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Surface Plasmon Resonance and Emission Light Properties of Polystyrene Sphere Thin Films

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1. Introduction

Dielectric micro-spheres show interesting phenomena that cannot be observed in bulk states, such as optical localization, photonic bandgap and so on [1-4]. For applications in thin film devices, it is very important to fabricate ordered monosphere films and to evaluate structural and optical properties of the films [5, 6]. The attenuated total reflection (ATR) utilizing surface plasmon resonance, that is, surface plasmon spectroscopy (SPS), is one of useful techniques to evaluate thickness and/or optical properties of thin films [7-12]. Furthermore, emitted light through the prism can be observed due to reverse irradiation in the SPS Kretschmann configuration [9-12]. This emitted light is induced by surface plasmon excitation, i.e., the part of the energy of the surface plasmon is emitted through the prism as far-field light. This phenomenon is very promising for developing new sensors, optical devices and so on [12].

In this study, films of polystyrene (PS) micro-spheres were fabricated, and surface morphologies of the films were observed using atomic force microscopy (AFM). The SPS and emitted light properties due to the reverse irradiation were also investigated in the prism/silver/PS sphere film of the Kretschmann configurations.

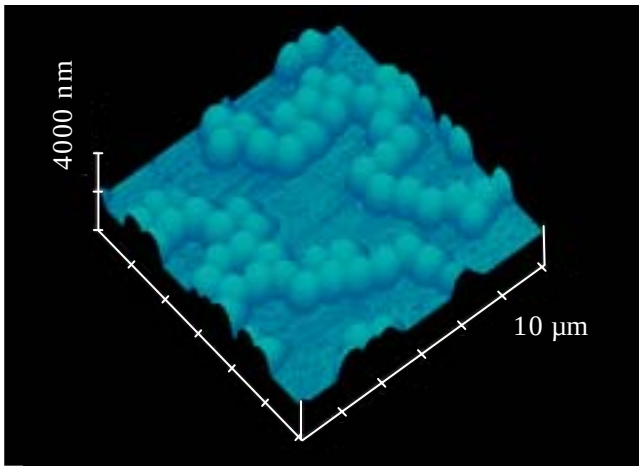
2. Experimental Details

The PS spheres of 1.0 μm diameter were mainly used in this study. Sphere array films were fabricated using the liquid film method described in literature [5, 6]. Ethanol containing 4 wt% 1.0-μm-spheres was dropped on glass substrates or glass substrates coated with Ag film. After the substrates were left for certain time (t_L) for solvent evaporation, the substrates were spun at 4000 rpm for 20 s and the sphere films were obtained.

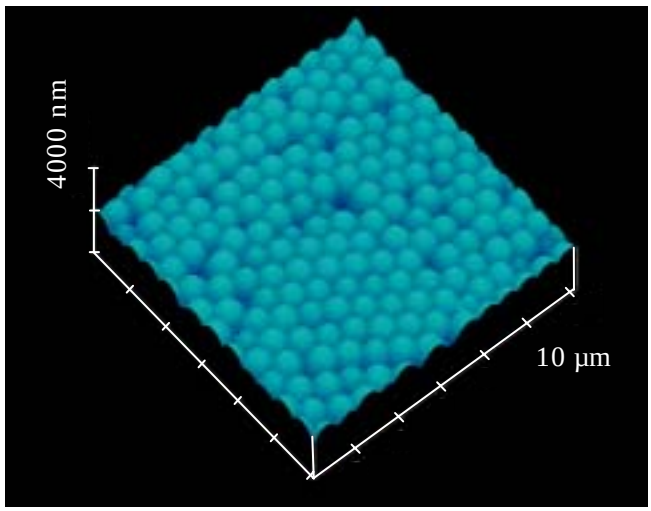
The sample surface was observed using atomic force microscopy (AFM, Digital Instruments, Nanoscope III-a). The SPS and emitted light measurements were carried out for prism/Ag film/sphere film system. The SPS curves were observed using a He-Ne laser with wavelength of 632.8 nm. BK-7 (n=1.515) and S-TIH53 (n=1.847) half-cylindrical prisms were used in this study. Emitted light through the prism was observed around dip angles of SPS curves when the laser beam was irradiated normal to the film from the air. Such emitted light is due to surface plasmon excitations that is induced by surface roughness such as PS particles on the Ag films [11].

3. Results and Discussion

Figures 1(a) and 1(b) show AFM images of the 1.0-μm-PS sphere films on glass substrates. The solvent evaporation times in the fabrication process, t_L, were 1 and 2 min. The sphere coverage on the substrates strongly depends on t_L. Although there are some defects, densely packed, hexagonal structure was observed in Fig. 1(b). For the film with t_L of 3 min, formation of multilayered structure of the spheres was observed.

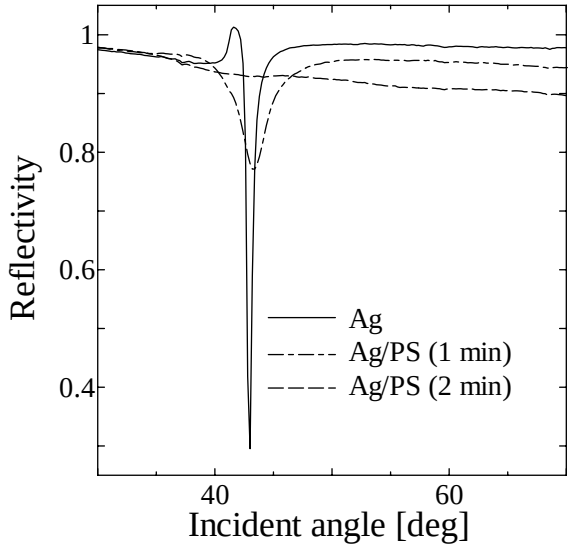


(a) t_L = 1 min

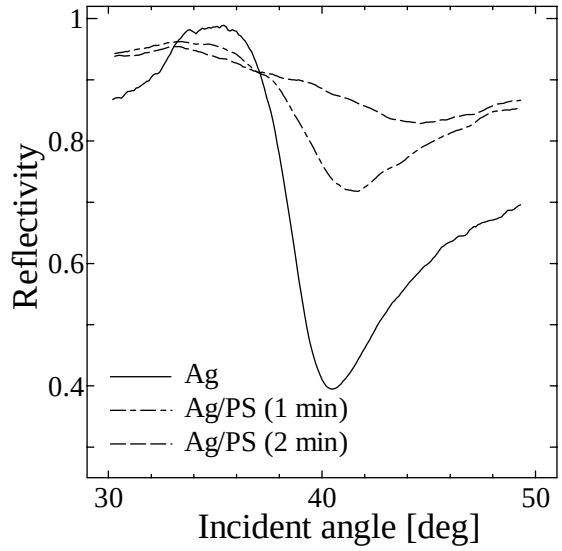


(b) t_L = 2 min

Fig. 1. AFM images of the PS sphere films.



(a) BK-7 prism (n = 1.515)



(b) S-TIH53 prism (n = 1.847)

Fig. 2. SPS Properties of the PS sphere films obtained using different prism.

Figures 2(a) and 2(b) show the SPS curves of the PS films with t_L of 1 and 2 min. The curves in Figs. 2(a) and 2(b) were obtained using BK-7 and S-TIH53 prism, respectively. In Fig. 2(a), SPS dips become shallow with the coverage, that is, the amount of the sphere in the film, and the dip almost disappear when the film has a densely packed structure as shown in Fig.1 (b). The other hand, SPS dips can be observed for the packed film in the SPS curves using S-TIH53 prism, as shown in Fig.2 (b). Moreover, the dip angle shifted with the coverage. The difference of the SPS curves in Fig. 2(a) and (b) is considered to be due to the refractive index of the prism. The refractive index of the polystyrene (1.59) is larger than that of the BK-7 prism and is smaller than that of S-TIH53 prism. Surface plasmon can be excited using the S-TIH53 prism because of the total reflection at the prism surface.

The emission lights through the prisms were also observed for the films. For both BK-7 prism/Ag/PS film and S-TIH53 prism/Ag/PS film systems, the emission peak angles almost corresponded to the SPS dip angles in Fig. 2(a) and 2(b), which indicated that the emissions were due to surface plasmon excitations. Emission peaks also depended on the sphere packing in the film for the S-TIH53 prism/Ag/PS film system.

3. Conclusions

PS micron sphere films were fabricated and the structure and the SPS properties were investigated. Sphere films with excellent packed structures obtained by controlling the solvent evaporation time in the fabrication process. The SPS properties strongly depended on the coverage and the refractive index of the prisms. The emitted light through the prism due to reverse irradiation in the SPS Kretschmann configuration was also observed and the peak angles of the emitted light property almost corresponded with the dip angles of the SPS curves. The light is considered to be caused by the surface plasmon excitation. It is thought that the results are useful for developing new kinds of optical devices.

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