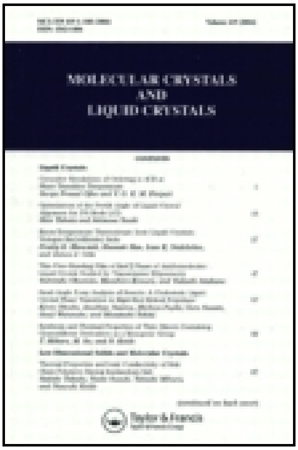

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Surface Plasmon Emission Light from Ag/MgF_2/Organic Dye/MgF_2/Ag Films

Keizo Kato [a c], Masaki Imaia [b c], Yasuo Ohdaira [b c], Kazunari Shinbo [b c] & Futao Kaneko [b c]

[a] Graduate School of Science and Technology, Niigata University, Ikarashi, Niigata, Japan

[b] Department of Electrical and Electronic Engineering, Niigata University, Ikarashi, Niigata, Japan

[c] Center for Transdisciplinary Research, Niigata University, Ikarashi, Niigata, Japan

Version of record first published: 22 Sep 2010

To cite this article: Keizo Kato, Masaki Imaia, Yasuo Ohdaira, Kazunari Shinbo & Futao Kaneko (2007): Surface Plasmon Emission Light from Ag/MgF_2/Organic Dye/MgF_2/Ag Films, Molecular Crystals and Liquid Crystals, 472:1, 51/[441]-59/[449]

To link to this article: http://dx.doi.org/10.1080/15421400701544901

Mol. Cryst. Liq. Cryst., Vol. 472, pp. 51/[441]–59/[449], 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701544901

Surface Plasmon Emission Light from Ag/MgF$_2$/Organic Dye/MgF$_2$/Ag Films

Keizo Kato
Graduate School of Science and Technology, Niigata University, Ikarashi, Niigata, Japan; Center for Transdisciplinary Research, Niigata University, Ikarashi, Niigata, Japan

Masaki Imaia
Yasuo Ohdaira
Kazunari Shinbo
Futao Kaneko
Department of Electrical and Electronic Engineering, Niigata University, Ikarashi, Niigata, Japan; Center for Transdisciplinary Research, Niigata University, Ikarashi, Niigata, Japan

The attenuated total reflection (ATR) properties and emission light due to surface plasmon (SP) excitations have been investigated in the prism/Ag/MgF$_2$/organic dye/MgF$_2$/Ag structure. Poly(2-methoxy-5-(2′-ethyl-hexyloxy)-1,4-phenylenevinylene) (MEH-PPV) was used as the organic dye. SPs were excited at the interfaces of Ag/air, Ag/MgF$_2$ and MgF$_2$/Ag in this structure, and the resonant curve due to the SP excitations was observed by the ATR measurement. The emission light through the prism was observed using various light incidences by reverse and usual irradiations. When the incident light angle was fixed to an SP resonant angle as SPs were excited at two interfaces of Ag/MgF$_2$ and MgF$_2$/Ag, the strongest emission light was observed. The emission light spectra at various emission angles were measured and the emission light was related to photoluminescence of the organic dyes, and the intensity and the spectra strongly depended on the emission angles.

Keywords: attenuated total reflection; emission light; MEH-PPV; organic dye; surface plasmon

This work was partially supported by a Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science.

Address correspondence to Keizo Kato, Graduate School of Science and Technology, Niigata University, 2-8050, Ikarashi, Niigata 950-2181, Japan. E-mail: keikato@eng.niigata-u.ac.jp

INTRODUCTION

Various studies on organic devices of ultrathin films have been carried out. For the development of organic devices with high efficiency, it is quite important to evaluate the structure and functions of the ultrathin films. The attenuated total reflection (ATR) method utilizing surface plasmon (SP) excitation at the interface between metal and dielectric ultrathin films, that is, the surface plasmon resonance (SPR) method is one of very useful techniques for evaluation of dielectric properties of the ultrathin films and sensing [1,2]. SPs are a coupling mode of free electrons and light, and they can be resonantly excited on metal surfaces in the Kretschmann and the Otto configurations by electromagnetic waves due to the total reflection of a p-polarized laser beam [1]. SPs are two-dimensional optical waves and propagate along the surfaces with strong electromagnetic waves, that is, evanescent waves, which decay exponentially away from the surfaces. SPs are also utilized in near-field optics where electromagnetic waves with light frequency are localized in structures smaller than the light wavelength [3]. It is considered that SPs are very important and useful for the application to optical nano-devices [3].

Recently, emission light was observed through the prism in the Kretschmann configuration for the ATR method, when metal ultrathin films on the prism or organic ultrathin films with metal ultrathin films on the prism were directly irradiated from air by a laser beam, that is, reverse irradiation [3–7]. The emission light depended on the surface roughness of the films [6]. The intensities and the spectra of the emission lights strongly depended on the emission angles and the emission light was also related to the photoluminescence of organic dyes [7–10]. In this work, the SP excitations and the emission light were investigated in thye prism/Ag/MgF_2/organic dye/MgF_2/Ag structure with two metal thin layers for SP excitations in both Kretschmann and Otto configurations.

EXPERIMENTAL

The ATR and emission light measurements were carried out for the Ag/MgF_2/Ag and Ag/MgF_2/organic dye/MgF_2/Ag samples. Figure 1 shows the sample configuration of the ATR and emission light measurements for the prism/Ag/MgF_2/oeganic dye/MgF_2/Ag structure. The MgF_2 film is transparent and it has no optical absorption. Poly(2-methoxy-5-(2′-ethyl-hexyloxy)-1,4-phenylenevinylene) (MEH-PPV), which is a photoluminescent dye, was used as the organic dye. The Ag and MgF_2 films were deposited by vacuum evaporation method

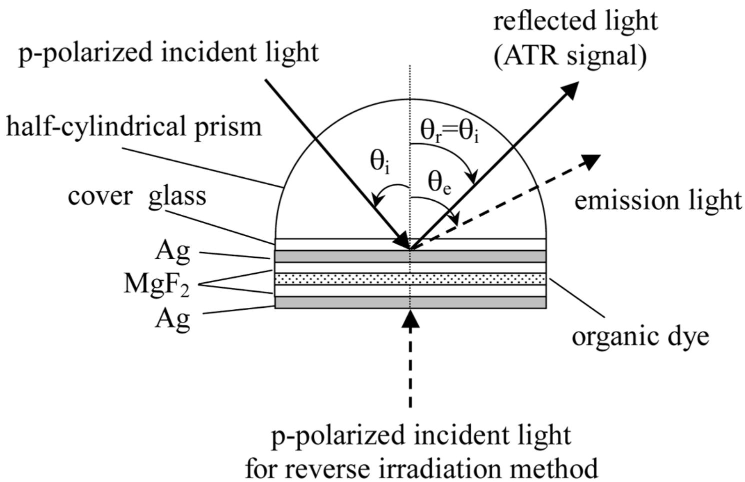

FIGURE 1 Sample configuration of ATR and SP emission light measurements for the Ag/MgF_2/organic dye/MgF_2/Ag structure.

and MEH-PPV film was deposited by spin-coating method. The optical absorption and photoluminescent peaks of the MEH-PPV film were observed at around 500 nm and around 610 nm, respectively.

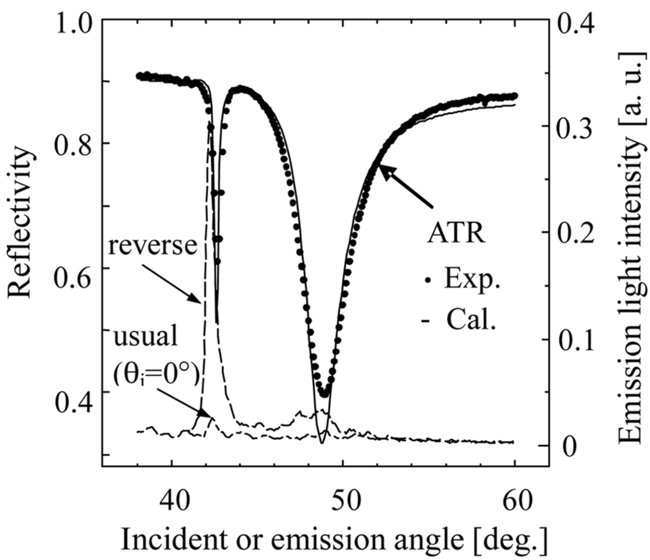

FIGURE 2 ATR and emission light properties for the Ag/MgF_2/Ag sample measured at 632.8 nm by the reverse and usual irradiations.

The Ag/MgF_2/Ag or Ag/MgF_2/MEH-PPV/MgF_2/Ag sample was attached to the bottom of a half-cylindrical prism using a matching oil. The emission light through the prism was observed by the reverse irradiation [6,7]. The emission light for the usual irradiation in the ATR method was also observed. A p-polarized He-Ne laser with the wavelength of 632.8 nm were used for the incident light in the measurement of Ag/MgF_2/Ag sample. An p-polarized Ar^+ laser with the wavelength of 488.0 nm was also used for the incident light in the measurement of Ag/MgF_2/MEH-PPV/MgF_2/Ag sample. The emission lights were observed as a function of emission angle θ_e. A sharp-cut filter that eliminate lights of wavelength below 520 nm was used for the measurement of emission light intensity. A photomultiplier tube was used for detecting the emission light. Detailed descriptions of the emission light measurement have been reported elsewhere [7,8].

RESULTS AND DISCUSSION

Figure 2 shows the ATR and emission light properties for the prism/Ag(50 nm)/MgF_2(260 nm)/Ag(50 nm) structure measured at

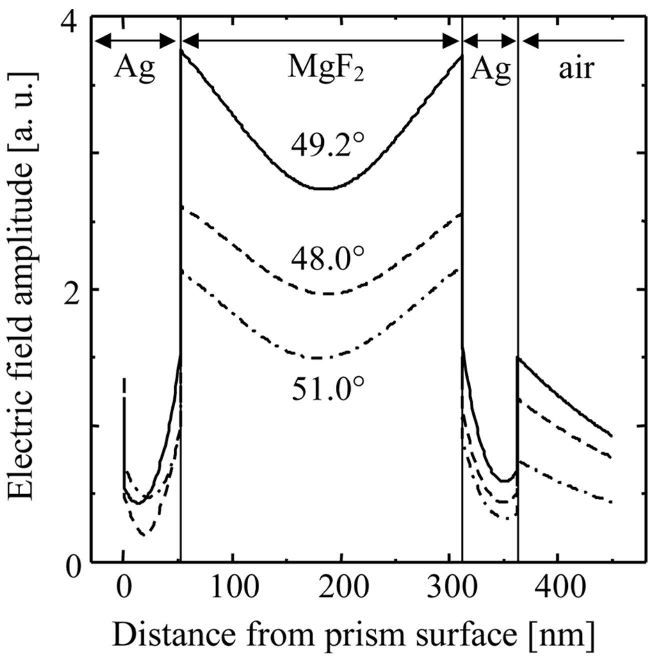

FIGURE 3 Electric field amplitude distribution in the Ag/MgF_2/Ag sample calculated for the incident beam at 632.8 nm.

632.8 nm. The dots and solid curve indicate the experimental and calculated results of ATR property. The theoretical ATR curve were calculated from Fresnel's formula and it agreed with the experimental values well. The dashed curves indicate the emission light properties measured by usual and reverse irradiations. In the usual irradiation, the incident angle θ_i was 0°. In the ATR property, a sharp dip at around 43° and a large dip at around 49° are observed. The resonant dip at around 43° was caused by the SP excitation at the Ag/air interface and the resonat dip at around 49° was caused by the SP excitations at the Ag/MgF_2 and MgF_2/Ag interfaces. The intensity of the emission light measured by the reverse irradiation was stronger than that measured by the usual irradiation, but both specra were the same. Both emission light properties show the peaks at almost the same angles as the resonant angles of the ATR property. This result indicates that the emission lights are caused by the SP excitations mediated surface roughness of Ag thin films [5,6].

The electric fields in the Ag/MgF_2/Ag sample were calculated using a transfer matrix method [11]. The result is shown in Figure 3. The calculations were carried out at the incident light angles θ_i of 48.0°,

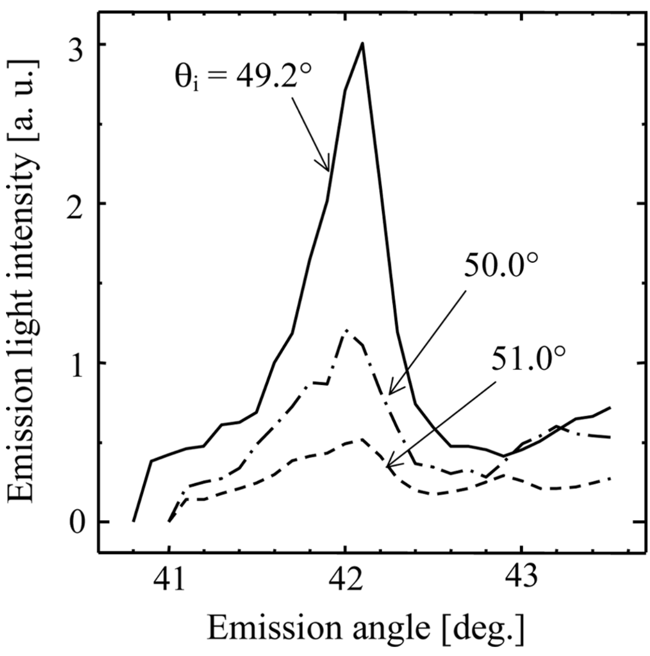

FIGURE 4 Emission light properties for the Ag/MgF_2/Ag sample measured at 632.8 nm by the usual irradiation at the different fixed incident light angles.

49.2° and 51.0°. It is found that the electric fields at the interfaces of Ag/air, Ag/MgF_2 and MgF_2/Ag are enhanced by the SP excitations. The strong electric field are obtained at 49.2° for the SP excitations at the $Ag/MgF_2$and MgF_2/Ag interfaces.

Figure 4 shows the emission light properties for the prism/ $Ag/MgF_2/Ag$ structure measured at 632.8 nm by the usual irradiation at the different fixed incident light angles θ_i. When the incident light angle θ_i was fixed to the angle of 49.2° for the SP excitations at the $Ag/MgF_2$and MgF_2/Ag interfaces, the emission light was observed at around the SP excitation angles of the Ag/air interface. The intensity of the emission light measured at the SP excitation angle was extremely large.

Figure 5 shows the ATR property for the prism/Ag(25 nm)/ MgF_2(180 nm)/MEH-PPV(40 nm)/MgF_2(145 nm)/Ag(40 nm) structure measured at 488.0 nm. The lower resonant angle of around 44° is due to the SP excitation at the Ag/air interface and the higher resonant angle of around 72° is due to the SP excitation at the Ag/MgF_2 and MgF_2/Ag interfaces.

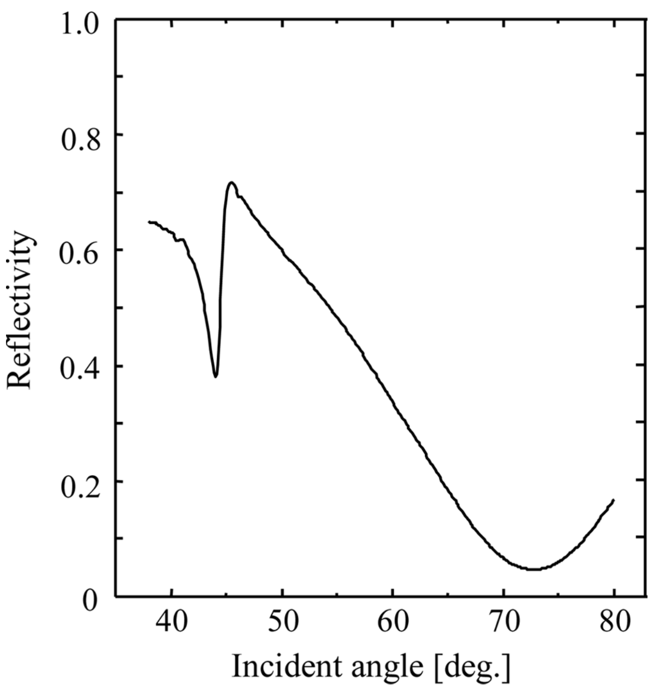

FIGURE 5 ATR properties for the Ag/MgF_2/MEH-PPV/MgF_2/Ag sample measured at 488.0 nm by the usual and reverse irradiations.

The emission light properties for the prism/Ag(25 nm)/MgF_2(100 nm)/MEH-PPV(40 nm)/MgF_2(60 nm)/Ag(40 nm) structure are shown in Figure 6. The emission light measured at the incident angle θ_i of 72.0° of SP excitation had the largest intensity. The emission angle corresponded to the resonant angle of the ATR curve measured at around the photoluminescence wavelength of the MEH-PPV dye. It was found that the emission light intensity and the spectra strongly depended on the emission angles and the emission light was also related to the photoluminescence of the organic dye.

Figure 7 shows the spectra of emission lights at various emission angles for the Ag/MgF_2/ MEH-PPV/MgF_2/Ag structure measured at 488.0 nm at the incident angle θ_i of 72.0° by the usual irradiation. The peaks of the spectra at the lower emission angles were observed at longer wavelengths than. On the contrary, the peaks of the spectra at the higher emission angles were observed at shorter wavelengths. It is found that the spectra of the emission light strongly depends on the emission angle. The emission light is considered to be observed by the following process. The organic dye was excited by the incidet laser light and evanescent waves were induced by the molecular luminescence. Multiple SPs with various number of vibrations on metal

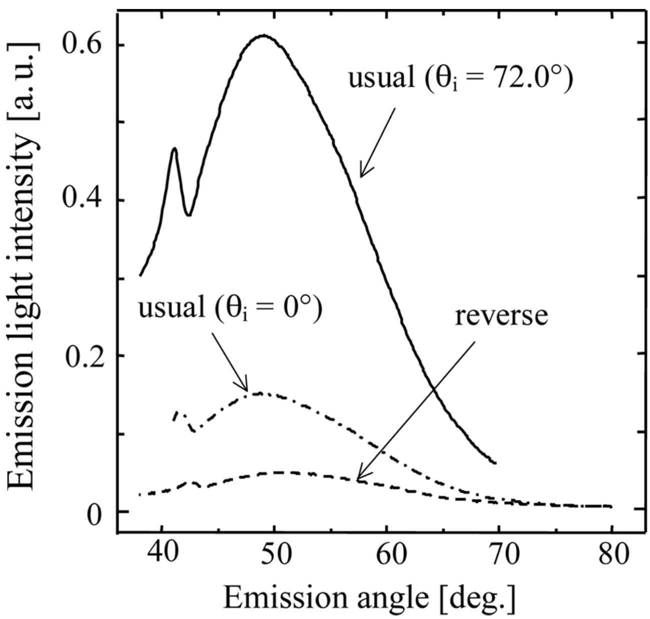

FIGURE 6 Emission light properties for the Ag/MgF_2/MEH-PPV/MgF_2/Ag sample measured at 488.0 nm by the usual and reverse irradiations.

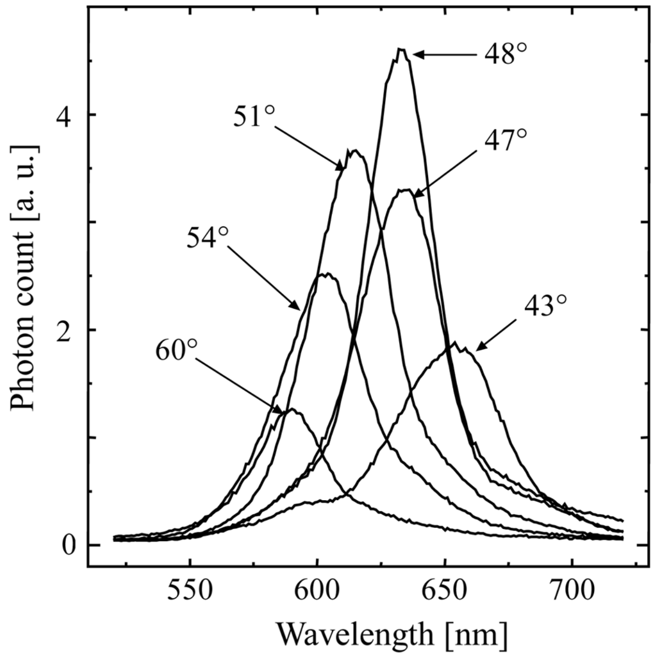

FIGURE 7 Spectra of emission lights at various emission angles for the Ag/MgF_2/MEH-PPV/MgF_2/Ag sample measured at 488.0 nm at the incident angle of 72.0° by the usual irradiation.

surface were excited by the evanescent waves. Then emission light were observed due to near-field coupling of the propagating multiple SPs [9,10]. Further investigation on the emission light from the prism/Ag/MgF_2/organic dye/MgF_2/Ag structure is under way.

CONCLUSION

ATR and SP emission light properties were investigated for the $Ag/MgF_2/Ag$ and Ag/MgF_2/MEH-PPV/MgF_2/Ag samples. In both samples, SPs were excited at the interfaces of Ag/air, Ag/MgF_2 and MgF_2/Ag in this structure, and the resonant ATR curve due to the SP excitations was observed. Extremely large emission lights were also observed in the vicinity of the interface of Ag/Air, when the incident light is fixed to the SP excitation angle of Ag/MgF_2 and MgF_2/Ag. When the incident light angle was fixed to an SP resonant angle as SPs were excited at two interfaces of Ag/MgF_2 and MgF_2/Ag, the strongest emission light was observed. The emission light was related to photoluminescence of the organic dyes, and the intensity and the spectra strongly depended on the emission angles. It is thought that SP emission light is useful for application to new optical devices.

REFERENCES

[1] Agranovich, V. M. & Mills, D. L. (Eds.). (1982). *Surface Polaritons*, North-Holland, Amsterdam.

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

[3] Kawata, S. (Ed.). (2001). *Near-Field Optics and Surface Plasmon Polaritons*, Springer: Berlin.

[4] Pockrand, I., Brillante, A., & Möbius, D. (1980). *Chem. Phys. Lett.*, *69*, 499.

[5] Hayashi, S., Kume, T., Amano, T., & Yamamoto, K. (1996). *Jpn. J. Appl. Phys.*, *35*, L331.

[6] Kato, K., Terakado, M., Shinbo, K., Kaneko, F., & Wakamatsu, T. (2001). *Thin Solid Films*, *393*, 97.

[7] Nakano, T., Terakado, M., Shinbo, K., Kato, K., Kaneko, F., Kawakami, T., & Wakamatsu, T. (2002). *Jpn. J. Appl. Phys.*, *41*, 2774.

[8] Kaneko, F., Sato, T., Terakado, M., Nakano, T., Shinbo, K., Kato, K., Tsuboi, N., Wakamatsu, T. & Advincula, R. C. (2003). *Jpn. J. Appl. Phys.*, *42*, 2511.

[9] Kaneko, F., Wakui, K., Hatakeyama, H., Toyoshima, S., Shinbo, K., Kato, K., Kawakami, T., Ohdaira, Y., & Wakamatsu, T. (2004). *Jpn. J. Appl. Phys.*, *43*, 2335.

[10] Shinbo, K., Toyoshima, S., Ohdaira, Y., Kato, K., & Kaneko, F. (2005). *Jpn. J. Appl. Phys.*, *44*, 599.

[11] Born, M. Wolf, E. (Eds.). (1980). *Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light*, Pergamon: Oxford.