



- (51) International Patent Classification:
H03H 9/17 (2006.01) *H01L 41/08* (2006.01)
G11B 9/00 (2006.01)
- (21) International Application Number:
PCT/US2016/028770
- (22) International Filing Date:
22 April 2016 (22.04.2016)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
62/152,731 24 April 2015 (24.04.2015) US
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(US).
- (81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,

DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT,
HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR,
KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG,
MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM,
PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC,
SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ,
GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

[Continued on next page]

(54) Title: MEMS PROCESS POWER

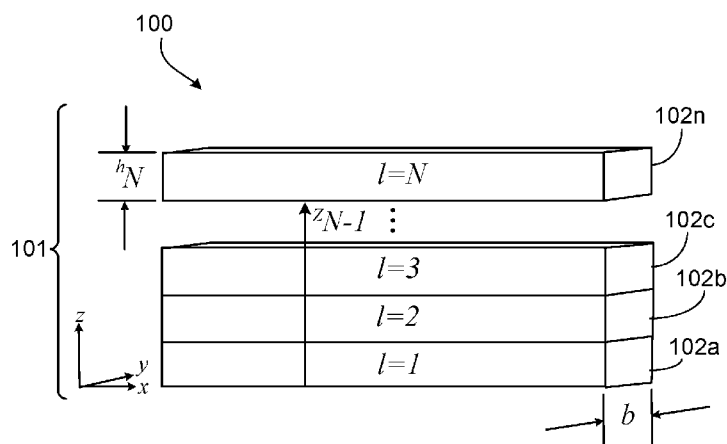


FIG. 1

(57) Abstract: A transducer includes a first piezoelectric layer; and a second piezoelectric layer that is above the first piezoelectric layer; wherein the second piezoelectric layer is a more compressive layer with an average stress that is less than or more compressive than an average stress of the first piezoelectric layer.



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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

MEMS PROCESS POWER

SUMMARY

A transducer includes a first piezoelectric layer; and a second piezoelectric layer that is above the first piezoelectric layer; wherein the second piezoelectric layer is a more compressive layer with an average stress that is less than or more compressive than an average stress of the first piezoelectric layer. In an example, the transducer includes a stack of layers that comprise the first and second piezoelectric layers, wherein a third layer in the stack is between the first and second piezoelectric layers. The second piezoelectric layer is fabricated by adjusting a bias power to a level that produces a vertical stress that is less than or more compressive than a vertical stress of the first piezoelectric layer. A vertical stress of the second piezoelectric layer offsets a vertical stress of the first piezoelectric layer to eliminate deflection in the acoustic transducer. The transducer comprises a MEMS transducer, an acoustic transducer, a piezoelectric transducer or a microphone.

In some examples, a method includes depositing a first piezoelectric layer on a substrate; depositing an intervening layer on the first piezoelectric layer; obtaining information indicative of a first vertical stress of the first piezoelectric layer; determining a second vertical stress that offsets the first vertical stress such that a combination of the first and second vertical stresses is a substantially zero deflection of the transducer; selecting a bias power that produces the second vertical stress; and depositing, using the selected bias power, the second piezoelectric layer on the intervening layer. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

In this example, deposition of the second piezoelectric layer uses the selected bias power throughout an entirety of deposition of the second piezoelectric layer. The actions include adjusting a bias power on a deposition tool to be the selected bias power. The intervening layer is a layer of molybdenum.

In another example, a transducer includes a first piezoelectric layer; and a second piezoelectric layer that is above the first piezoelectric layer; wherein the second piezoelectric layer has an average stress that compensates for a non-uniform amount of stress through a thickness of the first piezoelectric layer such that the first and second piezoelectric layers lie

substantially flat. In this example, the second piezoelectric layer compensates for the non-uniform amount of stress by being more compressive than the first piezoelectric layer, when the stress of the first piezoelectric layer becomes more tensile (increases) as the thickness of the first piezoelectric layer increases, or by being more tensile than the first piezoelectric layer, when the stress of the first piezoelectric layer becomes more compressive (decreases) as the thickness of the first piezoelectric layer increases. A compressive layer is a layer that deflects downwards and wherein a tensile layer is a layer that deflects upwards.

In still another example, a system of one or more computers can be configured to perform particular operations or actions (e.g., described above) by virtue of having software, firmware, hardware, or a combination of them installed on the system that in operation causes or cause the system to perform the actions. One or more computer programs can be configured to perform particular operations or actions by virtue of including instructions that, when executed by data processing apparatus, cause the apparatus to perform the actions.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a transducer device.

FIGS. 2-10 are plot diagrams.

FIG. 11 is a flowchart of a process for fabricating a transducer device.

DETAILED DESCRIPTION

A transducer device (e.g., a microphone) includes multiple (e.g., two) piezoelectric layers and the other layers are very thin. There are various types of transducer devices, e.g., acoustic transducer devices, microphones, energy harvesters, resonators, Microelectromechanical systems (MEMS) transducer devices, and so forth. In a MEMS transducer, two piezoelectric layers are used, e.g., to obtain twice the amount of energy that would be obtained from a non-MEMS transducer.

Referring to FIG. 1, transducer device 100 is fabricated as cantilever 101 or a plate. In this example, cantilever 101 includes a cantilevered beam (hereinafter “beam”). Cantilever 101 includes various layers 102a ... 102n of materials, with each layer including its own vertical stress (as shown in a vertical stress profile). In order to fabricate a level (e.g., flat) cantilever that does not bend, the average stresses among various layers 102a ... 102n are balanced to achieve a flat device. Balancing of the stresses is facilitated by cantilever 101

comprising different types of materials at various layers 102a ... 102n, such that the different materials have different stresses, which can be used to balance each other out.

In general, the curvature of a multi-layer cantilever is computed (e.g., by a system) in accordance with the following equation:

$$\kappa = \frac{1}{EI} \int_0^{z_N} \sigma(z) \cdot (z - c) dz$$

where κ (kappa) is curvature (e.g., second derivative of displacement), σ is the film residual stress (as a function of z), z is a distance from a bottom of cantilever 101. Each of layers 102a ... 102n has an associated height. For example, the height of layer 102n is h_N . In this example, cantilever 101 can be characterized in accordance with the following equations:

$$EI = \frac{b}{3} \sum_{i=1}^N E_i \left[(z_i - c)^3 - (z_{i-1} - c)^3 \right]$$

and

$$c = \frac{1}{2} \frac{\sum_{i=1}^N E_i (z_i^2 - z_{i-1}^2)}{\sum_{i=1}^N E_i (z_i - z_{i-1})}$$

where E_i is the modulus of elasticity of layer i and b is the beam width. EI is the product of the Young's modulus (E) and the moment of inertia (I), and c is the neutral axis, the z location at which a deflected plate does not get longer or shorter. σ is not a constant. Rather, σ is a

function of z , i.e., $\sigma(z)$. If the integral shown above (e.g., $\int_0^{z_N} \sigma(z) \cdot (z - c) dz$) is equal to zero

throughout the thickness of the multi-layer cantilever, the cantilever is going to be flat.

Accordingly, the integral will have different values for σ at the different layers. So, for the top AlN layer, σ is used to adjust the offset, e.g., by adjusting the bias power. That is, via adjustment of the bias power, the amount of vertical stress of the two piezoelectric layers offset each other for minimal or zero deflection. In this example, a “recipe” is determined for an appropriate bias power to provide a required offset, e.g., an offset at which the cantilever lies flat (e.g., as determined by visual inspection or by application of the foregoing equations). As such, σ of the bottom AlN layer will have a different value from σ of the top AlN layer. So, σ for the top layer is adjusted (via the bias power) to make it more compressive, so that when you integrate through z the cantilever has zero curvature.

In a MEMS device, two piezoelectric layers are used. Aluminum nitride (AlN) is one type of piezoelectric material used for a piezoelectric layer. In some example, the AlN is doped aluminum nitride (AlN doped with scandium) to obtain AlN with higher sensitivity and output signal. In still other example, other materials could be used in fabricating a beam or transducer using the techniques described herein.

Aluminum nitride (AlN) becomes more tensile as it is deposited. If the average stress of two piezoelectric layers (e.g., two AlN layers) in a stack (of layers that form the cantilever) are the same, a cantilever will not be flat but will bend up.

To address this issue of curvature in MEMS devices, a deposition recipe can be adjusted in order to achieve a film that does not become more tensile as it gets thicker. For example, continual adjustment of gas flow rates throughout deposition can be used to eliminate a vertical stress profile of AlN. However, this continual adjustment technique may degrade the crystalline structures of a deposition layer.

Another technique is to adjust the stress of the second layer to achieve flat plates. For example, the average stress of the second layer is fabricated to be about 245 MPa more compressive than the first, to achieve flat plates (e.g., layers) for the cantilever.

Referring to FIG. 2, plot 200 includes curve 202 that expresses the relationship between stress and film thickness. In this example, as the thickness (of AlN) increases the stress increases, causing the layer to become more tensile as it gets thicker.

As shown in plot 200, the vertical stress of a layer increases as the thickness increases. In this example, the stress of the first piezoelectric layer becomes more tensile (increases) as the thickness of the first piezoelectric layer increases. In another example (not shown in FIG. 2), the stress of the first piezoelectric layer becomes more compressive (decreases) as the thickness of the first piezoelectric layer increases. A cantilever has multiple layers. However, in this case, the AlN layers constitute the majority of the beam thickness and the AlN layers mainly contribute to deflection.

Referring to FIG. 3, plot 300 includes curve 302 that expresses a relationship between residual stresses and beam thickness, e.g., for different portions of the beam (e.g., cantilever 101).

In the example of FIG. 3, the beam has a total thickness of 2 micrometers (μm). The first 0-1 μm of the beam comprises a first AlN layer and an average stress of 356 MPa. As

shown in FIG. 3, the amount of residual stress from 0-1 μm increases from approximately 0 MPa to almost 500 MPa, with the increase forming a vertical stress gradient. The second AlN layer corresponds to the portion of the beam that has a thickness of 1 μm to 2 μm and has the same residual stress profile and average stress as the first AlN layer.

Referring to FIG. 4, plot 400 includes line 402 to graphically illustrate the above integral (e.g., $\int_0^{z_N} \sigma(z) \cdot (z - c) dz$). In particular, line 402 represents a distance to the neutral axis, c , as a function of beam thickness.

Referring to FIG. 5, plot 500 includes areas 501, 502, which represent a total quantity under the integral, e.g., based on multiplying curve 300 in FIG. 3 by line 400 in FIG. 4. Area 502 represents that the total area under the integral is positive, in which case the curvature will be a positive number and the beam will bend up. Area 501 represents that the area under the integral is negative, in which case the curvature will be negative and the beam will bend down.

Referring to FIG. 6, plot 600 includes curve 602 which expresses a relationship between beam deflection and beam length. In this example, the curvature is 363/m and the deflection of a 350 μm long cantilever beam is shown by curve 602.

Because the AlN layers have the same stress profiles, the deflection increases across the length of the beam – as shown in FIG. 6. If bias powers are substantially (e.g., exactly) the same (e.g., because the same recipe is being used) to deposit layers, then each piezoelectric layer will have substantially the same stress.

In order to reduce the beam deflection, the average stress of the second AlN layer can be reduced. In this example, the average stress of the second AlN layer has been reduced by 137 MPa. Referring to FIG. 7, plot 700 includes curve 702 that represents the stress profile of the two layers. Referring to FIG. 8, plot 800 includes areas 802, 804, which represent the area under the integral. The adjusted stress profile now provides a curvature of -0.3/m, much closer to zero than the curvature above. Referring to FIG. 9, plot 900 includes line 902, which represents the relationship between beam length and beam deflection, e.g., of the beam in this example in which the average stress of the second AlN layer is reduced by 137 MPa.

In operation, a deposition tool deposits various layers on a substrate to fabricate the cantilever beam. The deposition tool allows for the adjustment of bias power. By adjusting

the bias power, the vertical stress of the two piezoelectric layers offset each other for minimal or zero deflection, as shown in plots 700, 800, 900 of FIGS. 7-9, respectively.

Referring back to FIG. 7, the first AlN layer (corresponding to the portion of the beam from approximately 0-1 μm and represented in plot 700 as the beam thickness from 0-1 μm) has an amount of residual stress increasing from approximately 0 MPa to almost 500 MPa. The second AlN layer (corresponding to the portion of the beam from approximately 1-2 μm and represented in plot 700 as the beam thickness from 1-2 μm) has an amount of residual stress increasing from approximately -100 MPa to almost 400 to offset the amount of residual stress in the first AlN layer. In this example, the second AlN layer is deposited with a bias power that differs from the bias power used in depositing the first AlN layer. The vertical stress of the second AlN layer offsets the vertical stress of the first AlN layer such that a combination of these vertical stresses is a substantially zero vertical deflection.

The difference between the average residual stress of the first layer and the average residual stress of the second layer produces an offset that reduces (or eliminates) deflection in the cantilever beam, causing the beam to lie flat. If the second layer has an average stress that is less than or more negative than the average residual stress of the first layer, then an offset is formed that causes the cantilever to bend downward. In particular, the top layer of AlN (e.g., the second layer) is fabricated to be a compressive layer to compensate for the vertical stress in both the bottom and top layers of AlN (e.g., the first layer) and any stress imparted by other layers in the cantilever beam (e.g., such as molybdenum layers).

Generally, bias power includes a direct current (DC) deliberately made to flow, or DC voltage deliberately applied, between two points (e.g., between the chamber and the sputter target). A type of bias power is radio frequency (rf) power (e.g., rf bias power), which deposition tools apply to wafers in fabricating the cantilevers. In using the deposition tool, a wafer is placed face down on a platen. Rf power (e.g., in the range of 30–300 W) is applied between the target and the wafer, creating low energy ion bombardment during film growth (e.g., growth of a film as a layer).

Referring to FIG. 10, plot 1000 includes curve 1002 that represents the relationship between bias power and stress. Stress is a function of rf bias power. In this example, the stress is for 1000 nm thick AlN films. There is a defined relationship between stress and bias power, in which stress decreases as bias power increases. So, to obtain a top AlN layer of a particular amount of vertical stress that is required to offset the vertical stress profile of the

bottom AlN layer, a system consistent with this disclosure determines the average stress of the top layer (needed to eliminate deflection) and adjusts the bias power to obtain that average stress, in accordance with the defined relationship between bias power and stress.

In this example, the bias power affects sigma. An increase in the bias power causes sigma to decrease. By increasing the bias power, the average stress in a layer is decreased. By decreasing the bias power, the average stress in a layer increases. Referring back to FIG. 7, the bias power is used to shift the average amount of stress of the second AlN layer to be lower, so decreasing the average stress – to make it more compressive, more negative stress. In this example, the bias power is an input on the sputter tool and bias power is not continuously adjusted during deposition, to ensure quality and integrity of the deposited layers. That is, adjustment of the bias during deposition (as opposed to determining an amount of bias power to be applied to obtain a compressive layer), may reduce the structural quality of a layer. Film stress can be adjusted in ways other than adjusting RF bias, such as by adjusting Ar or N2 gas flow rates.

Referring to FIG. 11, a system (or a fabrication device) implements process 1100 for fabricating a transducer. In operation, the system deposits (1102) a first piezoelectric layer on a substrate. The system also deposits (1104) an intervening layer on the first piezoelectric layer. The system obtains (1106), e.g., from an external data repository or from execution of instructions for determining a vertical stress, information indicative of a first vertical stress of the first piezoelectric layer. The system determines (1108) a second vertical stress that offsets the first vertical stress such that a combination of the first and second vertical stresses is a substantially zero deflection of the transducer. The system selects (1110) a bias power that produces the second vertical stress. The system deposits (1112), using the selected bias power, the second piezoelectric layer on the intervening layer. In this example, deposition of the second piezoelectric layer uses the selected bias power throughout an entirety of deposition of the second piezoelectric layer. The system also adjusts a bias power on a deposition tool to be the selected bias power. In this example, the intervening layer is a layer of molybdenum.

The techniques described herein may be used to compensate for a non-uniform amount of stress through a thickness of the first piezoelectric layer, e.g., by making the second layer more compressive or tensile. A non-uniform amount of stress causes deflection, whether upwards or downwards. That is, the foregoing equations may be used to determine

and to adjust an initial (or original) curvature of layers and an entire cantilever, e.g., whether that initial curvature is positive or negative. In this example, an acoustic transducer includes a first piezoelectric layer; and a second piezoelectric layer that is above the first piezoelectric layer; wherein the second piezoelectric layer has an average stress that compensates for a non-uniform amount of stress through a thickness of the first piezoelectric layer such that the first and second piezoelectric layers lie substantially flat, e.g., by having less than a threshold amount of curvature or deflection. The second piezoelectric layer compensates for the non-uniform amount of stress by being more compressive than the first piezoelectric layer, when the first piezoelectric layer is a tensile layer, or by being more tensile than the first piezoelectric layer, when the first piezoelectric layer is a compressive layer. A compressive layer is a layer that deflects downwards and a tensile layer is a layer that deflects upwards.

The techniques describes herein may be used to fabricate a beam or a plate. In turn, an acoustic transducer or a transducer may be comprised of one or a plurality of these beams/plates.

Embodiments can be implemented in digital electronic circuitry, or in computer hardware, firmware, software, or in combinations thereof. Apparatus can be implemented in a computer program product tangibly embodied or stored in a machine-readable storage device for execution by a programmable processor; and method actions can be performed by a programmable processor executing a program of instructions to perform functions by operating on input data and generating output. The techniques described herein can be implemented advantageously in one or more computer programs that are executable on a programmable system including at least one programmable processor coupled to receive data and instructions from, and to transmit data and instructions to, a data storage system, at least one input device, and at least one output device. Each computer program can be implemented in a high-level procedural or object oriented programming language, or in assembly or machine language if desired; and in any case, the language can be a compiled or interpreted language.

Suitable processors include, by way of example, both general and special purpose microprocessors. Generally, a processor will receive instructions and data from a read-only memory and/or a random access memory. Generally, a computer will include one or more mass storage devices for storing data files; such devices include magnetic disks, such as internal hard disks and removable disks; magneto-optical disks; and optical disks. Storage

devices suitable for tangibly embodying computer program instructions and data include all forms of non-volatile memory, including by way of example semiconductor memory devices, such as EPROM, EEPROM, and flash memory devices; magnetic disks such as internal hard disks and removable disks; magneto-optical disks; and CD-ROM disks. Any of the foregoing can be supplemented by, or incorporated in, ASICs (application-specific integrated circuits).

Other embodiments are within the scope and spirit of the description and the claims. Additionally, due to the nature of software, functions described above can be implemented using software, hardware, firmware, hardwiring, or combinations of any of these. The use of the term “a” herein and throughout the application is not used in a limiting manner and therefore is not meant to exclude a multiple meaning or a “one or more” meaning for the term “a.” Additionally, to the extent priority is claimed to a provisional patent application, it should be understood that the provisional patent application is not limiting but includes examples of how the techniques described herein may be implemented.

A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit and scope of the claims and the examples of the techniques described herein.

WHAT IS CLAIMED IS:

1. A transducer comprising:
a first piezoelectric layer; and
a second piezoelectric layer that is above the first piezoelectric layer;
wherein the second piezoelectric layer is a more compressive layer with an average stress that is less than or more compressive than an average stress of the first piezoelectric layer.
2. The transducer of claim 1, further comprising:
a stack of layers that comprise the first and second piezoelectric layers, wherein a third layer in the stack is between the first and second piezoelectric layers.
3. The transducer of claim 1, wherein the second piezoelectric layer is fabricated by adjusting a bias power to a level that produces a vertical stress that is less than or more compressive than a vertical stress of the first piezoelectric layer.
4. The transducer of claim 1, wherein a vertical stress of the second piezoelectric layer offsets a vertical stress of the first piezoelectric layer to eliminate deflection in the acoustic transducer.
5. The transducer of claim 1, wherein the transducer comprises a MEMS transducer, an acoustic transducer, a piezoelectric transducer or a microphone.
6. A method of fabricating a transducer, comprising:
depositing a first piezoelectric layer on a substrate;
depositing an intervening layer on the first piezoelectric layer;
obtaining information indicative of a first vertical stress of the first piezoelectric layer;
determining a second vertical stress that offsets the first vertical stress such that a combination of the first and second vertical stresses is a substantially zero deflection of the transducer;
selecting a bias power that produces the second vertical stress; and
depositing, using the selected bias power, the second piezoelectric layer on the intervening layer.

7. The method of claim 6, wherein deposition of the second piezoelectric layer uses the selected bias power throughout an entirety of deposition of the second piezoelectric layer.

8. The method of claim 6, further comprising:
adjusting a bias power on a deposition tool to be the selected bias power.

9. The method of claim 6, wherein the intervening layer is a layer of molybdenum.

10. A transducer comprising:
a first piezoelectric layer; and
a second piezoelectric layer that is above the first piezoelectric layer;
wherein the second piezoelectric layer has an average stress that compensates for a non-uniform amount of stress through a thickness of the first piezoelectric layer such that the first and second piezoelectric layers lie substantially flat.

11. The transducer of claim 10, wherein the second piezoelectric layer compensates for the non-uniform amount of stress by being more compressive than the first piezoelectric layer, when the stress of the first piezoelectric layer becomes more tensile (increases) as the thickness of the first piezoelectric layer increases, or by being more tensile than the first piezoelectric layer, when the stress of the first piezoelectric layer becomes more compressive (decreases) as the thickness of the first piezoelectric layer increases.

12. The transducer of claim 11, wherein a compressive layer is a layer that deflects downwards and wherein a tensile layer is a layer that deflects upwards.

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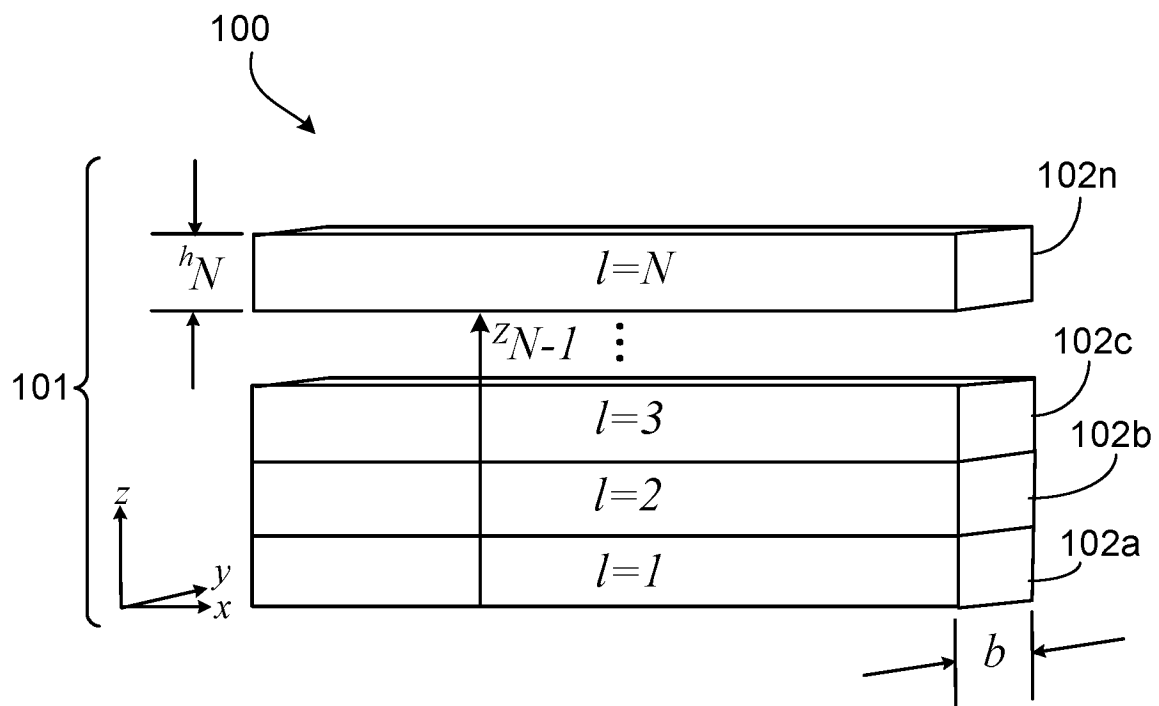


FIG. 1

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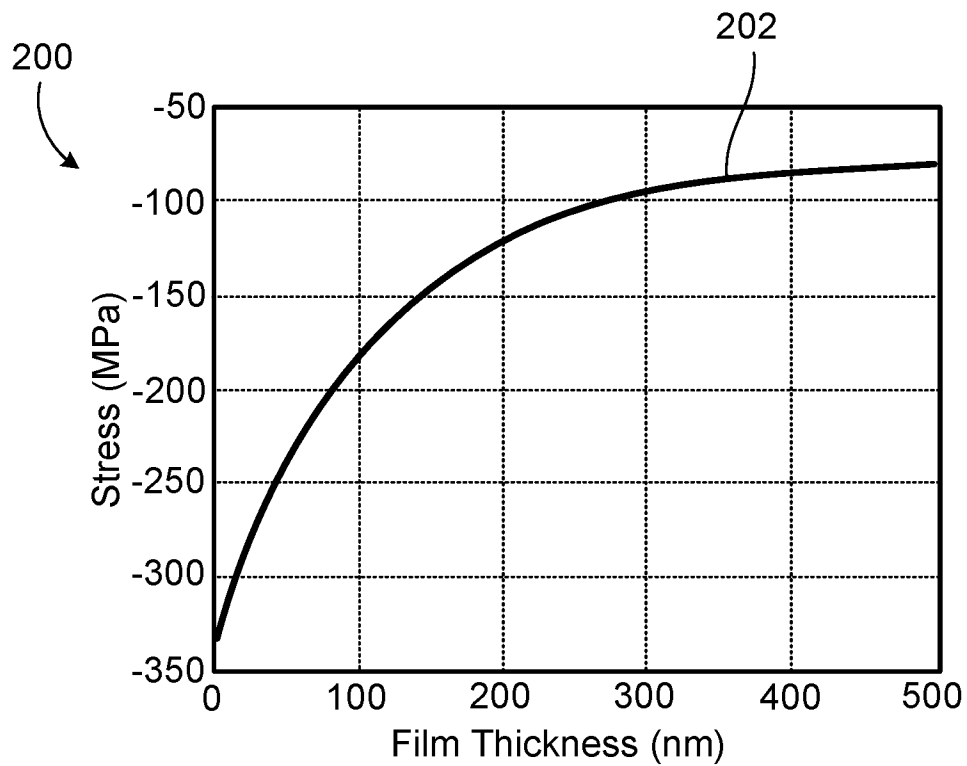


FIG. 2

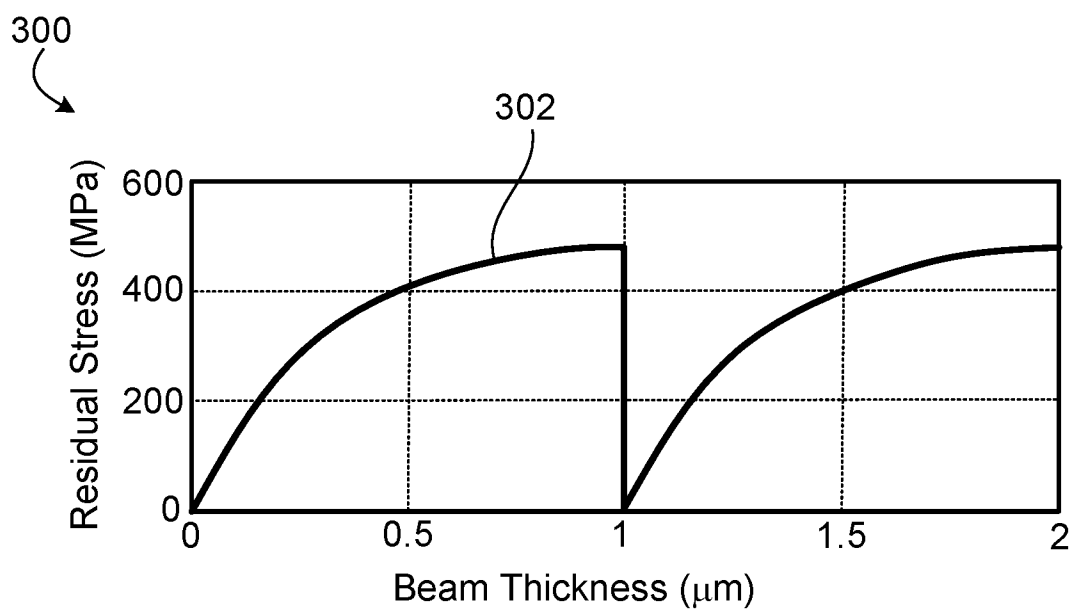


FIG. 3

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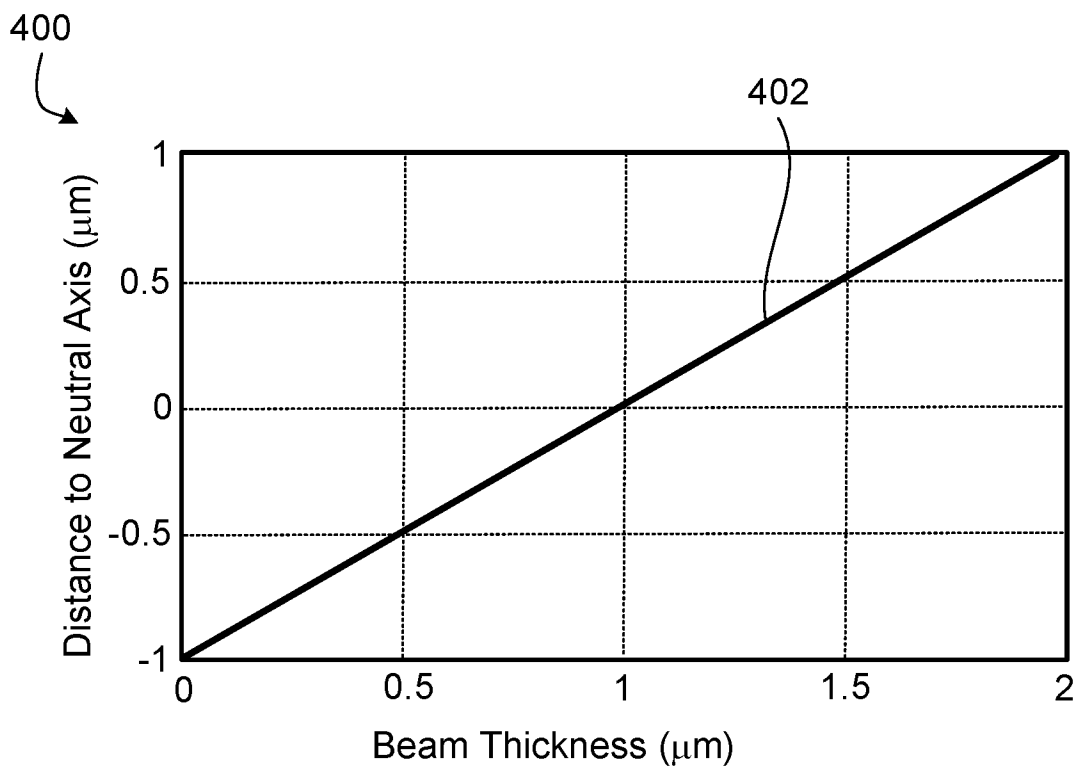


FIG. 4

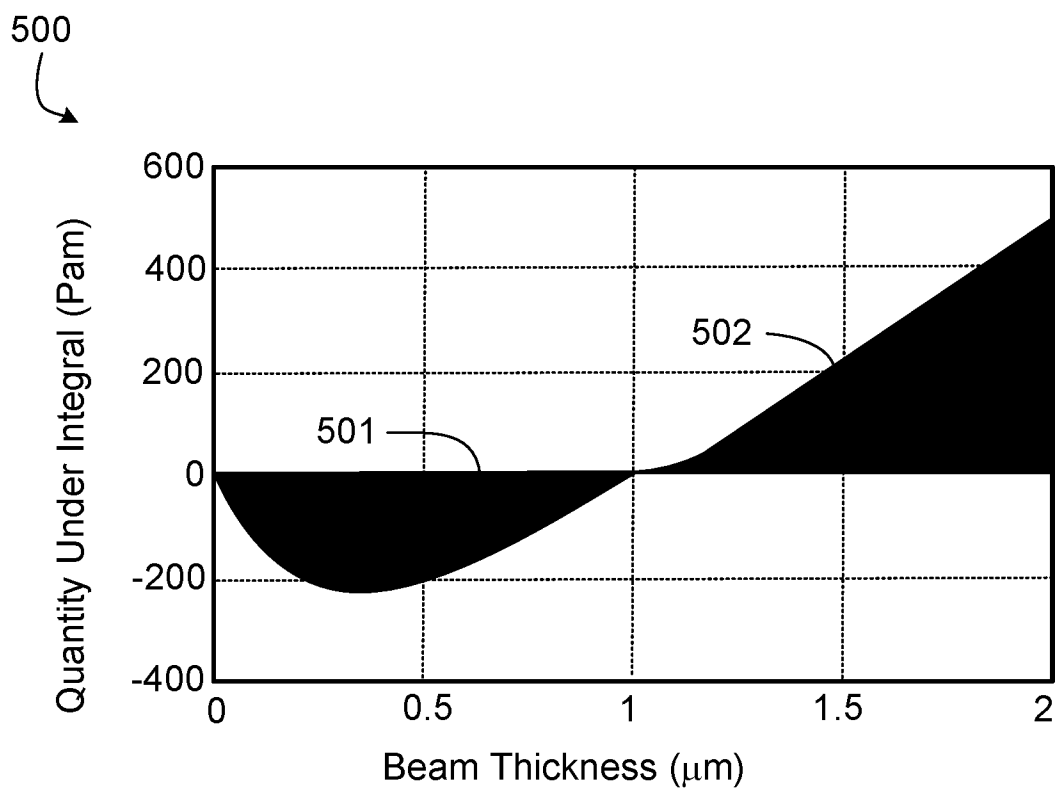


FIG. 5

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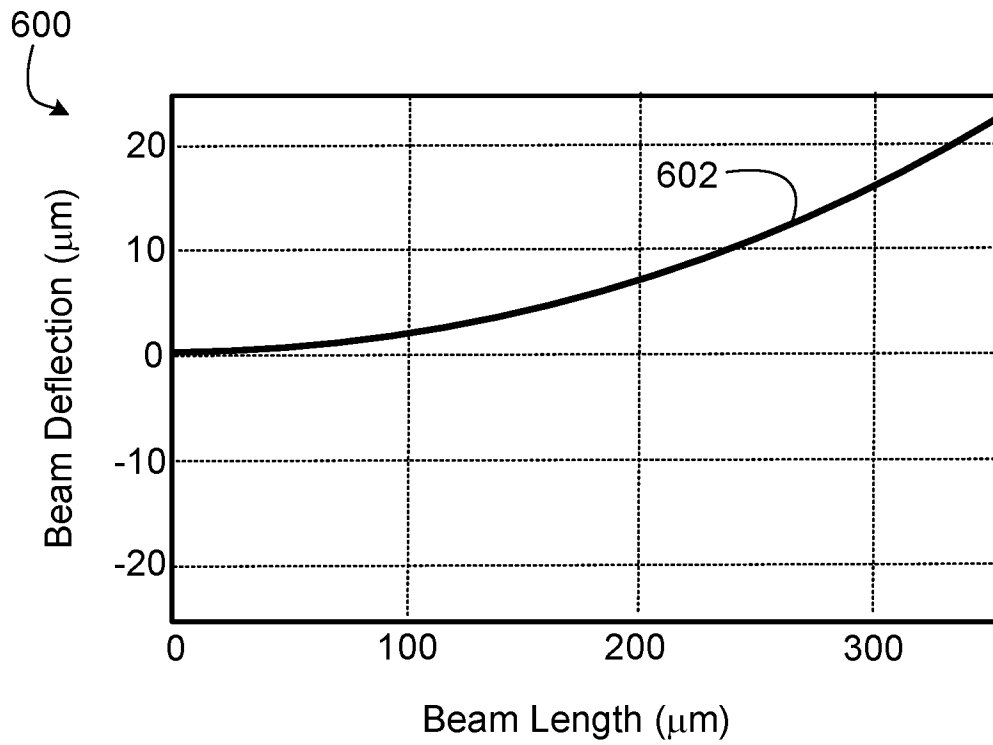


FIG. 6

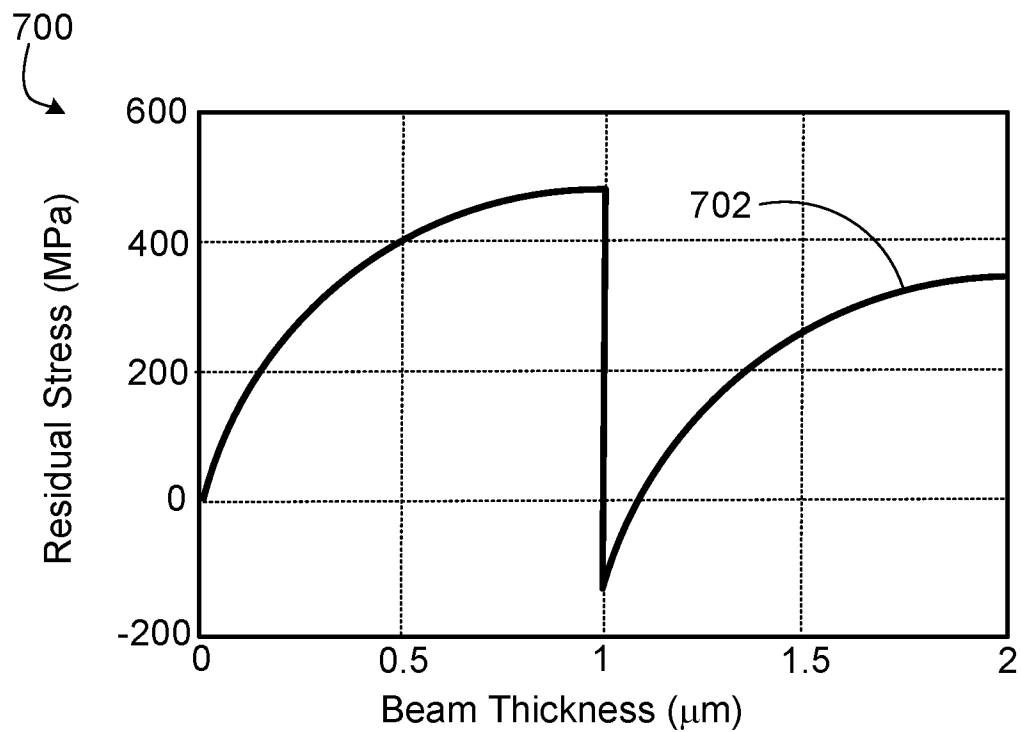


FIG. 7

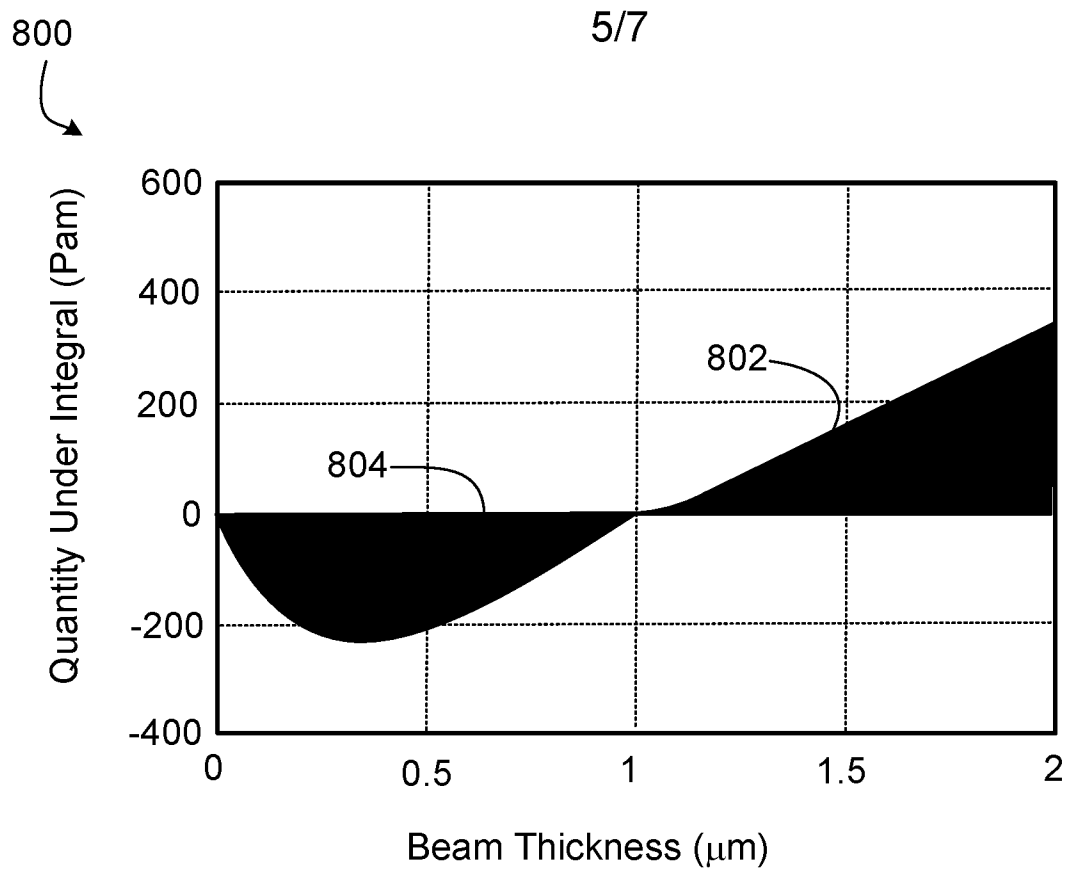


FIG. 8

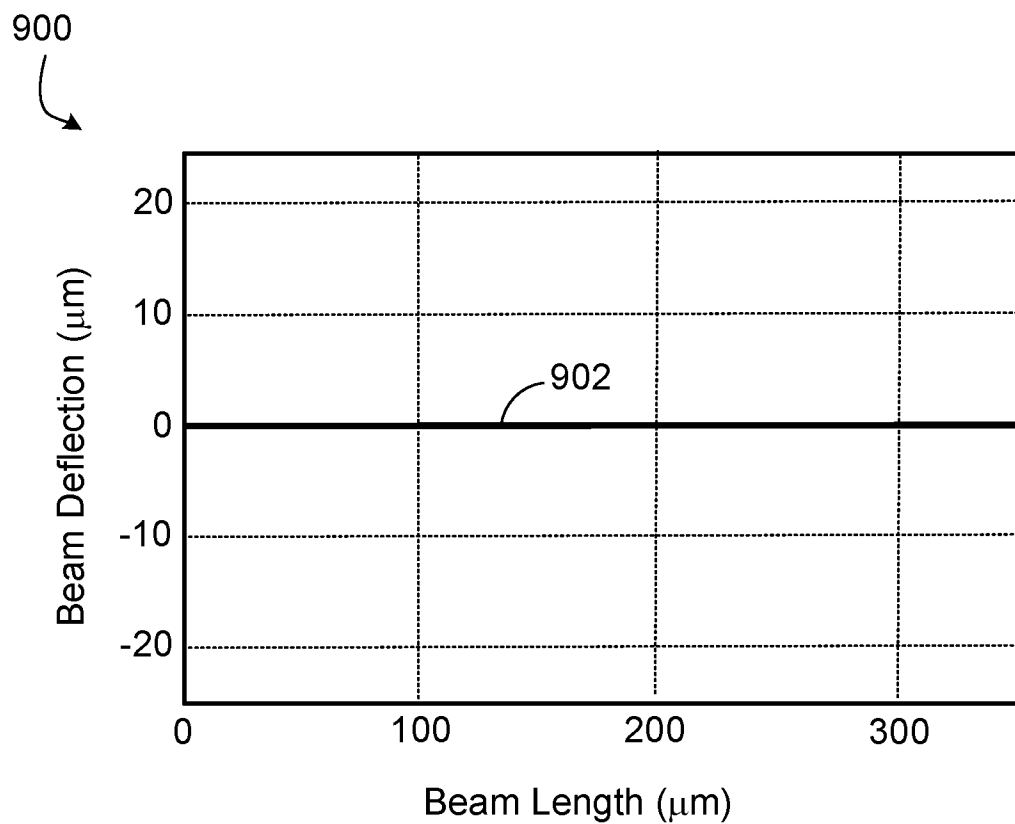


FIG. 9

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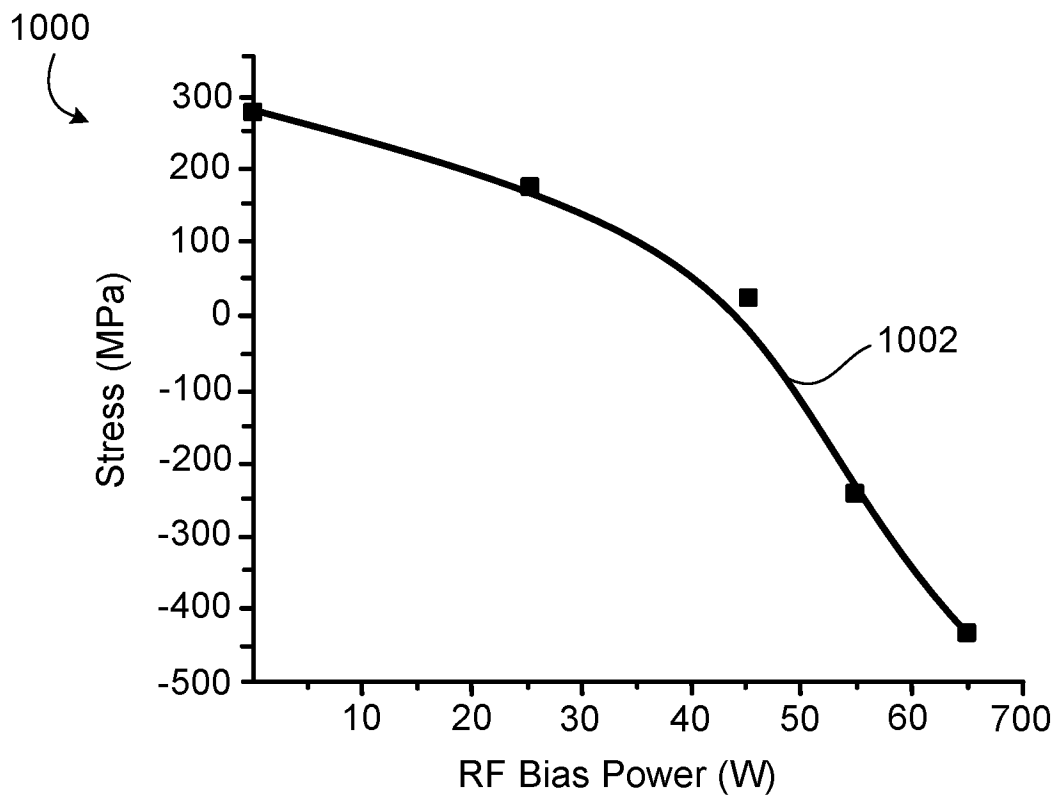


FIG. 10

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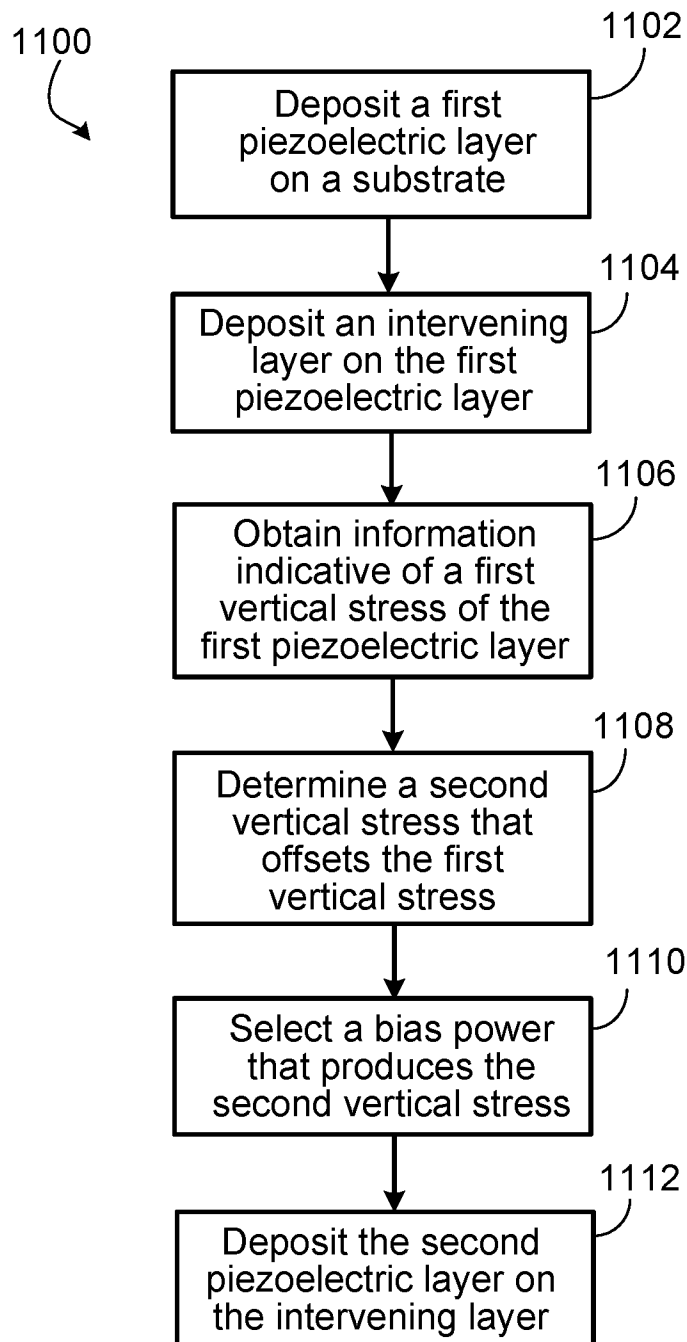


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/028770

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H03H 9/17; G11B 9/00; H01L 41/08 (2016.01)

CPC - H03H 9/171; G11B 9/02; H03H 9/02015 (2016.05)

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)

IPC - H03H 9/17; G11B 9/00; H01L 41/08

CPC - H03H 9/171; G11B 9/02; H03H 9/02015

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC- 310/327, 330, 331, 332, 334, 342 (keyword delimited)

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

Orbit, Google Patents, Google Scholar

Search terms used: transducer, piezoelectric, compressive, stress, vertical, deflection, offset

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0122317 A1 (FAZZIO et al) 29 May 2008 (29.05.2008) entire document	1-5
Y	US 2006/0023606 A1 (LUTWYCHE et al) 02 February 2006 (02.02.2006) entire document	1-5
Y	US 2010/0148637 A1 (SATOU) 17 June 2010 (17.06.2010) entire document	3, 4
A	US 2014/0292941 A1 (SEIKO EPSON CORPORATION) 02 October 2014 (02.10.2014) entire document	1-5
A	US 5,861,702 A (BISHOP et al) 19 January 1999 (19.01.1999) entire document	1-5



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

15 August 2016

Date of mailing of the international search report

02 SEP 2016

Name and mailing address of the ISA/

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, VA 22313-1450

Facsimile No. 571-273-8300

Authorized officer

Blaine R. Copenheaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2016/028770

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
See supplemental page

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-5

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.

Continued from Box No. III Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claims 1-5, drawn to a transducer.

Group II, claims 6-9, drawn to a method of fabricating a transducer.

Group III, claims 10-12, drawn to a transducer comprising: a first piezoelectric layer.

The inventions listed as Groups I, II and III do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: the special technical feature of the Group I invention: wherein the second piezoelectric layer is a more compressive layer with an average stress that is less than or more compressive than an average stress of the first piezoelectric layer as claimed therein is not present in the invention of Groups II and III. The special technical feature of the Group II invention: obtaining information indicative of a first vertical stress of the first piezoelectric layer; selecting a bias power that produces the second vertical stress; and depositing, using the selected bias power, the second piezoelectric layer on the intervening layer as claimed therein is not present in the invention of Groups I or III. The special technical feature of the Group III invention: compensates for a non-uniform amount of stress through a thickness of the first piezoelectric layer such that the first and second piezoelectric layers lie substantially flat as claimed therein is not present in the invention of Groups I or II.

Groups I, II and III lack unity of invention because even though the inventions of these groups require the technical feature of a transducer comprising: a first piezoelectric layer; and a second piezoelectric layer that is above the first piezoelectric layer, this technical feature is not a special technical feature as it does not make a contribution over the prior art.

Specifically, US 2014/0292941 A1 (SEIKO EPSON CORPORATION) 02 October 2014 (02.10.2014) teaches a transducer comprising: a first piezoelectric layer (Para. 33); and a second piezoelectric layer that is above the first piezoelectric layer (Paras. 34-35).

Since none of the special technical features of the Group I, II or III inventions are found in more than one of the inventions, unity of invention is lacking.