ap
Asian Journal of Physics Vol. 24, No 2 (2015) 225-230

Micro-prism test chip for surface plasmon resonance

Benny L Chan and Suganda Jutamulia*
EcoLife Technologies, LLC and
Department of Biomedical Engineering, University of Northern California
1300 Valley House Drive #100-7, Rohnert Park, CA 94928, USA

A disposable micro-prism test chip for surface plasmon resonance measurement comprises a micro-tray having at least one through window and a micro-prism mounted on the micro-tray. The micro-tray also has a half-through cavity facing the micro-prism. The surface of the micro-prism in the through window is coated with a thin metal layer. The disposable micro-prism test chip is disposed after at least one use. The micro-prism is fabricated by pulling a heated preform, where the preform has the same cross-section as that of the pulled micro-prism. © Anita Publications. All rights reserved.

Keywords: Surface plasmon resonance, SPR, disposable micro-prism test chip, pulled micro-prism, glass preform, micro-tray, thin metal layer, silicon wafer

1 Introduction

Surface plasmon resonance (SPR) affinity biosensor relies on the measurement of the molecular binding induced refractive index changes and therefore it is label-free technology [1-3]. Due to its high sensitivity, selectivity, and real-time measurement capability, SPR biosensor has become the technology of choice for researchers within the pharmaceutical and biomedical industry to characterize molecular interaction kinetic, thermodynamics, and concentration. SPR biosensors can support an incredible range of applications from qualitative binding to high resolution kinetic analysis. Nearly any interaction involving biological systems including low molecular weight components, proteins, nucleic acids, antibody, and even lipid surface environments are amenable to these instruments.

The SPR based technology continues to expand and improve to become an indispensable analytical tool in biomedical research. Although a tremendous progress has been made in modern days SPR equipment, SPR equipment is mostly based on bulky optics. Portable miniaturized SPR equipment with low cost disposable part is still in demand.

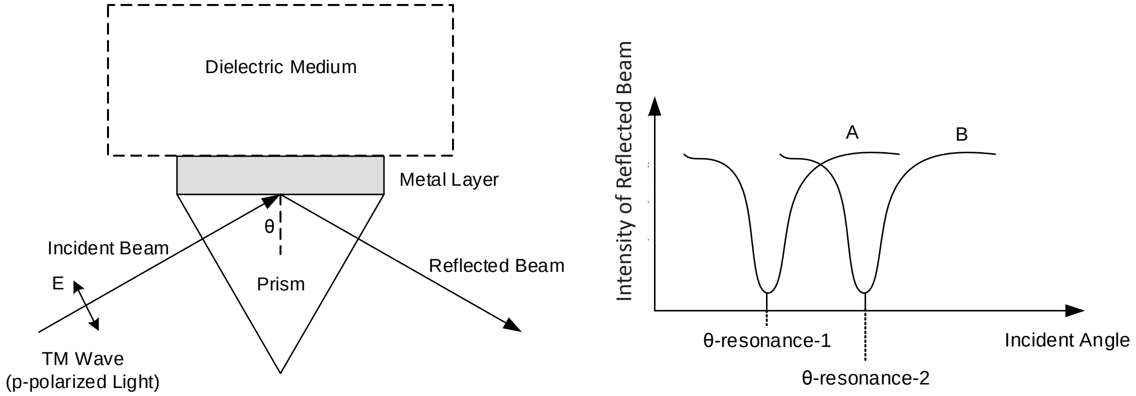
2 Kretschmann configuration

Figure 1A shows the Kretschmann configuration [4] using prism coupling to generate SPR. The Kretschmann configuration typically comprises a bulky glass prism. A side of the glass prism is coated with a thin metal layer. For example, the thin metal layer may have a thickness of about 50 nm. Thin metal layer is in direct contact with a dielectric medium of lower refractive index. When a TM wave (p-polarized) light beam, is incident through the prism on a prism metal interface, the incident beam is reflected. When the incident angle θ of the incident beam is larger than the critical angle between the prism and the dielectric medium without the thin metal layer, an evanescent wave is produced perpendicular to the prism metal interface. The evanescent wave propagates from the prism into the dielectric medium through the thin metal layer and decays exponentially. The evanescent wave is characterized by the incidence angle θ and the dielectric constant of the prism.

The surface plasmon wave (SPW) is a TM electromagnetic wave which propagates at the interface between the dielectric medium and the thin metal layer. The SPW is characterized by the dielectric constants of the thin metal layer and the dielectric constant of the dielectric medium. At a particular resonance incidence angle, θ-resonance, of the incident beam, the energy of the evanescent wave is transferred to excite the SPW. Accordingly, the intensity of the reflected beam is reduced when the energy of the incident beam is transferred to the SPW through the evanescent wave.

Corresponding author :
e-mail: suganda@sbcglobal.net (Suganda Jutamulia)

Figure 1B shows the intensity of the reflected beam as function of the incident angle θ. At the resonance condition, there is transfer of energy from the incident beam to SPW propagating at the interface between the dielectric medium and the thin metal layer resulting in a reduction of intensity of the reflected beam. The intensity of the reflected beam of curve A shows a sharp dip at resonance angle θ-resonance-1. The value of θ-resonance-1 can be determined from curve A, which may be obtained from measurement. If the dielectric constants of the prism and the thin metal layer are known, the dielectric constant of the dielectric medium can be determined. Thus the dielectric constant and also the refractive index of the dielectric medium in contact with the thin metal layer can be determined. Furthermore, when the refractive index of the dielectric medium changes, the reflectance dip shifts to another angle accordingly. For example curve A shifts to curve B, θ-resonance-1 shifts to θ-resonance-2. If the refractive index of a solution is related to the concentration of a component in the solution, the concentration of the component can be determined as well.



(A) (B)

Fig 1. (A) Kretschmann configuration using prism coupling to generate SPR. (B) Intensity of the reflected beam as function of the incident angle θ.

3 Fabrication of micro-prism

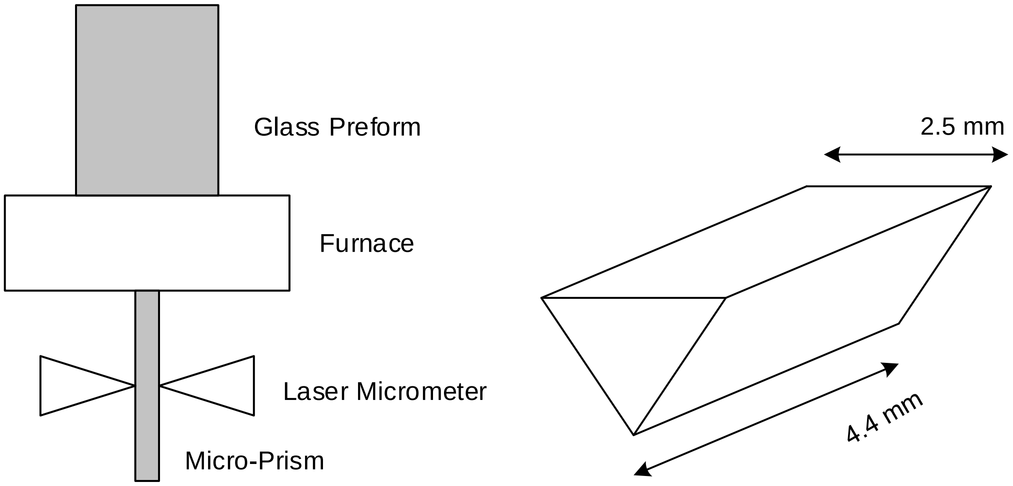
In the proposed system [5], the bulky glass prism of Fig 1A is replaced with a micro-prism, which is fabricated by a special technique similar to a glass fiber drawing technique. The micro-prism serves as a part of a disposable test chip. In the conventional approach, the disposable test chip and prism are two separate components, the bulk prism is built in to the equipment and the disposable test chip is usually a piece of glass slide with processed bio-specific element on the top surface. The disposable test chip, e.g., glass slide, is attached to the bulk prism with index matching fluid and will be discarded after a single or multiple uses. In the proposed system, there is no disposable glass slide. The micro-prism is disposable. Since no glass slide test chip is required, the need of using index matching fluid will be eliminated and the switching between tests will be easy.

The fabrication method for micro-prism is similar to the glass fiber drawing technique. Due to the nature of this glass drawing technique, because it includes cross-sectional size reduction and fire polish, the drawn micro-prism exhibits very high quality surface finish without any subsequent grinding and polishing. Thus the cost may be tremendously low.

There are three major advantages of drawing micro-prism: (1) no initial or subsequent mold cost is required, (2) the precision and product uniformity is excellent, and (3) the combination geometry reduction and fire polishing nature of this process produces very high quality diffraction limited surface finish that may improve the quality of SPR measurement result.

The process involves a drawing tower similar to that for optical fiber production as shown in Figure 2A. The drawing process is relatively straightforward. A glass preform having a shape of prism is suspended vertically above a furnace or oven and lowered slowly. Once inside the heat zone, the lowest part of the glass preform softens and is pulled from below at a rate exceeding that of the feed into the furnace depending on the desired cross-sectional size reduction. The proper pull rate can be calculated based on the feed rate and the conservation of mass in and mass out. The furnace may be temperature controlled. The size of the micro-prism pulled from the furnace may be in-situ close loop controlled by a laser micrometer during the pulling. The drawn micro-prism can be segmented to an appropriate length.

Figure 2B shows an exemplary geometry of a fabricated equilateral triangular micro-prism. Each side of the drawn micro-prism may be approximately 2.5 mm. The length of the segmented micro-prism may be approximately 4.4 mm for a test chip. One side surface of the micro-prism is coated with a thin metal layer, for example, the metal may be gold, silver, aluminum, copper, or other suitable metals.



(A) (B)

Fig 2. (A) Drawing process of micro-prism. (B) Geometry of fabricated micro-prism.

4 Disposable micro-prism test chip

Figure 3 shows schematically a disposable micro-prism test chip (MPTC) of the proposed system [5]. The MPTC comprises a micro-tray and a micro-prism mounted on the micro-tray. The micro-tray can be a silicon tray. The micro-tray can be a molded plastic tray or a metal tray as well. The micro-tray comprises a first through window for forming a first or reference cell on the micro-prism, a second through window for forming a second or sample cell on the micro-prism, and a half-through cavity facing the micro-prism. Epoxy, glue, cement, or other adhesives may fill the trenches of the micro-tray for mounting the micro-prism on the micro-tray. The micro-tray may comprise only one through window or more than two through windows as well. The surface of the micro-prism in the through widow or windows is coated with a thin metal layer.

Figure 4A shows schematically a top view of the micro-tray. As seen from the top view, the micro-tray comprises the first through window and the second through window. Figure 4B shows schematically a bottom view of the micro-tray. As seen from the bottom view, in addition to the first through window and the second through window, the micro-tray also comprises the half-through cavity and the trenches. The half-through cavity and the trenches may have the same etched depth, or may have different etched depth. The half-through cavity and the trenches are facing the micro-prism.

Adhesives may fill the trenches, and the micro-prism may be mounted on the micro-tray. After the micro-prism is mounted on the micro-tray, the top surface of the whole assembly is coated with metal, for example, gold, silver, aluminum, or copper. In this manner, the surface of the micro-prism exposed by the first and second through windows is coated with metal, while the surface of the micro-prism in the half-through cavity is not coated, since it is covered by the micro-tray.

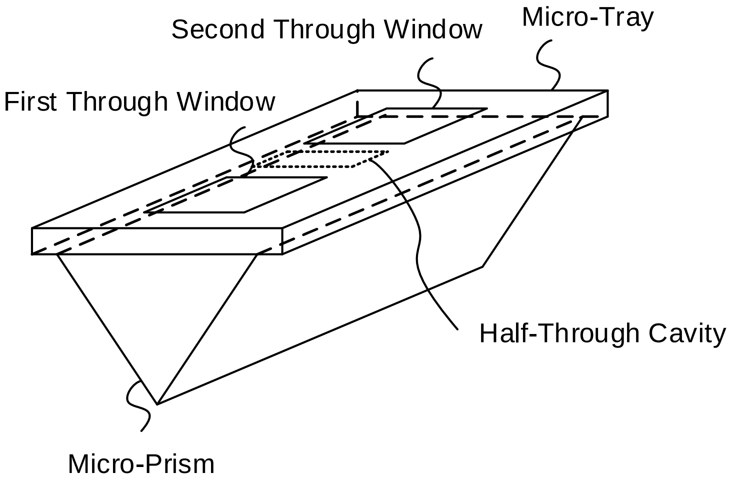


Fig 3. Disposable micro-prism test chip (MPTC) comprising a micro-tray and a micro-prism mounted on the micro-tray.

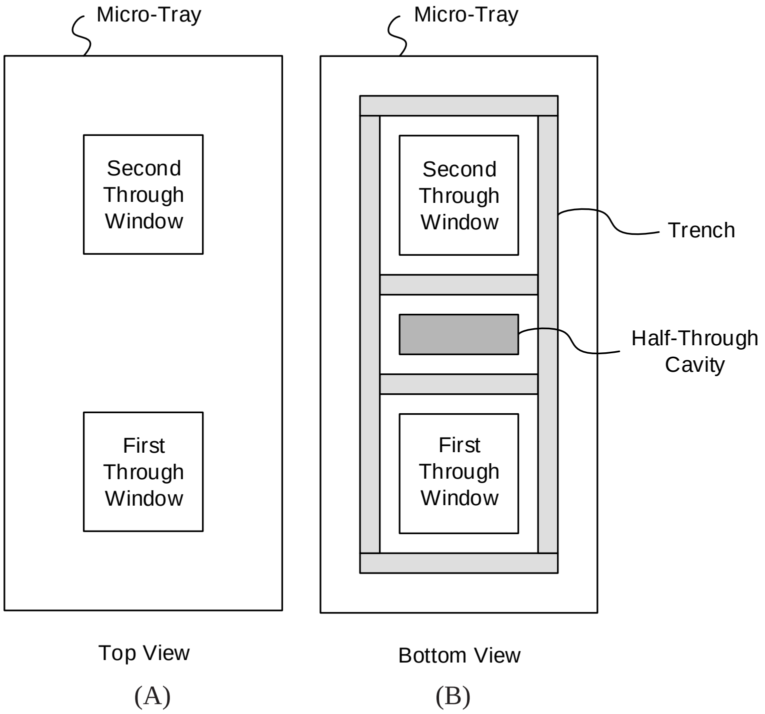


Fig 4. (A) Top view of micro-tray. (B) Bottom view of micro-tray.

The function of the half-through cavity is to provide calibration reference. The half-through cavity contains air. No metal layer is coated on the surface of micro-prism in the half-through cavity. The critical angle is defined at the interface of prism and air. For example, the prism may be made of glass having an index of refraction of 1.5. The index of refraction of air is 1. Thus, the critical angle is 41.81° (sin 41.81° = 1/1.5). If the incident angle at the interface is equal or larger than 41.81° it will be reflected, and if the incident angle is less than 41.81°, the incident light will leave the prism and will not be reflected. Accordingly, the boundary of the detected reflected light and undetected transmitted light at the detector corresponds to the critical angle, which may be used for calibration of the incident angle of the reflected light at the detector.

5 Silicon wafer processing

Figure 5 shows schematically an exemplary silicon wafer [5]. The silicon wafer comprises a number of bands. Each band comprises a number of silicon trays. The silicon wafer may comprise hundreds or thousands of silicon trays. Each silicon tray comprises the first through window, the second through window, the half-through cavity, and trenches. A silicon tray may comprise only one window or more than two windows as well.

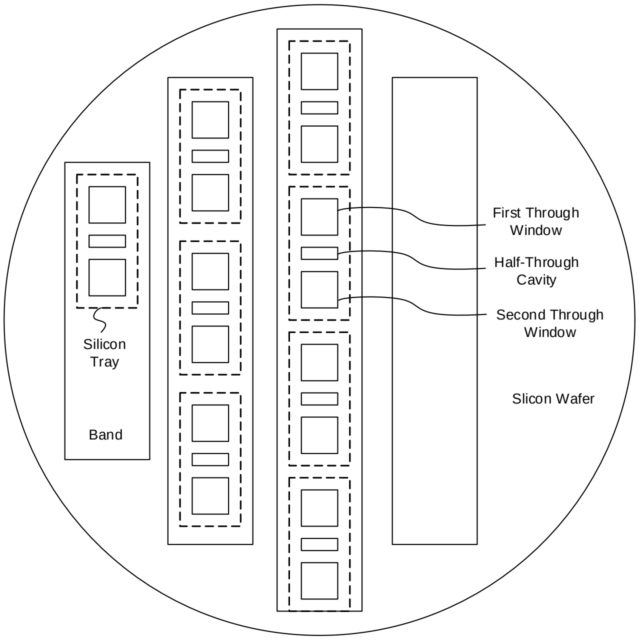


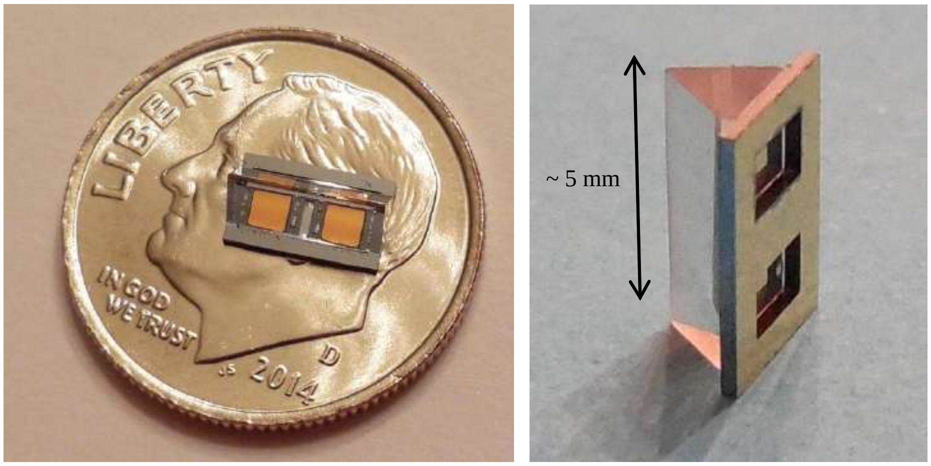
Fig 5. Silicon wafer comprising a number of bands, each band comprising a number of silicon trays.

Adhesives are properly applied at trenches (see Fig 4B) for mounting micro-prisms on the silicon wafer. Micro-prisms having corresponding lengths are disposed on the silicon wafer and registered with each band. After the micro-prisms are mounted on the silicon wafer, the micro-prisms are coated with a thin metal layer through the through windows of the silicon trays. The metal layer on the surface of silicon wafer may be taken away in the following process, or may be left remaining on the surface of the silicon tray. After the coating of micro-prism, the silicon wafer is singulated to form each MPTC comprising a piece of micro-prism mounted on a piece of silicon tray.

Alternatively, the thin metal layer may be coated after the micro-prism and silicon tray are singulated. It is also possible that the micro-prism is first coated with the thin metal layer before mounting on the silicon wafer.

6 Experimental results

Figure 6A shows a fabricated disposable micro-prism test chip on a US dime. For reference, the diameter of the US dime is 17.91 mm. Figure 6B is the close-up of the fabricated disposable micro-prism test chip. The surface of the silicon tray is coated with gold. The surface of the micro-prism is also coated with gold through the windows of the silicon tray. A complete system including a laser diode and a CMOS image sensor is under study.



(A) (B)

Fig 6. (A) Photograph of fabricated micro-prism test chip on a US dime. (B) Close-up photograph of fabricated micro-prism test chip.

References

1. Liedberg B., Nylander C., Lundstrom I. "Surface plasmon resonance for gas detection and biosensing," *Lab Sensors Actuat,* 4(1983) 299-304.
2. Zhang L, Uttamchandanai D, Optical chemical sensing employing surface plasmon resonance, *Electron Lett*, 23 (1988)1469-1470.
3. Homola J, Yee S, Gauglitz G, Surface plasmon resonance sensors: Review, *Sensors and Actuators B*, 54(1999) 3-15.
4. Kretschmann E, Reather, H., Radiative decay of nonradiative surface plasmon excited by light, *Z Naturf*, 23A (1968)2135-2136.
5. Chan B L, Jutamulia S, Micro-prism test chip, US Patent Application Number 14/120,049 (2014).

[*Received* : 05.12.2014 ; *accepted* : 11.12.2014]