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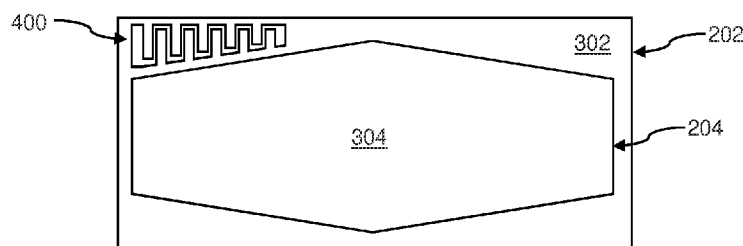


FIG. 4

(57) Abstract: An acousto-optical device includes an acousto-optical medium, a transducer attached to the acousto-optical medium and a temperature sensor arranged and configured to sense a temperature of the transducer.



ACOUSTO-OPTICAL DEVICE WITH INTEGRATED TEMPERATURE SENSOR CROSS-REFERNECE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/711,308, filed July 27, 2018, and U.S. Provisional Application No. 62/718,236, filed August 13, 2018, each of which is incorporated by reference in its entirety.

BACKGROUND

Acousto-optic (AO) device (AODs) can be used to steer laser beams for industrial machining and other applications. AODs are driven with electrical power that gets converted to acoustic power within the device by means of a transducer. The transducers can be catastrophically damaged when they overheat, which can happen easily if the electrical power required to achieve the desired beam scanning performance is high. This is especially true of AOD's meant for use with laser beams in the near-IR wavelength range of 800 nm to 1600 nm. AOD's used for near-IR lasers tend to have more expensive construction. This might include slow manufacturing processes, expensive materials, extensive testing, or additional cooling mechanisms that not only add cost, but likely also degrade performance.

In view of the above, it can be desirable to monitor the AOD temperature and use the results of the monitoring to avoid driving the AOD in a manner causes the transducers to overheat. Typically, thermocouples are used as temperature sensors, but they're bulky and they tend to give faulty readings when they're in a high power RF environment (i.e., as is often present in and around the AOD). It can also be difficult to use non-contact infra-red (IR) temperature sensors because the object having the temperature to be measured (i.e., the electrode of the transducer) is highly reflective to the thermal IR signals that the IR temperature sensors use to operate.

SUMMARY

One embodiment of the present invention can be generally characterized as an acousto-optical device that includes an acousto-optical medium; and a transducer attached to the acousto-optical medium. The transducer can include a piezo-electric material having a first surface and a second surface opposite the first surface; a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and a temperature sensor attached to the second surface of the piezo-electric material. In this embodiment, the temperature sensor is operative to sense a temperature of the transducer.

Another embodiment of the present invention can be generally characterized as a device that includes an acousto-optical medium; a transducer attached to the acousto-optical medium; and a non-contact temperature sensor. The transducer can include a piezo-electric material having a first surface and a second surface opposite the first surface; a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and a second electrode attached to the second surface of the piezo-electric material. The non-contact temperature sensor can be arranged such that at least a portion of the transducer is within a field of view of the non-contact temperature sensor. In this embodiment, the non-contact temperature sensor is operative to sense a temperature of the portion of the transducer within the field of view thereof.

Yet another embodiment of the present invention can be generally characterized as an acousto-optical device that includes an acousto-optical medium; and a transducer attached to the acousto-optical medium. In this embodiment, the transducer can include a piezo-electric material having a first surface and a second surface opposite the first surface; a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and a second electrode attached to the second surface of the piezo-electric material, wherein at least a portion of the second electrode is patterned into a resistive temperature device (RTD).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 schematically illustrates an acousto-optic deflector (AOD) and associated circuitry for driving the AOD.

FIGS. 2 and 3 illustrate partial perspective views of exemplary configurations in which the transducer shown in FIG. 1 may be provided, according to some embodiments.

FIG. 4, 5 and 6 schematically illustrate temperature sensors, according to various embodiments, for sensing the temperature of the transducer shown in FIG. 1 and 3.

DETAILED DESCRIPTION

Example embodiments are described herein with reference to the accompanying drawings. Unless otherwise expressly stated, in the drawings the sizes, positions, etc., of components, features, elements, etc., as well as any distances therebetween, are not necessarily to scale, but are exaggerated for clarity. In the drawings, like numbers refer to like elements

throughout. Thus, the same or similar numbers may be described with reference to other drawings even if they are neither mentioned nor described in the corresponding drawing. Also, even elements that are not denoted by reference numbers may be described with reference to other drawings.

The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art. As used herein, the singular forms “a,” “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It should be recognized that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. Unless otherwise specified, a range of values, when recited, includes both the upper and lower limits of the range, as well as any sub-ranges therebetween. Unless indicated otherwise, terms such as “first,” “second,” etc., are only used to distinguish one element from another. For example, one node could be termed a “first node” and similarly, another node could be termed a “second node”, or vice versa.

Unless indicated otherwise, the term “about,” “thereabout,” etc., means that amounts, sizes, formulations, parameters, and other quantities and characteristics are not and need not be exact, but may be approximate and/or larger or smaller, as desired, reflecting tolerances, conversion factors, rounding off, measurement error and the like, and other factors known to those of skill in the art. Spatially relative terms, such as “below,” “beneath,” “lower,” “above,” and “upper,” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element or feature, as illustrated in the FIGS. It should be recognized that the spatially relative terms are intended to encompass different orientations in addition to the orientation depicted in the FIGS. For example, if an object in the FIGS. is turned over, elements described as “below” or “beneath” other elements or features would then be oriented “above” the other elements or features. Thus, the exemplary term “below” can encompass both an orientation of above and below. An object may be otherwise oriented (e.g.,

rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may be interpreted accordingly.

The section headings used herein are for organizational purposes only and, unless explicitly stated otherwise, are not to be construed as limiting the subject matter described. It will be appreciated that many different forms, embodiments and combinations are possible without deviating from the spirit and teachings of this disclosure and so this disclosure should not be construed as limited to the example embodiments set forth herein. Rather, these examples and embodiments are provided so that this disclosure will be thorough and complete, and will convey the scope of the disclosure to those skilled in the art.

FIG. 1 schematically illustrates an acousto-optic deflector (AOD) and associated circuitry for driving the AOD. Referring to FIG. 1, the AOD (identified at 100) includes an acousto-optic (AO) medium 102 and a transducer 104 attached to one side (e.g., a “first side 102a”) of the AO medium 102. The AO medium 102 can be formed of a material such as crystalline germanium (Ge), gallium arsenide (GaAs), wulfenite (PbMoO₄), tellurium dioxide (TeO₂), crystalline quartz, glassy SiO₂, arsenic trisulfide (As₂S₃), lithium niobate (LiNbO₃), or the like or any combination thereof. The AOD 100 can also include an absorber 106 attached to a second side of the AO medium 102, which is opposite to the first side 102a of the AO medium 102. As will be recognized by those of ordinary skill, AODs utilize diffraction effects caused by one or more acoustic waves propagating through the AO medium 102 (i.e., along a “diffraction axis” of the AOD 100) to diffract an incident optical wave (i.e., an incident beam of laser energy 110a) contemporaneously propagating through the AO medium 102 (i.e., along an “optical axis” within the AOD 100). Diffracting the incident beam of laser energy 110a produces a diffraction pattern that typically includes zeroth- and first-order diffraction peaks, and may also include other higher-order diffraction peaks (e.g., second-order, third-order, etc.). As is known in the art, the portion of the diffracted beam of laser energy in the zeroth-order diffraction peak is referred to as a “zeroth-order” beam, the portion of the diffracted beam of laser energy in the first-order diffraction peak is referred to as a “first-order” beam, and so on. Generally, the zeroth-order beam and other diffracted-order beams (e.g., the first-order beam, etc.) propagate along different beam paths upon exiting the AO medium 102 (e.g., through an optical output side of the AO medium 102). For example, the zeroth-order beam (illustrated in FIG. 1 at 110b) propagates

along a zeroth-order beam path, the first-order beam (illustrated in FIG. 1 at 110c) propagates along a first-order beam path, and so on.

Acoustic waves are typically launched into the AO medium 102 by applying an RF drive signal to the transducer 104. Characteristics of the RF drive signal (e.g., amplitude, frequency, phase, etc.) can be controlled (e.g., based on one or more control signals output by a controller 112 to adjust the manner with which the incident beam of laser energy 110a is diffracted. For example, the frequency of the applied RF drive signal will determine the angle, θ , to which the first order beam 110c is deflected. As is known in the art, θ can be calculated as follows:

$$\theta = \frac{\lambda \cdot f}{v}$$

where λ is the optical wavelength of beam of laser energy, f is the frequency of the applied RF drive signal, and v is the velocity of the acoustic wave in the AO medium 102.

As shown in FIG. 1, additional components, such as an RF synthesizer 114, an RF amplifier 116 and impedance matching circuitry 118, are provided. The RF synthesizer 114 generates and outputs an RF signal having a frequency corresponding to a control signal output by the controller 112. The RF amplifier 116 amplifies the RF signals output by the RF synthesizer 114 to thereby produce the aforementioned RF drive signal, which is applied to the transducer 104 via the impedance matching circuitry 118 (e.g., through a plurality of wires 120, as is known in the art). Communication between the controller 112 and the RF synthesizer is facilitated by the communication interface 122.

Generally, the transducer 104 of the AOD 100 includes a piezo-electric crystal interposed between two electrodes. One electrode of the transducer 104 (e.g., a “bottom electrode”) is thus interposed between one surface (e.g., a “first surface”) of the piezo-electric crystal and the first side 102a of the AO medium 102 and another electrode of the transducer 104 (e.g., a “top electrode”) is provided on another surface (e.g., a “second surface, opposite the first surface) of the piezo-electric crystal. Each electrode of the transducer 104 is typically formed of multiple layers, wherein adjacent layers differ from one another, mainly by the type of metal, although non-metallic layers can also be used. The piezo-electric crystal is typically rectangular in shape, and relatively thin (i.e., in comparison to its length and width). The bottom and top electrodes can be formed of one or more metal layers in any suitable manner known in the art (e.g., chemical vapor deposition, sputtering, atomic-layer deposition, etc.). The top electrode can be

formed by patterning metal layer(s) (e.g., using a photolithography process, etc.) that have been deposited or otherwise formed on the piezo-electric crystal.

FIGS. 2 and 3 illustrate partial perspective views of exemplary configurations in which the transducer 104 may be provided, according to some embodiments. Referring to FIGS. 2 and 3, the transducer 104 includes a bottom electrode 200, a piezo-electric crystal 202 and a top electrode 204. The bottom electrode 200 and the top electrode 204 of the transducer 104 is typically formed of multiple layers, wherein adjacent layers differ from one another, mainly by the type of metal (e.g. gold, platinum, silver, copper, or lead), although non-metallic layers can also be used. For example, the bottom electrode 200 can be formed as a multi-layer structure having a plurality of layers (e.g., layers 200a, 200b and 200c), wherein adjacent ones of the layers are formed of different materials, as described above. Likewise, the top electrode 204 can be formed as a multi-layer structure having a plurality of layers (e.g., layers 204a, 204b, 204c and 204d), wherein adjacent ones of the layers are formed of different materials, as described above.

In the embodiment shown in FIG. 3, the shape of the bottom electrode 200 generally corresponds to that of the first surface of the piezo-electric crystal 202, but is slightly smaller in size than the first surface of the piezo-electric crystal 202. Thus, a portion of the bottom electrode 200 can be exposed by the piezo-electric crystal 202. In FIG. 3, the surface of the portion of the bottom electrode 200 exposed by the piezo-electric crystal 202 is indicated generally at 300, and is also referred to herein as the “exposed bottom electrode surface 300.” The top electrode 204 is typically smaller than the second surface piezo-electric crystal 202 and has a different shape from that of the second surface of the piezo-electric crystal 202. For example, the top electrode 204 can have a trapezoidal or hexagonal shape. Thus, a portion of the second surface of the piezo-electrical crystal 202 can be exposed by the top electrode 204. In FIG. 3, the portion of the second surface of the piezo-electrical crystal 202 is indicated generally at 302, and is also referred to herein as the “exposed piezo-electrical crystal surface 302.” The impedance matching circuitry 118 may be electrically connected to the bottom electrode 200 via one or more wires 120 bonded to the exposed bottom electrode surface 300. Likewise, the impedance matching circuitry 118 may be electrically connected to the top electrode 204 via one or more wires 120 bonded to an exterior surface 304 of the top electrode 204.

In FIG. 1, the AOD 100 is illustrated as being provided with only a single transducer 104. It should be appreciated, however, that the AOD 100 may be provided with multiple transducers, such as transducer 104. Also, although FIGS. 1 to 3 illustrate the transducer 104 as including only a single piece of piezo-electric crystal 202 having only one top electrode 204 attached thereto, it should be appreciated that the transducer 104 may be provided with multiple top electrodes 204 attached to a common piece of piezo-electric crystal 202, as is known in the art.

As mentioned above, the transducer 104 can be catastrophically damaged if it overheats, which can happen easily if the electrical power required to achieve the desired beam scanning performance is high. Accordingly, some embodiments of the present invention – discussed in greater detail below – are directed to temperature sensors for sensing, detecting or otherwise monitoring the temperature of the transducer 104. Generally, and as will be discussed in greater detail below, the temperature sensor can be characterized as a “contact-type” temperature sensor, or as a “non-contact-type” temperature sensor. A contact-type temperature sensor is attached (e.g., directly attached) to the piezo-electric crystal 202, is attached (e.g., directly attached) to the top electrode 204, is integrally formed with the top electrode 204, or any combination thereof. A non-contact-type temperature sensor is not attached to the piezo-electric crystal 202 or to the top electrode 204. Rather, the non-contact-type temperature sensor is located remotely from the piezo-electric crystal 202 and/or the top electrode 204.

In one embodiment, the AOD 100 includes a temperature sensor attached to the piezo-electric crystal 202. For example, and with reference to FIG. 4, a temperature sensor 400 may be attached to the exposed piezo-electrical crystal surface 302 of the piezo-electric crystal 202. Although FIG. 4 illustrates only one temperature sensor 400, it will be appreciated that multiple temperature sensors 400 can be provided (e.g., at different areas of the exposed piezo-electrical crystal surface 302). In the illustrated embodiment, the temperature sensor 400 is provided as surface-type resistive temperature device (RTD). The RTD can, for example, be formed from a resistive material such as platinum, nickel, copper, etc., and be formed by a process that involves depositing the resistive material onto the exposed portion of the second surface of the piezo-electric crystal (e.g., by sputter deposition) followed by patterning the deposited resistive material (e.g., by etching a meander pattern into the deposited material, etc.). Optionally, laser-trimming is applied to the meander pattern to tune the RTD to a desired nominal resistance value. Lead wires (not shown) can be bonded to pads at the sides of the meander pattern, and

sensor circuitry (also not shown) coupled to the lead wires can be provided to detect, sense, convert or otherwise interpret changes in resistivity of the RTD to monitor temperature (in any suitable manner known in the art) at the site where the RTD is attached to the exposed portion. In another embodiment, the temperature sensor may be provided as a thermistor (e.g., a negative temperature coefficient (NTC) thermistor, a positive temperature coefficient (PTC) thermistor, or the like or any combination thereof) attached to the piezo-electric crystal 202 (e.g., at the exposed piezo-electrical crystal surface 302). The thermistor may be provided as an addition to, or as an alternative to, the RTD.

In another embodiment, and with reference to FIG. 5, one or more or all layers of the top electrode 204 are patterned to form an RTD. In this embodiment, one or more or all of layers of the top electrode 204 (e.g., any of layers 204a, 204b, 204c, 204d, or any combination thereof) is formed of a resistive material such as platinum, nickel, copper, etc., and patterned so as to form an RTD, as described above. Lead wires (not shown) can be bonded to the sides of the meander pattern (e.g., at sides 500 and 502) of the RTD, and sensor circuitry (also not shown) coupled to the lead wires can be provided to detect, sense, convert or otherwise interpret changes in resistivity of the top electrode 204 to monitor temperature (in any suitable manner known in the art).

In another embodiment, and with reference to FIG. 6, the top electrode 204 is provided as a plurality of electrode strips 600 and a plurality of connecting members 602. Each of the plurality of electrode strips 600 may be formed as a multi-layer structure having a plurality of layers, for example, provided and formed as discussed above with respect to the multi-layer structure of the top electrode 204. The connecting members 602 electrically connect multiple electrode strips 600 to each other. In one embodiment, the connecting members 602 have an electrical resistivity that is less than or equal to the electrical resistivity of each of the electrode strips 600. Generally, the connecting members 602 are formed as one or more wires, patterned metallic structures, or the like or any combination thereof. Although FIG. 6 illustrates alternating connecting members 602 as connected to alternating ends of adjacent electrode strips 600, it will be appreciated that each connecting member 602 can be connected to an electrode strip 600 at any suitable or beneficial position of connecting member 602. Lead wires (not shown) can be bonded to electrode strips 600 such as electrode strips 600a and 600b, and sensor circuitry (also not shown) coupled to the lead wires can be provided to detect, sense, convert or

otherwise interpret changes in resistivity of the top electrode 204 to monitor temperature (in any suitable manner known in the art).

In FIG. 6, each of the electrode strips 600 has an exterior surface 604, which functions similarly as the exterior surface 304. Accordingly, the exterior surfaces 604 of all electrode strips 600 can be considered as equivalent to the exterior surface 304 of the top electrode 204 as shown in FIGS. 2 to 5. Accordingly, the impedance matching circuitry 118 may be electrically connected to the top electrode 204 via one or more wires 120 bonded to an exterior surface 604 of one or more electrode strips 600.

In other embodiments, the temperature sensor is provided as one or more non-contact-type temperature sensors. Examples of non-contact-type temperature sensors that may be used include an infra-red (IR) sensor, a thermorefectance imaging system, or the like or any combination thereof. As is known in the art, an IR sensor is a device that detects heat and converts it into an electrical signal, which may be processed to discern (at least approximately) the temperature of the object from which the heat was emitted. As is known in the art, thermorefectance imaging systems discern the temperature of a surface based on a change in optical reflectivity of the surface as a function of the temperature at the surface. Generally, a non-contact-type temperature sensor can be arranged (e.g., fixed to a frame, etc.) such that at least a portion of the exposed piezo-electrical crystal surface 302, at least a portion of the exterior surface 304 of the top electrode 204, or a combination thereof, is within a sensing range or field (e.g., a “field of view”) of the non-contact-type temperature sensor. The non-contact-type temperature sensor can be coupled to sensor circuitry (not shown) to detect, sense, convert or otherwise interpret signals output from the non-contact-type temperature sensor to monitor temperature (in any suitable manner known in the art) of the surface that is within the sensing range of the non-contact-type temperature sensor.

When the temperature sensor is provided as an IR sensor, the exposed piezo-electrical crystal surface 302 can, optionally, be coated with a material possessing high emissivity. Also optionally, optics (not shown) can be provided to isolate the measurement of IR radiation by the IR sensor to within a small region of the exposed piezo-electrical crystal surface 302, rather than detecting the temperature of the surrounding materials (e.g., which may include a portion of the top electrode 204).

The top electrode 204 will typically have a very low IR emissivity, and so sensing the temperature of the top electrode 204 with an IR sensor would result in a measurement of the temperature of whatever object is reflected by the top electrode 204. Accordingly, in an embodiment in which the non-contact-type temperature sensor is provided as an IR sensor, the exterior surface 304 of the top electrode 204 may be coated with a high emissivity material to measure the temperature of the top electrode 204 more reliably. Depending on the situation in which the AOD 100 is intended to be driven, it is possible that acoustic waves generated within the piezo-electric crystal 202 can be transmitted through the top electrode 204 and into the high emissivity material coating on the exterior surface 304, and possibly be absorbed in the high emissivity material coating. Such absorption has the potential to exacerbate existing heating problems within the AOD 100 or distort sound waves inside the piezo-electric crystal 202 to degrade the diffraction efficiency of the AOD 100. Accordingly, coating the exterior surface 304 of the top electrode 204 with the high-emissivity material may be suitable or desirable in some, but not all, situations.

Advantages of the temperature sensor embodiments discussed herein include:

- beneficial measurement of the temperature of the transducer 104 itself, rather than some part of the AO medium 102 or neighboring mechanical structures (e.g., frames, housings, coolant tubes, etc.);
- temperature measurements can be monitored to lower the risk of damaging the transducer 104 while driving the AOD 100;
- lower risk of damage to the transducer 104 enables safe high-power driving (overdriving) thereof.
- safe high-power driving enables cheaper and/or better performing AOD's, particularly for near-IR wavelengths where higher powers are often needed.

The foregoing is illustrative of embodiments and examples of the invention, and is not to be construed as limiting thereof. Although a few specific embodiments and examples have been described with reference to the drawings, those skilled in the art will readily appreciate that many modifications to the disclosed embodiments and examples, as well as other embodiments, are possible without materially departing from the novel teachings and advantages of the invention. Accordingly, all such modifications are intended to be included within the scope of the invention as defined in the claims. For example, skilled persons will appreciate that the subject matter of

any sentence, paragraph, example or embodiment can be combined with subject matter of some or all of the other sentences, paragraphs, examples or embodiments, except where such combinations are mutually exclusive. The scope of the present invention should, therefore, be determined by the following claims, with equivalents of the claims to be included therein.

WHAT IS CLAIMED IS:

1. An acousto-optical device comprising:
an acousto-optical medium; and
a transducer attached to the acousto-optical medium, the transducer including:
a piezo-electric material having a first surface and a second surface opposite the first surface;
a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and
a temperature sensor attached to the second surface of the piezo-electric material, wherein the temperature sensor is operative to sense a temperature of the transducer.
2. The acousto-optical device of claim 1, wherein the temperature sensor is a resistive temperature device (RTD).
3. The acousto-optical device of claim 2, wherein the resistive temperature device is a surface-type resistive temperature device.
4. The acousto-optical device of claim 3, further comprising a plurality of wires bonded to the temperature sensor, wherein the plurality of wires are electrically connected to impedance matching circuitry.
5. The acousto-optical device of claim 1, wherein the temperature sensor is a thermistor.
6. The acousto-optical device of claim 1, wherein the transducer further includes a second electrode attached to the second surface of the piezo-electric material.
7. The acousto-optical device of claim 6, wherein the temperature sensor and the second electrode are physically separate from one another.
8. The acousto-optical device of claim 6, wherein the temperature sensor and the second electrode are formed of the same material.

9. A device comprising:
an acousto-optical medium;
a transducer attached to the acousto-optical medium, the transducer including:
a piezo-electric material having a first surface and a second surface opposite the first surface;
a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and
a second electrode attached to the second surface of the piezo-electric material;
and
a non-contact temperature sensor arranged such that at least a portion of the transducer is within a field of view of the non-contact temperature sensor, wherein the non-contact temperature sensor is operative to sense a temperature of the portion of the transducer within the field of view thereof.
10. The device of claim 9, wherein the non-contact temperature sensor includes an infra-red (IR) sensor.
11. The device of claim 9, wherein the non-contact temperature sensor includes a thermoreflectance imaging system.
12. The device of claim 9, wherein the second electrode is excluded from the field of view of non-contact temperature sensor.
13. The device of claim 9, wherein the second electrode is within the field of view of non-contact temperature sensor.
14. The device of claim 9, wherein the piezo-electric material is within the field of view of non-contact temperature sensor.
15. The device of claim 14, wherein the second electrode is within the field of view of non-contact temperature sensor.

16. An acousto-optical device comprising:
- an acousto-optical medium; and
 - a transducer attached to the acousto-optical medium, the transducer including:
 - a piezo-electric material having a first surface and a second surface opposite the first surface;
 - a first electrode interposed between the first surface of the piezo-electric material and the acousto-optical medium; and
 - a second electrode attached to the second surface of the piezo-electric material,
- wherein at least a portion of the second electrode is patterned into a resistive temperature device (RTD).

ACOUSTO-OPTICAL DEVICE WITH INTEGRATED TEMPERATURE SENSOR

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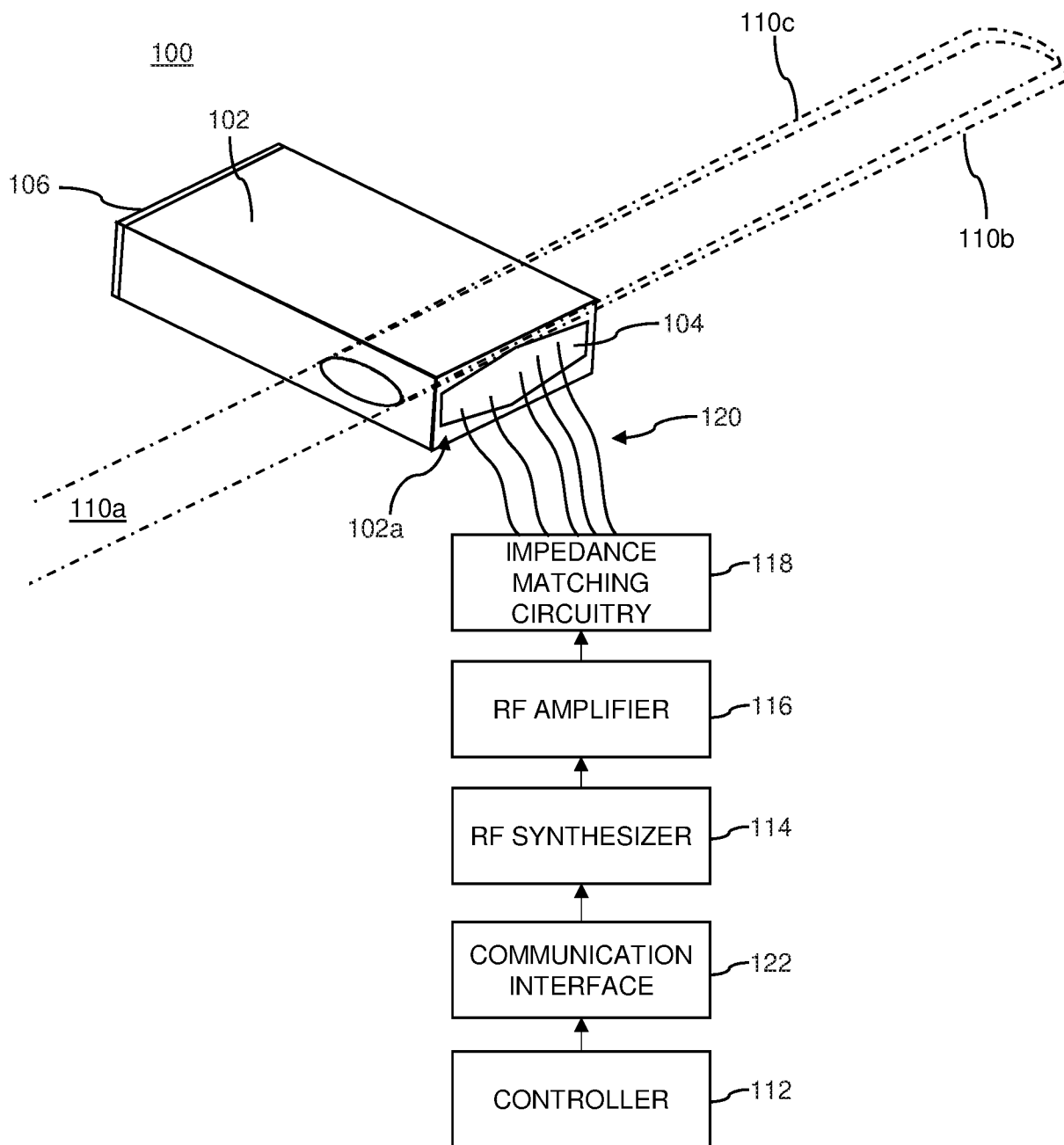


FIG. 1

ACOUSTO-OPTICAL DEVICE WITH INTEGRATED TEMPERATURE SENSOR

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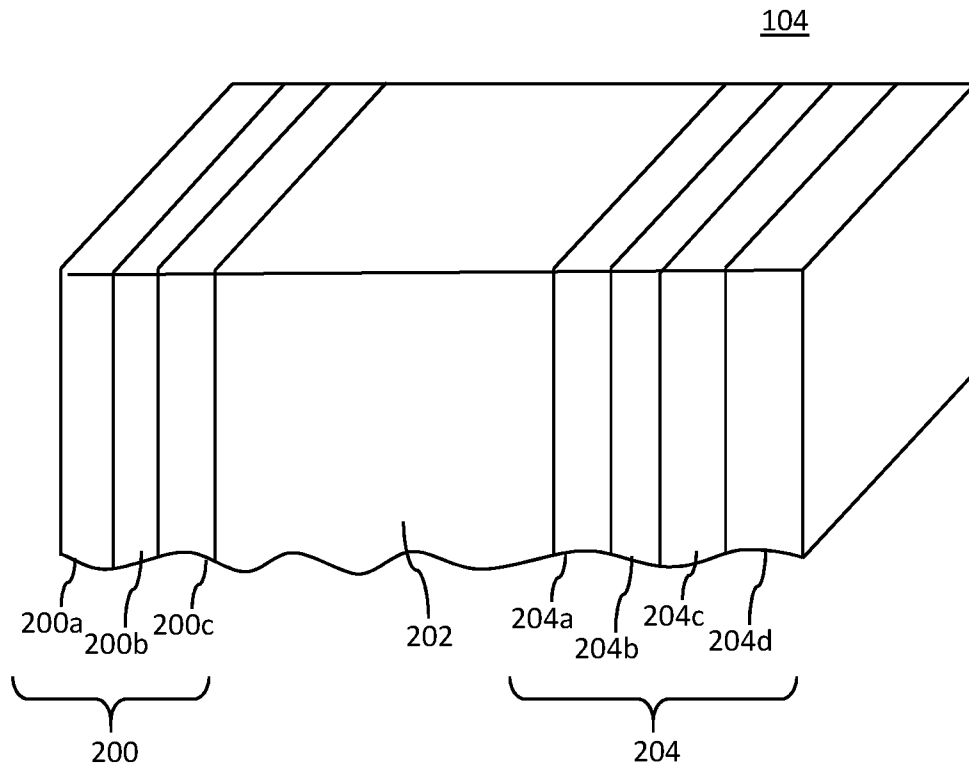


FIG. 2

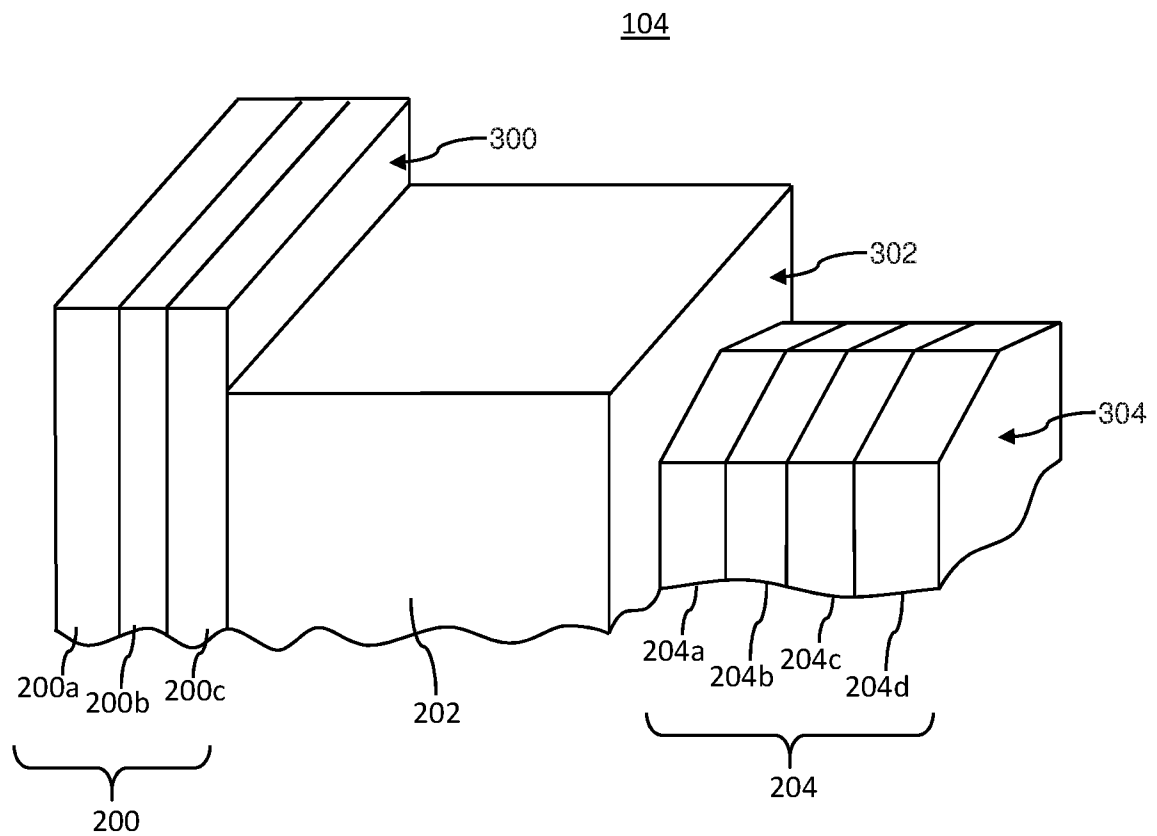


FIG. 3

ACOUSTO-OPTICAL DEVICE WITH INTEGRATED TEMPERATURE SENSOR

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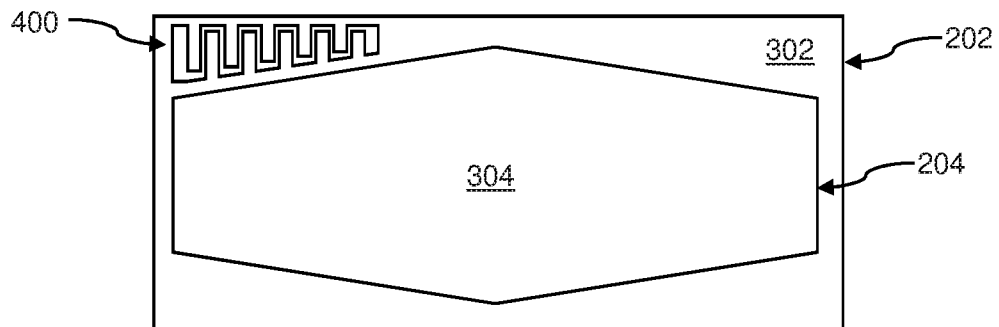


FIG. 4

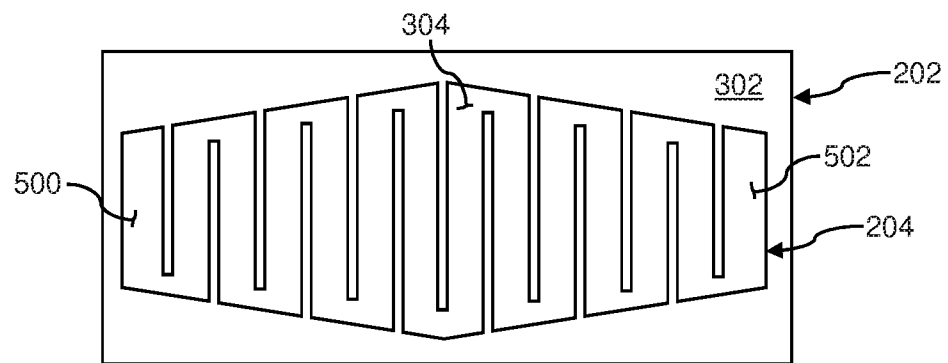


FIG. 5

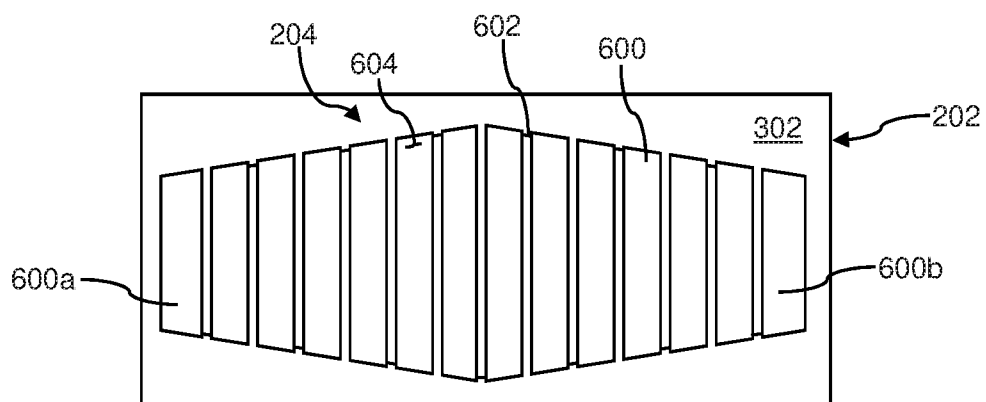


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2019/043463**A. CLASSIFICATION OF SUBJECT MATTER****G02F 1/33(2006.01)i, G02F 1/1333(2006.01)i**

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)

G02F 1/33; A61B 5/00; A61B 5/01; A61N 7/02; B81B 7/00; G02F 1/11; G05D 23/19; G05D 7/06; H04R 23/00; G02F 1/1333

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & keywords: acousto-optical, temperature, sensor, piezo-electric, transducer

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011-0304900 A1 (BERND WIDZGOWSKI et al.) 15 December 2011 See paragraphs [0026], [0056]–[0057]; and figures 9–10.	1–16
Y	US 2016-0221822 A1 (INFINEON TECHNOLOGIES AG.) 04 August 2016 See paragraphs [0026], [0071]; and figures 1–4.	1–8, 16
Y	US 2016-0157732 A1 (BIO ECHO NET INC.) 09 June 2016 See paragraphs [0064]–[0065], [0069]; and figure 1.	9–15
Y	CN 103028204 A (BEIJING 3H MEDICAL TECHNOLOGY CO., LTD.) 10 April 2013 See paragraphs [0055]–[0056].	9
Y	JP 60-097320 A (AGENCY OF IND. SCIENCE & TECH.) 31 May 1985 See figure 4.	9
A	KR 10-2012-0119838 A (LTS CO., LTD.) 31 October 2012 See paragraphs [0028]–[0029]; and figure 2.	1–16



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

28 November 2019 (28.11.2019)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2019/043463

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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CN 103028204 A	10/04/2013	None	
JP 60-097320 A	31/05/1985	None	
KR 10-2012-0119838 A	31/10/2012	None	