Design and Fabrication of Array Format SPR Chips in Microstructure Monolayers Detection

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Abstract-Surface Plasmon Resonance (SPR) has been used in biosensing techniques since 1980s. Optical coupling to surface plasmon resonance is evidenced by attenuated total reflection (ATR) method. SPR sensors characterize the thickness and index of refraction changes of ultrathin films at noble metal surfaces. A SPR chip can be a disposable component for the SPR sensing system. The array format SPR chip performs as a parallel detection platform to various bio-molecules immobilized on sensor surface. With the advantages of high sensitivity and label free sample preparation of SPR techniques, array format SPR chip holds a strong capability in real time imaging system. In this research, we demonstrate the design and fabrication of array format SPR chip. A 50 nm gold layer is thermal evaporated on substrate. We use alkanethiols group to build highly organized microstructures on gold surface after evaporation. The self-assemble alkanethiols monolayers spontaneously form highly organized monolayers on gold surface and immobilize biomolecules on gold surfaces. The final parallel detection goal is reached by SPR imaging system. A SPR imaging system consists of HeNe laser source, array format SPR chip, and photodetector. SPR imaging investigates in-situ measurement and provides high spatial resolution in micro scale biosensing.

Key words: Surface plasmon resonance, biosensing, SPR imaging

I. Introduction

Surface plasmon resonance (SPR) is a phenomenon of near-field optics. An evanescent light wave can generate surface plasmons by coupling photon with surface plasma waves near the surface of a metal, usually noble metals, aluminum, or even semiconductors [1]. When the evanescent wave matches with the resonance condition of surface plasmon and transforms photon energy with surface plasma wave, surface plasmon resonance appears on the interface of metal and surrounding medium. The wave vector of the surface plasmon can be written as

$$K_{sp} = \frac{\omega}{c}\sqrt{\frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2}} \quad (1),$$

where ω is the angular frequency of surface plasma wave, ε_1 represents the dielectric constant of metal, and ε_2 is the dielectric constant of surrounding medium [2]. The Kretschmann configuration of SPR sensor (Fig.1) can easily couple incident light source by attenuated internal reflection (ATR) method [3]. A dip in the reflectance curve exhibits resonance of surface plasmons at the incident angle of SPR condition (Fig. 2). SPR is highly sensitive to surface properties, especially refractive index and thickness.

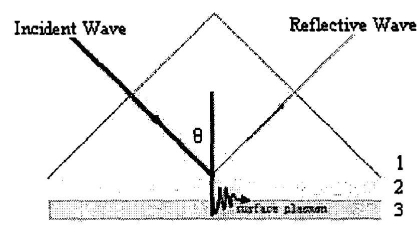


Fig. 1 Kretschmann Configuration. 1. high refractive index prism, 2. metal layer, 3. dielectric layer, and . SPR angle

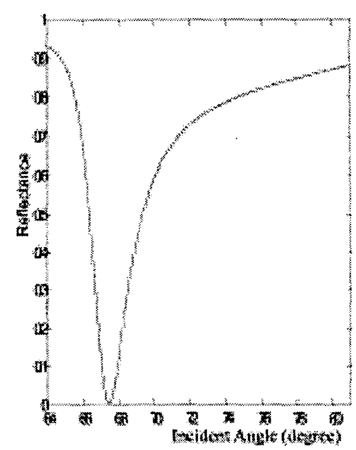


Fig.2 Reflectance of light as a function of incident angle. The sharpest dip of incident angle is associated with surface plasmon resonance

SPR optical sensor has been applied in gas or biomolecular detection since 1980s [4,5]. In general, a SPR sensing system often consists of three subsystems, including an optical system, a SPR sensing component, and an optoelectrical detection system. The research purpose in this paper is to propose a well-defined design and microelectromechanical system (MEMS) based fabrication process of SPR sensing component. A glass substrate is photopatterned with microarray format and vapor deposited a 50 nm gold film as SPR excitation layer. The SPR chip surface with array pattern creates a parallel platform for various biomolecules adsorption on different surface area of one single chip. Alkanthiol self-assembly monolayers are also used for chemical modification on gold surface and controls the adsorption of proteins in our experiment [6].

II. Methodology

A. SPR Chip Design

Array format design on SPR chip is designed for parallel detection purpose. The array element size ranges from 40 μm × 40 μm to 200 μm × 200 μm squares. Each element can be considered as an individual sensing site for enough distance separation from each other. The design tool is AutoCAD2000 software (Autodesk, Inc.). Each design file is printed out on a plastic transparency film and the lateral resolution is within 4 μm limits (Fig. 3). This plastic photomask is compatible with standard lithography process and can be an economical replacement of standard photomask in the chip fabrication.

B. MEMS-based Chip Fabrication

The fabrication process is shown in block diagram format in lower portion of Fig. 4. First the glass substrate (Pyrex) is cleaned with acid piranha solution (a 3:1 mixture of concentrated sulfuric acid with hydrogen peroxide). Then coat with an optical photoresist (Shipley S1813) and transfer pattern by photolithography process. Under high vacuum condition below 10^{-6} Torr through the whole process, first deposit 1 nm chromium film for adhesion layer and then deposit gold film by thermal evaporation apparatus (ULVAC Co., MDEL CRTM-6000). The gold film thickness is 50 nm at a rate of 1Å per second, as determined by a quarts crystal monitor during deposition. After deposition, a lift-off process removes residual phtoresist medium on glass substrate by immersing in acetone solution. The annealing treatment is performed in a temperature-controlled box furnace in atmospheric pressure. The annealing temperature of 300 °C is determined by qualitative results of previous trial experiments. Annealing temperature is raised up to 300 °C and cooled down gradually at 0.3 °C per minute decay in order to relieve residual stress of gold film and rearrange surface roughness.

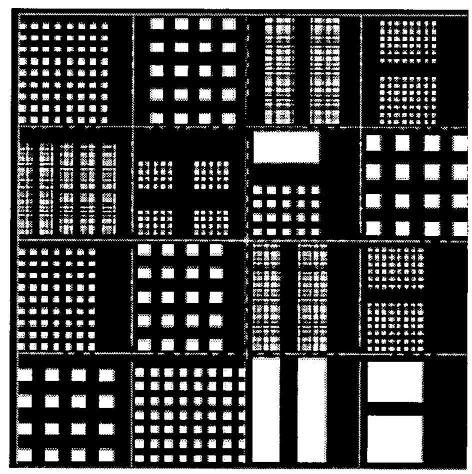


Fig. 3 Array pattern profile on 4-inch glass wafer.

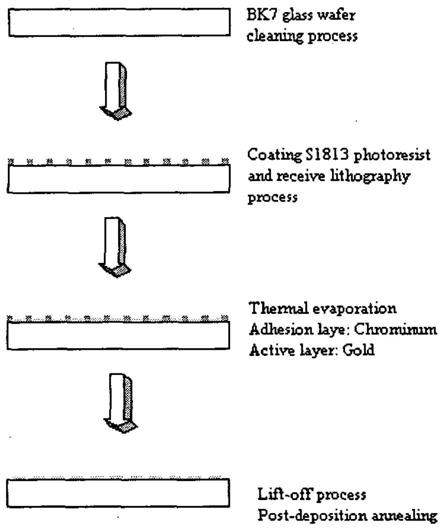


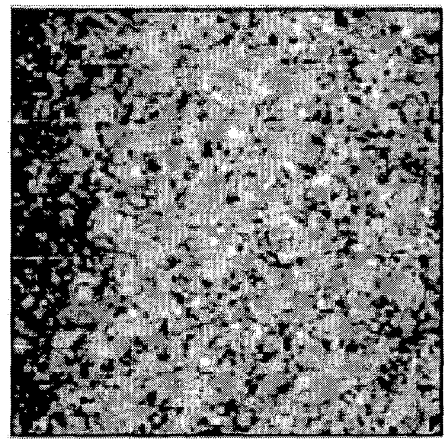
Figure. 4 Block diagram of SPR chip fabrication

C. Biomolecule Immobilization on Gold Surface

The cystamine-glutaraldehyde method is chosed for albumin immobilization on gold surface. The SPR chip is immersed in 10 mM cystamine dihydrochloride (Aldrich) solution for 10 minutes and subsequently washed in PBS buffer solution. Then gold surface is chemically modified with a self-assembly monolayer of alkanethiols and results in a highly oriented monolayer on it. Then immediately immerse in glutaraldehyde (Aldrich) solution (2.5 %) for 10 minutes and also rinse in PBS buffer solution. A droplet of albumin protein solution (100 μg/ml) is deposited on chemical modified surface for 10 minutes. Non-covalently attached proteins are removed by rinsing with buffer solution.

III. Results and Discussion

The surface morphology of gold film is measured by using surface profiler (TENCOR Co., Alpha-Step 500) and two Atomic force microscopy instruments (Thermo Co., and TD-MDK Co.). The line profile from the surface profiler measurement shows the average surface roughness is within 1 nm. The two dimensional $8\,\mu m \times 8\,\mu m$ profile from AFM imaging (Figure. 5, 6) reveals rms roughness of 3.342 nm on gold film and 2.345 nm on glass substrate. Despite amorphous influence of glass substrate, the surface roughness increases approximately 1 nm after gold deposition. The gold film can be regarded as a polycrystalline plane [7]. A crystalline flat gold film insures homogeneous and highly packed self-assembly monolayers microstructure on gold surface. The post-deposition annealing process at low annealing process at low annealing temperature 300 °C may smooth out surface roughness [8]. With optimization of fabrication parameters, we have developed a well-defined design and fabrication schemes of SPR chips.



(164,208) x: 5.10 μm y: 6.475 μm z: 0.01935 μm

Fig. 5 AFM imaging of bare gold film on glass substrate. Sanning area- x:5.10 μm, y: 6.745 μm, z: 0.01935 μm

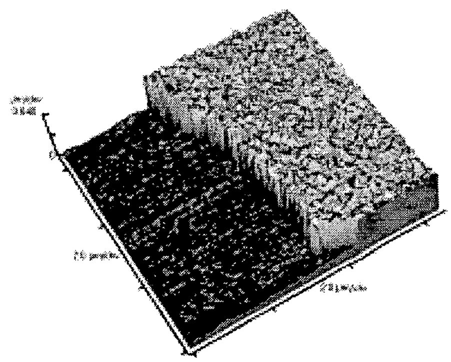


Fig. 6 AFM 2-dimension imaging reconstruction of gold ridge on glass wafer.

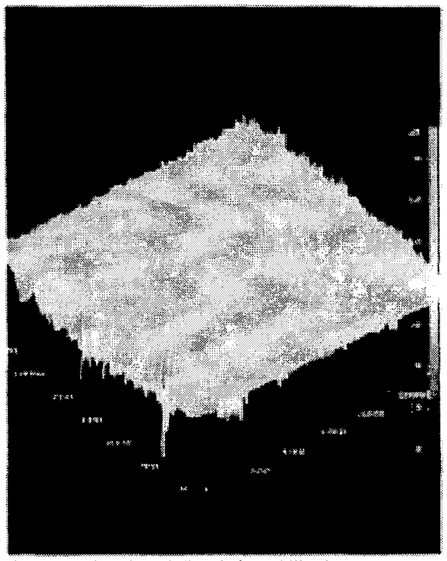


Fig. 7 AFM imaging of albumin immobilization on SPR chip. Scanning area- x: 10 μm , y: 10 μm

IV. Conclusion

SPR array chip can visualize a multianalyte-monitoring platform under identical conditions. A SPR imaging system is going to integrate SPR chips in the near future. The p-polarized light incident onto SPR chip surface at resonant angle by ATR method. A CCD camera detects reflective intensity of plane image [9, 10]. Sophisticated changes of surface refractive index or thickness on SPR chip surface give rise to pixel intensity changes of CCD imaging.

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