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(54) **PRESSURE SENSING DEVICE AND PRESSURE SENSING APPARATUS**

(71) Applicant: **National Chiao Tung University**, Hsinchu City (TW)

(72) Inventors: **Tsan-Wen Lu**, Hsinchu City (TW); **Chun Wang**, New Taipei City (TW); **Po-Tsung Lee**, Hsinchu County (TW)

(73) Assignee: **National Chiao Tung University**, Hsinchu City (TW)

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(52) **U.S. Cl.**

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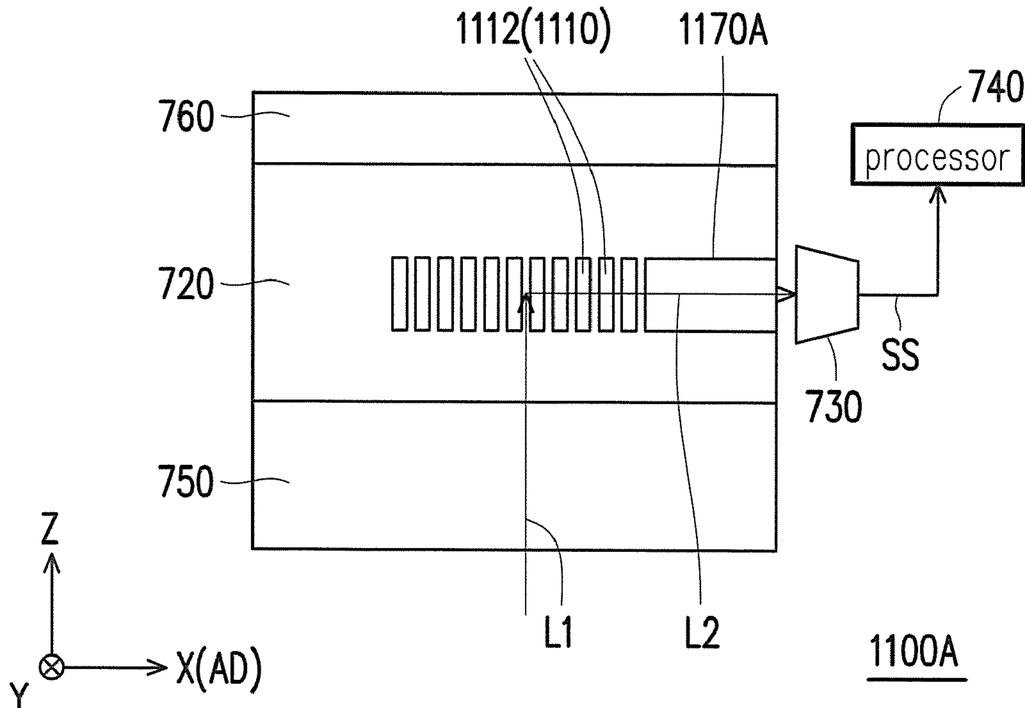
(57) **ABSTRACT**

A pressure sensing device including a light source, at least one resonant structure, a cladding body, a first substrate and a second substrate is provided. The light source is configured to provide an original broadband light. The resonant structure includes a plurality of semiconductor rod structures arranged into a row at intervals along a single arranging direction, and each of the semiconductor rod structures has a lattice constant on the arranging direction. The original broadband light is transmitted between the semiconductor rod structures, and a resonant light is produced, wherein each of the semiconductor rod structures has a length perpendicular to the arranging direction and has a width parallel to the arranging direction, the length and the width are less than the wavelength of the resonant light. The cladding body completely covers the semiconductor rod structures of the at least one resonant structure. The cladding body and the at least one resonant structure are interposed between the first substrate and the second substrate. When a pressure is applied on at least one of the first substrate and the second substrate, the pressure is transmitted to the cladding body along a direction perpendicular to the arranging direction, a deformation corresponding to the pressure is occurred on the cladding body and the semiconductor rod structures on the arranging direction, and a wavelength of the resonant light is changed according to the deformation. Besides, a pressure sensing apparatus is also provided.



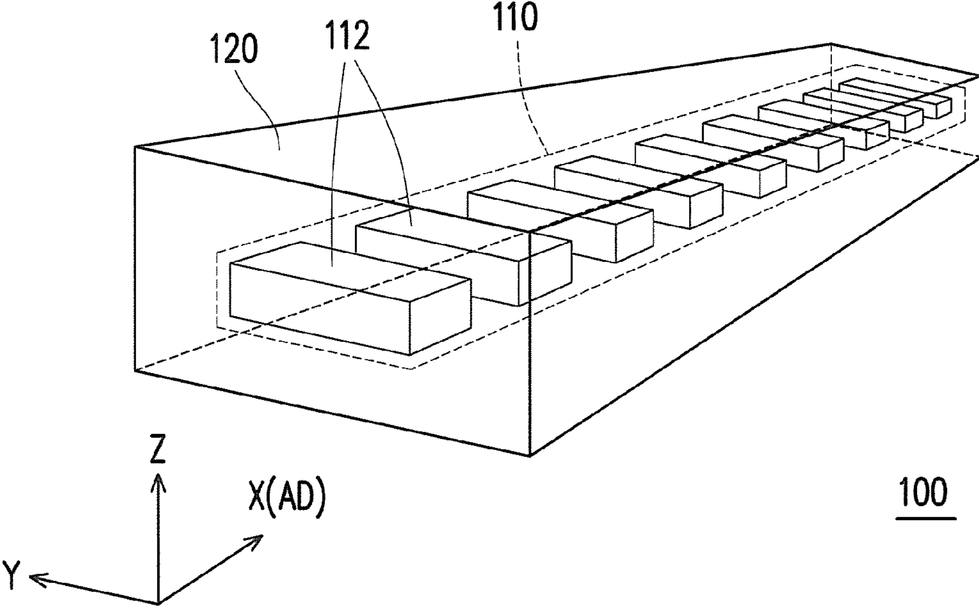


FIG. 1A

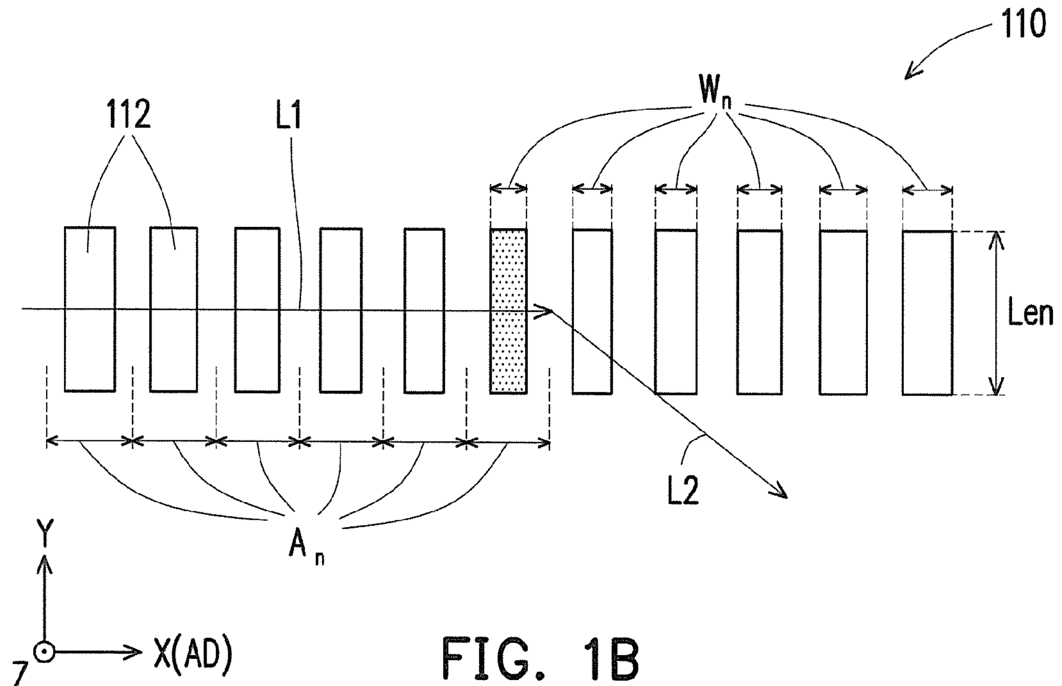


FIG. 1B

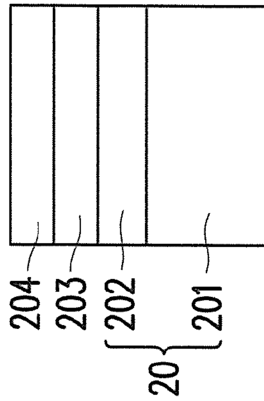


FIG. 2A

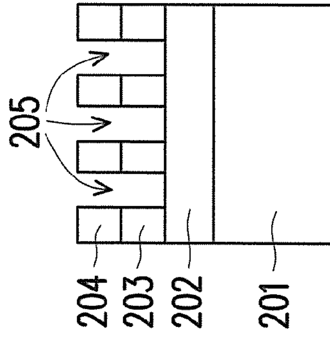


FIG. 2B

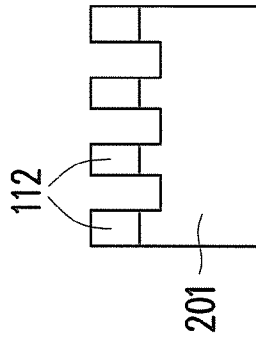


FIG. 2C

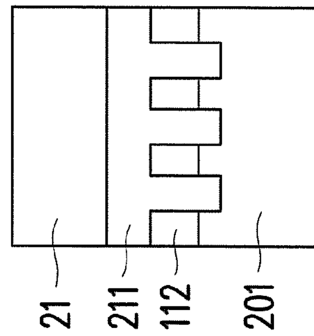


FIG. 2D

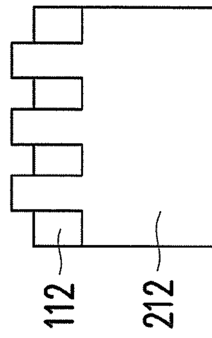


FIG. 2E

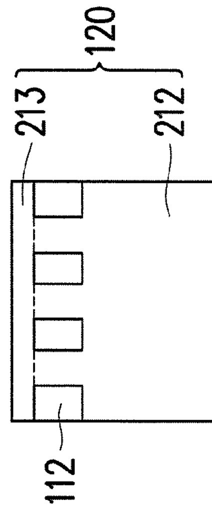


FIG. 2F

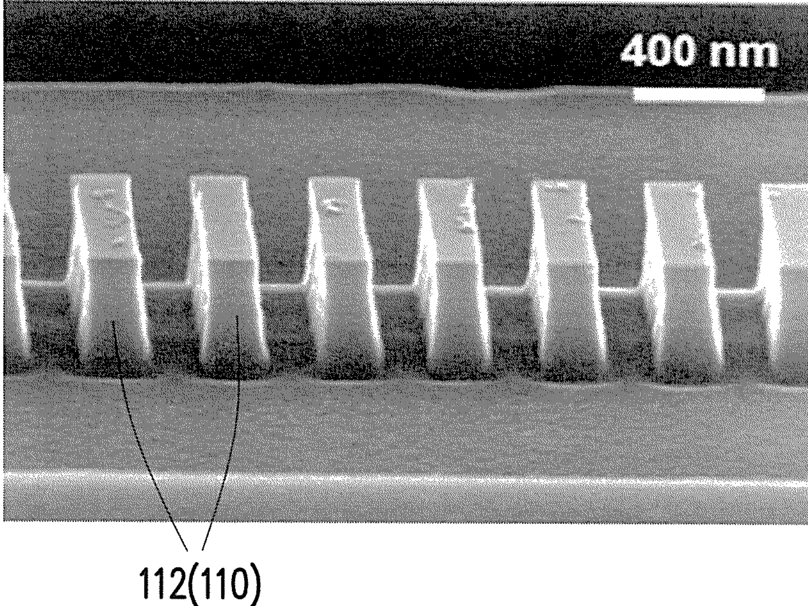


FIG. 3A

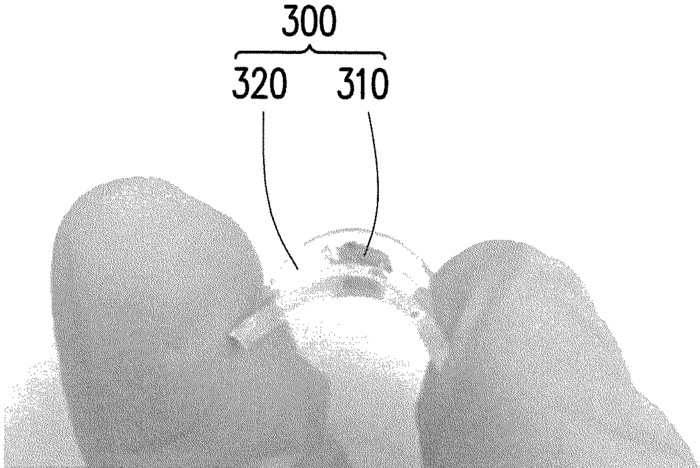


FIG. 3B

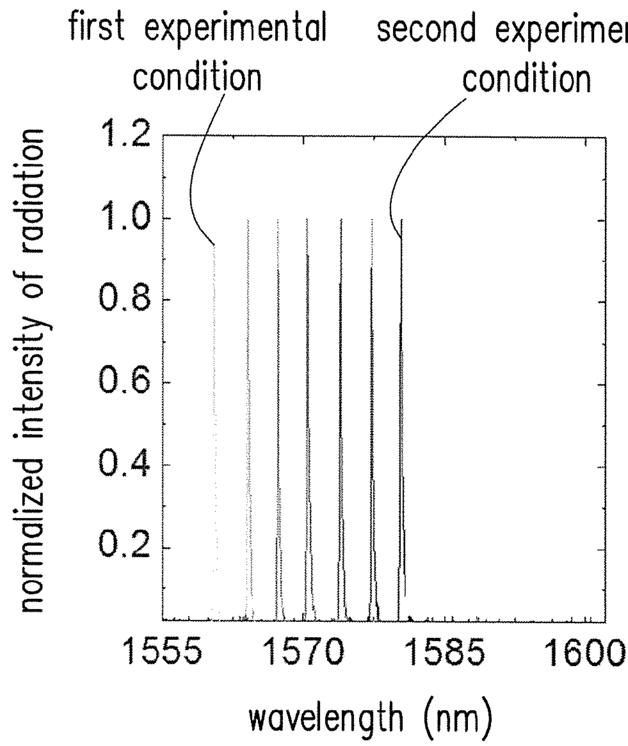


FIG. 3C

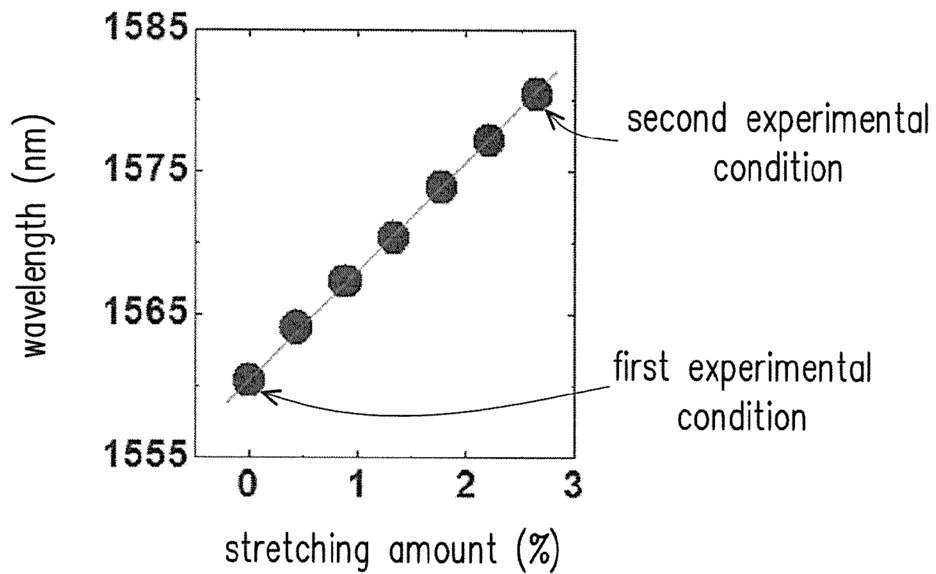


FIG. 3D

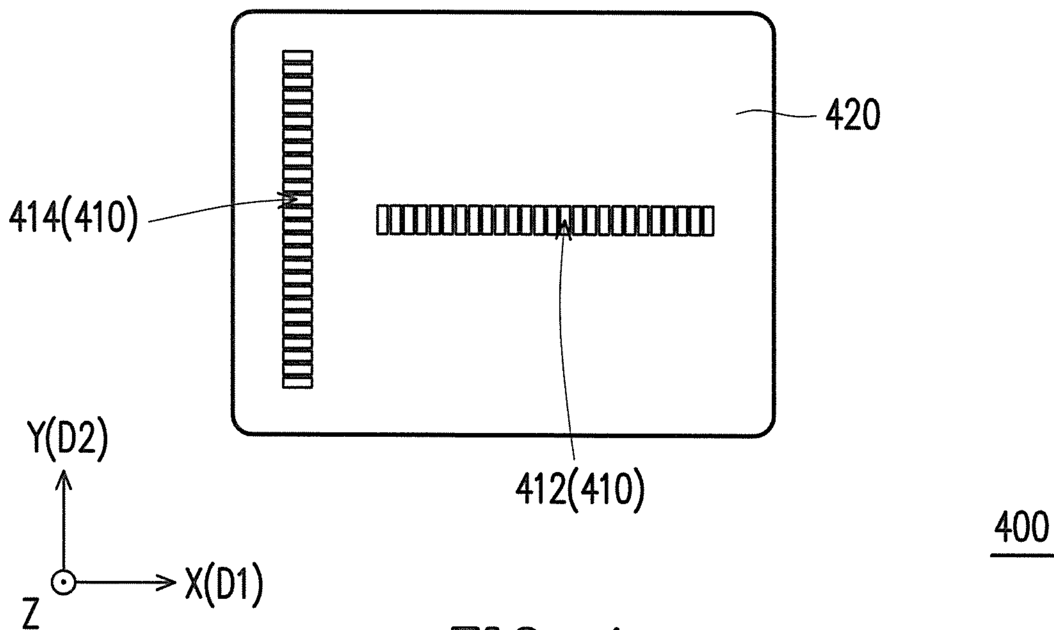


FIG. 4

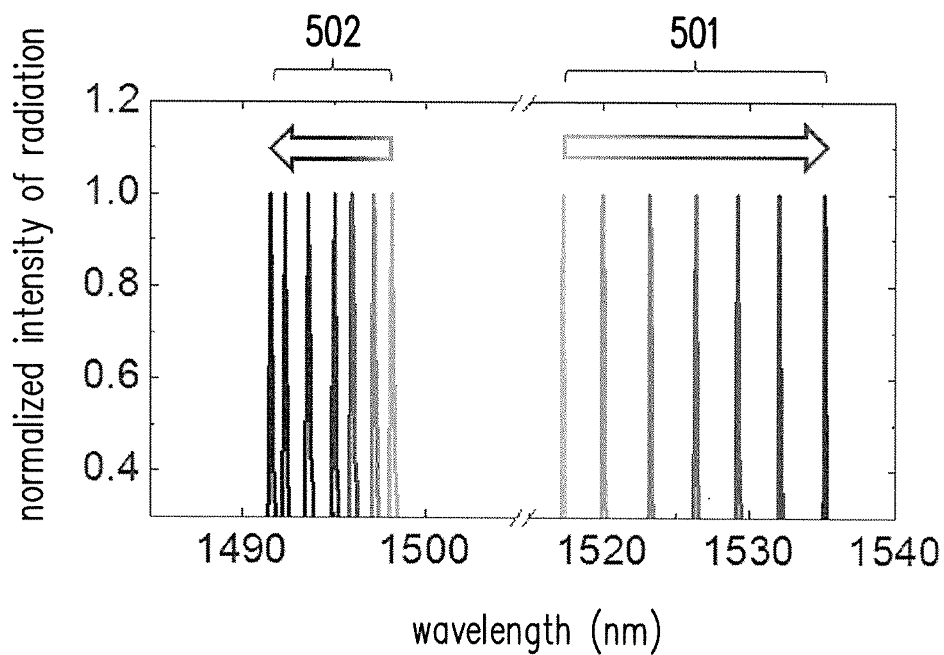


FIG. 5

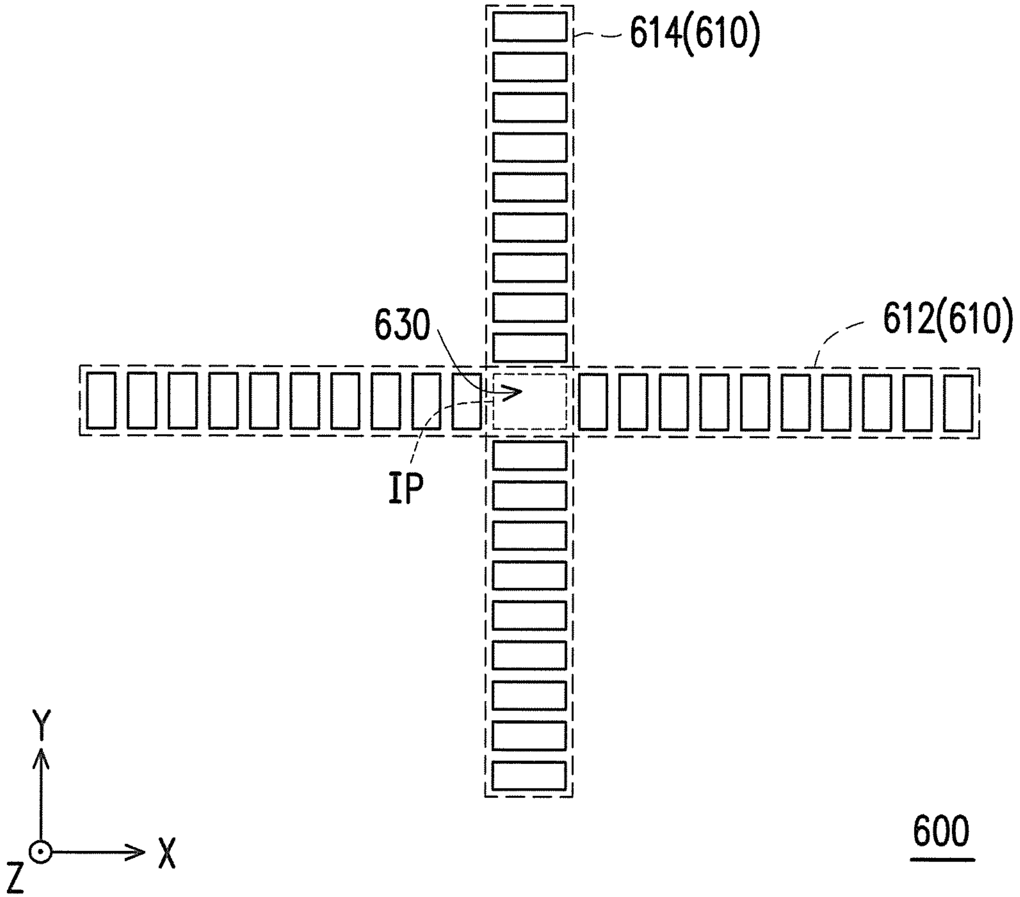


FIG. 6

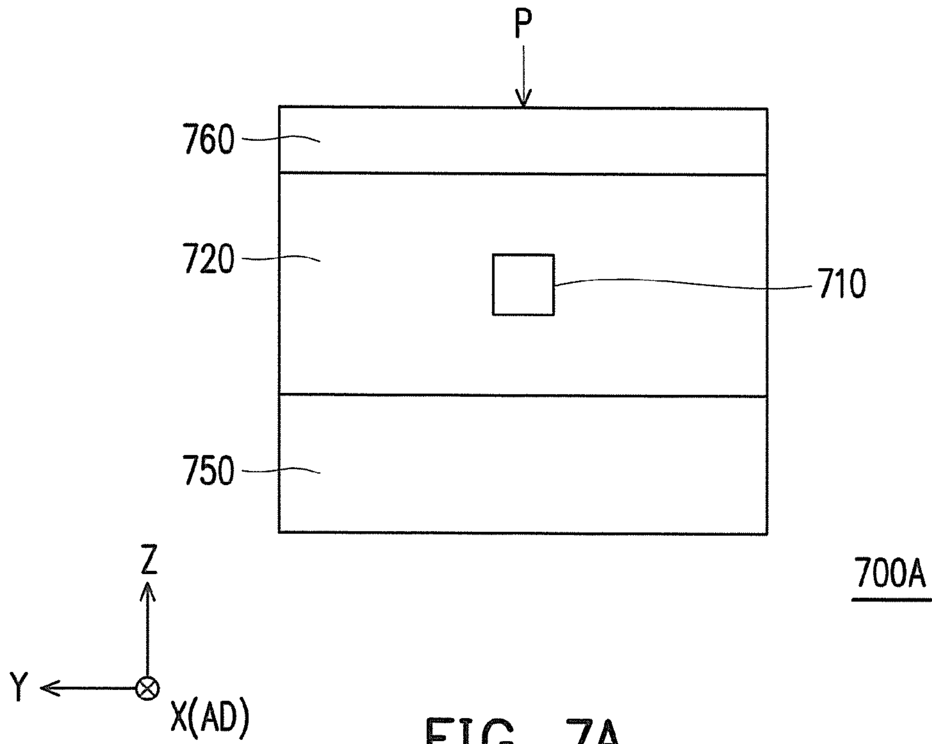


FIG. 7A

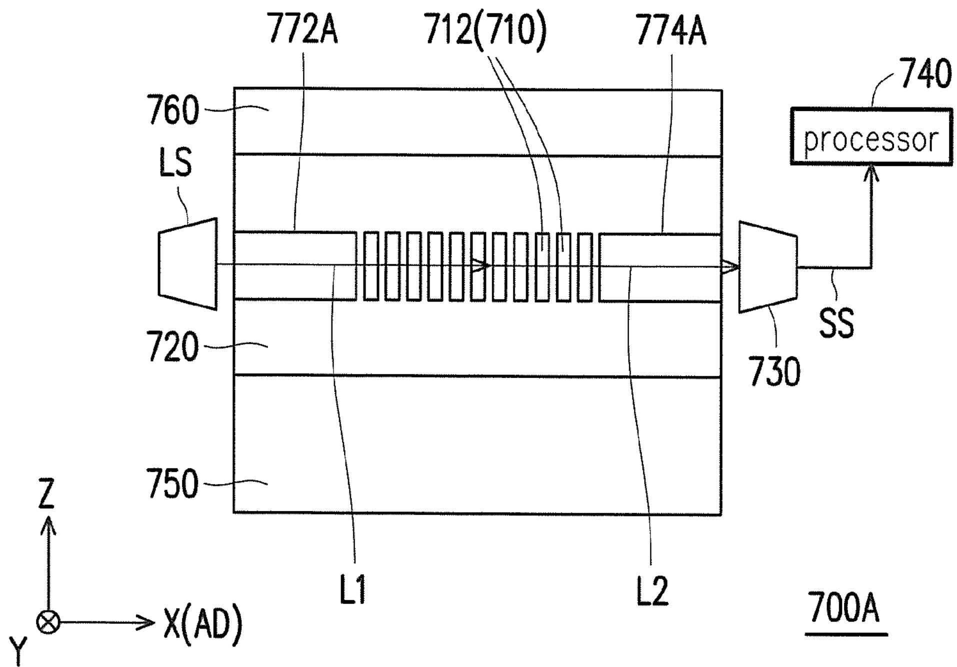


FIG. 7B

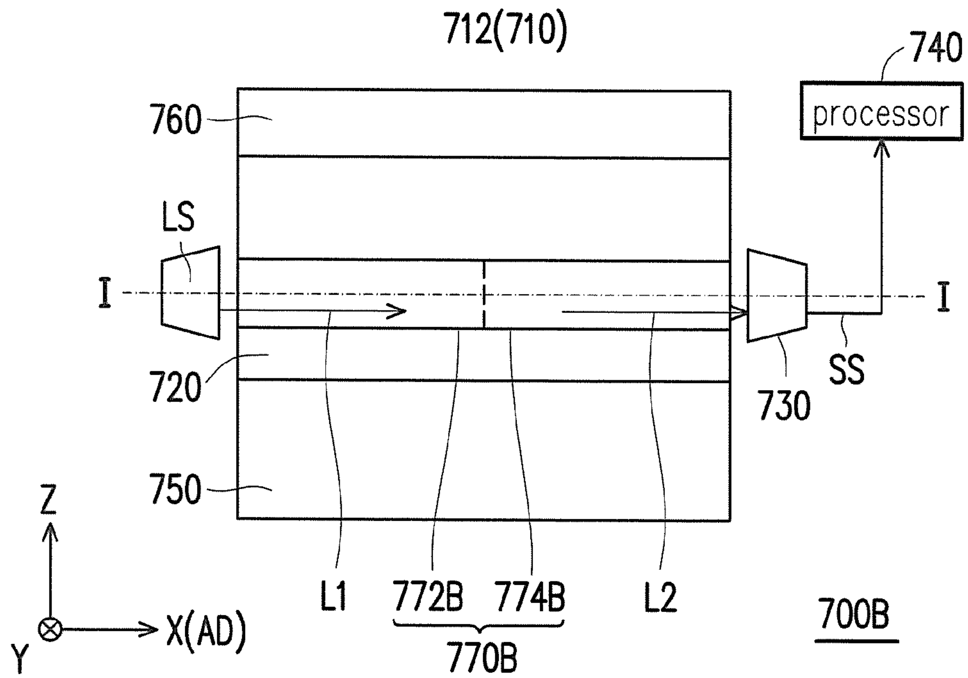


FIG. 7C

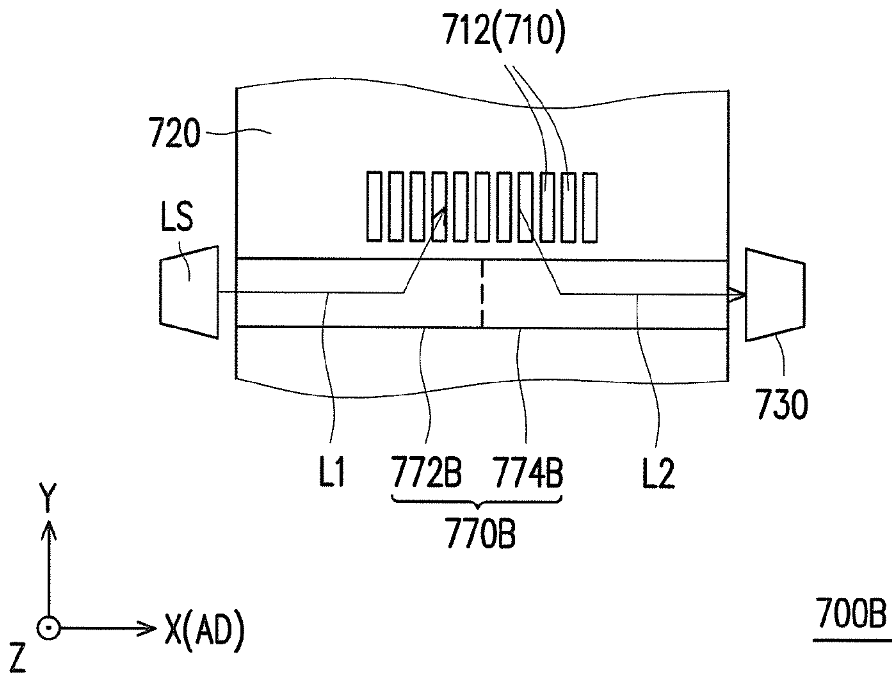


FIG. 7D

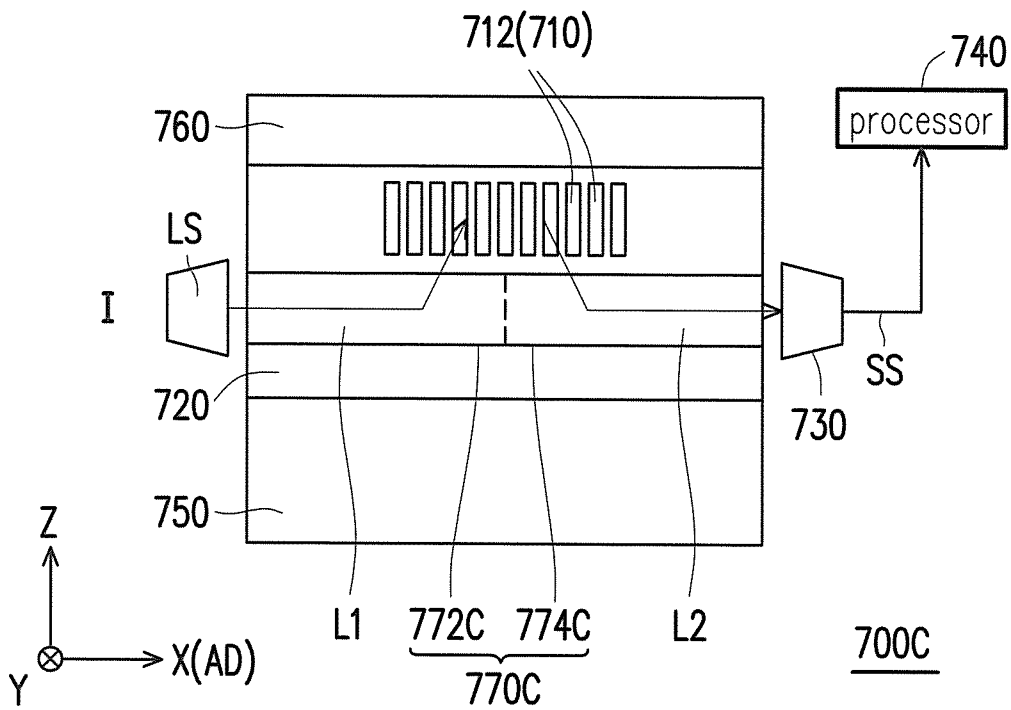


FIG. 7E

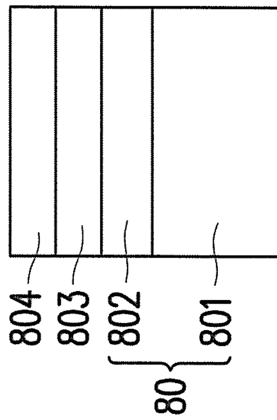


FIG. 8A

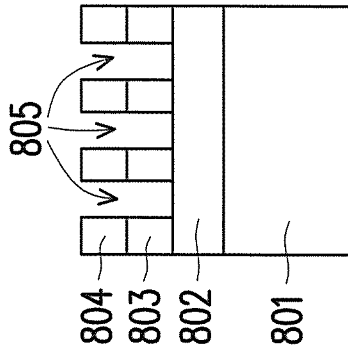


FIG. 8B

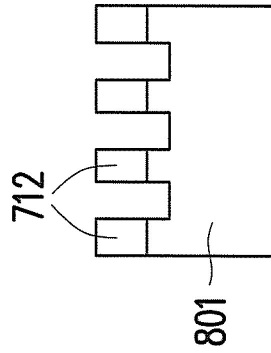


FIG. 8C

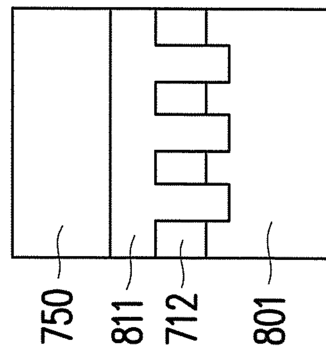


FIG. 8D

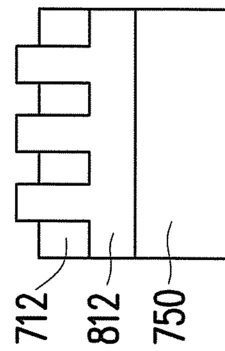


FIG. 8E

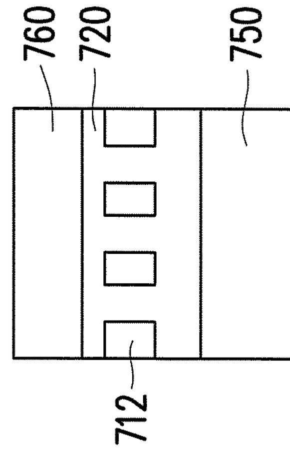


FIG. 8F

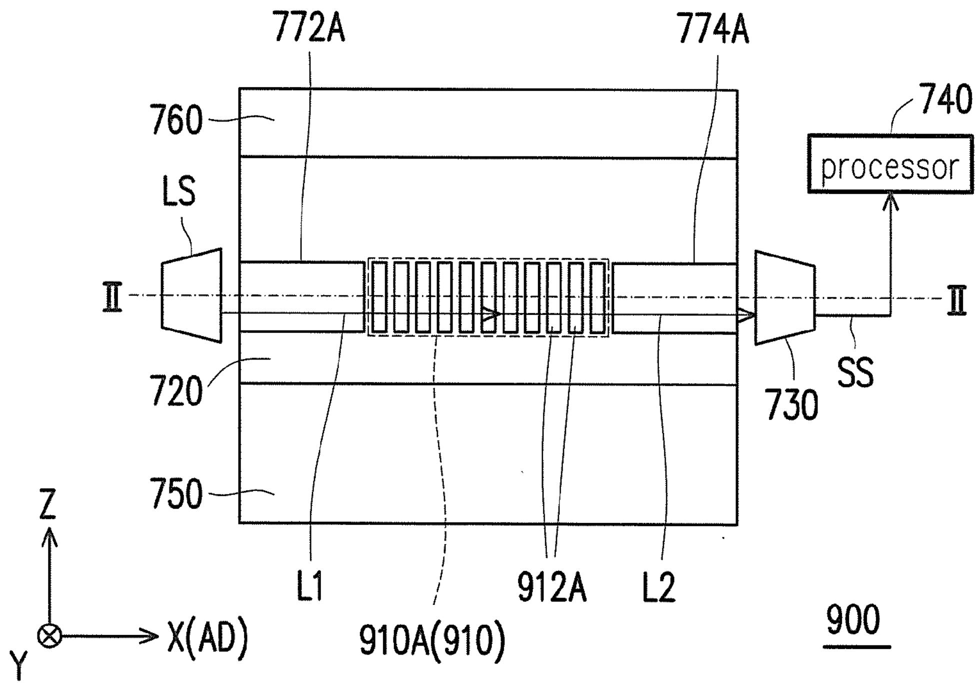


FIG. 9A

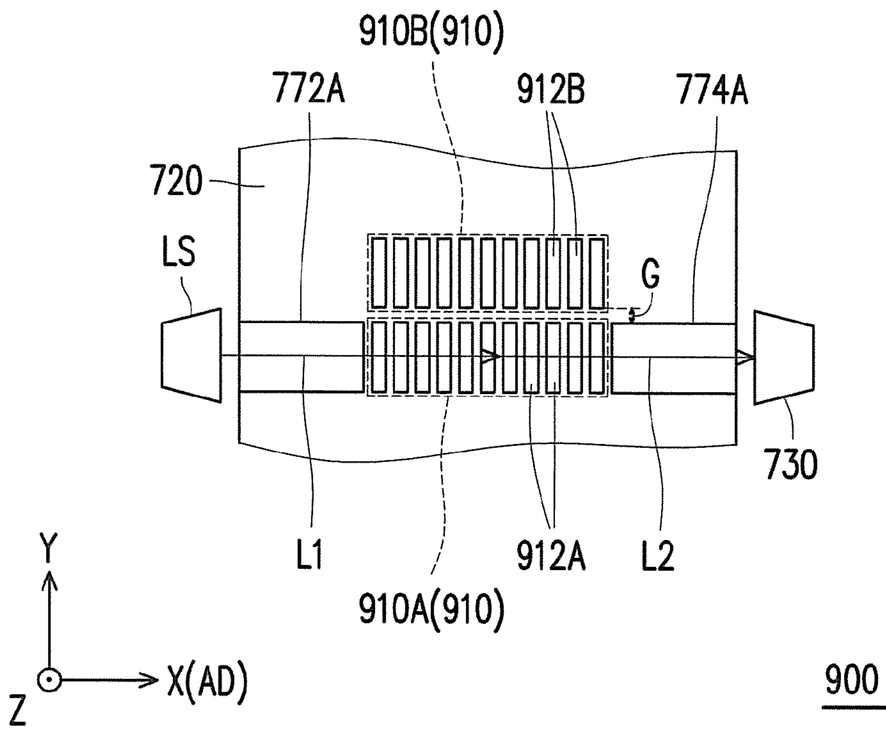


FIG. 9B

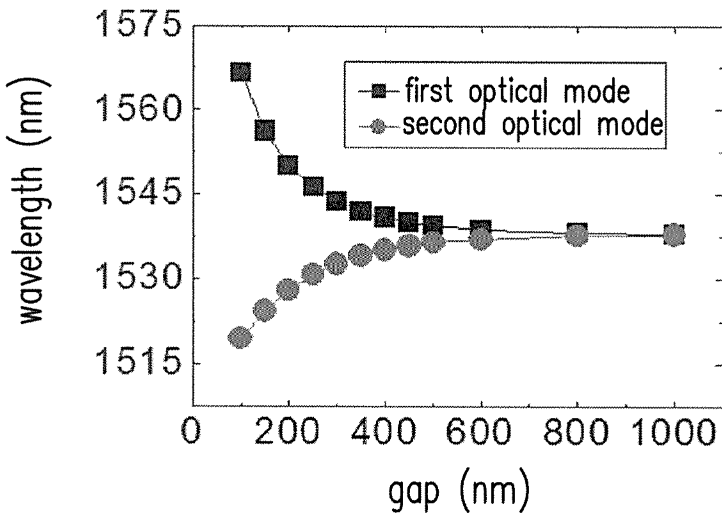


FIG. 10

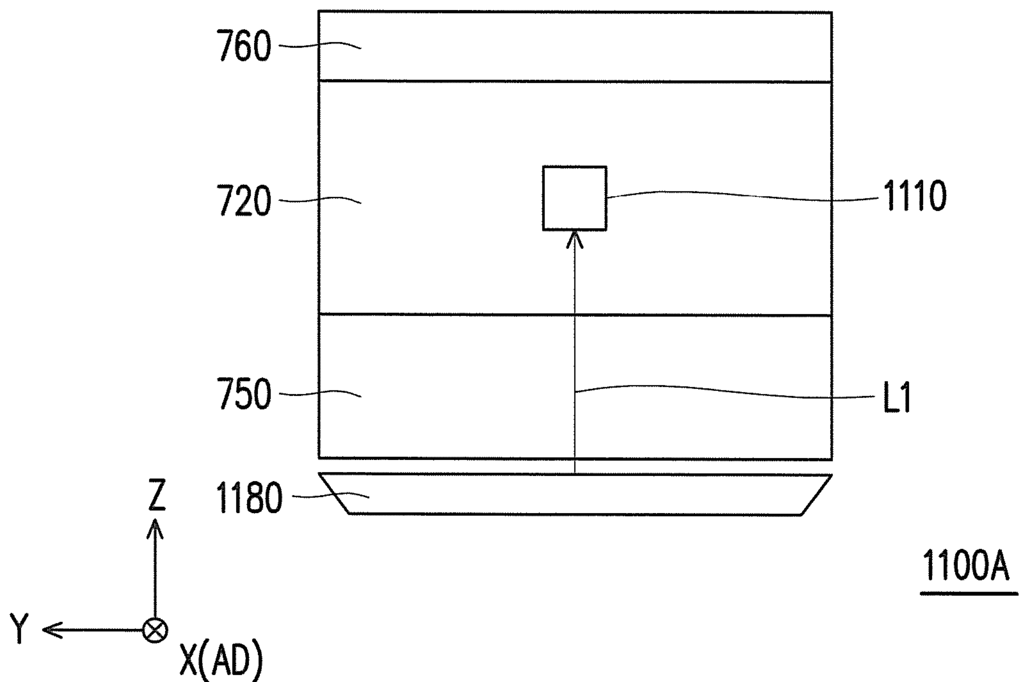


FIG. 11A

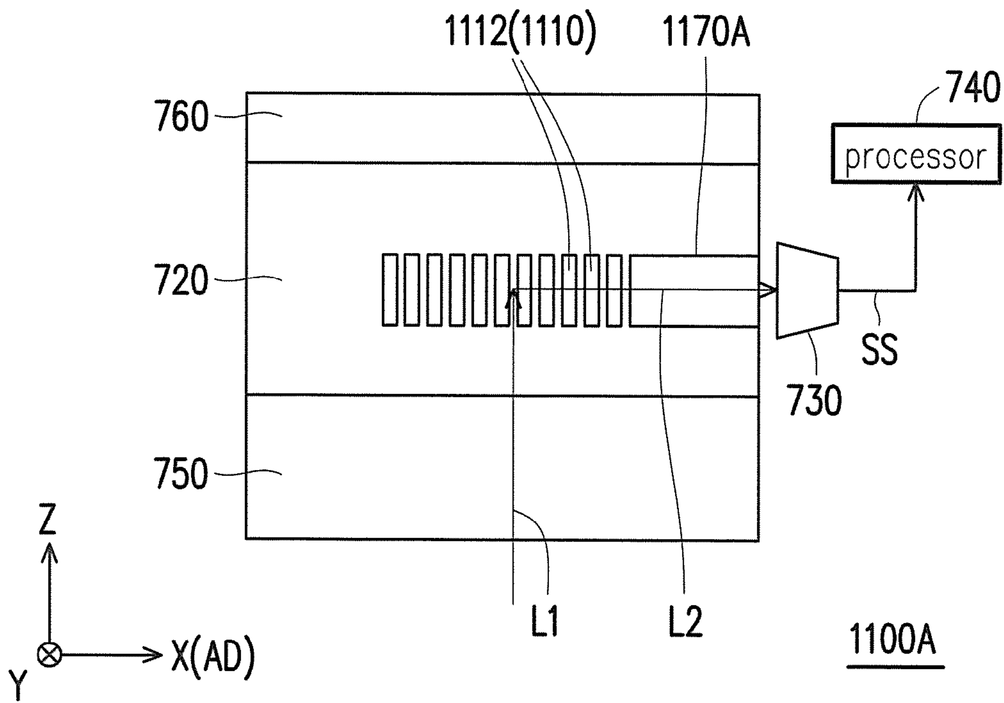


FIG. 11B

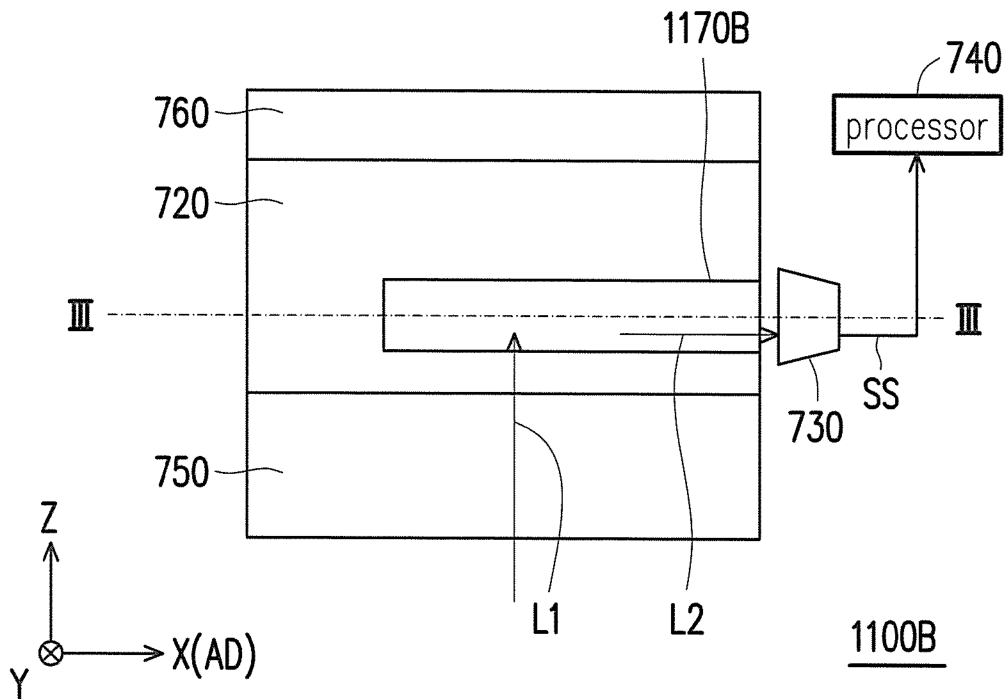


FIG. 11C

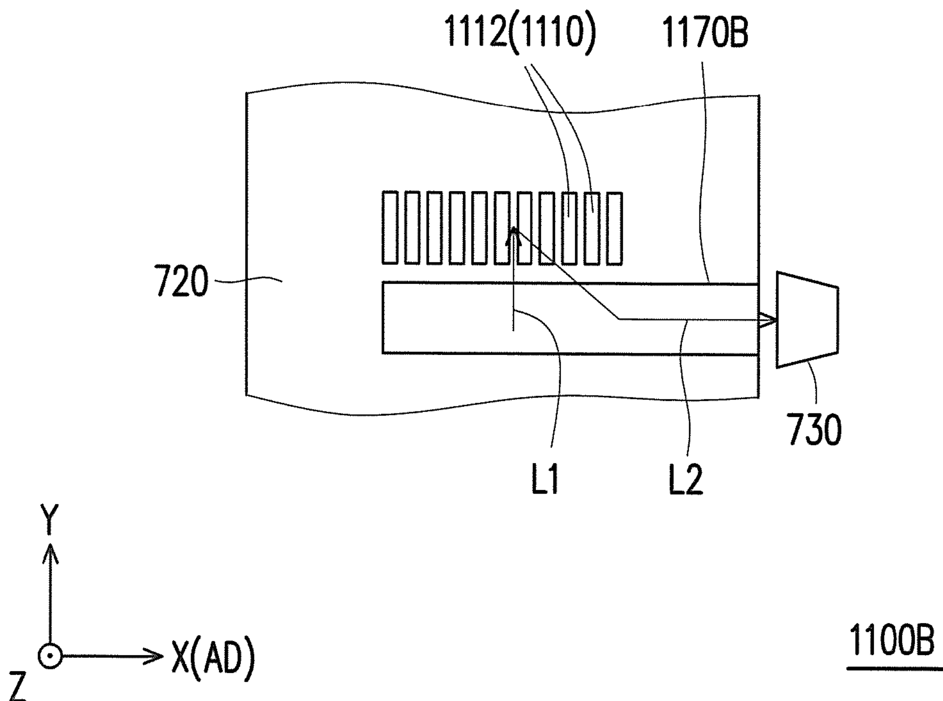


FIG. 11D

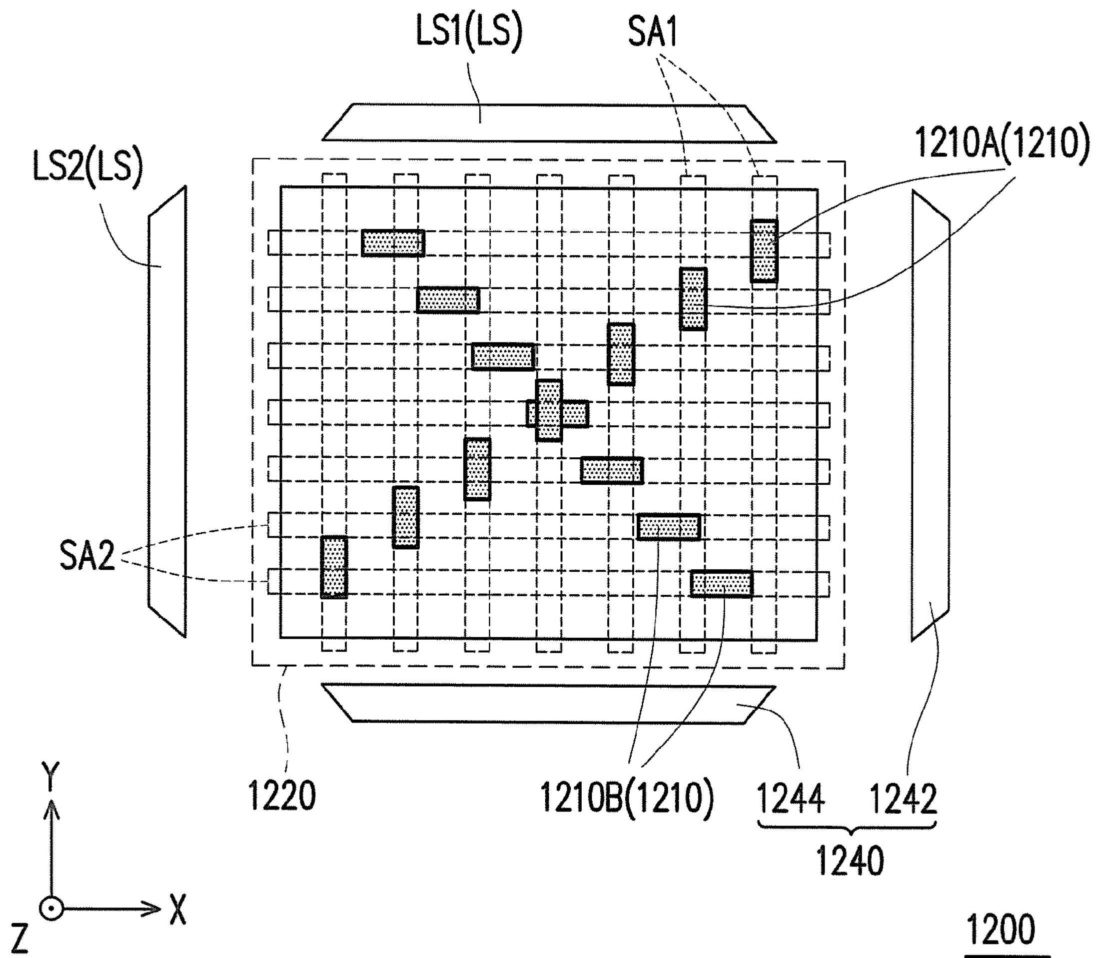


FIG. 12

PRESSURE SENSING DEVICE AND PRESSURE SENSING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims the priority benefit of Taiwan application serial no. 105131875, filed on Oct. 3, 2016. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a sensing device and a sensing apparatus with an adjustable resonant wavelength, and particularly relates to a pressure sensing device and a pressure sensing apparatus having adjustable laser.

2. Description of Related Art

[0003] Through the design of different defects inside the refractive index periodic artificial meta-material having photonic band and photonic band gap effect, the refractive index periodic artificial meta-material has been widely applied in the wavelength scale in recent years, and guides, prohibits or restricts the light waves with extremely low optical loss. Compared to the traditional micro-optical system based on the total reflection effect, the building of the photonic integrated chip with various nano-optical components based on above-mentioned artificial meta-material has the advantages of lower loss, high component density, smaller integrated dimension, and so on.

[0004] Through the design of localized defect in such artificial meta-material, the nanocavity with extremely low optical loss can be formed. The resonance mode within cavity usually has the characteristics of single wavelength, high coherence, high directional radiation. Currently, such nanocavity has been adapted to achieve the optical components such as filters, switches, buffers, light-emitting diodes, lasers, solar cells, etc.

[0005] However, due to the compromise of the process simplicity and yielding requirements in manufacturing process, such nanocavity components are mostly manufactured on the two dimensional thin slab based on semiconductor or other dielectric materials. Although the nanocavity has a size close to the wavelength size, the meta-material arranged and expanded in two dimensions leads to disadvantage of extremely large device footprints of the components.

[0006] In addition, such nanocavity device based on meta-material having geometric difference with the optical waveguides commonly used in the photonic integrated chips. Generally, for achieving the low-loss optical interconnection, complicated geometric designs are needed. That is, such nanocavity device has the disadvantage of low compatibility with the traditional optical waveguide.

[0007] On the other hand, the resonant wavelength adjustability of such nanocavity devices have been widely discussed in literatures. Specifically, the wavelength adjustability mentioned herein is referred to as "reversible and repeatable wavelength adjusting". The principle of adjusting the resonant wavelength lies in changing the resonant condition of the nanocavity through applied variables. Currently, the methods of adjusting the resonant wavelength can be divided into two ways.

[0008] The first way is changing the refractive index of the nanocavity itself or the surrounding mediums. About the change of the refractive index of the nanocavity, it can be achieved by methods of changing the temperature of the nanocavity, concentration of the injection of free carrier, and so on. About the change of the refractive index of the surrounding materials, it can be achieved by adjusting the concentrations of the refractive-index-adjustable gas and liquid, or liquid crystals able to be changed in their refractive index by voltage controlling. However, in the above methods, the range of the wavelength adjustability is usually limited by the variable range of the refractive index of the material.

[0009] The second way to achieve wavelength adjustability is directly changing the nanocavity structure. For instance, the wavelength adjustability can be achieved by the methods such as approaching the nanocavity by external perturbation (such as nano-micro-probe, micro-fiber), or changing the coupling length of the resonance mode using the microelectromechanical systems. Although these methods can obtain high wavelength adjustability, the design of complicated structures is usually needed to achieve significant change of the micro-structure. That results in their difficulty in integrating within the integrated photonic chip.

[0010] Therefore, the issue of developing the optical component with adjustable resonant wavelength having characteristics such as smaller device footprint, high compatibility with the conventional optical waveguides, and high wavelength adjustability is one of the key development priorities in the field.

SUMMARY OF THE INVENTION

[0011] The invention provides a pressure sensing device with excellent sensing sensitivity and having smaller device footprint.

[0012] The invention provides a pressure sensing apparatus with excellent sensing sensitivity and having smaller device footprint.

[0013] The pressure sensing device of the embodiment of the invention includes a light source, at least one resonant structure, a cladding body, a first substrate and a second substrate. The light source is configured to provide an original broadband light. A resonant structure includes a plurality of semiconductor rod structures periodically arranged into a row along a single arranging direction, and each of the semiconductor rod structures has a lattice constant on the arranging direction. The original broadband light propagates in the semiconductor rod structures, and produces a resonant light. Each of the semiconductor rod structures has a length perpendicular to the arranging direction and has a width parallel to the arranging direction. The length and the width are shorter than the wavelength of the resonant light. The cladding body completely covers the semiconductor rod structures of the at least one resonant structure. The cladding body and the at least one resonant structure are interposed between the first substrate and the second substrate. When a pressure is applied on at least one of the first substrate and the second substrate, the pressure is transmitted to the cladding body in a direction perpendicular to the arranging direction. A deformation corresponding to the pressure is occurred on the cladding body and the

semiconductor rod structures on the arranging direction. A wavelength of the resonant light changes according to the deformation.

[0014] In an embodiment of the invention, the pressure sensing device further includes a detector and a processor. The detector receives the resonant light to produce the spectral signal. The processor calculates a deformation value of the deformation according to a change of the spectral signal.

[0015] In an embodiment of the invention, the pressure sensing device further includes a first light-guiding portion and a second light-guiding portion. The first light-guiding portion and the second light-guiding portion are disposed in the cladding body along the arranging direction. The first light-guiding portion is configured to guide the original broadband light into a resonant structure, and the second light-guiding portion is configured to guide the resonant light into the detector.

[0016] In an embodiment of the invention, the first light-guiding portion, the semiconductor rod structures of a resonant structure and the second light-guiding portion are arranged into a row along the arranging direction. An end of the first light-guiding portion faces the light source, and another end of the first light-guiding portion faces the semiconductor rod structures. An end of the second light-guiding portion faces the semiconductor rod structures and another end of the second light-guiding portion faces the detector.

[0017] In an embodiment of the invention, the first light-guiding portion and the second light-guiding portion are connected to form into a light-guiding structure, and disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction.

[0018] In an embodiment of the invention, the number of the at least one resonant structure is two. The resonant structures include a first resonant structure and a second resonant structure. The semiconductor rod structures of the first resonant structure are arranged into a first row, the semiconductor rod structures of the second resonant structure are arranged into a second row parallel and adjacent to the first row, and the semiconductor rod structures on the first row and the semiconductor rod structures on the second row have a gap on a gap direction perpendicular to the arranging direction.

[0019] In an embodiment of the invention, when the pressure is transmitted to the cladding body on a direction simultaneously perpendicular to the arranging direction and perpendicular to the gap direction, a deformation is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the gap direction, so that the gap is changed. The wavelength of the resonant light changes according to the change of the gap.

[0020] In an embodiment of the invention, the light source is a back light source, disposed on a side of the cladding body, and a material of the semiconductor rod structures includes a semiconductor material having a direct bandgap.

[0021] In an embodiment of the invention, the pressure sensing device further includes a light-guiding structure disposed in the cladding body. The semiconductor rod structures of a resonant structure and the light-guiding structure are arranged into a row along the arranging direction. An end of the light-guiding structure faces the semiconductor rod structures and another end of the light-guiding structure faces the detector. The light-guiding structure is configured to guide the resonant light into the detector.

[0022] In an embodiment of the invention, the pressure sensing device further includes a light-guiding structure, disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction, and an end of the light-guiding structure faces the detector. The resonant light enters the light-guiding structure through a coupling, and the light-guiding structure is configured to guide the resonant light into the detector.

[0023] The pressure sensing device of the embodiment of the invention includes a light source, a plurality of resonant structures, a cladding body, a first substrate and a second substrate. The light source is configured to provide an original broadband light. Each resonant structure includes a plurality of semiconductor rod structures arranged into a row at intervals along a single arranging direction, and each of the semiconductor rod structures has a lattice constant on the arranging direction. At least part of the resonant structures arranged along a first direction, wherein at least part of the resonant structures is arranged along a second direction different from the first direction. The original broadband light enters at least part of the resonant structures and is transmitted between the semiconductor rod structures, and a plurality of resonant lights are produced. Each of the semiconductor rod structures of a resonant structure has a length perpendicular to the arranging direction and has a width parallel to the arranging direction, and the length and the width is smaller than a wavelength of the resonant light. The cladding body completely covers the semiconductor rod structures of the resonant structures. The cladding body and the resonant structures are interposed between the first substrate and the second substrate. A pressure is applied on at least one of the first substrate and the second substrate, and the pressure is transmitted to the cladding body along a direction perpendicular to the arranging direction, a deformation corresponding to the pressure is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the arranging direction, so that a value of the lattice constants is changed. The wavelength of the resonant lights changes according to the change of the lattice constants.

[0024] In an embodiment of the invention, the pressure sensing apparatus further includes a detector and a processor. The detector receives the resonant lights of at least part of the resonant structures to produce a plurality of spectral signals. The processor calculates an occurring location of the deformation and a deformation value of the deformation according to the spectral signals.

[0025] In an embodiment of the invention, the pressure sensing apparatus further includes a plurality of first light-guiding portions and a plurality of second light-guiding portions. A first light-guiding portion and a second light-guiding portion are disposed in the cladding body along the arranging direction. A first light-guiding portion is configured to guide the original broadband light into a resonant structure, and a second light-guiding portion is configured to guide the resonant light into the detector.

[0026] In an embodiment of the invention, an above-mentioned first light-guiding portion, the semiconductor rod structures of a resonant structure and a second light-guiding portion are arranged into a row along the arranging direction. An end of the first light-guiding portion faces the light source, and another end of the first light-guiding portion

faces the semiconductor rod structures, an end of the second light-guiding portion faces the semiconductor rod structures and another end of the second light-guiding portion faces the detector.

[0027] In an embodiment of the invention, an above-mentioned first light-guiding portion and a second light-guiding portion are connected to form into a light-guiding structure, and disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction. An end of the light-guiding structure faces the light source and another end of the light-guiding structure faces the detector.

[0028] In an embodiment of the invention, the resonant structures include a plurality of first resonant structures and a plurality of second resonant structures. The semiconductor rod structures of a first resonant structure are arranged into a first row, the semiconductor rod structures of a second resonant structure are arranged into a second row parallel and adjacent to the first row, and the semiconductor rod structures on the first row and the semiconductor rod structures on the second row have a gap on a gap direction perpendicular to the arranging direction.

[0029] In an embodiment of the invention, when the pressure is transmitted to the cladding body on a direction simultaneously perpendicular to the arranging direction and perpendicular to the gap direction, a deformation is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the gap direction, so that the gap is changed. The wavelength of the resonant light changes according to the change of the gap.

[0030] In an embodiment of the invention, the light source is a back light source, disposed on a side of the cladding body, and a material of the semiconductor rod structures of the resonant structures includes a semiconductor material having a direct bandgap.

[0031] In an embodiment of the invention, the pressure sensing apparatus further includes a plurality of light-guiding structures disposed in the cladding body. The semiconductor rod structures of a resonant structure and a light-guiding structure are arranged into a row along the arranging direction. An end of the light-guiding structure faces the semiconductor rod structures and another end of the light-guiding structure faces the detector. The light-guiding structure is configured to guide the resonant light into the detector.

[0032] In an embodiment of the invention, the pressure sensing apparatus further includes a plurality of light-guiding structures. A light-guiding structure is disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction, and an end of the light-guiding structure faces the detector. The resonant light enters the light-guiding structure through a coupling, and the light-guiding structure is configured to guide the resonant light into the detector.

[0033] Based on the above, in the pressure sensing device and the pressure sensing apparatus of an embodiment of the invention, a resonant structure includes a plurality of semiconductor rod structures arranged into a row at intervals along the arranging direction. The original broadband light is transmitted between the semiconductor rod structures, and produces a resonant light. In addition, the cladding body is configured to completely cover the semiconductor rod structures of the resonant structures. When an external force or pressure is applied on the cladding body, a deformation corresponding to the external force is occurred on the cladding body and the semiconductor rod structures. Therefore, in the pressure sensing device and the pressure sensing apparatus of the embodiment of the invention, the wavelength of the resonant light changes according to the deformation corresponding to the pressure, and the pressure sensing device and the pressure sensing apparatus sense the applied pressure according to the wavelength of the resonant light, so as to achieve the pressure sensing, and have excellent sensitivity and smaller device footprint.

[0034] To make the above features and advantages of the invention more comprehensible, several embodiments accompanied with drawings are described in detail as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

[0036] FIG. **1**A is a perspective diagram of the optical device in an embodiment of the present invention.

[0037] FIG. **1**B is a top view of the resonant structure in the embodiment of FIG. **1**A.

[0038] FIG. **2**A to FIG. **2**F illustrates the production flow chart of the optical device in the embodiment of FIG. **1**A.

[0039] FIG. **3**A is an electron microscopy image of the semiconductor rod structures not being covered by the cladding body yet in the optical device of an embodiment of the invention.

[0040] FIG. **3**B illustrates the optical device in the embodiment of FIG. **3**A being able to receive an external force to produce a deformation.

[0041] FIG. **3**C illustrates a diagram of the normalized intensity of laser radiation versus wavelength under different stretching amount when the optical structure in the embodiment of FIG. **1**A is configured to be a nano-laser device.

[0042] FIG. **3**D illustrates a diagram of the wavelength of the laser light of the optical device in the embodiment of FIG. **1**A versus the stretching amount.

[0043] FIG. **4** is a top schematic view of the optical device in another embodiment of the present invention.

[0044] FIG. **5** is a laser differential spectrum of the optical device in the embodiment of FIG. **4** under the stretching of single direction.

[0045] FIG. **6** is a top schematic view of the optical device in another embodiment of the present invention.

[0046] FIG. **7**A is a schematic cross-sectional view of a pressure sensing device in an embodiment of the invention.

[0047] FIG. **7**B is a schematic cross-sectional view of a pressure sensing device on another direction in the embodiment of FIG. **7**A.

[0048] FIG. **7**C is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention.

[0049] FIG. **7**D is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **7**C along line I-I.

[0050] FIG. **7**E is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention.

[0051] FIG. **8**A to FIG. **8**F illustrates the production flow chart of the pressure sensing device in the embodiment of FIG. **7**A.

[0052] FIG. **9**A is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention.

[0053] FIG. **9**B is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **9**A along line II-II.

[0054] FIG. **10** illustrates a diagram of the laser light wavelength of the two optical modes of the pressure sensing device in the embodiment of FIG. **9**A versus the coupling gap.

[0055] FIG. **11**A is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention.

[0056] FIG. **11**B is a schematic cross-sectional view of a pressure sensing device on another direction in the embodiment of FIG. **11**A.

[0057] FIG. **11**C is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention.

[0058] FIG. **11**D is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **11**C along line III-III.

[0059] FIG. **12** is a schematic top view of a pressure sensing apparatus in an embodiment of the invention.

DESCRIPTION OF THE EMBODIMENTS

[0060] Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

[0061] FIG. **1**A is a perspective diagram of the optical device in an embodiment of the present invention. Referring to FIG. **1**A, in the embodiment, the optical device **100** includes at least one resonant structure **110** and a cladding body **120**, the resonant structure **110** includes a plurality of semiconductor rod structures **112**, the semiconductor rod structures are periodically arranged into a row at intervals along the arranging direction AD, and have a lattice constant A_n on the arranging direction, A_n represents the lattice constant of the n-th semiconductor rod structure **112** counted from the center to the both sides. The cladding body **120** completely covers the semiconductor rod structures **112** of the at least one resonant structure **110**.

[0062] In the embodiment, the optical device **100** is located in a space constructed by a first axis X, a second axis Y, and a third axis Z, for example, wherein the first axis X is parallel to the arranging direction AD. The first axis X is perpendicular to the second axis Y and also perpendicular to the third axis Z, and the second axis Y is perpendicular to the third axis Z.

[0063] FIG. **1**B is a top view of the resonant structure in the embodiment of FIG. **1**A, please refer to FIG. **1**B, specifically, each semiconductor rod structure **112** has a length Len perpendicular to the arranging direction AD and has the same width or different width W_n parallel to the arranging direction AD. Among the above, W_n represents the width of the n-th semiconductor rod structure **112** counted from the center to the both sides.

[0064] In the embodiment, the optical device **100** further includes a light source (not shown), configured to provide an original broadband light L**1**. The original broadband light L**1** enters the resonant structure **110** and is transmitted between the semiconductor rod structures **112**, wherein at least one resonant light L**2** is included between the semiconductor rod structures **112**, forms into a stationary wave along the arranging direction AD and is resonance amplified, the resonant light L**2** is included in the original broadband light L**1**, and the full width at half maximum of the resonant light L**2** on the spectrum is less than the full width at half maximum of the original broadband light L**1** on the spectrum; the length Len and the width W_n of the semiconductor rod structure **112** is less than the wavelength of the resonant light L**2**, and the wavelength of the resonant light L**2** can be adjusted through changing the width W_n, the lattice constant A_n, and the length Len. Specifically, in some embodiments, the width W_n of each of the semiconductor rod structures **112** are the same. However, in some embodiments, the semiconductor rod structures **112** of the resonant structure **110** can be designed to have different width W_n, so that the photonic band gap and the mode band gap effect is formed to further produce a limited optical limiting effect on the resonant light L**2**, and the full width at half maximum of the resonant light L**2** on the spectrum is further narrowed.

[0065] Specifically, referring to FIG. **1**B, the widths W_n and the lattice constants A_n of the semiconductor rod structures **112** are increased linearly from the center of the row arranged by the semiconductor rod structures **112** to the both sides of the row. Specifically, the linear increase follows the following correlation:

$$W_{n+1}=W_n+x \tag{1}$$

$$A_{n+1}=A_n+y \tag{2}$$

wherein W_{n+1} represents the width of the (n+1)-th semiconductor rod structure **112** counted from the center to the both sides. In addition, A_{n+1} represents the lattice constant of the (n+1)-th semiconductor rod structure **112** counted from the center to the both sides.

[0066] In the embodiment, x is 10 nm, for example, and y is also 10 nm, for example. However, in some embodiments, the x and y can be less than 10 nm, to increase the light limiting ability of the resonant structure **110**, or, the x and y can also be greater than 10 nm, to decrease the manufacturing difficulty, the invention is not limited thereto.

[0067] In addition, in the above-mentioned embodiment, the cladding body **120** completely covers the semiconductor rod structures **112** of the resonant structure **110**, so that the cladding body **120** and the semiconductor rod structures **112** form a symmetrical structure on all three directions along each dimension (the direction of the first axis X, the direction of the second axis Y, and the direction of the third axis Z, for example), and the symmetrical structure can achieve the symmetry distribution resonance mode, which has lower optical loss. However, in some embodiments, the cladding body **120** can also selectively not cover the semiconductor rod structures **112**. In these embodiments, the cladding body **120** and the semiconductor rod structures **112** therein have an asymmetry distribution resonance mode. In addition, because the semiconductor rod structures **112** of the embodiments are partially exposed in the air, the thermal conductivity thereof is poorer, and because the semiconductor rod structures **112** are not completely covered by the cladding body **120**, when a deformation corresponding to the external force is occurred on the cladding body **120**, the semiconductor rod structures **112** may be detached.

[0068] In the above-mentioned embodiment, when an external force is applied on the cladding body **120**, the cladding body **120** is configured to drive the semiconductor rod structures **112** to produce a deformation corresponding to the external force, wherein the deformation includes stretching, compression or twist. The cladding body **120** is, for example, a polymer material able to produce a deformation corresponding to the external force, and transparent to the wavelength of the resonant light L**2**, so as to avoid the optical loss due to the absorption of the material; furthermore, the cladding body has a low optical refractive index, therefore a refractive index difference between the cladding body **120** and the semiconductor rod structures **112** is large enough, so as to reduce the optical loss of the optical nanocavity in the direction other than the photonic band gap and the mode band gap. Specifically, the refractive index of the cladding body **120** is equal to or less than 2, for example, equal to or less than 1.6, preferably. For example, the material of the cladding body **120** includes polydimethylsiloxane (PDMS), but the invention is not limited thereto.

[0069] In the embodiment, the production method of the light source can be provided through the utilization of the photoluminescence semiconductor material as the semiconductor rod structures **112**, so that the optical structure forms a nano-laser device through the above-mentioned resonant process; the semiconductor materials are semiconductor materials with direct bandgap, for example, or epitaxial structure having quantum confinement structure. For example, the material of the semiconductor rod structures **112** is material having quantum well or quantum dot structure, the invention is not limited thereto.

[0070] FIG. **2**A to FIG. **2**F illustrates the production flow chart of the optical device in the embodiment of FIG. **1**A. Referring to FIG. **2**A, a semiconductor wafer **20** is prepared. The semiconductor wafer **20** includes a semiconductor substrate **201** and an epitaxial layer **202**, wherein the epitaxial layer **202** includes a photoluminescence or non-photoluminescence semiconductor material, and the epitaxial layer **202** is formed on the semiconductor substrate **201**. Then, a first mask layer **203** and a second mask layer **204** are sequentially formed on the epitaxial layer **202**. Then, referring to FIG. **2**B, the lithography is used to define the semiconductor rod structure complementary pattern **205** on the second mask layer **204**, then, the development and fixing are performed, the lithography mentioned herein is referred to as the one able to achieve the sub-wavelength resolution, such as electron beam lithography, deep ultraviolet (DUV), or extreme Ultraviolet (EUV) optical lithography. Afterward, the dry etching process is used to transfer the semiconductor rod structure complementary pattern **205** to the first mask layer **203**, and remove the remaining second mask layer **204** simultaneously. Referring to FIG. **2**C, then, the dry etching process is used to transfer the semiconductor rod structure complementary pattern **205** on first mask layer **203** to the epitaxial layer **202**, so as to form the semiconductor rod structures **112**. Afterward, the first mask layer **203** remained on the semiconductor rod structures **112** is removed by the chemical etching method.

[0071] Then, referring to FIG. **2**D, a polymer substrate **21** able to produce a deformation corresponding to the external force is provided, and a layer of unhardened polymer material adhesive layer **211** is spin coated on the surface of the polymer substrate **21** and the surface of the semiconductor wafer **20** (that is, a portion of the surface of the semiconductor substrate **201** and the surface of the semiconductor rod structures **112**) respectively. Afterward, the polymer substrate **21** and the semiconductor wafer **20** are placed in a negative pressure environment for half an hour, bonded together, and baked for 12 hours under 60° C. At this time, the polymer substrate **21** and the polymer material adhesive layer **211** form into a hardened polymer cladding layer **212** (as illustrated in FIG. **2**E). Then, referring to FIG. **2**E and FIG. **2**F, under room temperature, the chemical selective wet etching is used to remove the semiconductor substrate **201**. In addition, another layer of unhardened polymer cladding layer **213** is spin coated on the surface of the semiconductor rod structures **112** and the surface of the polymer cladding layer **212**, to completely cover the semiconductor rod structures **112**. Then, a baking under 60° C. is performed for 12 hours, to form a hardened cladding body **120**.

[0072] FIG. **3**A illustrates the electron microscopy image of the semiconductor rod structures not being covered in the cladding body yet in the optical device of an embodiment of the present invention, and FIG. **3**B illustrates the optical device in the embodiment of FIG. **3**A being able to receive an external force to produce a deformation. In the embodiment, the optical device **300** is similar to the optical device **100** in the embodiments of FIG. **1**A to FIG. **1**B, the elements and related descriptions can be referred to the optical device **100** in the embodiments of FIG. **1**A to FIG. **1**B, and will not be repeated herein. In the embodiment, the optical device **300** includes a resonant structure **310** and a cladding body **320**, and the cladding body **320** totally covers the resonant structure **310**. In addition, referring to FIG. **3**B, when an external force (such as the bending, stretching and compression forces provided by the fingers) is applied on the cladding body **320**, a deformation corresponding to the external force is occurred on the cladding body **320** and the semiconductor rod structures (not shown) of the resonant structure **310**.

[0073] FIG. **3**C illustrates a diagram of the normalized intensity of laser radiation versus wavelength under different stretching amount when the optical structure in the embodiment of FIG. **1**A is configured to be a nano-laser device. Referring to FIG. **3**C, in FIG. **3**C, the "wavelength" on the horizontal axis represents the wavelength of the resonant light L**2**, and the "normalized intensity of laser radiation" on the vertical axis represents the normalized value of the light intensity of the resonant light L**2** of the laser component.

[0074] In the embodiment, the structure change of the optical device **100** is driven by the stretching of the cladding body **120** caused by an external force along the direction of the first axis X, and the external force is provided when the laser of the resonant light L**2** is provided by the optical device **100**. In FIG. **3**C, "first experimental condition" represents the diagram of the normalized intensity of laser radiation of the resonant light L**2** versus wavelength when the stretching amount of the cladding body **120** caused by the external force is 0 (that is, the stretching is not performed), and "second experimental condition" represents the diagram of the normalized intensity of laser radiation of the resonant light L**2** versus wavelength when the stretching amount of the cladding body **120** is 2.6%. The stretching amount mentioned herein is defined by the value change of the length when the optical device **100** or the cladding body **120** is stretched by the external force. In addition, the diagrams of the normalized intensity of laser radiation of the

resonant light L**2** versus wavelength under other experimental conditions are also included between the "first experimental condition" and the "second experimental condition". The experimental conditions are referred to the stretching amount between 0 and 2.6%.

[0075] In the embodiment, a deformation corresponding to the external force is occurred on the cladding body **120** and the semiconductor rod structures (not shown), so that the lattice constants of the semiconductor rod structures are changed, and the wavelength of the resonant light L**2** is adjusted according to the change of the lattice constants. Specifically, in the process that the stretching amount of the cladding body **120** is increased from 0 to 2.6%, the lattice constants are increased gradually, so that the emission spectrum of the optical device **100** is red shifted linearly. For example, compared to the emission spectrum of the "first experimental condition", the emission spectrum of the "second experimental condition" has the red shift phenomenon more obviously. Referring to FIG. **3**D, the "stretching amount" on the horizontal axis represents the stretching amount of the length along the direction AD after the cladding body **120** of the optical device **100** receives the external force. In addition, the "wavelength" on the vertical axis represents the wavelength of the resonant light L**2**. In the embodiment, when the cladding body **120** of the optical device **100** receives the external force and has 1% stretching amount, the radiation wavelength can red shift 7.65 nm, for example.

[0076] In the embodiment, a deformation corresponding to the external force can occur on the cladding body **120** and the semiconductor rod structures (not shown) through the application of the external force to the optical device **100**. By doing so, the structure of the resonant structure **110** of the optical device **100** is adjusted due to the external force, and the adjustment of the wavelength of the resonant light L**2** can be shown. In addition, when the external force is removed, the resonant structure **110** of the optical device **100** can get back to the state before the application of the external force, so that the wavelength of the resonant light L**2** is adjusted back to the state before the application of the external force.

[0077] In the embodiment, the wavelength of the resonant light L**2** can be adjusted through the stretching of the external force on the cladding body **120** along the direction of the first axis X, and wavelength adjusting range under different communication wavelength range can be completely or partially covered, including S, S+C+L, and C+L communication frequency band.

[0078] FIG. **4** is a top schematic view of the optical device in another embodiment of the present invention. Referring to FIG. **4**, the optical device **400** in the embodiment of FIG. **4** is similar to the optical device **100** in the embodiments of FIG. **1**A to FIG. **1**B, the elements and related descriptions can be referred to the optical device **100** in the embodiments of FIG. **1**A to FIG. **1**B, and will not be repeated herein. The difference between the optical device **400** and the optical device **100** are described as follows. In the embodiment, except for being configured as the wavelength adjustable laser device, the optical device **400** can also be configured as an active structural mechanic tensile sensor. Specifically, the number of the at least one resonant structures **410** of the optical device **400** is 2, and the resonant structures **410** includes a first resonant structure **412** and a second resonant structure **414**. The semiconductor rod structures of the first resonant structure **412** are arranged along the first direction D**1**, and the semiconductor rod structures of the second resonant structure **414** are arranged along the second direction D**2** perpendicular to the first direction D**1**. In addition, in the embodiment, the first direction D**1** is parallel to the direction of the first axis X, for example. And the second direction D**2** is parallel to the direction of the second axis Y, for example. In addition, the cladding body **420** of the optical device **400** completely covers the semiconductor rod structures of the resonant structures **410**. Furthermore, the optical device **400** further includes a detector (not shown) and a processor (not shown) coupled to the detector. The detector receives the resonant light from the first resonant structure **412** to produce the first spectral signal, and the detector receives the resonant light from the second resonant structure **414** to produce second spectral signal. When an external force is applied on the cladding body **420**, a deformation is occurred on the cladding body **420** and the semiconductor rod structures of the resonant structures **410**, and the processor calculates the deformation value of the deformation according to the first spectral signal and the second spectral signal.

[0079] In the embodiment, the optical device **400** can be applied in the strain sensing of the environmental mechanics, for example. The minimum detectable stretching amount ΔS_{det} of the environmental mechanical strain sensing device microchips can be described by $\Delta S_{det}=R_S/\delta\lambda$, wherein R_S represents the nanocavity wavelength response under 1% stretching amount, and $\delta\lambda$ represents the minimum reliable resolution of the resonant mode on the spectrum, that is, the full width at half maximum of the radiation signal of the optical device **400**. For example, in the embodiment of FIG. **1**A, when the cladding body **120** of the optical device **100** receives stretching amount of 1%, the radiation wavelength can red shift 7.65 nm, for example, and the R_S is 7.65 nm/%. In addition, $\delta\lambda$ is the wavelength uncertainty measured by performing repeating test on the optical device **100**. For example, the wavelength uncertainty of the optical device **100** in the embodiment of FIG. **1**A is 0.55 nm. In the embodiment, when the optical device **400** is used in strain sensing, the minimum detectable stretching amount ΔS_{det} can be calculated through the nanocavity wavelength response R_S under 1% stretching amount and the wavelength uncertainty $\delta\lambda$. For example, the minimum detectable stretching amount ΔS_{det} of the optical device **400** is 0.072%.

[0080] FIG. **5** is a laser differential spectrum of the optical device in the embodiment of FIG. **4** under the stretching of single direction. Referring to FIG. **5**, in the embodiment, the material of the cladding body **420** of the optical device **400** has a positive Poisson Ratio. When the cladding body **420** receives an external force on the direction of the first axis X to be stretched, a compression strain thereof with a ratio of about 0.33 will be produced on the direction of the second axis Y. Therefore, in the first resonant structure **412** and the second resonant structure **414** disposed in the cladding body **420**, the resonant light produced thereby displays the wavelength change caused by structural stretching and compression respectively. Specifically, when the cladding body **420** receives an external force on the direction of the first axis X to be stretched, the resonant light produced by the first resonant structure **412** produces radiation wavelength red shift **501** as illustrated in FIG. **5**, and the resonant light of the second resonant structure **414** produces radiation wavelength blue shift **502** as illustrated in FIG. **5**. For example,

under the application of 2.5% stretching amount along the direction of the first axis X on the cladding body **420** of the optical device **400**, the change in the signal differential between the radiation wavelength red shift **501** and the radiation wavelength blue shift **502** reaches 24.7 nm, for example. That is, the nanocavity wavelength response R_S under 1% stretching amount significantly increases to 9.9 nm/%, and the minimum detectable stretching amount ΔS_{det} decreases to 0.056%. In the embodiment, because the first resonant structure **412** and the second resonant structure **414** are perpendicular to each other, when the cladding body is stretched along a single direction, the deformation occurred thereon respectively are different, that is, each of the resonant light wavelength change trends are different, therefore, when the optical device **400** is used as a strain sensing device, a higher sensing sensitivity of the device can be achieved through signal differential.

[0081] FIG. **6** is a top schematic view of the optical device in another embodiment of the present invention. The optical device **600** in the embodiment of FIG. **6** is similar to the optical device **400** in the embodiments of FIG. **4**, the elements and related descriptions can be referred to the optical device **400** in the embodiments of FIG. **4**, and will not be repeated herein. The difference between the optical device **600** and the optical device **400** are described as follows. In the embodiment, the optical device **600** includes a plurality of resonant structures **610**, and the resonant structures **610** includes a first resonant structure **612** and a second resonant structure **614**. The first resonant structure **612** and the second resonant structure **614** intersects to form the intersection position IP, and the optical device **600** further includes the common nanocavity structure **630** located on the intersection position IP. Specifically, the first resonant structure **612** and the second resonant structure **614** share the same common nanocavity structure **630**, and at least 2 resonant modes having different resonant properties exist in the common nanocavity structure **630**. Because when the first resonant structure **612** and the second resonant structure **614** are sharing the common nanocavity structure **630**, the resonant modes thereof have extremely high single polarization property respectively (the resonant mode of the first resonant structure **612** and the second resonant structure **614** are the polarization on the direction of the second axis Y and the polarization on the direction of the first axis X respectively), therefore, the resonant modes of the two won't effect each other. Therefore, the resonant modes of the first resonant structure **612** and the second resonant structure **614** can be emitted from the same common nanocavity structure **630**. In the embodiment, similar to the optical device **400** of FIG. **4**, because the first resonant structure **612** and the second resonant structure **614** are perpendicular to each other, when the cladding body is stretched along a single direction, the deformation occurred thereon respectively are different, that is, each of the resonant light wavelength change trends are different, therefore, when the optical device **600** is used as a strain sensing device, a higher sensing sensitivity of the device can be achieved through signal differential. In addition, the optical device **600** has more symmetrical structure layout, so better design flexibility can be provided in the integrated optical path design. Also, the operation method of sharing single common nanocavity structure **630** to achieve single nanocavity with two modes makes the optical device **600** has the effect of lower design complexity and easy production.

[0082] FIG. **7**A is a schematic cross-sectional view of a pressure sensing device in an embodiment of the invention, and FIG. **7**B is a schematic cross-sectional view of a pressure sensing device on another direction in the embodiment of FIG. **7**A. Referring to FIG. **7**A and FIG. **0**.**7**B, in the embodiment, the pressure sensing device **700**A includes a light source LS, at least one resonant structure **710** and a cladding body **720**. The light source LS is configured to provide an original broadband light L**1**. A resonant structure **710** includes a plurality of semiconductor rod structures **712** arranged along the arranging direction AD at intervals. The original light LS enters a resonant structure **710** and is transmitted between the semiconductor rod structures **712**. In addition, the resonant structure **710** receives the original broadband light L**1** to produce the resonant light L**2**, and the full width at half maximum of the resonant light L**2** is less than the full width at half maximum of the original broadband light L**1**. In the embodiment, each of the semiconductor rod structures **712** has a length perpendicular to the arranging direction AD and has a width parallel to the arranging direction AD. For example, the length of each of the semiconductor rod structures **712** is parallel to the direction of the second axis Y, and the width of each of the semiconductor rod structures **712** is parallel to the direction of the first axis X, for example. Specifically, the length and width of each of the semiconductor rod structures **712** are less than the wavelength of the resonant light L**2**. In addition, each of the semiconductor rod structures **712** has lattice constant (not shown) on the arranging direction AD.

[0083] In the embodiment, the cladding body **720** completely covers the semiconductor rod structures **712** of the at least one resonant structure **710**. When the pressure P is transmitted to the cladding body **720** through the direction perpendicular to the arranging direction AD, a deformation corresponding to the pressure P is occurred on the cladding body **720** and the semiconductor rod structures **712** on the arranging direction AD, so that the value of the widths and the lattice constants of the semiconductor rod structures **712** is changed. The wavelength of the resonant light L**2** is adjusted according to the widths and the lattice constants. In addition, specifically, the pressure sensing device **700**A further includes a detector **730** and a processor **740**. The detector **730** receives the resonant light L**2** to produce a spectral signal, and the processor **740** calculates the deformation value of the deformation according to the spectral signal. In addition, the pressure sensing device **700**A further includes a first substrate **750** and a second substrate **760**. The cladding body **720** and the at least one resonant structure **710** are interposed between the first substrate **750** and the second substrate **760**. In the embodiment, the pressure P is applied on at least one of the first substrate **750** and the second substrate **760**, and the pressure P is transmitted to the cladding body **720** along the direction perpendicular to the arranging direction AD (such as the direction of the third axis Z).

[0084] Referring to FIG. **7**B, in the embodiment, the pressure sensing device **700**A further includes a first light-guiding portion **772**A and a second light-guiding portion **774**A. The first light-guiding portion **772**A and the second light-guiding portion **774**A are disposed in the cladding body **720** along the arranging direction AD. The first light-guiding portion **772**A is configured to guide the original broadband light L**1** into a resonant structure **710**, and the second light-guiding portion **774**A is configured to guide the

resonant light L**2** into the detector **730**. Specifically, the first light-guiding portion **772**A, the semiconductor rod structures **712** of the resonant structure **710** and the second light-guiding portion **774**A are arranged into a row along the arranging direction AD. An end of the first light-guiding portion **772**A faces the light source LS, and another end of the first light-guiding portion **772**A faces the semiconductor rod structures **712**. An end of the second light-guiding portion **774**A faces the semiconductor rod structures **712** and another end of the second light-guiding portion **774**A faces the detector **730**. The original light L**1** enters the resonant structure **710** through coupling, and the resonant light L**2** enters the second light-guiding portion **774**A through coupling.

[0085] In the embodiment, the semiconductor rod structures **712** can be non-direct bandgap semiconductor material or semiconductor material without quantum structure, for example. In addition, the first light-guiding portion **772**A, the semiconductor rod structures **712** and the second light-guiding portion **774**A are connected into a straight line to achieve the direct coupling. Specifically, the original broadband light L**1** emitted by the light source LS enters the resonant structure **710** through direct coupling, and the resonant structure **710** receives the original broadband light L**1** to produce the resonant light L**2**. Then, the resonant light L**2** is also transmitted to the second light-guiding portion **774**A through direct coupling, and the resonant light L**2** transmitted to the second light-guiding portion **774**A is received by the detector **730**.

[0086] In the embodiment, the material of the first substrate **750** and the second substrate **760** includes semiconductor material, semiconductor oxide material or material with a rigidity factor far greater than the cladding body **720**, for example, the invention is not limited thereto. Specifically, the pressure P of the embodiment is applied on the second substrate **760**, the first substrate **750** is configured as the support of the pressure sensing device **700**B, and the thickness thereof is far greater than the thickness of the cladding body **720** and the thickness of the second substrate **760**, for example, the invention is not limited thereto. In addition, the material of the second substrate **760** is material transparent to the original broadband light L**1**, for example. That is, when the original broadband light L**1** passes the second substrate **760**, the second substrate **760** doesn't absorb the original broadband light L**1**, or, the absorbance of the second substrate **760** toward the original broadband light L**1** is ignorable. Specifically, the material of the second substrate **760** can include glass or quartz, for example, the invention is not limited thereto.

[0087] In the embodiment, the second substrate **760** is configured to sustain the pressure P on the direction of the third axis Z. The pressure P causes the cladding body **720** interposed between the first substrate **750** and the second substrate **760** to produce an expansion deformation along the direction of the first axis X and the direction of the second axis Y. The expansion deformation can cause the semiconductor rod structures **712** to produce lattice expansion, so as to change the wavelength of the resonant light L**2**. Specifically, the change of the wavelength of the resonant light L**2** can be configured to measure the value of the pressure P. In addition, the first light-guiding portion **772**A and the second light-guiding portion **774**A are continuous dielectric structure with respect to the semiconductor rod structures **712**. Therefore, when the cladding body **720** receives the pressure P to deform, the first light-guiding portion **772**A and the second light-guiding portion **774**A don't deform. That is, the guide-in efficiency and the guide-out efficiency of the optical signal at the first light-guiding portion **772**A and the second light-guiding portion **774**A are not affected by the application of the pressure P. In the embodiment, the detector **730** receives the resonant light L**2** before and after the pressure application, so as to measure the change of the spectral signal thereof, and the processor **740** calculates the deformation value of the deformation according to the change of the spectral signal. Therefore, the value of the pressure P can be measured by the deformation value, so as to achieve the sensing of the pressure P. In the embodiment, the pressure sensing device **700**A calculates the deformation corresponding to the applied pressure P according to the light after the wavelength adjustment, to achieve the pressure sensing.

[0088] FIG. **7**C is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention, and FIG. **7**D is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **7**C along line I-I. Referring to both FIG. **7**C and FIG. **7**D, the pressure sensing device **700**B in the embodiment of FIG. **7**C is similar to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, the elements and related descriptions can be referred to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, and will not be repeated herein. The difference between the pressure sensing device **700**B and the pressure sensing device **700**A are described as follows. In the embodiment, the first light-guiding portion **772**B and the second light-guiding portion **774**B of the pressure sensing device **700**B are connected to form the light-guiding structure **770**B. The light-guiding structure **770**B is disposed beside the semiconductor rod structures **712** of the resonant structure **710** arranged along the arranging direction AD. An end of the light-guiding structure **770**B faces the light source LS and another end of the light-guiding structure **770**B faces the detector **730**. The original broadband light L**1** of the light source LS enters the resonant structure **710** through coupling, and the resonant light L**2** enters the light-guiding structure **770**B through coupling. Specifically, the original broadband light L**1** enters the resonant structure **710** through lateral coupling, and the resonant light L**2** also enters the light-guiding structure **770**B through lateral coupling. The original broadband light L**1** of the present embodiment can enter the resonant structure **710** (as shown in FIG. **7**D) directly in the process of lateral coupling, and don't need to pass a plurality of semiconductor rod structures **712** first as the direct coupling (positive coupling). In addition, the resonant light L**2** can also directly leave the resonant structure **710** by the side in the process of lateral coupling. Therefore, the light energy consumption of the pressure sensing device **700**B in the embodiment is lower, the light coupling efficiency thereof is better.

[0089] FIG. **7**E is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention. Referring to FIG. **7**E, the pressure sensing device **700**C in the embodiment of FIG. **7**E is similar to the pressure sensing device **700**B in the embodiments of FIG. **7**C, the elements and related descriptions can be referred to the pressure sensing device **700**B in the embodiments of FIG. **7**C, and will not be repeated herein. The difference between the pressure sensing device **700**C and the pressure sensing device **700**B are described as follows. In the embodiment,

the first light-guiding portion **772**C and the second light-guiding portion **774**C of the pressure sensing device **700**C are connected to form the light-guiding structure **770**C. The light-guiding structure **770**C is disposed beside the semiconductor rod structures **712** of the resonant structure **710** arranged along the arranging direction AD. Different from the above-mentioned pressure sensing device **700**B, the light-guiding structure **770**C and the resonant structure **710** in the embodiment locate on different XY plane (that is, locate on different position on the direction of the third axis Z). That is, the line layout of the pressure sensing device **700**C is not limited on the two-dimensional plane, and can be expanded to the three-dimensional line layout. Compared to the pressure sensing device **700**B of the above-mentioned embodiment, the pressure sensing device **700**C of the embodiment has the effect of increasing the line density.

[0090] FIG. **8**A to FIG. **8**F illustrates the production flow chart of the pressure sensing device (pressure sensing device **700**B) in the embodiment of FIG. **7**A. Referring to FIG. **8**A, first, a semiconductor wafer **80** is prepared, includes a semiconductor substrate **801** and an epitaxial layer **802**, wherein the epitaxial layer **802** includes a non-direct bandgap or direct bandgap semiconductor material, and the epitaxial layer **802** is formed on the semiconductor substrate **801**. Then, a first mask layer **803** and a second mask layer **804** are sequentially formed on the epitaxial layer **802**. Then, referring to FIG. **8**B, the semiconductor rod structure complementary pattern **805** is defined on the second mask layer **804** by lithography, then the development and fixing are performed. Afterward, the dry etching process is used to transfer the semiconductor rod structure complementary pattern **805** to the first mask layer **803**, and remove the remaining second mask layer **804** simultaneously. Referring to FIG. **8**C, the dry etching process is used to transfer the semiconductor rod structure complementary pattern **805** on first mask layer **803** to the epitaxial layer **802**, so as to form the semiconductor rod structures **712**. Afterward, the first mask layer **803** remained on the semiconductor rod structures **712** is removed by the chemical etching method.

[0091] Then, referring to FIG. **8**D, the first substrate **750** is provided, wherein the material of the first substrate **750** includes the semiconductor material or the semiconductor oxide material, for example. In addition, a layer of unhardened polymer material adhesive layer **811** is spin coated on the surface of the first substrate **750** and the surface of the semiconductor wafer **80** (that is, a portion of the surface of the semiconductor substrate **801** and the surface of the semiconductor rod structures **712**) respectively. Afterward, the first substrate **750** and the semiconductor wafer **80** are placed in a negative pressure environment for half an hour, bonded, and baked for 12 hours under 60° C. At this time, the polymer material adhesive layer **811** form into a hardened polymer cladding layer **812** (as illustrated in FIG. **8**E). Then, referring to FIG. **8**E and FIG. **8**F, under room temperature, the chemical selective wet etching is used to remove the semiconductor substrate **801**. In addition, a layer of unhardened polymer cladding layer is spin coated on the surface of the semiconductor rod structures **712** and the surface of the polymer cladding layer **812**, to completely cover the semiconductor rod structures **712**. In addition, a second substrate **760** spin-coated with a layer of unhardened polymer cladding layer is provided, and the second substrate **760** and the first substrate **750** are adhered together. Then, the whole device is baked under 60° C. for 12 hours, to form a hardened cladding body **720**. In addition, an appropriate light source LS is provided, so as to provide an original broadband light into the cladding body **720**. In such a way, the manufacturing of the optical device of the embodiment is completed.

[0092] In addition, the pressure sensing device **700**C in the embodiment of FIG. **0.7**E can be obtained by the manufacturing flowchart similar to FIG. **8**A to FIG. **8**D. Specifically, first, two structures similar to the illustration in FIG. **8**E is manufactured, one of them has the light-guiding structure **770**C and the first substrate **750**, another one has the resonant structure **710** and the second substrate **760**. Then, the two structures are bonded under the observation of the optical alignment system with nanometer-micrometer scale resolution. Specifically, the optical alignment system is optical microscope, for example.

[0093] FIG. **9**A is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention, and FIG. **9**B is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **9**A along line II-II. The pressure sensing device **900** in the embodiments of FIG. **9**A and FIG. **9**B is similar to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, the elements and related descriptions can be referred to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, and will not be repeated herein. The difference between the pressure sensing device **900** and the pressure sensing device **700**A are described as follows. In the embodiment, the number of the at least one resonant structures **910** of the pressure sensing device **900** is 2, and the resonant structures **910** includes a first resonant structure **910**A and a second resonant structure **910**B. The semiconductor rod structures **912**A of the first resonant structure **910**A are arranged into a first row, the semiconductor rod structures **912**B of the second resonant structure **910**B are arranged into a second row parallel and adjacent to the first row. In addition, the original broadband light L**1** from the light source LS enters one of the first resonant structure **910**A and the second resonant structure **910**B. Specifically, the semiconductor rod structures **912**A of the first row and the semiconductor rod structures **912**B of the second row have the gap G on the gap direction GD perpendicular to the arranging direction AD. In the embodiment, when the pressure P is transmitted to the cladding body **720** perpendicularly with respect to the arranging direction AD, the lattice constant expansion along the arranging direction AD and the increase of the gap G along the gap direction GD are occurred on the semiconductor rod structures **912**A, **912**B of the resonant structures **910** and the cladding body **720**, and the wavelength of the resonant light L**2** is changed according to the increase of the lattice constant and the gap G.

[0094] FIG. **10** illustrates a diagram of the laser light wavelength of the two optical modes of the pressure sensing device in the embodiment of FIG. **9**A versus the coupling gap. Referring to FIG. **10**, specifically, the two nanocavity system can be compared to a diatomic system, wherein the two optical mode of the two resonant system can be compared to the energy state of bonding, anti-bonding in the diatomic system. The first resonant structure **910**A and the second resonant structure **910**B in the embodiment of FIG. **9**A form into an optical analogy structure of diatomic structure, for example, and the structure forms a coupling nanocavity, and coupling-split into the mode similar to the bonding and anti-bonding optical coupling resonant anode

in the diatomic system from the original mode of the single nanocavity. In the embodiment, the two mode have a high energy level (short wavelength) and a low energy level (long wavelength) respectively. When the gap G between the semiconductor rod structures **912**A of the first row and the semiconductor rod structures **912**B of the second row is changed, the optical coupling resonance mode wavelength thereof corresponding to the first resonant structure **910**A and the second resonant structure **910**B also changes accordingly.

[0095] In FIG. **10**, the vertical axis represents the wavelength of the resonant light L**2** of the pressure sensing device **900**, the horizontal axis represents the gap G between the semiconductor rod structures **912**A of the first row and the semiconductor rod structures **912**B of the second row. In addition, "first optical mode" represents the diagram of the wavelength of the resonant light L**2** under bonding mode versus gap G, and the "second optical mode" represents the diagram of the wavelength of the resonant light L**2** under anti-bonding mode versus gap G. In the embodiment, when the gap G is far greater than the appropriate coupling distance, the first resonant structure **910**A has nearly no interaction with the second resonant structure **910**B, that is, the coupling is not occurred. In addition, the bonding mode and the anti-bonding mode have the same resonant mode wavelength. However, with the decrease of the gap G, a difference is produced between the resonant mode wavelength of the bonding mode and the resonant mode wavelength of the anti-bonding mode. When the gap G is less than the optical near field coupling length, the coupling effect thereof becomes very significant, and an obvious difference is produced between the resonant mode wavelength of the bonding mode and the resonant mode wavelength of the anti-bonding mode. In the embodiment, the dependency between the wavelength and the gap G can be applied in the measuring method of the strain (pressure P) sensing, for example.

[0096] In the embodiment, when the pressure P is applied on the second substrate **760** to cause the cladding body **720** to expand along the direction of the first axis X and the direction of the second axis Y, because the lattice constants of the semiconductor rod structures **912**A of the first row and the lattice constants of the semiconductor rod structures **912**B of the second row are increased on the direction of the first axis X, a wavelength red shift is increased in the resonant mode wavelength of the anti-bonding mode. In addition, because the gap G on the direction of the second axis Y is increased, the coupling distance between the first resonant structure **910**A and the second resonant structure **910**B is increased, therefore, another wavelength red shift is increased in the resonant mode wavelength of the anti-bonding mode. Specifically, compared to the pressure sensing device **700**A of FIG. **7**A, the pressure sensing device **900** of the embodiment can obtain greater wavelength response under the same applied pressure, therefore, having the higher sensing response and sensitivity.

[0097] FIG. **11**A is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention, and FIG. **11**B is a schematic cross-sectional view of a pressure sensing device on another direction in the embodiment of FIG. **11**A. Referring to FIG. **11**A and FIG. **0.11**B, the pressure sensing device **1100**A in the embodiment of FIG. **11**A is similar to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, the elements and related descriptions can be referred to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, and will not be repeated herein. The difference between the pressure sensing device **1100**A and the pressure sensing device **700**A are described as follows. In the embodiment, the light source of the pressure sensing device **1100**A is back light source **1180**, disposed on a side of the cladding body **720**. Specifically, the back light source **1180** is disposed on a side of the first substrate **750** away from the cladding body **720**, for example. In addition, the resonant structure **1110** includes a plurality of semiconductor rod structures **1112**, and the material of the semiconductor rod structures **1112** includes semiconductor material having direct bandgap, or material having quantum structure, the back light source **1180** is configured to excite the resonant structure **1110** to produce an original broadband light L**1**. In an embodiment, the pressure sensing device **1100**A further includes a light-guiding structure **1170**A disposed in the cladding body **720**. The semiconductor rod structures **1112** of the resonant structure **1110** and the light-guiding structure **1170**A are arranged into a row on the same XY plane (for example, the plane formed by the first axis X and the second axis Y) along the arranging direction AD. In addition, an end of the light-guiding structure **1170**A faces the semiconductor rod structures **1112** and another end of the light-guiding structure **1170**A faces the detector **730**. The light-guiding structure **1170**A is configured to guide the resonant light into the detector. Specifically, the semiconductor rod structures **1112** and the light-guiding structure **1170**A are connected into a straight line to achieve the direct coupling, and the resonant light L**2** produced by the production of the original broadband light L**1** from the resonant structure **1110** enters the light-guiding structure **1170**A through coupling. Then, the resonant light L**2** transmitted to the light-guiding structure **1170**A is received by the detector **730**. In the embodiment, the resonant structure **1110** and the light-guiding structure **1170**A can also be disposed as the illustration in FIG. **7**E, on the different XY plane (that is, on the different position along the direction of the third axis X).

[0098] In the embodiment, the material of the semiconductor rod structures **1112** includes the semiconductor material having direct bandgap or material having quantum structure, the back light source **1180** can excite the resonant structure **1110** to produce an original broadband light L**1**, effectively resonating in the resonant structure **1110** to produce the resonant light L**2**. Therefore, the first light-guiding portion **772**A in the embodiment of FIG. **7**A to FIG. **7**B doesn't have to be disposed in the pressure sensing device **1100**A necessarily to coupling-enter the original broadband light L**1** into the resonant structure **1110**, so that the pressure sensing device **1100**A has more simplified device structure. Compared to the pressure sensing device **700**A in the embodiments of FIG. **7**A to FIG. **7**B, the pressure sensing device **1100**A has simpler line layout and lower original broadband light precision preset requirements.

[0099] FIG. **11**C is a schematic cross-sectional view of a pressure sensing device in another embodiment of the invention, and FIG. **11**D is a schematic cross-sectional view of the pressure sensing device in the embodiment of FIG. **11**C along line III-III. Referring to both FIG. **11**C and FIG. **11**D, the pressure sensing device **1100**B in the embodiments of FIG. **11**C and FIG. **11**D is similar to the pressure sensing device **1100**A in the embodiments of FIG. **11**A and FIG.

11B, the elements and related descriptions can be referred to the pressure sensing device **1100**A in the embodiments of FIG. **11**A and FIG. **11**B, and will not be repeated herein. The difference between the pressure sensing device **1100**B and the pressure sensing device **1100**A are described as follows. In the embodiment, the light-guiding structure **1170**B of the pressure sensing device **1100**B is disposed beside the semiconductor rod structures **1112** of the resonant structure **1110** arranged along the arranging direction AD, and an end of the light-guiding structure **1170**B faces the detector **730**. The resonant light L**2** enters the light-guiding structure **1170**B through a coupling, and the light-guiding structure **1170**B is configured to guide the resonant light L**2** into the detector **730**. Specifically, the resonant light L**2** of the embodiment can directly leave the resonant structure **1110** by the side through the lateral coupling. Therefore, the optical loss of the pressure sensing device **1100**B in the embodiment is lower, the light coupling efficiency thereof is better.

[0100] FIG. **12** is a schematic top view of a pressure sensing apparatus in an embodiment of the invention. Referring to FIG. **12**, in the embodiment, the pressure sensing apparatus **1200** includes a plurality of first sensing units SA**1** arranged periodically along the direction of the first axis X and a plurality of second sensing units SA**2** arranged periodically along the direction of the second axis Y. Each of the first sensing units SA**1** and the second sensing units SA**2** includes a resonant structure **1210** and a light-guiding structure, for example. The resonant structures **1210** include a plurality of resonant structures **1210**A located on the first sensing unit SA**1** and a plurality of resonant structures **1210**B located on the second sensing units SA**2**. In addition, the resonant structures **1210** and the light-guiding structures can be chosen from the resonant structures and the light-guiding structures of the above-mentioned embodiments, or the resonant structures and the light-guiding structures of other types. Specifically, each of the first sensing units SA**1** and the second sensing units SA**2** includes the first light-guiding portion **772**A, the resonant structure **710** and the second light-guiding portion **774**A in the embodiments of FIG. **7**A to FIG. **7**B, for example, or the light-guiding structure **770**B and the resonant structure **710** in the embodiments of FIG. **7**C, or the first light-guiding portion **772**A, the resonant structure **910** and the second light-guiding portion **774**A in the embodiments of FIG. **9**, or the resonant structure **1110** and the light-guiding structure **1170**A in the embodiments of FIG. **11**A to FIG. **11**B, or the resonant structure **1110** and the light-guiding structure **1170**B in the embodiments of FIG. **11**C. Or, in some embodiments, according to the practical design requirements, each of the first sensing units SA**1** and the second sensing units SA**2** includes the combination of the resonant structure and the light-guiding structure (the first light-guiding portion, the second light-guiding portion) in the embodiments of FIG. **7**A to FIG. **7**B, FIG. **7**C to FIG. **7**D, FIG. **7**E, FIG. **9**A to FIG. **9**B, FIG. **11**A to FIG. **11**B and FIG. **11**C, for example, the invention is not limited thereto.

[0101] In the embodiment, at least part of the first sensing units SA**1** and at least part of the second sensing units SA**2** locate on different location along the direction of the third axis Z in the cladding body **1220**, that is, locate on different XY plane. Specifically, the cladding body **1220** completely covers the semiconductor rod structures of the resonant structures **1210**. The resonant structures **1210**A of the first sensing units SA**1** are arranged along the first direction (such as the oblique arrangement of the resonant structures **1210**A in FIG. **12**), and the resonant structures **1210**B of the second sensing units SA**2** are arranged along the second direction different from the first direction (such as the oblique arrangement of the resonant structures **1210**B in FIG. **12**). In addition, the semiconductor rod structures of each resonant structure **1210**A are arranged along the direction of the second axis Y at intervals, for example, and the semiconductor rod structures of each resonant structure **1210**B are arranged along the direction of the first axis X at intervals, for example, the invention is not limited thereto.

[0102] In the embodiment, when the pressure is transmitted to the cladding body **1220** through the direction perpendicular to the arranging direction of the semiconductor rod structures of the resonant structures **1210**, a deformation corresponding to the pressure is occurred on the semiconductor rod structures of the resonant structures **1210** and the cladding body **1220** along the arranging direction thereof. Therefore, the size or/and gap G (such as the gap G of FIG. **9**B) of the lattice constants of the semiconductor rod structures are changed. At least part of the resonant structures **1210** receives the original broadband light (not shown) emitted by the light source LS to produce the resonant light (not shown), and the wavelength of the resonant light is changed according to the change of the lattice constants or/and the gap G.

[0103] Specifically, the semiconductor rod structures of the resonant structures **1210** locate on different regions of the plane formed by the direction of the first axis X and direction of the second axis Y, so as to measure of received force on different regions on the plane. In the embodiment, the light source LS of the pressure sensing apparatus **1200** includes the first light source LS**1** and the second light source LS**2**, and the first light source LS**1** and the second light source LS**2** are multi-output light source device, for example. The first light source LS**1** is configured to provide the original broadband light into the resonant structures **1210**A of the first sensing units SA**1**, and the second light source LS**2** is configured to provide the original broadband light to the resonant structures **1210**B of the second sensing units SA**2**.

[0104] In some embodiments, the light source of the pressure sensing apparatus **1200** is back light source, disposed on a side of the cladding body **1220**. Specifically, the back light source of the embodiments is located on a side of the cladding body **1220** along the direction of the third axis Z, for example, and the back light source is configured to excite the resonant structures **1210** of the first sensing units SA**1** and the second sensing units SA**2** to produce the original broadband light.

[0105] In addition, in the embodiment, the pressure sensing apparatus **1200** further includes a detector (not shown) and a processor **1240**. The detector receives the resonant light produced by at least part of the resonant structures **1210** respectively to produce a plurality of spectral signals, and the processor **1240** calculates the occurring location of the deformation produced correspondingly to the applied pressure and the deformation value of the deformation according to the spectral signal changes, so as to measure the location, value of the applied pressure or other information. Specifically, the processor **1240** includes a first multiplexer **1242** and a second multiplexer **1244**, the first multiplexer **1242** and the second multiplexer **1244** analyze the spectral signals from the resonant structures **1210** of the first sensing units

SA**1** and the second sensing units SA**2** respectively, for example. However, in some embodiments, the processor **1240** can also include multiplexer of other number, or have multiplexer structure of other types, the invention is not limited thereto.

[0106] Specifically, about the components such as the light source LS, the resonant structures **1210**, the cladding body **1220**, the detector (not shown) and the processor **1240** of the pressure sensing apparatus **1200**, enough instruction, recommendations and embodiment details can be obtained from the embodiments in FIG. **1**A to FIG. **11**C, and are not repeated herein. In the embodiment, the pressure sensing apparatus **1200** can calculate the deformation corresponding to the applied pressure according to the light after wavelength adjustment, to achieve the pressure sensing, and the sensing sensitivity thereof is excellent and the device footprint thereof is smaller.

[0107] Based on the above, in the optical device, the pressure sensing device and the pressure sensing apparatus of the embodiment of the invention, a resonant structure includes a plurality of semiconductor rod structures arranged into a row at intervals along the arranging direction. The light source provides the original broadband light entering the resonant structure from the outside or produced by the resonant structure, and transmitted in the semiconductor rod structures and between the semiconductor rod structures. The resonant structure receives the original broadband light to produce the resonant light, and the full width at half maximum of the resonant light is less than the full width at half maximum of the original broadband light. In addition, the cladding body completely covers the semiconductor rod structures of the resonant structures. When an external force or pressure is applied on the cladding body, a deformation corresponding to the external force is occurred on the cladding body and the semiconductor rod structures. Therefore, the deformation caused by an external force can be applied on the optical device of the embodiment of the invention, to perform the structural adjustment of the resonant structure, so that reliable and large range wavelength adjustment can be achieved. In addition, the optical device has small device footprint and the pattern is suitable for the integration of optical waveguide. Furthermore, in the pressure sensing device and the pressure sensing apparatus of the embodiment of the invention, the wavelength of the resonant light changes according to the deformation corresponding to the pressure, and the pressure sensing device and the pressure sensing apparatus sense the applied pressure according to the wavelength of the resonant light, so as to achieve the pressure sensing, and have excellent sensitivity and smaller device footprint.

[0108] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims and their equivalents.

What is claimed is:

1. A pressure sensing device, comprising:

a light source, configured to provide an original broadband light;

at least one resonant structure, wherein a resonant structure comprises a plurality of semiconductor rod structures arranged into a row at intervals along a single arranging direction, and each of the semiconductor rod structures has a lattice constant along the arranging direction; the original broadband light propagates between the semiconductor rod structures, and producing a resonant light, wherein each of the semiconductor rod structures has a length perpendicular to the arranging direction and has a width parallel to the arranging direction, the length and the width is shorter than a wavelength of the resonant light;

a cladding body, completely covering the semiconductor rod structures of the at least one resonant structure;

a first substrate and a second substrate, wherein the cladding body and the at least one resonant structure are interposed between the first substrate and the second substrate;

wherein when a pressure is applied on at least one of the first substrate and the second substrate, the pressure is transmitted to the cladding body along a direction perpendicular to the arranging direction, a deformation corresponding to the pressure is occurred on the cladding body and the semiconductor rod structures on the arranging direction, and the wavelength of the resonant light is changed according to the deformation.

2. The pressure sensing device according to claim **1**, further comprising a detector, receiving the resonant light to produce a spectral signal; and a processor, calculating a deformation value according to a change of the spectral signal.

3. The pressure sensing device according to claim **2**, further comprising a first light-guiding portion and a second light-guiding portion, the first light-guiding portion and the second light-guiding portion are disposed in the cladding body along the arranging direction, the first light-guiding portion is configured to guide the original broadband light into a resonant structure, and the second light-guiding portion is configured to guide the resonant light into the detector.

4. The pressure sensing device according to claim **3**, wherein the first light-guiding portion, the semiconductor rod structures of a resonant structure and the second light-guiding portion are arranged into a row along the arranging direction, an end of the first light-guiding portion faces the light source and another end of the first light-guiding portion faces the semiconductor rod structures, an end of the second light-guiding portion faces the semiconductor rod structures and another end of the second light-guiding portion faces the detector.

5. The pressure sensing device according to claim **3**, wherein the first light-guiding portion and the second light-guiding portion are connected to form into a light-guiding structure, and disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction.

6. The pressure sensing device according to claim **1**, wherein a number of the at least one resonant structure is two, the resonant structures comprises a first resonant structure and a second resonant structure, the semiconductor rod structures of the first resonant structure are arranged into a first row, the semiconductor rod structures of the second resonant structure are arranged into a second row parallel and adjacent to the first row, and the semiconductor rod structures on the first row and the semiconductor rod structures on the second row have a gap on a gap direction perpendicular to the arranging direction.

7. The pressure sensing device according to claim **6**, wherein when the pressure is transmitted to the cladding body through a direction simultaneously perpendicular to the arranging direction and perpendicular to the gap direction, a deformation is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the gap direction, so that the gap is changed, wherein the wavelength of the resonant light is changed according to the change of the gap.

8. The pressure sensing device according to claim **1**, wherein the light source is a back light source, disposed on a side of the cladding body, and a material of the semiconductor rod structures comprises a semiconductor material having a direct bandgap.

9. The pressure sensing device according to claim **2**, further comprising a light-guiding structure, disposed in the cladding body, the semiconductor rod structures of a resonant structure and the light-guiding structure are arranged into a row along the arranging direction, an end of the light-guiding structure faces the semiconductor rod structures and another end of the light-guiding structure faces the detector, wherein the light-guiding structure is configured to guide the resonant light into the detector.

10. The pressure sensing device according to claim **2**, further comprising a light-guiding structure, disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction, and an end of the light-guiding structure faces the detector, wherein the resonant light enters the light-guiding structure through a coupling, and the light-guiding structure is configured to guide the resonant light into the detector.

11. A pressure sensing apparatus, comprising:

a light source, configured to provide an original broadband light;

a plurality of resonant structures, wherein each of the resonant structures comprises a plurality of semiconductor rod structures arranged into a row at intervals along a single arranging direction, and each of the semiconductor rod structures has a lattice constant on the arranging direction; at least part of the resonant structures arranged along a first direction, wherein at least part of the resonant structures are arranged along a second direction different from the first direction; the original broadband light entering at least part of the resonant structures and transmitted between the semiconductor rod structures, and producing a plurality of resonant lights, wherein each of the semiconductor rod structures of a resonant structure has a length perpendicular to the arranging direction and has a width parallel to the arranging direction, the length and the width are less than a wavelength of the resonant light;

a cladding body, completely covering the semiconductor rod structures of the resonant structures;

a first substrate and a second substrate, wherein the cladding body and the resonant structures are interposed between the first substrate and the second substrate;

wherein when a pressure is applied on at least one of the first substrate and the second substrate, and the pressure is transmitted to the cladding body along a direction perpendicular to the arranging direction, a deformation corresponding to the pressure is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the arranging direction, so that a value of the lattice constants is changed, and the wavelength of the resonant lights is changed according to a change of the lattice constants.

12. The pressure sensing apparatus according to claim **11**, further comprising a detector, receiving the resonant lights of at least part of the resonant structures to produce a plurality of spectral signals; and a processor, calculating an occurring location of the deformation and a deformation value of the deformation according to the spectral signals.

13. The pressure sensing apparatus according to claim **12**, further comprising a plurality of first light-guiding portions and a plurality of second light-guiding portions, a first light-guiding portion and a second light-guiding portion are disposed in the cladding body along the arranging direction, a first light-guiding portion is configured to guide the original broadband light into a resonant structure, and a second light-guiding portion is configured to guide the resonant light into the detector.

14. The pressure sensing apparatus according to claim **13**, wherein a first light-guiding portion, the semiconductor rod structures of a resonant structure and a second light-guiding portion are arranged into a row along the arranging direction, an end of the first light-guiding portion faces the light source and another end of the first light-guiding portion faces the semiconductor rod structures, an end of the second light-guiding portion faces the semiconductor rod structures and another end of the second light-guiding portion faces the detector.

15. The pressure sensing apparatus according to claim **13**, wherein a first light-guiding portion and a second light-guiding portion are connected to form into a light-guiding structure, disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction, an end of the light-guiding structure faces the light source and another end of the light-guiding structure faces the detector.

16. The pressure sensing apparatus according to claim **11**, wherein the resonant structures comprises a plurality of first resonant structures and a plurality of second resonant structures, the semiconductor rod structures of a first resonant structure are arranged into a first row, the semiconductor rod structures of a second resonant structure are arranged into a second row parallel and adjacent to the first row, and the semiconductor rod structures on the first row and the semiconductor rod structures on the second row have a gap on a gap direction perpendicular to the arranging direction.

17. The pressure sensing apparatus according to claim **16**, wherein when the pressure is transmitted to the cladding body through a direction simultaneously perpendicular to the arranging direction and perpendicular to the gap direction, a deformation is occurred on the cladding body and the semiconductor rod structures of the resonant structures on the gap direction, so that the gap is changed, wherein the wavelength of the resonant light is changed according to the change of the gap.

18. The pressure sensing apparatus according to claim **12**, wherein the light source is a back light source, disposed on a side of the cladding body, and a material of the semiconductor rod structures of the resonant structures comprises a semiconductor material having a direct bandgap.

19. The pressure sensing apparatus according to claim **18**, further comprising a plurality of light-guiding structures, disposed in the cladding body, the semiconductor rod structures of a resonant structure and a light-guiding structure are

arranged into a row along the arranging direction, an end of the light-guiding structure faces the semiconductor rod structures and another end of the light-guiding structure faces the detector, wherein the light-guiding structure is configured to guide the resonant light into the detector.

20. The pressure sensing apparatus according to claim **18**, further comprising a plurality of light-guiding structures, wherein a light-guiding structure is disposed beside the semiconductor rod structures of a resonant structure arranged along the arranging direction, and an end of the light-guiding structure faces the detector, wherein the resonant light enters the light-guiding structure through a coupling, and the light-guiding structure is configured to guide the resonant light into the detector.

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