzed.

[0017] In a possible variant, a first pair of terminals is arranged at said mounting end of said fiber and said strain sensitive material is applied to said fiber in a first pattern extending between terminals of said first pair of terminals. The pattern of strain sensitive material may e.g. have the shape of a loop between the terminals that preferably extends over a substantial part of a longitudinal extension of said fiber between said mounting end and said free end. The arrangement is preferably such that both the upward extending branch (extending from the mounting end to the free end) and the downward extending branch (extending from the free end to the mounting end) of the loop are arranged in an area of the fiber which is exposed substantially uniformly to the mass flow to be analyzed. Both the upward extending branch and the downward extending branch are for instance arranged in a section of the outer surface of the fiber, which directly faces the impinging mass flow or both branches are instance arranged in a section of the outer surface of the fiber which faces away from the impinging mass flow. In these cases both the upward extending branch and the downward extending branch are subjected to the same mechanical stress (both being elongated or both being compressed) so

that a change in resistance due to the mechanical stress in both branches sums up to the entire dynamic signal. If one branch were facing the mass flow and one branch were facing away from the flow, the resulting changes in resistance would substantially compensate each other and the sensing element would not show a significant dynamic response to a bending action.

[0018] In an advantageous variant at least one further pair of terminals is arranged at said mounting end of said fiber and said strain sensitive material is applied to said fiber in at least one further pattern extending between terminals of said at least one further pair of terminals. The at least one further pattern of strain sensitive material may e.g. have the shape of a loop between the terminals that preferably extends over a substantial part of a longitudinal extension of said fiber between said mounting end and said free end. The at least one further pattern of strain sensitive material is preferably arranged in a different section of the outer surface of the fiber than the first pattern, so that said first pattern and said at least one further pattern are isolated from each other. This embodiment represents a multipole arrangement of a sensing element, which may advantageously be used to determine a flow direction with respect to the sensing fiber.

[0019] It will be noted that the sensing element may further comprise a protective layer, such as a resin layer, applied at least onto said strain sensitive material.

[0020] From the above description, it should be clear that the present invention describes a simplified measurement approach to assess local changes in material flow without affecting the overall fluid dynamical behavior. The invention proposes to use small strain-gauge-like bending sensitive filaments or foil-based flaps to be attached to the object at which a mass flow is to be analyzed. The filament / flap is provided with a thin Ni-C layer which changes its electrical resistance under mechanical stress. The mass flow will deform the filament or flap structure which creates an electrical signal proportional to the strength of the current. However, because of the tiny sensor geometry the transient mass flow will not be distorted and the pressure difference between both sides of the sensor substrate is negligible. The bending of the sensor is then driven by the flow resistance of the sensor, i.e. by the dissipation of kinetic energy.

[0021] In case the sensor substrate is of the same dimension as the flow (-filament) the perturbations of the flow yield a so-called pressure loss between front and back side of the sensor foil. Here the bending is driven by the dynamic pressure difference.

Brief Description of the Drawings

[0022] Preferred embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, which show:

Fig. 1: a top view of a sensor strip comprising three individual sensor flaps as well as an enlarged view of one of the sensor flaps,

Fig. 2: a side view of the sensor flap of fig. 1 when arranged in a mass flow;

Fig. 3: a top and a side view of a sensor flap with a different form;

Fig. 4: a top view of a sensor strip to be mounted in parallel to a mass flow comprising three individual sensor flaps in a staggered arrangement as well as an enlarged view of one of the sensor flaps,

Fig. 5: a side view of the sensor of fig. 4 when arranged in a mass flow;

Fig. 6: a side view and a cross sectional view of a first embodiment of a fiber based sensor element;

Fig. 7: a cross sectional view of a second embodiment of a fiber based sensor element;

Fig. 8: a schematic representation of an arrangement of several bending sensitive sensing elements for characterizing a mass flow in a tube;

Fig. 9: a graph of the electrical response of a flap sensor according to Fig 3 depending on a pressure of a mass flow in a tube;

Fig. 10: a schematic representation of the different application possibilities of the proposed flow sensors.

Description of Preferred Embodiments

[0023] Fig. 1 shows on the right a top view of a sensor strip 10 comprising three individual sensor flaps 12, 14 and 16 formed on a single strip of a carrier sheet 18, which may preferably be a flexible polymer film such as a polyimide film having a

thickness of about 75 μm to 100 μm or depending on the application even in the range of 40 μm . The left part of Fig. 1 shows an enlarged view of one of the sensor flaps 14. Fig. 2 shows a side view of the sensor flap 14 of fig. 1 when arranged in a mass flow 100.

[0024] The sensor flaps 12-16 of Fig. 1 are an integral part of the carrier sheet film 18 and are formed by cutting out a contour 20 of said flap e.g. by laser cutting. The laser cut 20 is performed such that the flap 14 comprises a bending end or bending line 22, at which the flap 14 forms an integral part of the sheet 18 and at which the flap 14 is bendable with respect to a plane of said sheet 18. Opposite to the bending end 22, the flap 14 has a free end 24 at which said flap is separated from the sheet 18.

[0025] The flap 14 is configured to be exposed to the mass flow 100 to be analyzed and to be deformed or bend (indicated by the reference numeral 26 in Fig. 2) by the mass flow 100 impacting on said flap.

[0026] The contour and/or the form of the flap may be adapted to the specific application and use of the flow sensor device. In the embodiment shown in fig. 1, the flap 14 has a generally rectangular form with a longitudinal extension between said bending end 22 and said free end 24 being substantially larger than the transverse extension along the bending end or bending line 22. In the embodiment shown in Fig. 3 of the sensor flap, the flap is specifically adapted to quantify the mass flow through a tube having a circular cross section. In this embodiment, the flap 14' has a generally disc shaped form or the form of a segment of a disc.

[0027] In the embodiment as shown in Fig. 1 to 3, the flaps 12-16 or 14' extend essentially in the plane of said sheet. These embodiments are particularly suited in applications, where the sensor strip is to be mounted perpendicularly to the mass flow 100 to be analyzed.

[0028] In these embodiments, a strain sensitive material 28 is then preferably applied to said flap 14, 14' in a pattern which extends over a substantial part of a longitudinal extension of said flap 14, 14' between said bending end 22 and said opposing free end 24. The strain sensitive material 28 preferably comprises a layer of metal containing carbon material, preferably a layer of nickel containing hydrogenated amorphous carbon (Ni:a-C:H) having e.g. a thickness of about 50-

70 nm. Metal containing carbon thin films can be prepared to exhibit piezoresistive properties with a high sensitivity to mechanical strain and with a temperature independent resistance. This advantageous combination of properties predisposes these films to be used as strain sensitive material for the flow sensors.

[0029] In order to further enhance the dynamic response to the bending, i.e. the sensitivity of the sensing element, the strain sensitive material 28 is preferably applied to said flap 14, 14' in a meandering pattern between electrical contact lines 30 and 32, said electrical contact lines for electrically connecting said strain sensitive material 28 to terminals of the bending sensitive sensor element. Such a configuration maximizes the length of the sensing path and thus the dynamic response of the sensor to the bending action.

[0030] In operation, the flap 14 is deviated (indicated by the reference numeral 26) from its normal orientation by the mass flow 100 and thereby subjected to a mechanical stress. The amount of mechanical stress resp. the amount of bending can be determined by the stress induced in the strain sensitive material 28. The configuration of the pattern extending from the bending end to the free end thereby ensures a very high dynamic response from the sensor element. A typical graph of the electrical response of a flap sensor according to Fig 3 depending on a pressure of a mass flow in a tube is shown as an example in Fig. 9.

[0031] It will be noted that for mechanical or chemical protection, the sensing element or sensing strip may further comprise a protective layer 34, such as a resin layer, applied at least onto said strain sensitive material 28 but preferably applied to the entire sensor strip. This resin layer may e.g. have a thickness of less than about 1 μm .

[0032] Fig. 4 and 5 illustrate a different embodiment of a flap based sensing element which is particularly suitable for characterizing a boundary layer of a mass flow directed parallel to a surface.

[0033] Fig. 4 shows on the right a top view of a sensor strip 110 comprising three individual sensor flaps 112, 114 and 116 formed in a staggered arrangement on a single strip of a carrier sheet 118, which may preferably be a flexible polymer film such as a polyimide film. The left part of Fig. 4 shows an enlarged view of one of

the sensor flaps 112. Fig. 5 shows a side view of the sensor flap 112 of fig. 4 when arranged in a mass flow 100.

[0034] The sensor flaps 112-116 are an integral part of the carrier sheet film 118. In contrast to the embodiment of Fig. 1 and 2, the flaps 112-116 do not extend in the plane of the carrier sheet 118, but are bent e.g. by thermoforming at their respective bending end 122 so as to extend substantially at a right angle with respect to the plane of the sheet 118. This embodiment is therefore particularly suited in applications, where the sensor strip is to be mounted flush on a surface along which the mass flow 100 to be analyzed passes.

[0035] The flaps 112-116 have a generally rectangular form with a transverse extension along the bending end or bending line 122 being substantially larger than the longitudinal extension between said bending end 122 and said free end 124. Due to the small longitudinal extension, the flaps 112-116 are into contact with only the boundary layers of the mass flow and therefore suitably to analyze the situation at the boundary layers along the surface.

[0036] With such an arrangement, the deformation or bending of the flap 112 itself is substantially reduced due to the small longitudinal extension of the flap 112. In this embodiment, the strain sensitive material 128 is therefore preferably applied to the flap 112 substantially only in the region of said bending end 122. In the shown embodiment, the strain sensitive material 128 comprises a strip of strain sensitive material which is arranged along the bending line 122 of the flap and extends between two conducting lines 130 and 132. It will be noted that in order to further enhance the dynamic response to the bending, i.e. the sensitivity of the sensing element, the strain sensitive material may be applied to said flap in a meandering pattern between electrical contact lines 130 and 132. Such a configuration maximizes the length of the sensing path and thus the dynamic response of the sensor to the bending action.

[0037] In operation, the flap 112 absorbs kinetic energy from the mass flow 100 and is deviated from its original orientation (indicated by the reference numeral 126). The bending end 122 of the flap 112 is accordingly subjected to mechanical stress which may be detected by means of the strain sensitive material 128 arranged along the bending end 122. A configuration of the pattern extending from

the bending end to the free end thereby may ensure a very high dynamic response from the sensor element.

[0038] As with the embodiment of Fig. 1 and 2, the sensor strip may be provided with a protection layer 138, e.g. having a thickness on about 1 μm , which is shown partially broken away in Fig. 4. The protective layer protects the conductive lines and the strain sensitive material mechanically and/or chemically.

[0039] In yet another embodiment, shown in Fig. 6 and 7, the flexible carrier element comprises a fiber 50 made of a flexible material, preferably a glass fiber or a polymer fiber. The fiber 50 may e.g. have a diameter of 200 μm . The fiber 50 comprises a mounting end 52 for mounting the fiber on a suitable support, such as a polymer film, so that, in operation, the free end 54 of the fiber 50 extends into the mass flow 100 to be analyzed. The arrangement may be such that the fiber extends substantially perpendicularly to the mass flow to be analyzed or at an angle different from 90°. It will be noted that due to the very small dimension of a flexible glass fiber, the embodiment as fiber 50 or filament is especially suited for minimizing a distortion of a mass flow to be analyzed.

[0040] A pair of terminals 56 and 58 is arranged at the mounting end 52 of the fiber 50. These terminals are configured and arranged for establishing an electrical contact with conducting lines on the support structure for the fiber so that the fiber may be electrically connected to the evaluation or detection circuit.

[0041] The strain sensitive material 60 is applied to the fiber 50 in a loop shaped pattern between the terminals 56 and 58 and the loop preferably extends over a substantial part of a longitudinal extension of said fiber 50 between the mounting end 52 and the free end 54.

[0042] The fiber 50 is preferably arranged in the mass flow such that both the first branch 60.1 (extending from terminal 56 to the free end 54) and the second branch 60.2 (extending from the free end 54 to terminal 58) of the loop shaped pattern are exposed substantially in the same way to the mass flow to be analyzed. As can be seen for instance in the cross sectional view in the right part of Fig. 6, the first and second branch 60.1 and 60.2 are arranged on the outer surface of the fiber in sections located either side of an imaginary plane extending in the direction of the mass flow. By this arrangement, both branches are

subjected to the same kind of mechanical stress when the fiber is bent, i.e. both branches are elongated or compressed in the same manner so that the variation of the electrical signal from both branches has the same polarity.

[0043] Another possible arrangement of the pattern of strain sensitive material is shown in the cross sectional view of Fig. 7. In this arrangement, the branches 60.1 and 60.2 are arranged in a front portion of the fiber 50, i.e. in a portion which faces the impinging mass flow 100. This embodiment further shows a second pattern of strain sensitive material with two branches 62.1 and 62.2 which are arranged in a rear region of the fiber 50, i.e. in a region which faces away from the impinging mass flow, so that the first pattern 60 and the further pattern (62; 62.1, 62.2) are isolated from each other. The two branches 62.1 and 62.2 of the second loop shaped pattern are in electrical contact with a second pair of terminals (not shown) on the mounting end 52 of the fiber. The sensing fiber is thereby provided with two independent sensing circuits which may be evaluated separately in the connected detection unit.

[0044] On the other hand, both sensing circuits may also be evaluated in a combined signal. If the fiber 50 bends under the influence of the mass flow 100, the strain sensitive material of the branches 60.1 and 60.2 of the first pattern will be elongated while the strain sensitive material of the branches 62.1 and 62.2 of the second pattern will be compressed. If the signals of both patterns are suitably combined, one can also increase the overall dynamic response of the sensing fiber.

[0045] It will be appreciated that the fiber may be provided with more than two patterns. Each of the patterns of sensitive material is then arranged in a well-defined angular section of the outer surface of the fiber. If the signals of the individual patterns are individually detected by the connected detection circuit, such a multipole arrangement of a sensing element may advantageously be used to determine a flow direction with respect to the sensing fiber.

[0046] It will be noted that like the flap based sensing elements, the sensing fiber also preferably comprises a protective layer 64, such as a resin layer, applied at least onto said strain sensitive material.

[0047] Fig. 8 shows a possible arrangement of a combined flow sensor element containing both sensing fibers and a flap based sensing element for the characterization of the mass flow in a tube 70. The flow sensor device includes two sensing fibers 72, which are mounted through the tube wall 74 so as to extend within the interior of the tube. A further flap based sensing element 76 (like the one shown in Fig. 3) is mounted at an end section of the tube and perpendicular to an axis of the tube. The configuration of the flap of sensing element 76 is preferably such that the dimension of the flap substantially corresponds to the dimension of the interior tube section. This can be seen in the right part of Fig. 8, which shows a front view of sensing element 76.

[0048] The sensing fibers 72 and the sensing flap 76 are preferably connected to a detection unit 78 for evaluation of the different sensing signals over time. With this sensing arrangement, the propagation of transient mass flow 100 along the tube may be timely monitored and analyzed.

[0049] The above described flow sensors have shown to enable a reliable characterization of static or transient mass flows. They enable a very fast detection with reaction times in the sub milliseconds range combined with a very high detection sensitivity. The flow sensors can be used for any kind of flow sensing devices (i.e. for the characterization of gas flows or of liquids, and enable the determination of the volumetric flow rate and/or the streaming control (turbulent, laminar) and/or pressure control.

[0050] Fig. 10 illustrates different application possibilities of the proposed flow sensors. The sensors may for instance be used for boundary layer measurement (laminar, turbulent) and /or flow characterization at

- a) a tube wall, lengthwise or peripheral, inside or outside of the tube
- b) a tube cross-section
- c) a surface of wing / airfoil
- d) surface models for wind tunnel experiments (buildings, bridges, cars, ...)

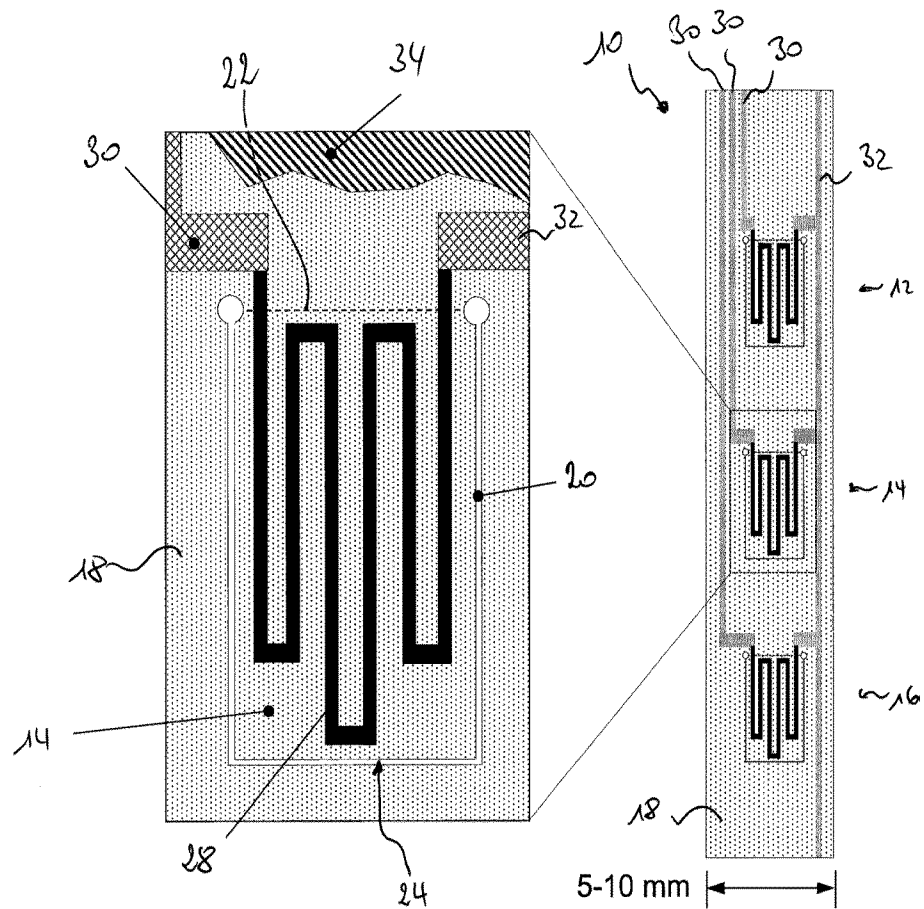
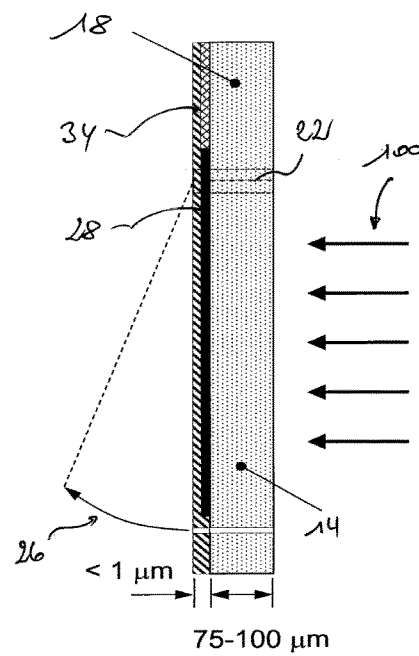
Claims

1. A flow sensor device for detecting at least one parameter of a mass flow, said flow sensor device comprising at least one bending sensitive sensor element to be arranged so as to extend into a mass flow to be analyzed, said bending sensitive sensor element having at least one property which is indicative of a deformation of said bending sensitive sensor element, and a detection unit operatively coupled to said bending sensitive sensor element for detecting a variation of at least one property and/or for quantifying said at least one property.
2. The flow sensor device according to claim 1, wherein said at least one bending sensitive sensor element comprises a flexible carrier element and a strain sensitive material applied to said flexible carrier element, said strain sensitive material being electrically connected between at least one pair of terminals of said at least one bending sensitive sensor element.
3. The flow sensor device according to claim 2, wherein said flexible carrier element comprises a flap made of a polymer film and preferably a flap made of a polyimide film.
4. The flow sensor device according to claim 3, wherein said flap is an integral part of a sheet of said polymer film, said flap being produced by cutting out a contour of said flap in such a way that said flap comprises a bending end, at which said flap forms an integral part of said sheet and at which said flap is bendable with respect to a plane of said sheet, and an opposing free end, at which said flap is separated from said sheet.
5. The flow sensor device according to claim 4, wherein said flap extends essentially in the plane of said sheet.
6. The flow sensor device according to claim 4, wherein said flap is bent at said bending end so as to extend at a certain angle α ($\alpha \neq 0$) with respect to said plane of said sheet.
7. The flow sensor device according to any one of claims 4 to 6, wherein said strain sensitive material is applied to said flap in a pattern which extends over

a substantial part of a longitudinal extension of said flap between said bending end and said opposing free end.

8. The flow sensor device according to claim 4 to 7, wherein said strain sensitive material is applied to said flap in a meandering pattern between electrical contact lines, said electrical contact lines for electrically connecting said strain sensitive material to said two terminals of said at least one bending sensitive sensor element.
9. The flow sensor device according to any one of claims 4 to 6, wherein said strain sensitive material is applied to said flap in the region of said bending end.
10. The flow sensor device according to any one of claims 4 to 9, wherein a plurality of flaps are formed in or from a single sheet of said polymer film.
11. The flow sensor device according to claim 2, wherein said flexible carrier element comprises a fiber made of a flexible material, preferably a glass fiber and/or a polymer fiber, and wherein said fiber comprising a mounting end and a free end, said mounting end for mounting said fiber on a suitable support so that, in operation, said free end extends into the mass flow to be analyzed.
12. The flow sensor device according to claim 11, wherein a first pair of terminals is arranged at said mounting end of said fiber and wherein said strain sensitive material is applied to said fiber in a first pattern extending between terminals of said first pair of terminals, said pattern extending over a substantial part of a longitudinal extension of said fiber between said mounting end and said free end.
13. The flow sensor device according to claim 12, wherein at least one further pair of terminals is arranged at said mounting end of said fiber and wherein said strain sensitive material is applied to said fiber in at least one further pattern extending between terminals of said at least one further pair of terminals, said at least one further pattern extending over a substantial part of a longitudinal extension of said fiber between said mounting end and said free end, and wherein said first pattern and said at least one further pattern are isolated from each other.

14. The flow sensor device according to any one of claims 2 to 13, wherein said strain sensitive material comprises a layer of metal containing carbon material, preferably a layer of nickel containing hydrogenated amorphous carbon (Ni:a-C:H).
15. The flow sensor device according to any one of claims 2 to 14, further comprising a protective layer applied at least onto said strain sensitive material.

**Fig. 1****Fig. 2**

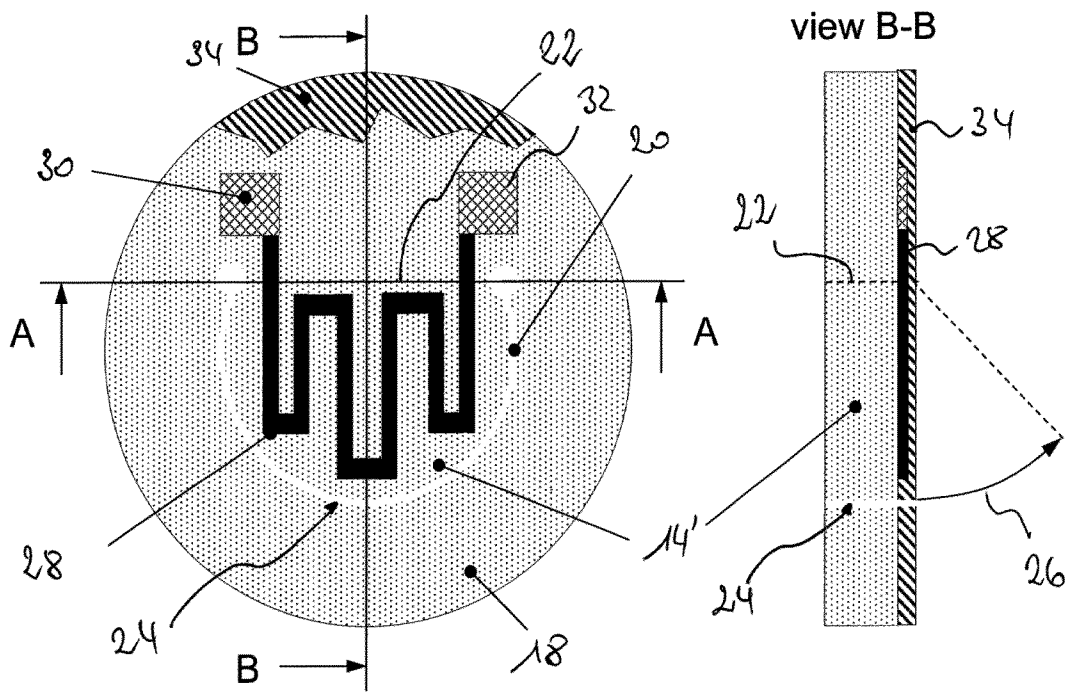


Fig. 3

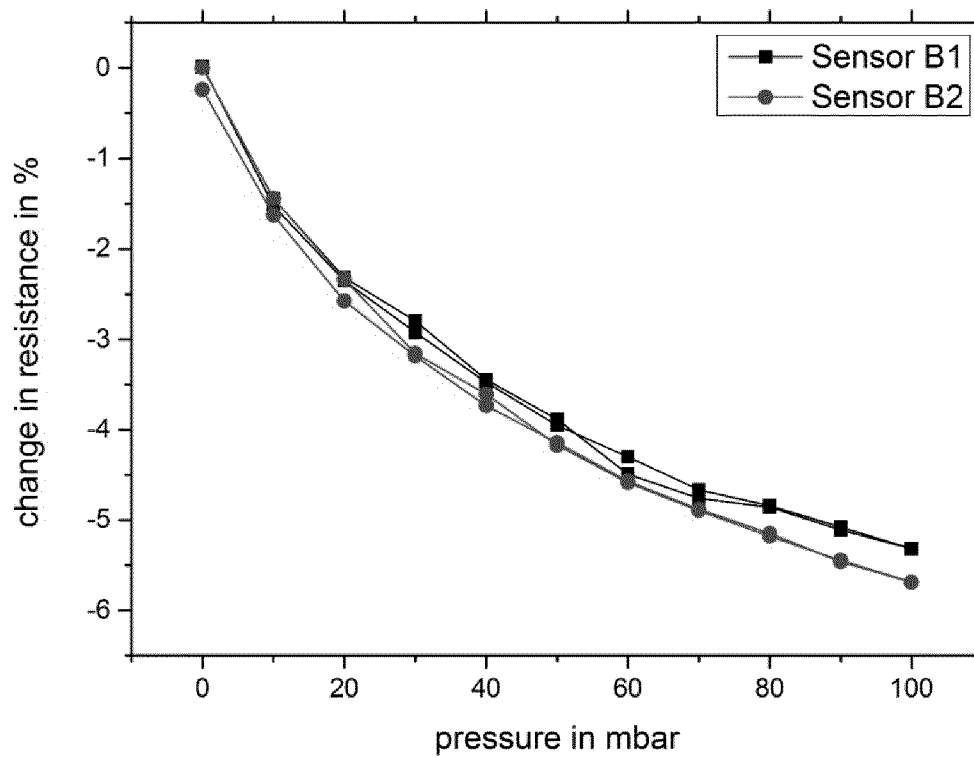


Fig. 9

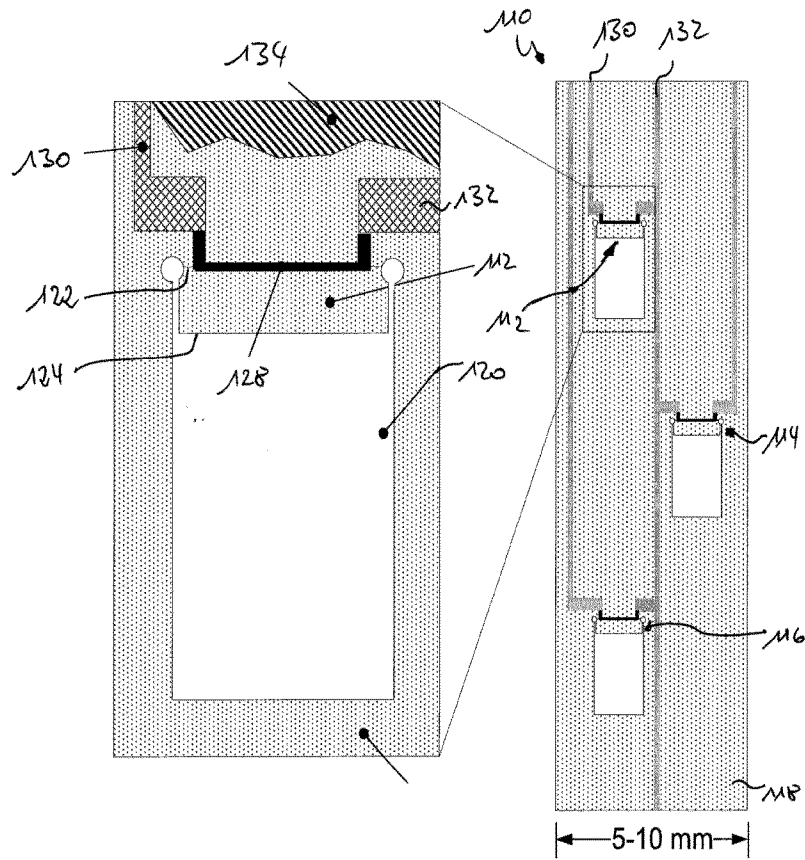


Fig. 4

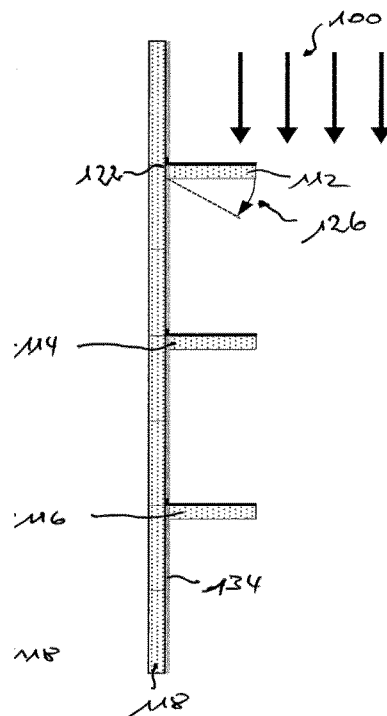


Fig. 5

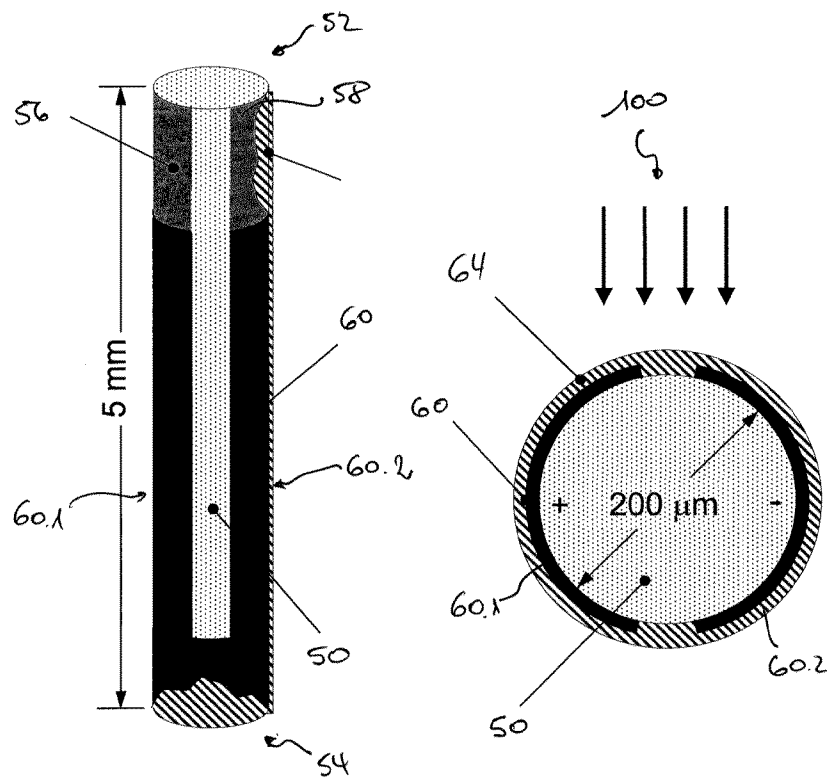


Fig. 6

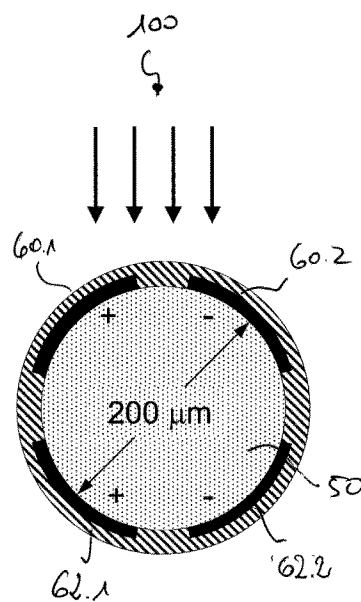
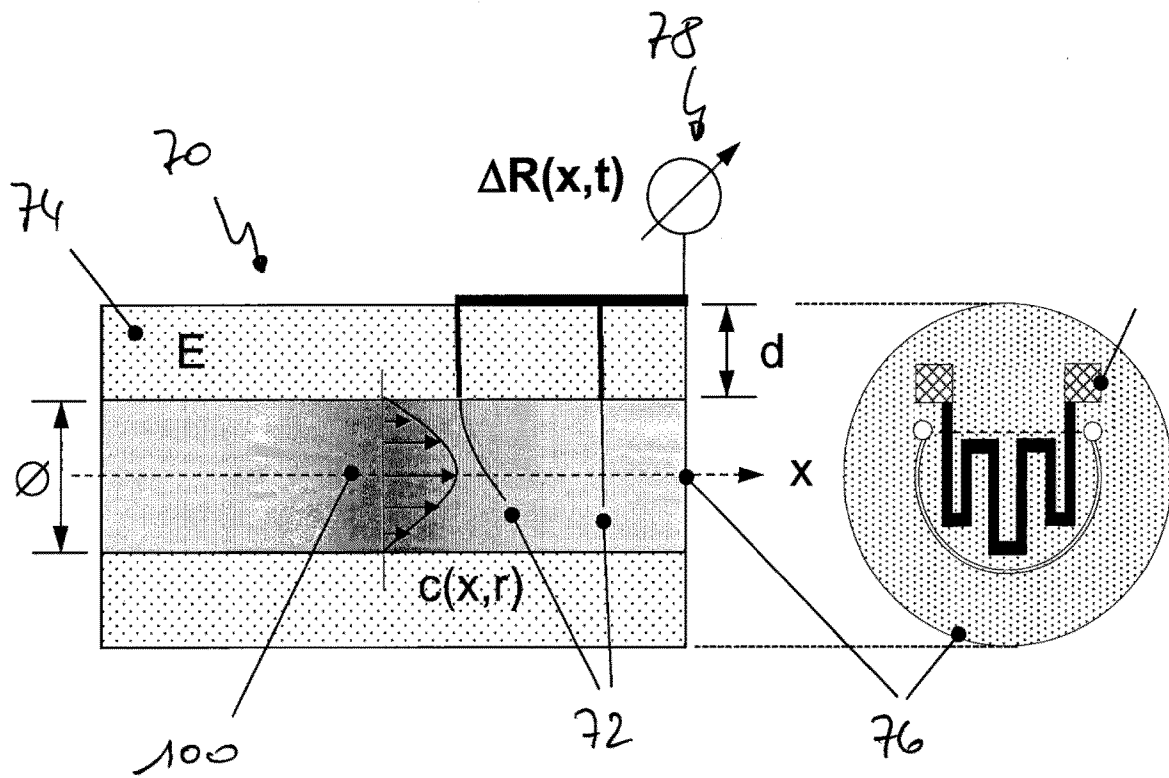
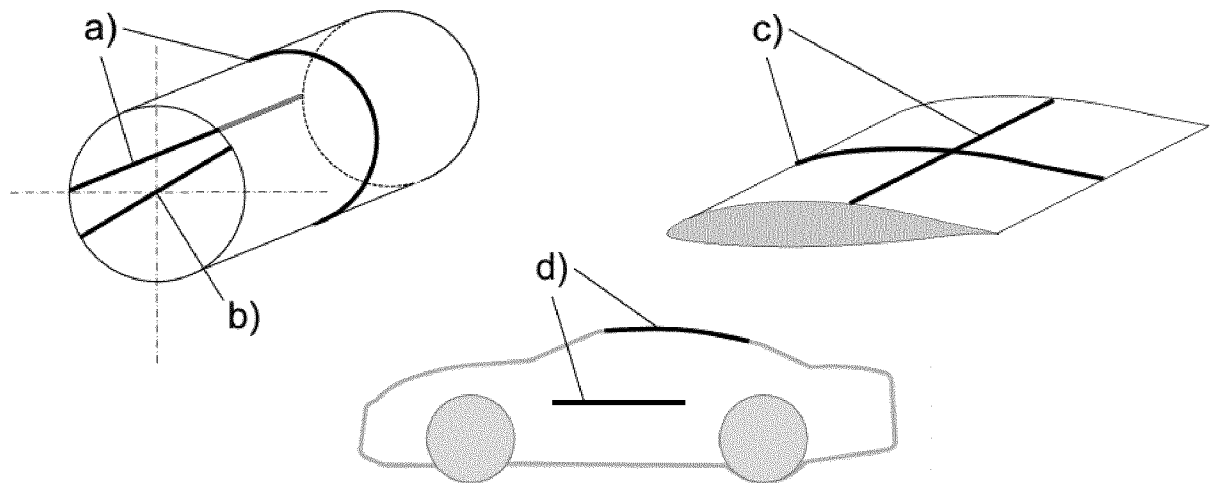


Fig. 7

**Fig. 8****Fig. 10**

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/059940

A. CLASSIFICATION OF SUBJECT MATTER

INV. G01F1/28

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)

G01F

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.
X	US 2004/094157 A1 (DANTANARAYANA MUDITHA PRADEEP [AU] ET AL) 20 May 2004 (2004-05-20)	1-7,9,14
Y	page 4, paragraph [0070] page 5, paragraph [0078] page 7, paragraph [0087] figures 1-5	8,10
X	US 2012/042715 A1 (LIU CHANG [US]) 23 February 2012 (2012-02-23)	1,2
Y	abstract page 1, paragraph [0003] page 2, paragraph [0046] figures 1, 2, 3, 16	10
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

12 October 2015

Date of mailing of the international search report

20/10/2015

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Authorized officer

Baytekin, Hüseyin

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2015/059940

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/277615 A1 (COIFMAN ROBERT E [US] ET AL) 1 November 2012 (2012-11-01)	1-3,15
Y	abstract page 4, paragraph [0055] figures 4A, 4D, 5 -----	8
X	US 3 878 714 A (PROTTA JEAN-CLAUDE ET AL) 22 April 1975 (1975-04-22) abstract column 1, lines 61-66 figures 1-3 -----	1,2, 11-13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/059940

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004094157	A1	20-05-2004	AT 532548 T 15-11-2011
		EP 1353718 A1	22-10-2003
		EP 2301616 A1	30-03-2011
		JP 4818569 B2	16-11-2011
		JP 4904315 B2	28-03-2012
		JP 2004522487 A	29-07-2004
		JP 2008264566 A	06-11-2008
		US 2004094157 A1	20-05-2004
		US 2013239971 A1	19-09-2013
		WO 02051486 A1	04-07-2002

US 2012042715	A1	23-02-2012	NONE

US 2012277615	A1	01-11-2012	NONE

US 3878714	A	22-04-1975	FR 2173962 A1 12-10-1973
		GB 1383731 A	12-02-1974
		NL 7300608 A	19-07-1973
		US 3878714 A	22-04-1975
