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Micro integrated planar optical waveguide type SPR Sensor.

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Cho et al.

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(45) **Date of Patent: Jan. 27, 2009**

(54) **MICRO INTEGRATED PLANAR OPTICAL WAVEGUIDE TYPE SPR SENSOR**

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(73) Assignee: **University of Central Florida Research Foundation, Inc.**, Orlando, FL (US)

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(51) **Int. Cl.**
G01N 21/55 (2006.01)

(52) **U.S. Cl.** **356/445**; 356/448

(58) **Field of Classification Search** 356/630–632, 356/432–435, 445–448; 382/144–145; 250/559.1–559.28
See application file for complete search history.

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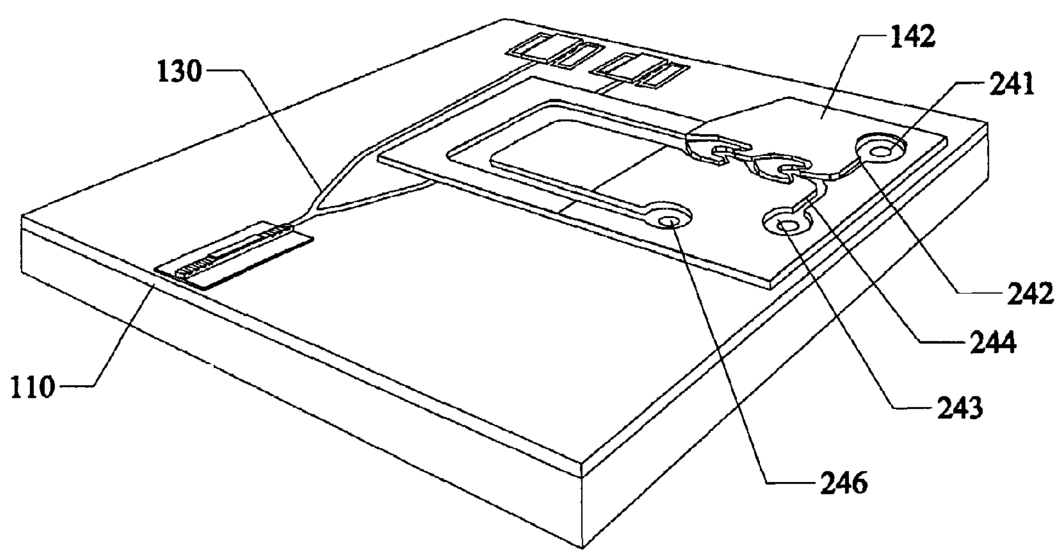
(57) **ABSTRACT**

An integrated optical waveguide type surface plasmon resonance (SPR) sensor having an optical waveguide with a corresponding SPR sensing area, photodetectors, and wavelength tunable laser or any kind of external tunable laser source/coupler formed on a substrate. In an embodiment, the laser is a wavelength tunable laser and optionally, the integrated device may include a power source on the substrate for providing a electric power to the wavelength tunable laser and the photodetectors, or a circuit for signal processing, or a microfluidic structure for routing a target sample to the SPR sensor area. The microfluidic structure optionally includes a mixer or a reaction chamber for mixing and allowing a physical or chemical reaction to occur, respectively. In an embodiment, plural planar integrated optical waveguide type SPR sensors may be fabricated on a substrate to form an array of SPR sensors.

21 Claims, 14 Drawing Sheets



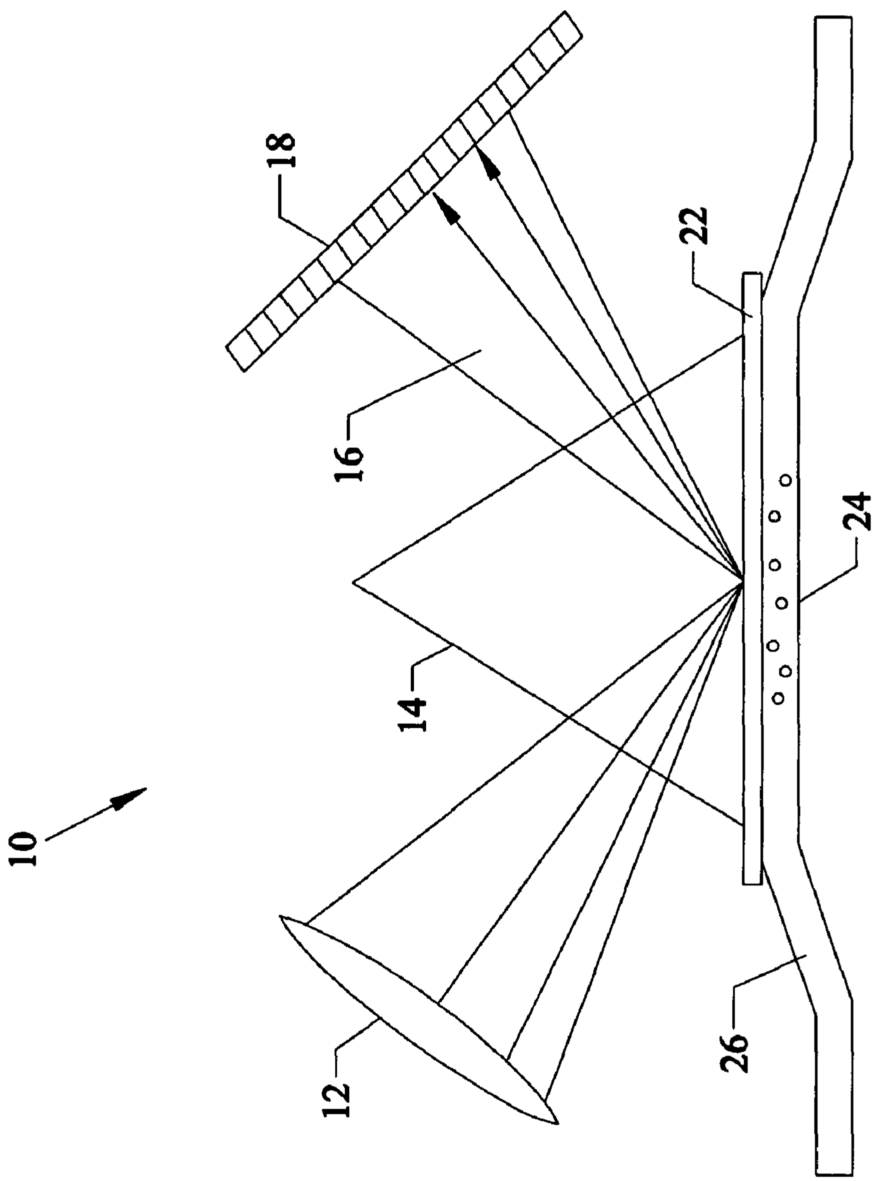


Fig.1

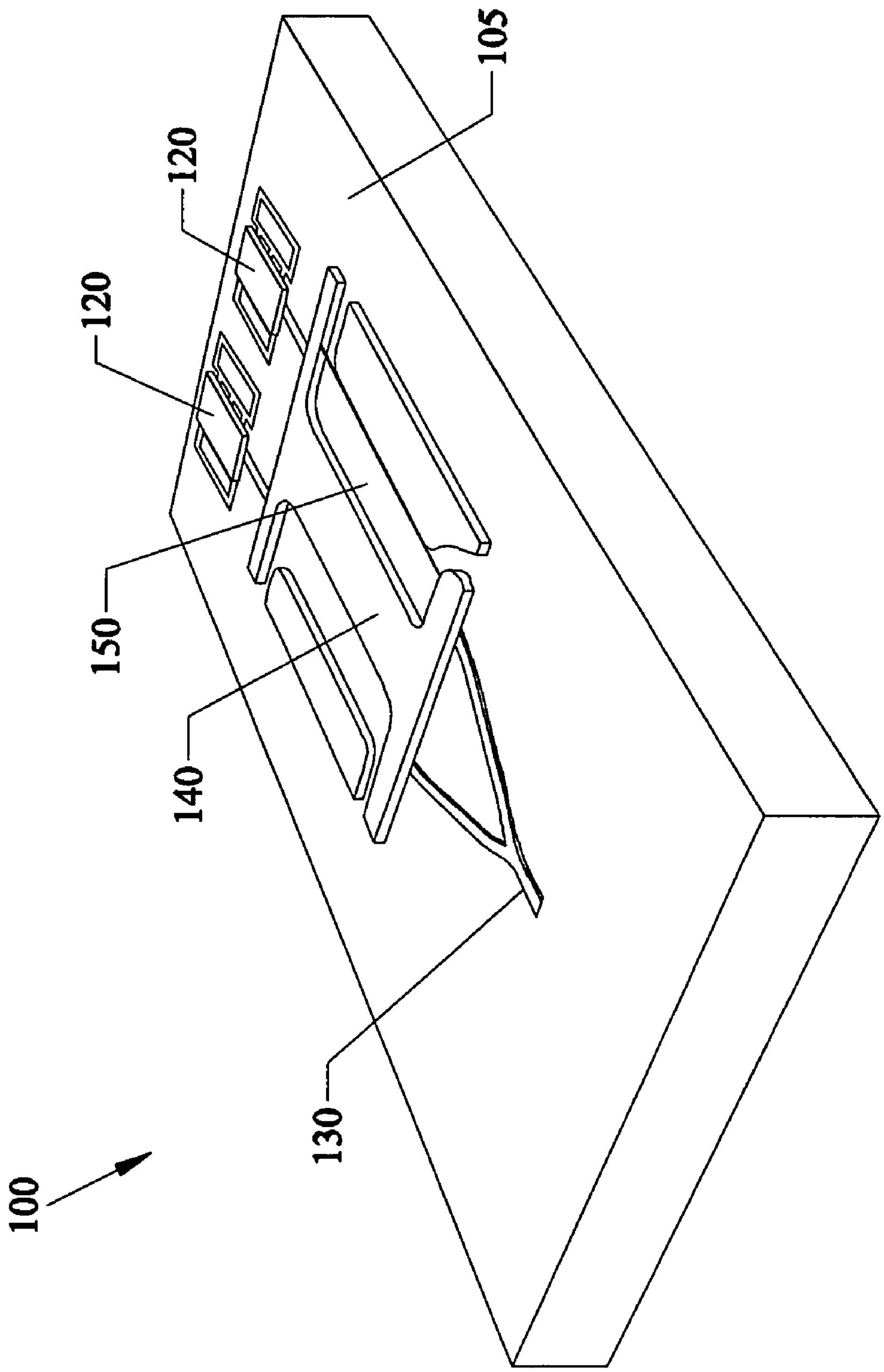


Fig.2

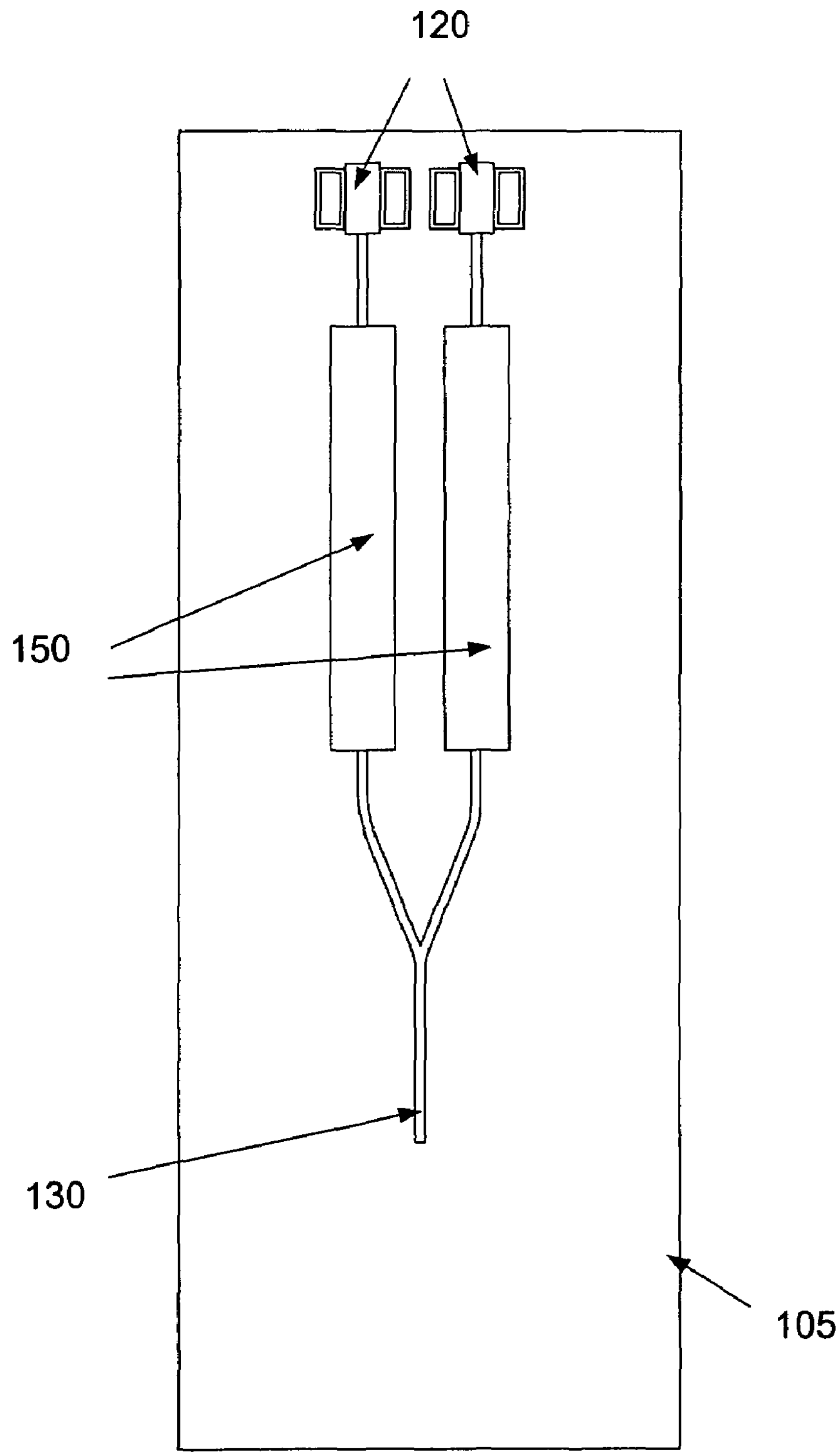


Fig. 3

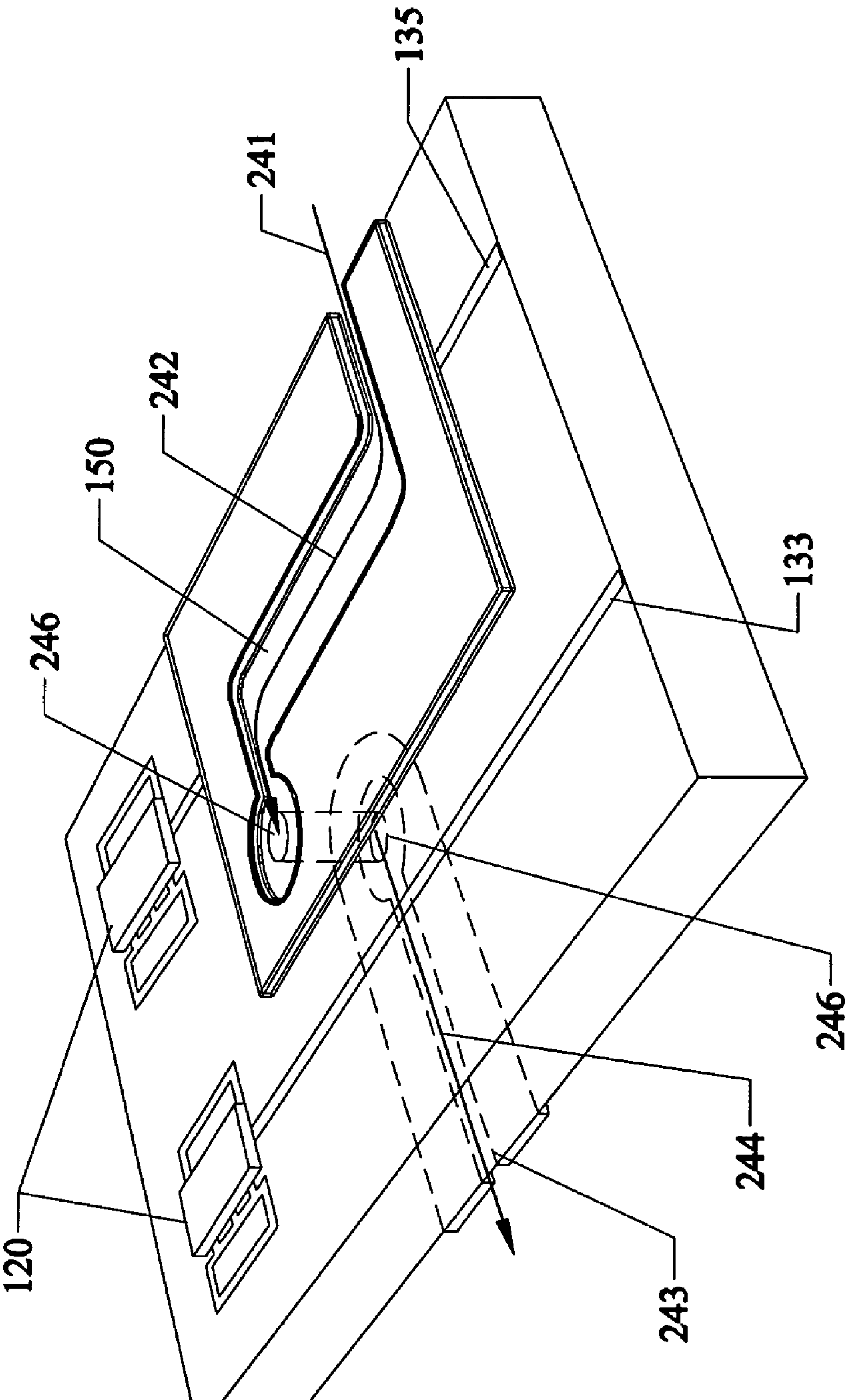


Fig.4

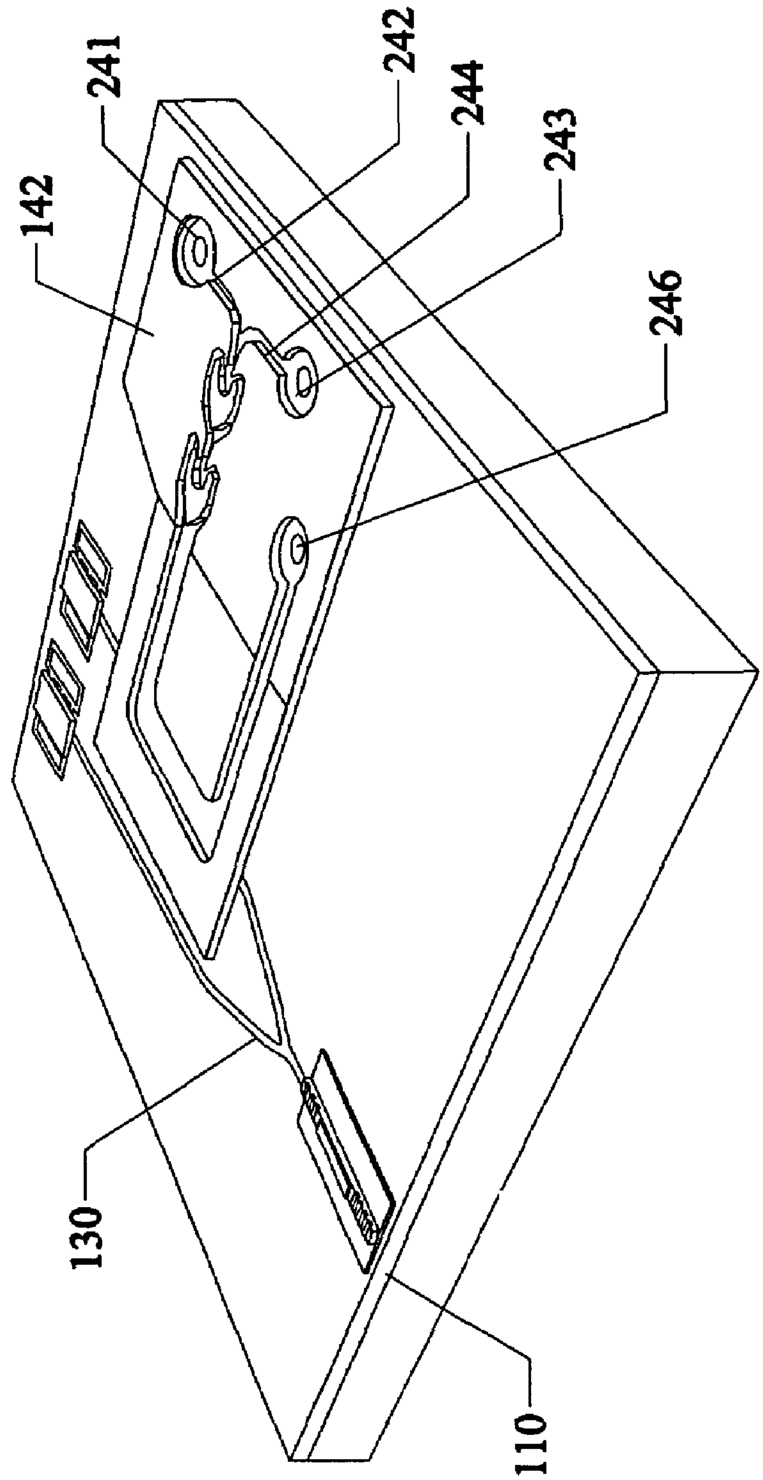


Fig.5a

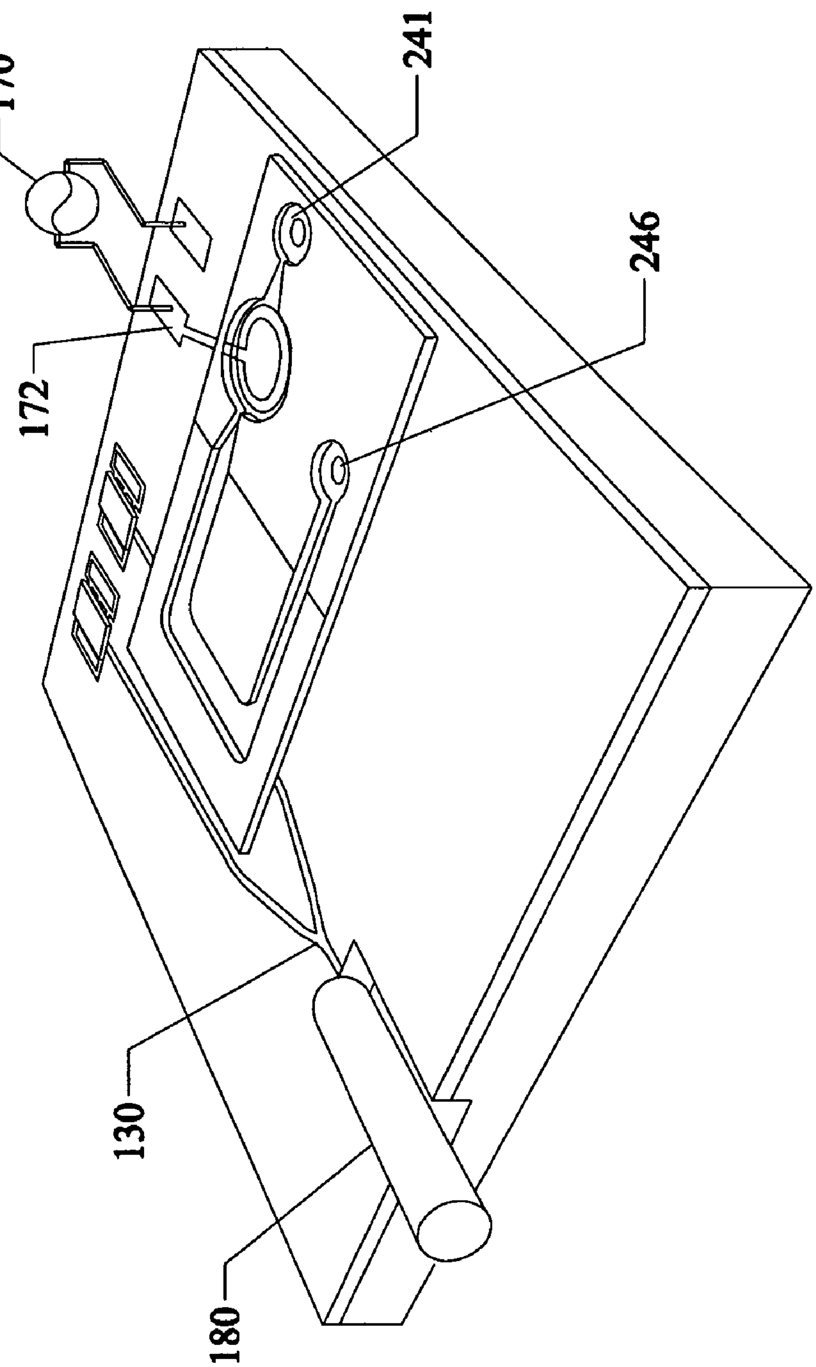


Fig.5b

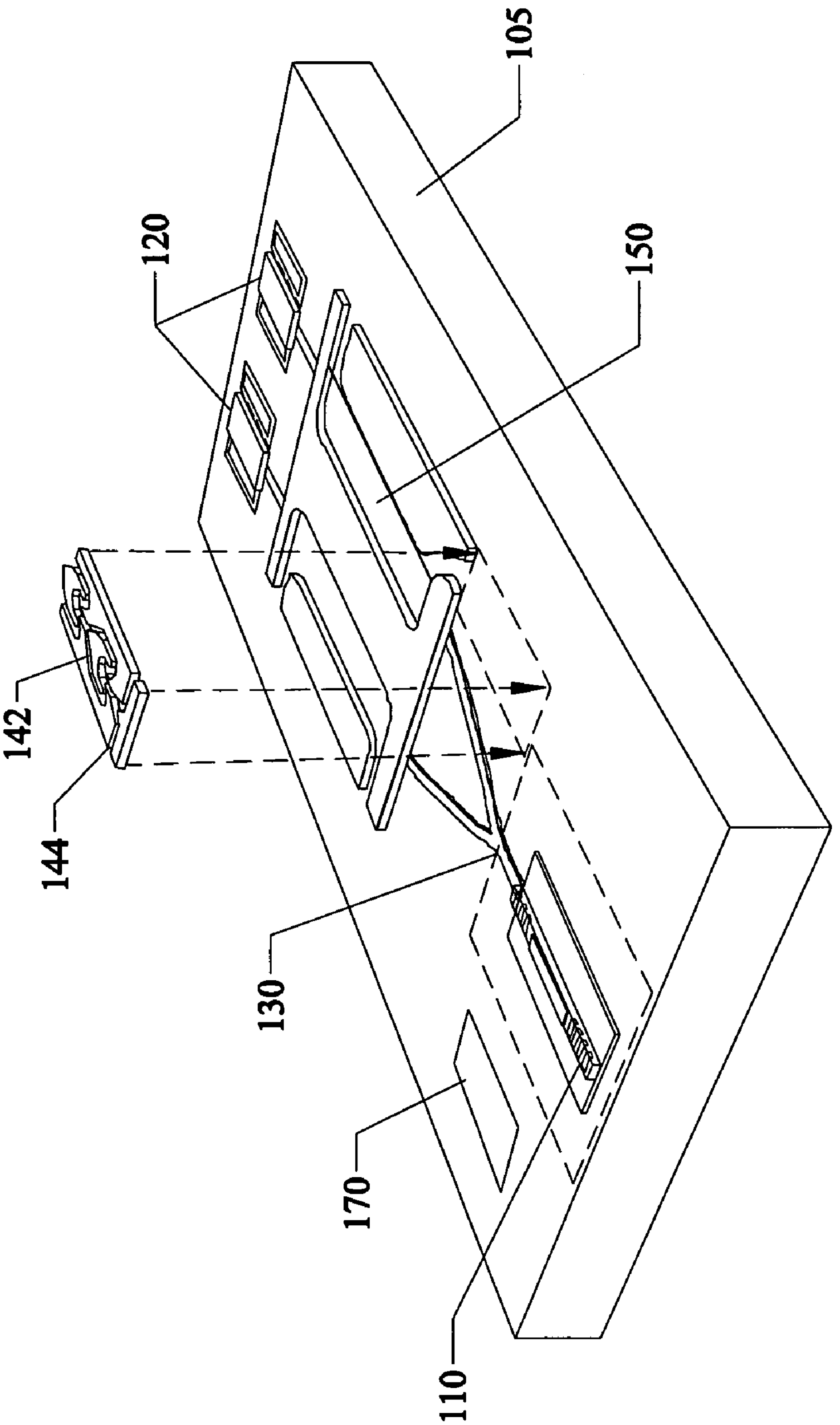


Fig.6

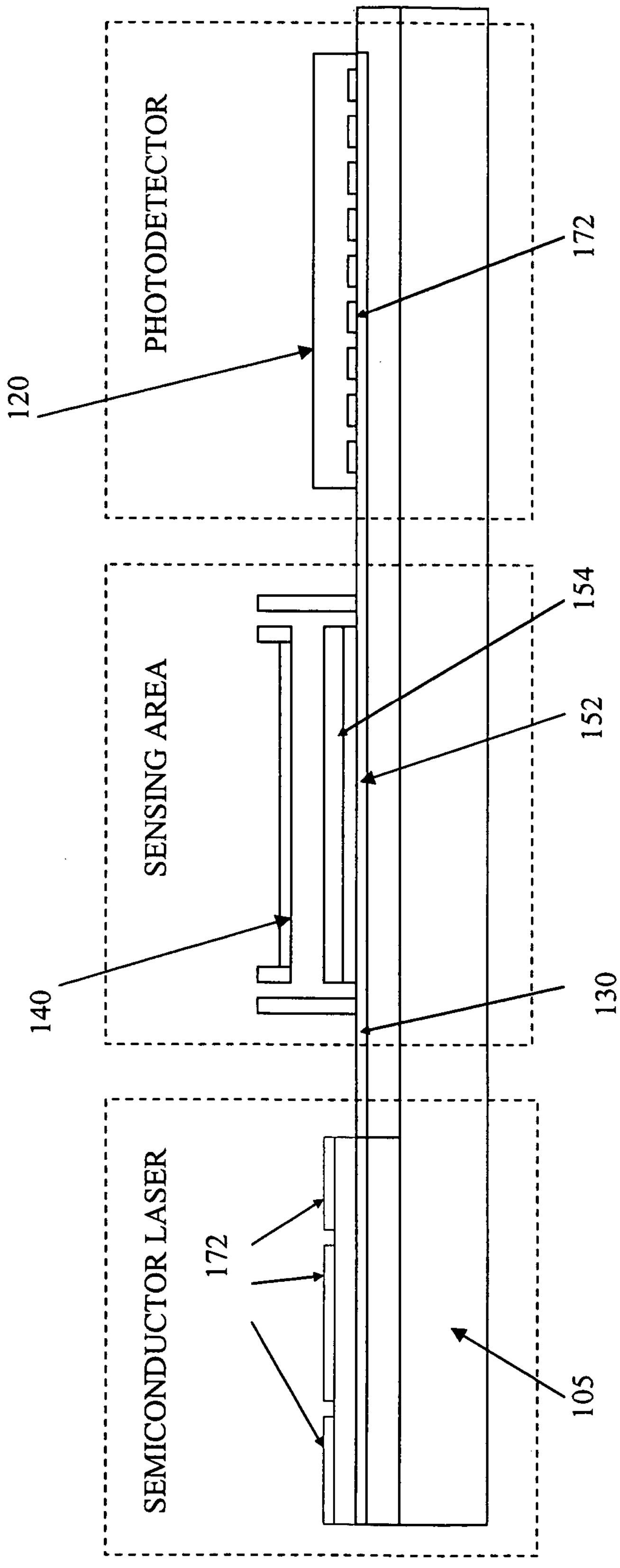

PHOTODETECTOR
120
172
SENSING AREA
154
152
140
130
SEMICONDUCTOR LASER
172
105

FIG. 7

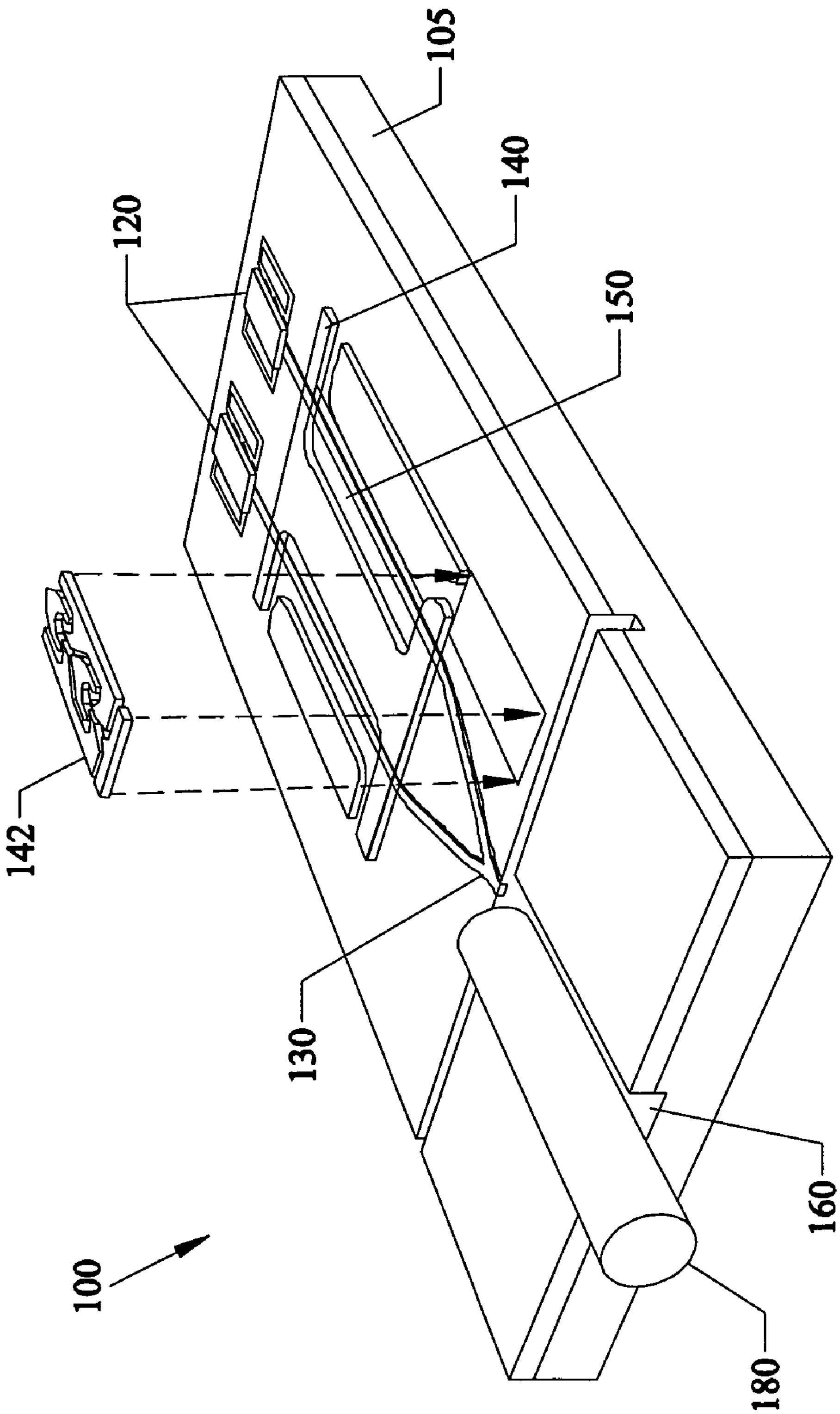


Fig.8

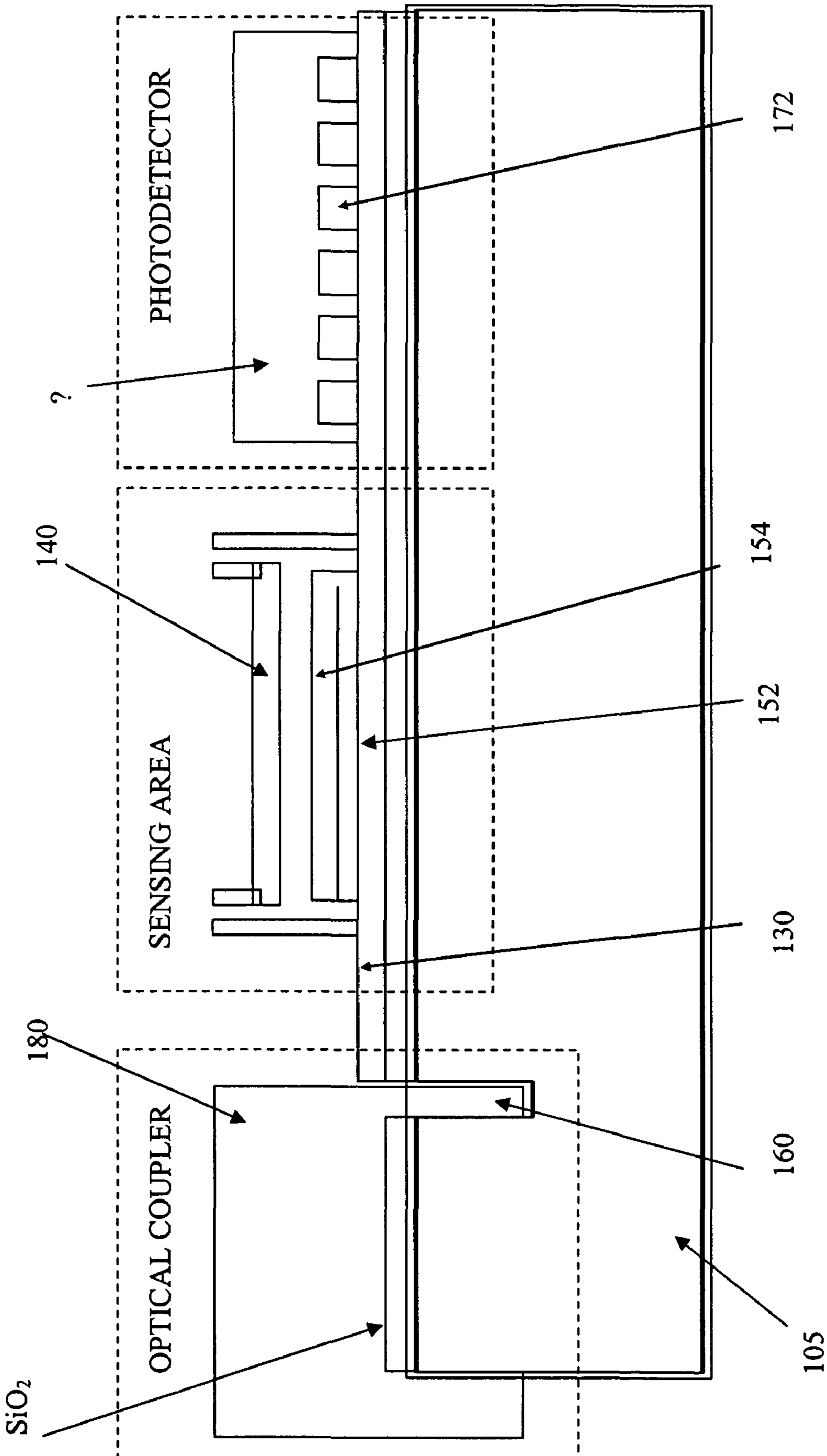

PHOTODETECTOR
?
172
SENSING AREA
140
154
152
130
OPTICAL COUPLER
180
160
105
SiO2

FIG. 9

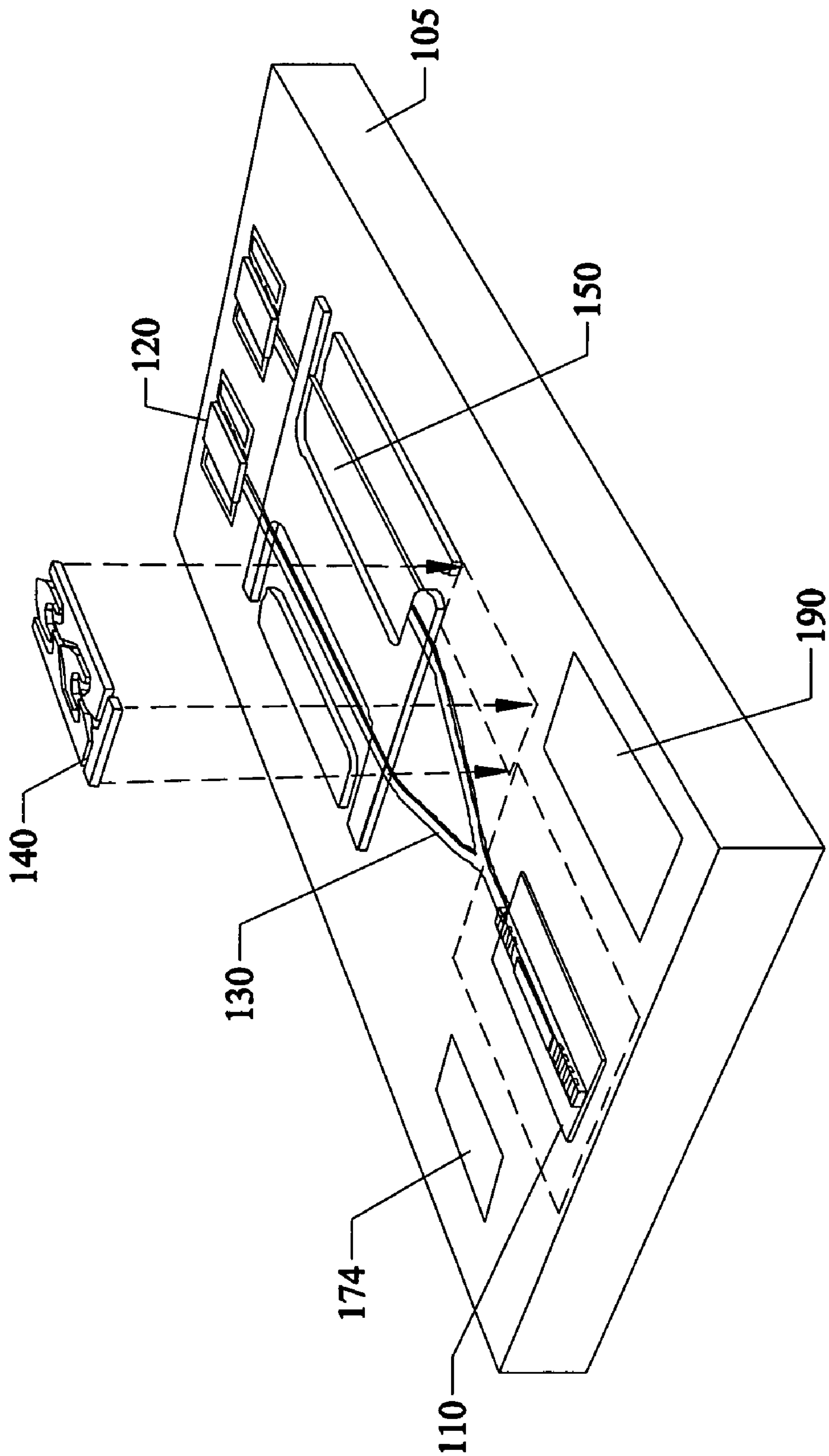


Fig.10

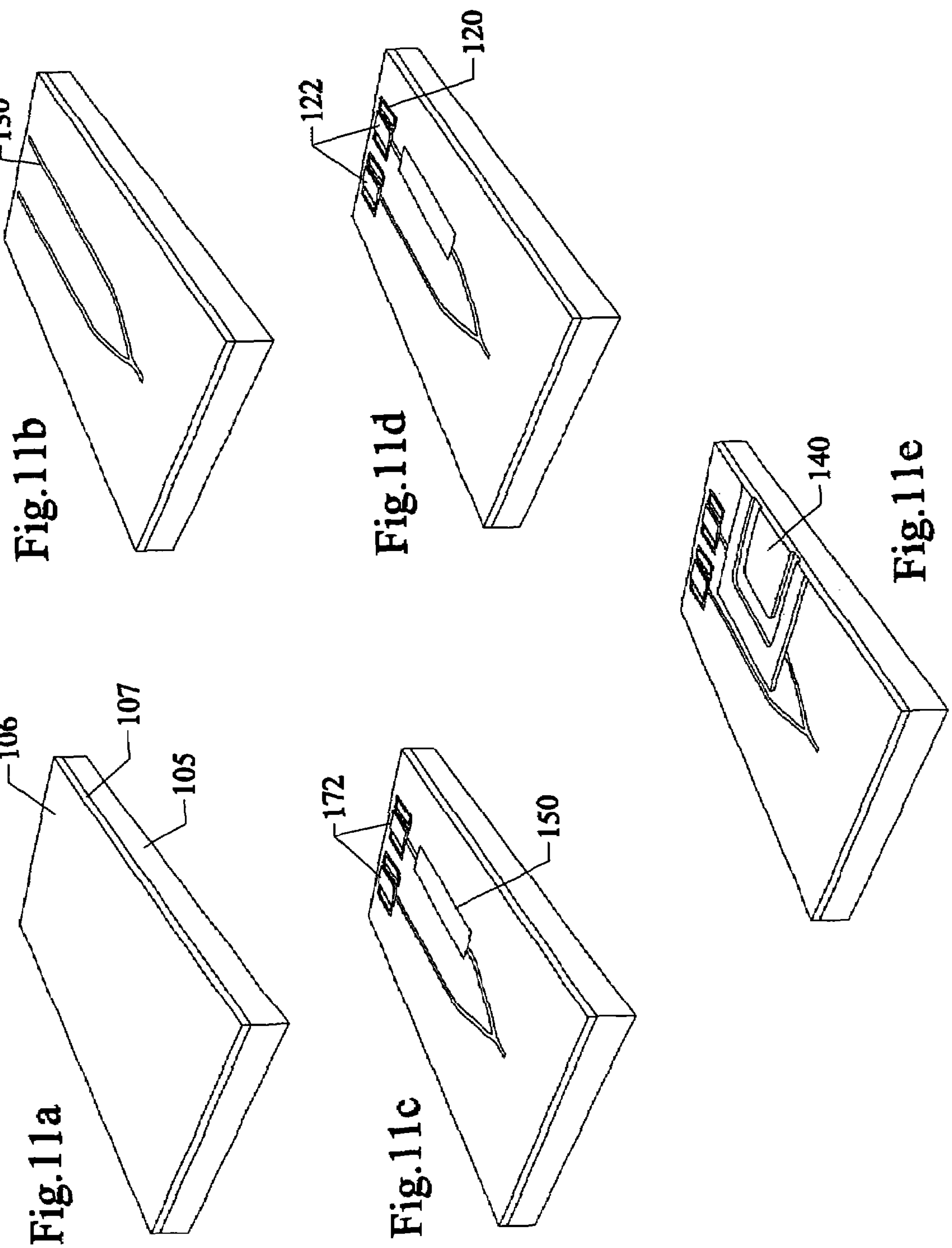


Fig.11a
106
107
105
Fig.11b
130
Fig.11c
172
150
Fig.11d
122
120
Fig.11e
140

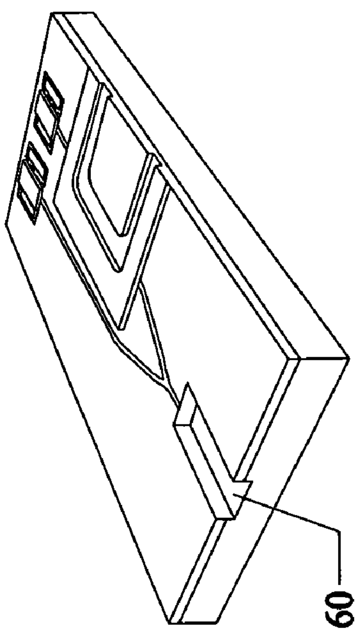


Fig.11f

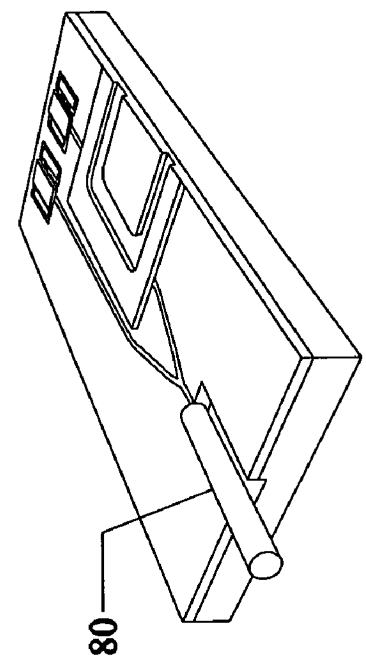


Fig.11g

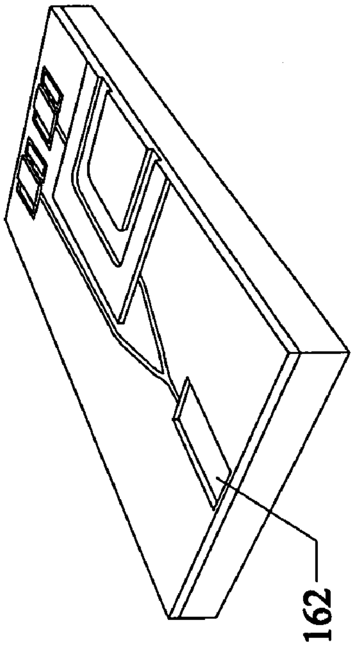


Fig.11h

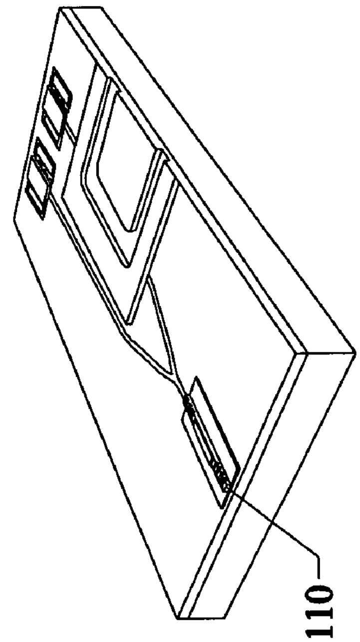


Fig.11i

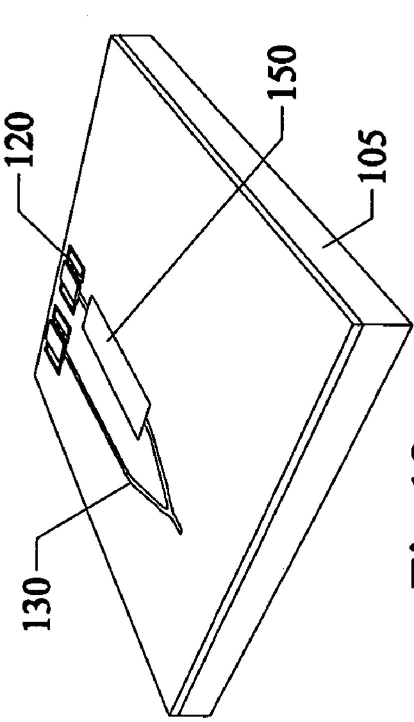


Fig.12a

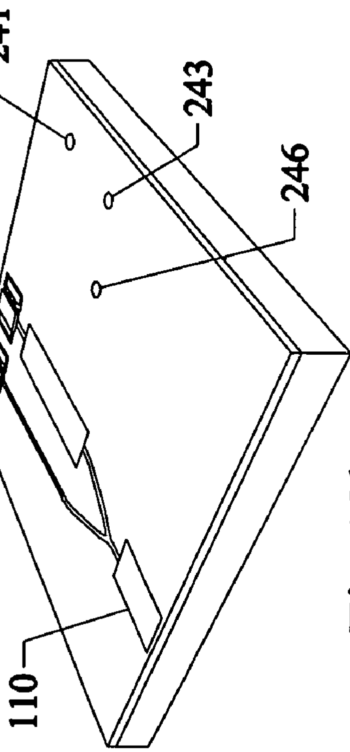


Fig.12b

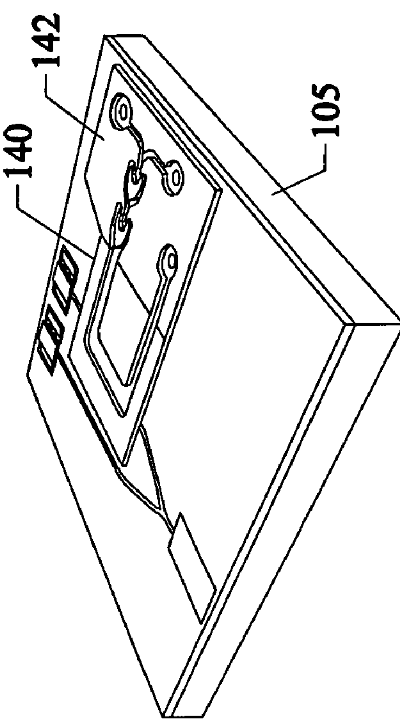


Fig.12c

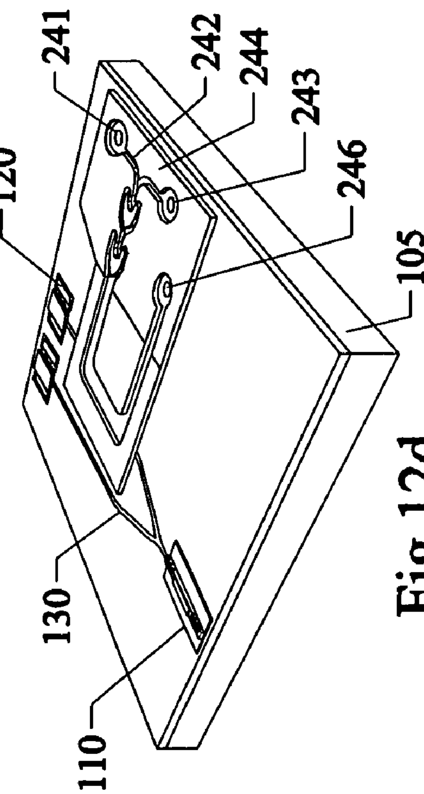


Fig.12d

MICRO INTEGRATED PLANAR OPTICAL WAVEGUIDE TYPE SPR SENSOR

This application claims the benefit of priority to U.S. Provisional Patent Application No. 60/635,725 filed on Dec. 10, 2004.

FIELD OF THE INVENTION

This invention relates to surface plasmon resonance sensors and, in particular, to methods, systems, apparatus and devices for integrating the optical waveguide, photodector, surface plasmon resonance (SPR) detection layer, and optionally included microfluidic structure on a single substrate to provide a micro integrated planar optical waveguide type surface plasmon resonance sensor.

BACKGROUND AND PRIOR ART

Basic working principle of surface plasmon resonance (SPR) sensor is inducing a spectrum of light into a sensing region and analyzing the absorption spectrum from the sensing region. Generally, inducing a spectrum of light on a sensing layer can be achieved in two ways; shining single wavelength of light with a range of incident angle or inducing a wavelength range of light. Sensor type is divided into two correspondingly; reflection type and waveguide type.

The reflection type SPR sensor **10**, as shown in FIG. **1**, works by applying single wavelength of light on the back side of a sensing layer with a range of angle and measuring the shifted amount of minimum light reflection angle before and after an analyte is induced to detection layer. The minimum light reflection angle is related with analyte's refractive index and detection layer metal. If the refractive index of analyte changes, the refractive index change would be reflected on the shift of minimum reflection angle. A conventional and commercially available SPR sensor **10** consists of optical components including a light source that produces a polarized light **12**, a prism **14**, and a CCD array **18**. The metal film **22** is prepared to have a functionalized surface for the adsorption of biochemical molecules from a fluidic sample **24**. The light source generates a polarized light **12** which is directed through the prism **14**, striking the metal film **22**. Reflected light **16** is detected by the CCD array **18**. As the fluid sample **24** passes through the fluidic channel **26**, the binding of the molecules changes the refractive index, which is monitored, conventionally, by the shift of the minimum reflection angle.

An advantage of the reflector SPR sensor is that it may include plural interactive surfaces, metal films **22**, to allow a multiple channel analysis of the sample **24**. However, a disadvantage of the reflector sensor is that the sensor is not fully integrated on a planar surface. Instead, optical components are located a distance from the planar surface to provide a polarized light that strikes, and is reflected from, the metal film **22**. Since the reflector type sensor is based on the measurement of the reflected light intensity, the CCD array for monitoring minimum light reflection peak is also located outside the plane. Thus, the reflector SPR sensor is "bulky".

Miniaturized reflector type SPR sensors are disclosed in U.S. Pat. Nos. 6,183,696 issued to Elkind et al on Feb. 6, 2001 and 6,191,847 issued to Melendez et al. on Feb. 20, 2001. The miniaturized sensors include a substrate which provides a sensor platform to which a light transmissive housing is coupled, substantially encapsulating the sensor platform. A light source is provided above the platform or on the platform substrate and includes a polarizer for producing the polarized light that strikes an SPR layer which is formed on the exterior

surface of the housing. A mirror, also located on the interior surface of the housing, deflects the light reflected from the SPR layer to a detector located on the sensor platform. The miniaturized reflector SPR sensor disclosed in the prior art may also include a power source, conversion electronics and a communication interface on the platform. Although most of the components are located on the platform, the housing is still necessary for contacting the target sample and reflecting the polarized light to the detector. While the overall size of the reflective SPR sensor is reduced, the resulting device is still bulky.

Another type of SPR sensor is waveguide type, which includes optical fiber type waveguide and planar waveguide. Fiber optic waveguides have a number of advantages over the bulkier prism-based sensors. Primarily, they can perform long distance detection for medical or otherwise sterile tasks. Fibers are also very small and have no moving parts, giving them a much broader range and making multiple sensor arrays a possibility.

A surface plasmon resonance sensor including plural optical waveguides and corresponding SPR sensor areas that permits the excitation of surface plasmons and plural fluidic channels is disclosed in U.S. Pat. No. 6,373,577 issued to Bräuer et al. on Apr. 26, 2002. In the Bräuer patent, an array of SPR waveguides are manufactured using technologies from semiconductor production and from integrated optics to provide plural parallel sensors on a single substrate located at a predefined distance from one another. Each strip-like optical waveguide that is expected to contact the sample fluid has at least one SPR sensor area including a metal layer that permits the excitation of surface plasmons. While the optical sensor disclosed in Bräuer provides plural waveguides with SPR surface areas and plural fluidic channels, external out-of-plane components are required to use the Bräuer optical sensor, namely, a light source, photodetectors and electronic components associated with operating the measurement device to which they are interfaced.

An alternative optical SPR detection device that is based on semiconductor laser array is disclosed in U.S. Pat. No. 6,469,785 issued to Duveneck et al. on Oct. 22, 2002. The Duveneck device comprises at least one light source, photodetector, an optical waveguide with a corresponding SPR area, and a fluidic channel in a single housing. The light source is a surface-emitting semiconductor laser located on a bottom substrate with the photodetector. An intermediate substrate above and separate from the bottom substrate includes at least one coupling-in grating and one coupling-out grating for coupling-in the emitted light from the surface-emitting laser to the optical waveguide and coupling-out to the photodetector. The optical waveguide includes a SPR surface area which contacts the target sample. A third substrate may be included a distance above the second substrate to form a fluidic reservoir for holding the target sample while in contact with the SPR sensor area.

While the Duveneck device may be enclosed to form a single unit, the device is bulky since the device requires a first substrate for the light source and detector and a separate second substrate for the coupling-in and coupling-out gratings, optical waveguide and corresponding SPR surface area. In an embodiment, the first, second and optional third substrate are enclosed in a housing with each substrate separated a predefined distance. In a second embodiment, the second substrate with the sensor layer is removable from the light source and detector on the first substrate. In still another embodiment, optical waveguides, such as an optical cable, are used to pass the light from the light source on the first substrate to the waveguide on the second substrate and back to the photodetector, thereby controlling the beam of the light. In the later embodiment, the first substrate may be located a further distance from the second substrate.

SUMMARY OF THE INVENTION

A first objective of the present invention is to provide methods, systems apparatus and devices that integrate light source and detection system and sensing layer and reduce the size of SPR sensor.

A second objective of the present invention is to provide methods, systems apparatus and devices to make planar SPR sensor structure and provide the availability of full integration of planar microfluidic components to the substrate.

A third objective of the present invention is to provide methods, systems apparatus and devices to allow for batch fabrication of the planar integrated optical waveguide type SPR sensor to reduce product cost.

A fourth objective of the present invention is to provide methods, systems apparatus and devices to make planar simple-structured SPR sensor and provide flexibility in fabrication.

A fifth objective of the present invention is to provide methods, systems apparatus and devices to remove external optical components and eliminate optical component alignment problem.

The methods, systems, apparatus and devices of the present invention advance the art by providing an integrated surface plasmon resonance (SPR) sensor comprising a substrate having an optical waveguide having a first end and a second end fabricated on the substrate, a light source coupled with the first end of the optical waveguide, at least one photodetector formed on the substrate coupled with the second end of the optical waveguide, at least one SPR sensor area formed to couple with a section of the optical waveguide between the light source and the at least one photodetector. A microfluidic structure having an inlet and an outlet can be optionally fabricated on the substrate for receiving a target sample, routing the target sample into contact with the at least one SPR sensor area and extracting the target sample, wherein the optical waveguide routes a light from the light source past the at least one SPR sensor area which evanescently penetrates the at least one SPR sensor area. In an embodiment, plural integrated SPR sensors may be integrated on a single substrate.

The light for detection may be induced from an integrated light source on the substrate or external light source coupled with optical fiber or any other types of optical coupler. Optionally, a fluidic structure having an inlet and outlet fluidic path and one or more of a reaction chamber and a mixer micro pump are formed on the substrate for routing the target sample. The integrated SPR sensor may also include a power source or a connection for receiving power and a user interface or a controller for controlling the integrated SPR sensor.

The present invention also provides a method for fabricating an integrated optical waveguide type surface plasmon resonance (SPR) sensor. The method includes providing a substrate, forming an optical waveguide on the substrate for routing a light from a light source to a photodector, forming a SPR sensor in contact with a section of the optical waveguide, forming an optical fluidic structure on the substrate to route a target sample past the SPR sensor, and forming the photodetector on the substrate that is coupled with the optical waveguide.

Further objects and advantages of this invention will be apparent from the following detailed description of preferred embodiments which are illustrated schematically in the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. **1** is a side view of a bulky reflection type SPR according to the prior art.

FIG. **2** is a perspective view of a planar integrated optical waveguide type SPR sensor according to an embodiment of the present invention.

FIG. **3** is a top view of the optical waveguide, overlying SPR sensing area and photodetectors fabricated on the planar substrate.

FIG. **4** is a perspective view of the microfluidic structure of the planar integrated optical waveguide type SPR sensor showing a reference branch and a sensing branch.

FIGS. **5***a* and **5***b* are perspective views of the microfluidic system fabricated and integrated on a planar surface wherein the optical waveguide is coupled with a semiconductor laser and an optical coupler, respectively.

FIG. **6** is a perspective view of alternative configuration of the planar integrated optical waveguide type SPR with optional microfluidic components.

FIG. **7** is side view of the planar integrated optical waveguide type SPR sensor shown in FIG. **6**.

FIG. **8** is a perspective view of an alternative configuration of the planar integrated optical waveguide type SPR sensor with an optical coupler light source.

FIG. **9** is side view of the optical coupler, the SPR sensor and the photodetector of the planar integrated optical waveguide type SPR shown in FIG. **8**.

FIG. **10** is a perspective view of an alternative configuration of the planar integrated optical waveguide type SPR sensor with an integrated semiconductor laser light source.

FIGS. **11***a*-**11***i* are perspective views of the planar integrated optical waveguide type SPR sensor at different steps of the fabrication process.

FIGS. **12***a*-**12***d* are perspective views of the planar integrated optical waveguide type SPR sensor at different steps of an alternative fabrication process.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Before explaining the disclosed embodiments of the present invention in detail it is to be understood that the invention is not limited in its application to the details of the particular arrangements shown since the invention is capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

The following is a list of the reference numerals used in the drawings and the detailed specification to identify components. In the description of the preferred embodiments and the figures, like components are identified by like reference numerals.

---

10 reflector type SPR sensor
12 polarized light
14 prism
16 reflected light
18 CCD array
22 metal film
24 fluidic sample
26 fluidic channel

-continued

100	planar integrated optical waveguide SPR sensor
105	substrate
106	SiON Layer
107	SiO_2 layer
110	wavelength tunable laser
120	photodectors
122	poly silicon layer
130	optical waveguide
133	reference branch
135	sensing branch
140	micro-fluidic components
142	micromixer
144	micro-fluidic chamber and channel
150	SPR sensing area
152	metal layer
154	dielectric layer
160	groove-optical fiber
162	grove-laser diode
170	power source
172	electrodes
174	battery
180	optical coupler
190	driving circuit
241	fluid inlet
242	top microfluidic channel
243	fluid outlet
244	bottom microfluidic channel
246	channel interconnection

The methods, systems, apparatus and devices of the present invention provide a planar integrated optical waveguide type surface plasmon resonance (SPR) sensor. A SPR sensor is the device that measures the changes of refractive index or dielectric constant near the surface of a thin metal layer, resulting from interaction of delocalized electrons in the metal film and photons from an incident light. The metal film is prepared to have a functionalized surface for the adsorption of biochemical molecules. The binding of the molecules changes the refractive index, which is monitored, conventionally, by the absorption peak shift.

As shown in FIG. **2**, in an embodiment the integrated SPR sensor **100** includes an optical waveguide **130**, SPR sensor areas **150** for surface plasmon generation, photodetectors **120**, and microfluidic components **140** fabricated on a single substrate **105**. FIG. **3** shows a top view of the substrate **105** on which the planar optical waveguide **130** is fabricated. The SPR sensor area **150** is formed to couple with a portion of the planar optical waveguide **130** and the photodetectors **120** are formed to couple with one end of the optical waveguide **130**. The other end of the optical waveguide interfaces with a light source. The planar integrated SPR sensor **100** is fabricated on substrate **105** using known technologies from semiconductor production and integrated optics.

The use of the optical waveguides **130** in the integrated SPR sensor **100** provides a simple way to control the optical path in the sensor system including efficient control of properties of the light and suppression of the effect of stray light. Integrating the optical waveguide **130**, the SPR sensor areas **150** and the photodetectors **120** on a single planar substrate **105** also reduces the size of the integrated SPR sensor **100** and allows for batch production.

Functionally, a light wave is guided by the optical waveguide and, entering the region with the SPR sensor area, it evanescently penetrates through the SPR sensor area. If the surface plasmon wavelength and the guided mode are phase-matched, the light source excites the surface plasmon at the outer surface of the SPR sensor area and is absorbed.

The planar integrated SPR sensor **100** optionally includes an integrated microfluidic structure **140**. The microfluidic structure **140** is fabricated on a two-dimensional flat surface of the substrate **105** as shown in FIGS. **12***a* through **12***d*, using interconnections **246** for coupling between the top and bottom fluidic channels **242** and **244**, respectively. FIG. **4** shows a section of the integrated SPR sensor microfluidic components fabricated on the substrate **105** in relation to the optical waveguide **130** and the photodetectors **120**. As shown, the microfluidic components include a top microfluidic channel **242**, a bottom microfluidic channel **244** and a microfluidic channel interconnection **246** for routing the target sample from the top channel **242** to the bottom channel **244**. The top microfluidic structure **242** brings the target sample in contact with the SPR sensor area in the sensing branch **135** while the bottom microfluidic structure **244** routes the target sample to contact another SPR sensor (not shown) in the reference branch **133**.

An inlet **241** is provided for receiving the target sample which after flowing into and through the bottom microfluidic channel **244**, is extracted through outlet **243**. The arrows indicate the flow of the target sample into the top microfluidic channel **242**, through an interconnection **246** to the bottom microfluidic channel **244** and out of the bottom microfluidic channel **244** outlet **243**. The fluidic channels shown in FIG. **4** are for illustration, alternative configurations of the microfluidic channels will be obvious to those skilled in the art.

In an alternative embodiment shown in FIGS. **5***a* and **5***b*, the planar integrated optical waveguide SPR sensor includes a microfluidic channel network and an optical waveguide coupled with a semiconductor laser **110** and an optical coupler **180**, respectively. The microfluidic channel network includes microfluidic components such as a microfluidic reaction chamber, and top and bottom channels **242** and **244**, respectively, and a power source as shown in FIG. **5***b* and alternatively includes a microfluidic mixer **142** as shown in FIG. **5***a*. Target samples are driven from external pumping sources or, alternatively, micro pumps are integrated into the microfluidic structure.

Microfluidic channels are used as a conduit for the sample introduction and inlets **241**, outlets **243** and interconnections **246** are used for routing the sample solutions to overcome 2-dimensional confinement and to allow flexibility in fluidic configuration. The optional reaction chambers are used for biological or chemical reactions while the optional micro mixers allow mixing of different biological or chemical samples. The micro pumps are used to deliver the sample solutions to the reaction chambers and over the optical sensing elements. Microfluidic components facilitate sample handling at the small scale while providing capability of sampling multiple assays and increases accuracy in the sample analysis.

In the embodiment shown in FIG. **6**, the integrated SPR sensor **100** includes a semiconductor laser **110**, such as a traditional edge-emitting semiconductor laser, in the optical system. The planar optical waveguide **130** couples the laser light to the SPR sensor area **150** that operates on the measuring principle of the surface plasmon resonance in order to measure the target sample brought into contact with the SPR sensing area **150**.

The semiconductor laser **110** is fabricated on the substrate **105** using known technologies along with the aforementioned components to allow the design and manufacture of a micro planar integrated SPR sensor. The main advantage of the integrated semiconductor laser is the fixed positioning of the light source relative to the planar optical waveguide, this eliminates the alignment problems associated with the prior art SPR sensors.

Alternatively, the integrated SPR sensor uses a wavelength tunable laser to obtain an absorption spectrum of the transmitted light and detect variations of refractive index by monitoring changes in the frequency corresponding to the maximum absorption. The use of wavelength tunable light source is essential for the operation of the integrated SPR sensor in this embodiment. Basically the SPR sensor is the combination of metal coated sensor head and a spectrometer for the analysis of modulated spectrum of the light from the sensor head. The tunable laser and photodetector combination functions as a spectrometer in this embodiment of the integrated SPR sensor of the present invention.

The tunable laser can be a current controlled tunable laser or other kinds of tunable laser. For example, distributed Bragg reflector (DBR) laser diode is fabricated by conventional semiconductor optoelectronic device manufacturing methods. In the case of Bragg grating based tunable laser, wavelength tuning can be realized by separately applying currents to the grating and non-grating sections. The current applied to the grating sections tunes the wavelength of operation while other current maintains optical gain for laser action. The integrated SPR sensor **100** includes a power source **170** as shown in FIG. **6**, or other means for providing a driving current for use by the tunable laser and a bias voltage for the photodetectors.

FIG. **7** is a side view of the planar integrated optical waveguide SPR sensor of FIG. **6** showing the substrate **105** and the components fabricated on the substrate **105**. The side view is divided into three sections showing fabrication of the wavelength tunable laser in the left section, the SPR sensing area in the center section and the photodetector in the section on the right. As shown, the waveguide **130** couples with the wavelength tunable laser at one end and with the photodetector at the opposite end. The SPR sensor area includes a thin metal layer **152** formed over a section of the optical waveguide **130** and a dielectric layer **154** deposited on the thin metal layer **152**. The photodetector and the wavelength tunable laser sections include electrodes **172** for receiving a driving current to power these wavelength tunable type devices.

FIGS. **11***a* through **11***i* show an example of fabrication steps for the integrated SPR sensor of the preferred embodiment. However, the fabrication steps and materials may be changed depending on the device structural requirements. On silicon or GaAs substrate **105**, SiO_2 and SiON layers **106** and **107**, respectively, are deposited (FIG. **11***a*) and by reactive ion etching, the optical waveguide **130** is patterned as shown in FIG. **11***b*. Metallic film such as gold is deposited and pattered for the SPR sensor head **150** over a section of the optical waveguide **130** and for the electrodes **172** for photodetector at one end of the optical waveguide **130** as shown in FIG. **11***c*. Alternatively, optical waveguide **130** is formed using photosensitive polymers such as SU-8 without reactive ion etching step.

Polysilicon **122** is deposited over the electrodes **172** as shown in FIG. **11***d* to make the photodetectors. As shown in FIG. **11***e*, microfluidic components **140** are made of photosensitive polymers such as SU-8 for routing the target sample into contact with the SPR sensor head **150**. Depending on the final configuration, different steps are taken. For optical fiber coupling type devices (FIGS. **11***f* and **11***g*), reactive ion etching is performed to make a groove **160** which is used as an optical coupler. Finally, the optical fiber **180** is inserted into the groove **160** as shown in FIG. **11***g*, forming the optical coupler. As shown in FIG. **11***h*, for the laser diode integrated type of SPR sensors, reactive ion etching is performed to make a groove **162** for hybrid assembly or embedding of tunable laser diode **110** which is integrated into the substrate **105**.

In the configuration shown in FIG. **8**, the planar integrated optical waveguide SPR sensor **100** includes an optical fiber **180** for coupling the light from an external light source (not shown). The integrated SPR sensor **100** in this embodiment includes a channel **160** formed in the substrate **105** and overlaying layers for coupling the optical fiber **180** with the optical waveguide **130**. FIG. **9** is a side view of the configuration shown in FIG. **8** divided into three sections. From left to right, the first section shows the coupling of the optical fiber **180** with the optical waveguide **130**, the center section shows the sensing area of the planar device and the right section shows the photodetector, all of which are fabricated on the planar substrate **105**.

As previously described for the embodiment shown in FIG. **6**, the optical waveguide **130** is formed on the substrate **105** and the corresponding SPR sensor area **150** is fabricated by forming the thin metal layer **152** on an area of the optical waveguide **150** and applying the dielectric layer **154** over the thin metal layer. The photodetector section shown on the right illustrates fabrication of photodetector **120** on the planar substrate **105** following the same process as previously described in regard to FIGS. **11***c* and **11***d* and as shown in FIGS. **11***f* and **11***g*, physical confinement of the optical fiber **180** is realized with groove **160** made by reactive ion etching wherein the optical fiber **180** fits into the groove **160**.

Alternatively, as shown in FIG. **10**, the integrated waveguide type SPR sensor includes a driving circuit **190** coupled with the substrate **105** for controlling the semiconductor laser **110** and the photodetectors **120**. The integrated SPR sensor may also include a power source or an interface for supplying power to the integrated SPR sensor as shown in FIG. **6** or a battery **174** as shown in FIG. **10**. The driving circuit may include a means for communicating via a variety of communication formats or may include integrated components such as a microprocessor based controller with memory and a user interface.

Combined integration of the driving circuits and the interconnected fluidic components with the SPR sensor enable a planar on-chip integrated waveguide type SPR sensor which reduces the size of the instruments incorporating the integrated device. Using standard IC fabrication techniques, electronic circuits for controlling wavelength and analysis of acquired signals can be fabricated on the substrate where the SPR sensor shares the same substrate and is made by the compatible micro fabrication process. Integration of components on a single substrate reduces the whole system into a chip size.

In an alternative embodiment, plural optical waveguide type SPR sensors are integrated on a single substrate, each sensor including a light source, waveguide and corresponding SPR sensor area and photodetector. In this embodiment of the invention, plural optical waveguides and corresponding SPR sensor areas may be arranged in parallel and simultaneously brought into contact with one or more target samples. The array of sensors in this embodiment may also include at least one fluidic structure. As previously described, the fluidic structure may include a fluidic channel, a micromixer and a fluidic reaction chamber. Alternatively, multiple optical waveguide type SPR sensors with various target analytes may be formed into an array to monitor multiple biological or chemical reactions simultaneously.

In this alternative embodiment, the multiple micro integrated optical waveguide SPR sensors interface with one another to form an array, however, they are not directly interfaced with one another. Instead, the individual SPR sensors are designed for specific target molecules or cells and the multiple SPR sensors are used to detect a variety of different target samples. For example, multiple strains of a virus, types 1, 2 and 2, can be detected using the array instead of using individual SPR sensor devices for detecting each type.

In summary, the present invention provides new methods, systems, apparatus and devices for micro fabrication of the SPR sensor components on the substrate which fundamentally advances the sensing technology by reducing the SPR sensor size, eliminating complexity in optical configurations and eliminating the problems associated with using out-of-plane components, such as alignment of the external light source.

The micro integrated SPR sensor includes an optical waveguide and corresponding SPR sensor area fabricated on a planar substrate. A photodetector formed on the substrate couples with one end of the optical waveguide and a light source is coupled with the other end of the optical waveguide. The light source is one of a wavelength tunable laser formed on the substrate and an optical fiber and corresponding optical coupler for coupling the light to the optical waveguide. In an embodiment, the micro integrated SPR sensor optionally includes a microfluidic structure fabricated on the substrate with the optical waveguide for routing a target sample to the SPR sensor area.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.

We claim:

1. A planar integrated surface plasmon resonance (SPR) sensor comprising:

a substrate having a first side and a second side;

an planar optical waveguide fabricated on a surface of the first side of the substrate, the optical waveguide having a first end and a second end;

a wavelength tunable emitter on a same surface of the substrate coupled with the first end of the optical waveguide wherein the wavelength of the emitted light is varied to obtain a transmission spectrum of light which passes through a sensing region for detecting variations in a refractive index by monitoring a maximum absorption peak shift in a wavelength domain;

at one single photodetector formed on the same surface of the substrate coupled with the second end of the optical waveguide for measuring a transmitted intensity of light exiting the second end of the planar optical waveguide; and

at least one SPR sensor area formed on the first side of the substrate to couple with a section of the optical waveguide between the wavelength tunable laser and the one single photodetector, wherein the optical waveguide routes a light from the light source past the at least one SPR sensor area which evanescently penetrates the at least one SPR sensor area.

2. The integrated SPR sensor of claim **1**, wherein the at least one SPR sensor area comprises:

an SPR sensing layer; and

an analyte selective layer on the SPR sensing layer.

3. The integrated SPR sensor of claim **1**, wherein each of the at least one SPR sensor area comprises:

a metal coated sensor head coupled with the section of the optical waveguide.

4. The integrated SPR sensor of claim **1**, wherein the light source comprises:

a wavelength tunable laser.

5. The integrated SPR sensor of claim **1**, wherein the light source comprises:

an edge-emitting semiconductor laser coupled with the first end of the optical waveguide.

6. The integrated SPR sensor of claim **1**, further comprising:

a power source coupled with the substrate for providing a driving current to the wavelength tunable laser.

7. The integrated SPR sensor of claim **1**, further comprising:

a voltage source coupled with the one single photodetector for providing a bias voltage to the one single photodetector.

8. The integrated SPR sensor of claim **1**, further comprising:

a communication interface coupled with the integrated SPR sensor to allow the integrated SPR sensor to communicate with a user via a communication format.

9. The integrated SPR sensor of claim **1**, further comprising:

a controller for controlling the operation of the integrated SPR sensor.

10. The integrated SPR sensor of claim **1**, wherein the planar optical waveguide comprises:

a sensing branch coupled with a first one of the at least one SPR sensor area, wherein a target sample is routed into contact with the first one of the at least one SPR sensor area; and

a reference branch coupled with a second one of the at least one SPR sensor area for providing a reference.

11. The integrated SPR sensor of claim **1**, further comprising:

a microfluidic structure having an inlet and an outlet with a channel therebetween fabricated on the substrate for receiving a target sample, routing the target sample into contact with the at least one SPR sensor area and extracting the target sample.

12. The integrated SPR sensor of claim **11**, wherein the microfluidic structure comprises:

at least one of a micro-fluidic reaction chamber, a micro-mixer and a micro pump fabricated on the substrate in connection with the channel.

13. A method for fabricating an integrated optical waveguide type surface plasmon resonance (SPR) sensor, the method comprising the steps of:

providing a substrate;

forming a planar optical waveguide on a surface of the substrate, the optical waveguide having a first end and a second end;

fabricating a wavelength tunable light emitter on a same surface of the substrate coupled with the first end of the planar optical waveguide, wherein the wavelength of emitted light is varied to obtain a transmission spectrum of light which passes through a sensing region for detecting variations in a refractive index by monitoring a maximum absorption peak shift in a wavelength domain;

forming a SPR sensor on the same surface of the substrate in contact with a section of the planar optical waveguide between the first end and the second end;

forming a fluidic structure on the substrate to route a target sample past the SPR sensor; and forming one single photodetector on the same surface of the substrate coupled with the second end of the planar optical waveguide, the tunable light emitter and photodetector combination functioning as a spectrometer.

14. The method of claim **13**, wherein the fabricating a wavelength tunable light emitter comprises the step of:

fabricating a wavelength tunable laser on the substrate, the wavelength tunable laser output coupled with the first end of the optical waveguide.

15. The method of claim **14** further comprising the step of:

fabricating a power source on the substrate for supplying a current to the wavelength tunable laser and a bias voltage to the one single photodetectors.

16. The method of claim **13**, further comprising the step of:

forming an optical coupler on the substrate to allow an optical fiber to couple a light to the first end of the optical waveguide.

17. The method of claim **13**, further comprising the step of:

forming a communication interface on the substrate for communication with the integrated SPR sensor during operation.

18. The method of claim **13**, wherein the step of forming a fluidic structure comprises the steps of:

forming an inlet and an outlet in the substrate for the introduction and extraction of the target sample from the integrated SPR sensor; and

forming at least one channel between the inlet and the outlet for routing the target sample past the SPR sensor area.

19. The method of claim **18**, further comprising the step of:

forming at least one of a microfluidic mixture and an optional microfluidic reaction chamber coupled with the at least one channel on the substrate for mixing of different biological and chemical samples and allowing biological and chemical reactions, respectively, to occur, wherein the fluidic structure facilitates sample handling at a small scale while providing capability of multiple assays and accuracy in sample analysis.

20. The method of claim **18**, further comprising the step of:

forming a micro pump on the substrate coupled with the fluidic structure to route the target sample between the inlet and the outlet and past the SPR sensor.

21. The method of claim **13**, further comprising the step of:

fabricating a controller on the substrate for controlling the operation of the integrated SPR sensor.

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