Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp287-288

F-3-03

Investigation of Transmission Light Induced by Grating-Coupled Long-Range Surface Plasmon Resonance and Its Use for Sensors

Hiroshi Nakajyo, Kazunari Shinbo, Naoki Obata, Chutiparn Lertvachirapaiboon, Yasuo Ohdaira, Akira Baba, Keizo Kato, and Futao Kaneko

Graduate School of Science and Technology, Niigata University
2-8050 Ikarashi, Nishi-ku, Niigata 950-2181, Japan
Phone: +81-25-262-7543 E-mail: kshinbo@eng.niigata-u.ac.jp

Abstract

Transmission light property was investigated for glass substrate/500-nm-thick fluoropolymer (CYTOP) with a grating structure/thin metal film/pure water system. Transmission light peaks were observed and the dispersion relation suggested that the peaks were due to long-range surface plasmon resonance (LRSPR). The silver film thickness and grating-pitch dependences were studied and remarkable transmission peaks were observed for 45-nm-thick silver film and 340-nm-grating pitch. The dependence on the refractive index of the ambient liquid was also observed and the transmission peak intensity was remarkable when LRSPR condition was fulfilled. Furthermore, the monitoring of polyelectrolyte layer-by-layer film deposition using transmission light was attempted.

1. Introduction

Surface plasmon resonance (SPR) is known to be a very promising technique for sensing adsorption phenomena and investigating thin film deposition [1]. Prism coupling is widely adopted to produce evanescent waves for SPR excitation. However, the prism sometimes prevents miniaturization of the sensor and a complicated measurement system is needed. Grating coupling is also known for SPR measurement [2]. This method enables the developments of a small sensor and a simple measurement setup. Additionally, it allows us to observe transmission light induced by SPR (T-SPR) [3]. Peaks can be observed in the transmission light spectra, and the intensity and wavelength are used for the SPR measurement.

Long-range SPR (LRSPR) can be induced on a thin metal film sandwiched with dielectrics having similar refractive indices [4]. The LRSPR propagates over a longer distance (a few mm to cm) than standard SPR (a few tens of μm). Additionally, LRSPR accompanies an intense electric field with a long penetration depth. Therefore, LRSPR is a very promising technique for molecular excitation and adsorption sensors. There have been some studies of grating coupled LRSPR [5], but the property of transmission light due to LRSPR (T-LRSPR) is rarely reported [6]. In this study, T-LRSPR was investigated for BK-7 glass/fluoropolymer CYTOP with a grating structure/metal film/pure water system. The dependences on metal film thickness, grating pitch, and refractive index of ambient media were investigated. T-LRSPR spectra were also observed with layer-by-layer (LbL) film deposition.

2. Experimental Design

CYTOP (CTL-809M) was purchased from ASAHI glass and was spin-coated to form a 500-nm-thick on a BK-7 slide glass. The grating structure was prepared on the CYTOP film by an imprinting method under 393 K and 10 MPa for 60 min. Commercially available optical discs (CD-R, DVD-R, and BD-R) were used as molds for imprinting. CYTOP exhibits a similar refractive index to water and was used to induce LRSPR. After the imprinting, a silver film with the desired thickness was evaporated. Finally, the substrate was set to a cell that can hold a solution. Pure water or a mixed solution of pure water and glycerol was put into the cell. The measurement setup is shown in Fig. 1.

A polarized white light was directed into the substrate at the desired angle. SPR can be induced by p-polarized light, so the transmission light of p-polarized light was divided by that of s-polarized light to obtain the T-SPR spectrum. SPR can be induced when a relationship expressed by following equation is fulfilled:

$$k_{SP} = (2\pi/\lambda)\sqrt{\varepsilon_D}\,\sin\theta + m(2\pi/\Lambda) \qquad (1)$$

where k_{SP} is the wavenumber of surface plasmon, λ is the wavelength of incident light in vacuum, ε_D is the dielectric constant of the ambient dielectric, θ is the incident angle, m is the diffracted order (0, ±1, ±2, …), and Λ is the grating pitch.

Furthermore, an observation of the layer-by-layer film deposition was conducted by applying appropriated solutions in the cell.

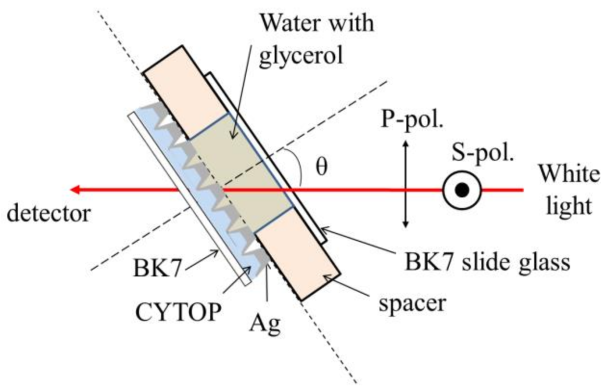

Fig. 1 Measuring setup.

3. Results and Discussion

Figure 2 shows the incident angle dependence of transmission light spectra for BK-7/CYTOP with a BD-R (320-nm-pitch) grating/45-nm-thick Ag film/pure water structure. Sharp peaks were observed and the peak wavelengths depended on the incident angle. To confirm that the peaks were due to LRSPR, the dispersion relations were investigated and the result is shown in Fig. 3. The solid curves are theoretical dispersion relations. That is, the LRSPR dispersion relation for BK-7/flat CYTOP without grating/45-nm-thick Ag film/pure water structure was calculated, and the contributions of grating for several diffraction orders were added. Furthermore, the experimental dispersion relation was obtained from the peak wavelength and light incident angle in Fig. 2, and the results are shown as dots. The experimental result almost corresponds to the theoretical one, suggesting that the transmission lights are due to LRSPR.

Transmission lights were investigated for samples with 15-, 30-, and 45-nm-thick silver films. Remarkable peaks were observed for 45-nm-thick silver, similar to the case of Kretschmann configuration of prism coupling. Additionally, the transmission light spectra were investigated for DVD-R (740-nm-pitch) and CD-R (1600-nm-pitch), and sharp and remarkable peaks were observed for BD-R sample as shown in Fig. 2. The reason has not been clarified, but the BD-R structure would be suitable for sensing applications.

The refractive index of the ambient liquid can be controlled by mixing water (1.3317 at 632.8 nm) and glycerol (1.4740). Figure 4 shows the transmission light spectra for various glycerol weight ratios. An intense peak was observed for 0 and 20 wt%, which is attributed to the fact that the refractive indices are close to cytop (1.3395) and the LRSPR excitation condition is fulfilled. A strong electric field would induce intense transmission light.

A layer-by-layer film deposition was also monitored and the peak wavelength and peak intensity changed with deposition. The T-LRSPR method can be used for monitoring refractive index and detecting molecular adsorption.

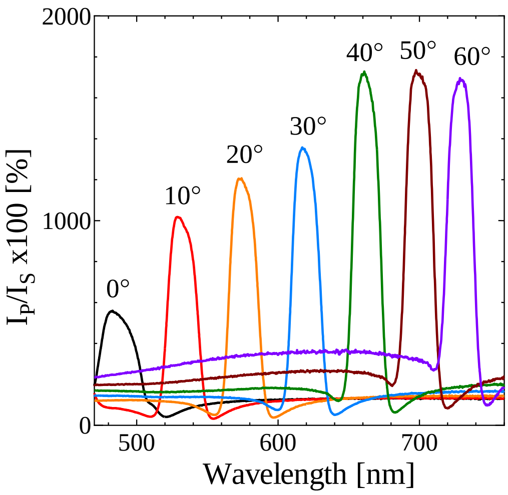

Fig. 2 Incident angle dependence of transmission light spectra for BK-7/500-nm-thick CYTOP with BD-R grating/45-nm-thick Ag/water structure.

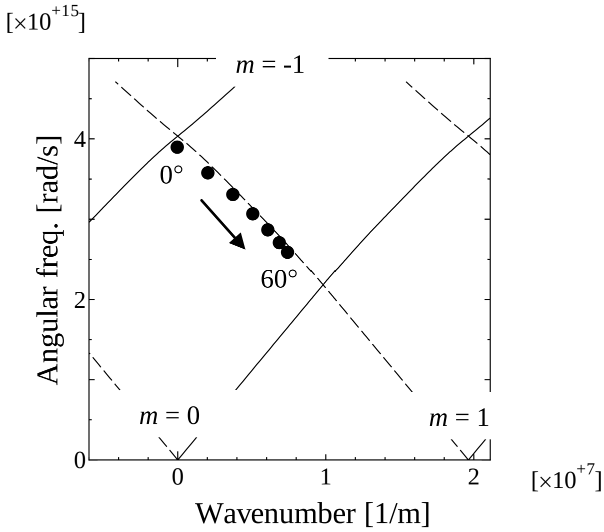

Fig. 3 Theoretical (curves) and experimental (dots) dispersion relations.

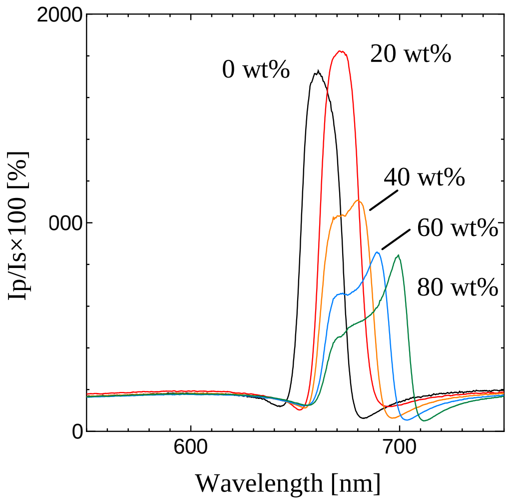

Fig. 4 Transmission light spectra for various ambient liquids.

4. Conclusion

Transmission light property was investigated for BK-7 glass/cytop with grating structure/Ag film/liquid system. Remarkable and sharp peaks were observed when the LRSPR excitation condition was fulfilled, and the transmission lights were estimated to be due to LRSPR. The transmission light depended on the refractive index of ambient liquid and film deposition, and could be used for developing compact sensors with a simple setup.

References

[1] V.M. Agranovich, D.L Mills (eds) *Surface polaritons.* Elsevier, Amsterdam (1982).

[2] W. Knoll, *Annu Rev Phys Chem* 49 (1998) 569.

[3] A. Baba, K. Tada, R. Janmanee, S. Sriwichai, K. Shinbo, K. Kato, F. Kaneko, P. Phanichphant *Adv Funct Mater*, 22 (2012) 4383.

[4] V.M. Shalaev, S. Kawata (eds) *Nanophotonics with surface plasmons.* Elsevier, Amsterdam (2007).

[5] G.S. Agarwal, *Phys Rev B*, 31(1985)3534

[6] K. Shinbo, K. Takizawa, N. Obata, C. Lertvachirapaiboon, A. Baba, K. Kato, F. Kaneko, *Mol. Cryst. Liq. Cryst.*, accepted.