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Effects of coating layer on the resonance curve of SPR sensor

コーティング層による SPR センサの共鳴曲線の変化

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1. Introduction

Photoacoustic microscopy (PAM) has attracted attention as a high contrast and non-invasive imaging technique for biological samples. PAM enables to obtain images of biological samples from the distribution of light absorbers such as hemoglobin. By irradiating the light absorber with a specific laser pulse, ultrasound waves are generated due to the photoacoustic effect. These ultrasound waves are usually measured by an ultrasound detector. However, the axial resolution of PAM is not suitable for imaging small cells due to narrow frequency band of the detector. Therefore, for higher resolution in the axial direction, an ultrasound detector with a wide frequency band, and working in the high frequency range is required [1].

In recent years, surface plasmon resonance (SPR) sensors have been reported as ideal ultrasonic detectors with wide frequency band and ultra-flat frequency responses [2]. SPR sensors detect signals due to the changes in the refractive index (RI) near the surface. This sensor is expected to be the future ultrasound detector for PAM, however, often becomes unstable due to the condition of the surface metal layer. In this study, a coating layer was mounted for the protection of receiving surface of SPR sensors. The effects of the coating layer on the reflectance of a SPR sensor was experimentaly investigated.

2. Surface plasmon resonance (SPR)

The surface plasmon resonance results from the electromagnetic excitations near the metal layer. SPR occurs when the momentum matches between the wave number of the evanescent wave k_{ev} (eq. 1) and the surface plasmon wave k_{sp} (eq. 2).

$$k_{sp} = \frac{\omega}{c}\left(\frac{n_d^2 n_m^2}{n_d^2 + n_m^2}\right)^{\frac{1}{2}} \quad (1)$$

$$k_{ev} = \frac{\omega}{c} n_p \sin\theta \quad (2)$$

where n_d, n_m and n_p indicate the RI of external medium, metal layer and base prism material, respectively.

The incident angle of the laser beam should be adjusted to the resonance angle (θ_{sp}), where k_{ev} matches k_{sp}. This angle depends on the refractive index of the metal layer, prism and external medium. At the resonance angle, the light reflectance at the metal surface is strongly attenuated. If the sound pressure is applied to the metal layer, the resonance angle changes because of the changes in the refractive index of the external medium [3]. Then, the SPR sensor may detect changes in the reflectance due to ultrasound.

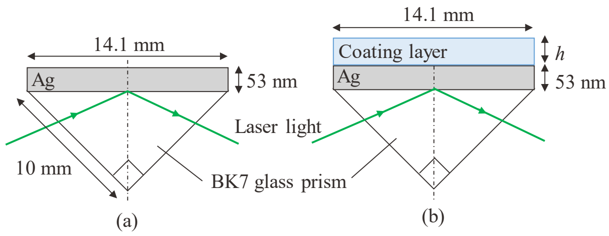

Fig. 1 The fabricated Kretschmann configuration SPR sensor. (a) Uncoated, (b) Teflon coated.

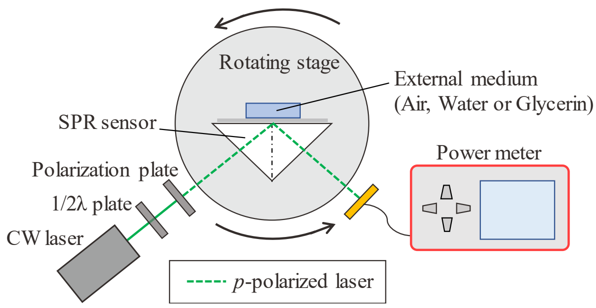

Fig. 2 Reflectance measurement system.

3. Sensor and experiments

Figure 1 shows the configuration of the SPR sensor. SPR stress sensors with Kretschmann configuration were used. The sensors were comprised of an Ag metal layer (53 nm) on the BK7 glass prism, deposited by an electron-beam deposition apparatus (EB1100, Canon Anelva Corp.). Ag surface of the SPR sensor was coated with fluorine resin (Teflon AF2400X, Chemours-Mitsui Fluoro-products Co.).

Table 1 Parameters of external materials.

Parameters	External materials		
	Teflon	Water	Glycerin
RI	1.29	1.33	1.47
Density [g/cm^3]	1.67	1.00	1.26

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Figure 2 shows the experimental system. The system was composed of a CW laser (mcp-3000, Laser Quantum, wavelength: 532 nm). The incident laser light was *p*-polarized. SPR sensors were installed on the rotating stage, and the reflectance was detected by a power meter (PM100D, Thorlabs Japan. Inc.). Reflectance as a function of the incident angle was observed when the external medium was air, water or glycerin.

4. Results and discussions

First, the effects of the coating layer on the resonance condition were investigated by changing layer thickness (h). **Figure 3** shows the shift angle $\Delta\theta_{sp}$ from the basic reflectance curve of the uncoated SPR sensor as a function of h. When the external material was water, the thicker h was, the more θ_{sp} shifted to the lower angle. Compared with the theoretical estimations [4] and experimental results, the experimental results of $|\Delta\theta_{sp}|$ were larger. However, in the case of h > 600 nm, $\Delta\theta_{sp}$ became almost constant, telling that surface plasmon wave was confined in the coating layer. In the following experiments, h value was set to thin thickness (100 nm) where surface plasmon waves could leak outside. Then the effects of external medium on the SPR condition was experimentally confirmed.

Figure 4(a) shows the reflectance curves of uncoated SPR sensors. As can be seen, θ_{sp} could not be observed in the case of glycerin, because no incident angle satisfies the resonance condition. The shift angle between air and water data was 30.2°. The results show that reflectance of uncoated SPR sensor is strongly affected by external medium. **Fig. 4(b)** shows reflectance curves of coated SPR sensors. The shift angle of θ_{sp} was up to 1.3°, showing that effects of external media on the reflectance curve was reduced. In the next step, the effects of ultrasound will be experimentally studied.

5. Summary

In this study, a coating layer was fabricated for the protection of receiving surface of SPR sensors. Effects of external medium on the shift angle of the resonance curves were small, but clearly observed. Further studies are needed in order to investigate the effects of the coating layer on the actual ultrasound detection by the SPR sensors.

References
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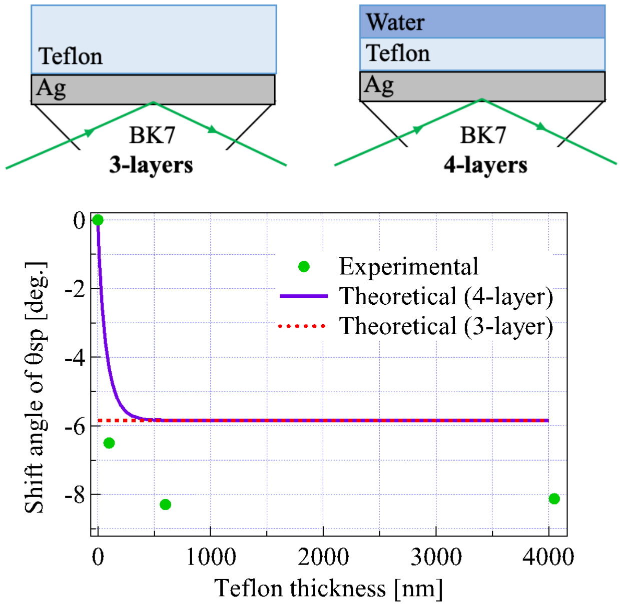

Fig. 3 Shift of resonance angle as a function of coating layer thickness.

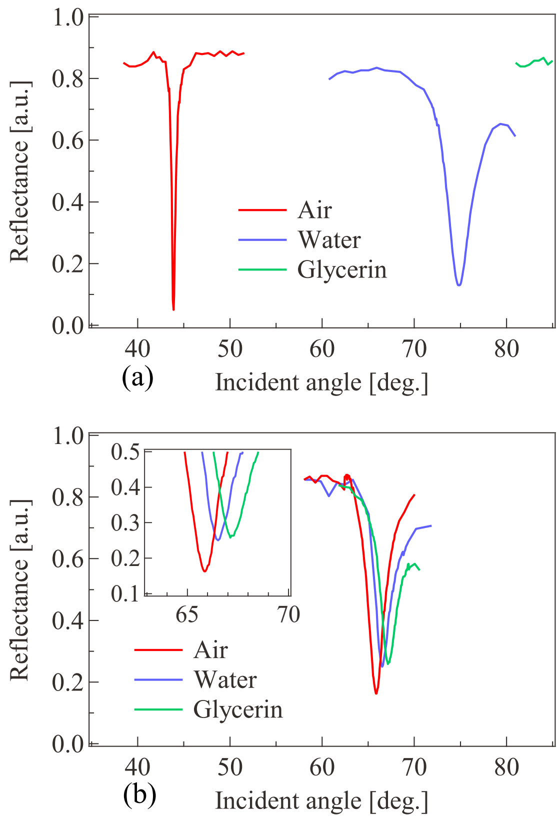

Fig. 4 Reflectance curve. (a)Uncoated SPR sensor. (b)Coated SPR sensor.

Table 2 θ_{sp} of SPR sensors.

Parameters	External material		
	Air	Water	Glycerin
Uncoated	43.9°	74.1°	N/A
Coated	65.8°	66.5°	67.1°