The Condition of Enhancement Effect of Surface Plasmons Excited in Near-Field Optical Structures

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Abstract: In this article, the condition of enhancement effect of Surface Plasmons (SPs) excited in near-field optical structures is demonstrated. If the system possesses smaller loss tangent metal-dielectric, the enhanced-filed intensity of SP is observed being increased. From the results of the analysis of Fresnel equations for a multilayer substrate in near-field optical structures, the higher dielectric coefficient for the prism will reduce the resonant angle, but, if reversely increases dielectric coefficient for intermediate layer, the resonant angle will be increased instead. The SP resonance condition is thus correlated with the loss tangent of the material and the enhanced filed intensity of SP of the system. [The Journal of American Science. 2006;2(3):90-92].

Keywords: surface plasmons; near-field optical structure; SP resonance; Fresnel equation

Introduction

Otto[1] first proposed the optical excitation of SPs by the method of attenuated total reflection (ATR). The SP is basically the transverse magnetic (TM) wave traveling along the metal-dielectric interface. The resonance modes are guided by electromagnetic field at the interface. SP has been used in various applications,[2-13] such as light modulators,[2-5] chemical sensors[6,7] photosignal Schottky diodes,[8,9] spectrometers[10] and so on. Most of the applications of SPs depend on the resonating behavior of SPs in multilayer system. The SP excited at the Sb/SiN interface can enhance the field intensity was first proposed by Tsai et al.[17] . However, the exciting mechanism of SPs has not been clearly understood yet. Basically, the excitation of SPs by light is denoted as a Surface Plasmon Resonance (SPR) for planar surfaces for nanometer-sized metallic structures. By implementing a mask layer to comprise a metal nanocluster-embedded dielectric film, such as Au film, AgO_x-type[18] film, are examples for the studies of generating optical-near field. In this report, the condition of the enhancement field density near metal film on SPs excited in near-field optical structure is demonstrated.

Theory

Consider a super-resolution near-field structure, as shown on Figure 1, in which the dielectric of medium 2 (ε_2) is equal to medium 4 (ε_4). Since the dielectric constant of medium 1 (ε_1) is higher than the dielectric constant (ε_2) or (ε_4), SP can be excited at the 2-3 interface or the 3-4 interface.

By using the Fresnel equations for a four-layer structure and the pole approximate expansion, the transmission coefficient can be expressed as following:

$$T_4 = 1 - \left| r_{12} \frac{(q - q_{23})(q - q_{34}) - \Delta q_{41}}{(q - q_{23})(q - q_{34}) - \Delta q_{42}} \right|^2 \qquad (1)$$

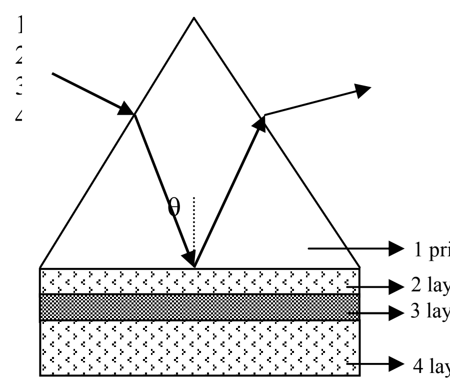

Figure 1. A diagram of the super-resolution near-field structure ($\varepsilon_1 > \varepsilon_4$). 1 indicates prism; layers 2 to 4 are the dielectric mediums; layer 4 is a metal medium

Calculation and discussion

In this study, an incident wavelength (λ) of the He-Ne laser (632.8 nm) and the dielectric constant of antimony (–22.36+35.21i) are assumed. Figure 2 depicts the plot of the transmission coefficient versus incident angle with four different prisms in the Super-RENS (m=4). In Figure 2, the parameters used are ε_2 =4.84, ε_3 =–22.36+35.21i, ε_4 =4.84, d_2 =170 nm, d_3 =25 nm, ε_1 =5.00 (pluses), 6.00 (solid line), 7.00 (dashed line), and 8.00 (dotted line), respectively. From Figure 2, each curve has a maximum value and, by proper selection of the parameters, the reflectivity maximum can be made to approach zero. In addition, the resonant angle decreases when the dielectric constant of the prism increases. Figure 3 depicts the transmission coefficient versus incident angle with four different dielectric constants of the intermediate layer in the Super-RENS (m=4). The parameters used are ε_1 =8.27, ε_3 =–22.36+35.21i, d_2 =170 nm, d_3 =25 nm, $\varepsilon_2 = \varepsilon_4$ =2.84 (pluses), 3.84 (solid line), 4.84 (dashed line), and 5.84 (dotted line), respectively. The resonant angle increases when the dielectric constant of the intermediate layer increases.

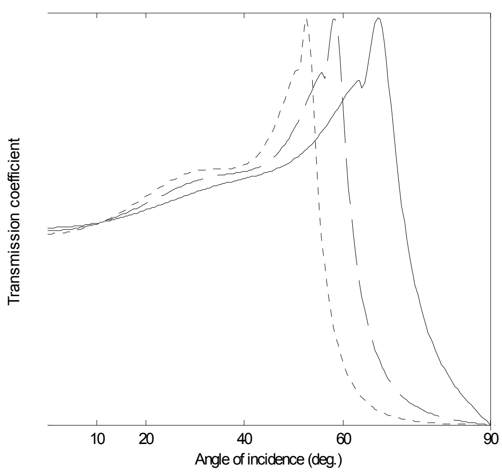

Figure 2. The plot of the transmission coefficient versus incident angle with four different prisms. The parameters used are ε_2 =4.84, ε_3 =–22.36+35.21i, ε_4 =4.84, d_2 =170 nm, d_3 =25 nm, ε_1 =5.00 (pluses), 6.00 (solid line), 7.00 (dashed line), and 8.00 (dotted line), respectively.

The plot of the transmission coefficient versus incident angle with four different dielectric constants of the metal film in the Super-RENS (m=4) is shown in Figure 4. The parameters used are ε_1 =8.27, ε_2 =4.84, d_2 =170 nm, d_3 =35 nm, ε_3 =–22.36+5.21i (dotted line), –22.36+15.21i (solid line), –22.36+25.21i (dashed line), and –22.36+35.21i (pluses), respectively. From Figure 4, the resonant angle decreases and the resonant half width increases when the imaginary part of the metal dielectric constant increases. In other words, the enhanced filed intensity is larger for a system using a metal with a smaller value of loss tangent. In Figure 5, it is shown the plot of the reflectivity versus incident angle with four different thicknesses of the metal film in the Super-RENS (m=4). The parameters used are ε_1 =8.27, ε_2 =4.84, ε_3 =–22.36+35.21i, d_2 =170 nm, d_3 =5 nm (dotted line), 15 nm (solid line), 25 nm (dashed line), and 35 nm (pluses), respectively.

From Figure 5, the reflectivity maximum can be made to approach one by proper selection of parameters. This is the optimum resonant condition for fabricating the Super-RENS.

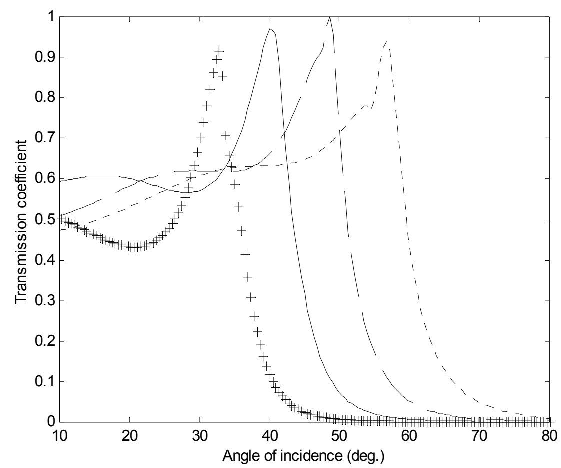

Figure 3. The plot of the transmission coefficient versus incident angle with four different dielectric constants of the intermediate layer. The parameters used are ε_1 =8.27, ε_3 =–22.36+35.21i, d_2 =170 nm, d_3 =25 nm, $\varepsilon_2 = \varepsilon_4$ =2.84 (pluses), 3.84 (solid line), 4.84 (dashed line), and 5.84 (dotted line), respectively.

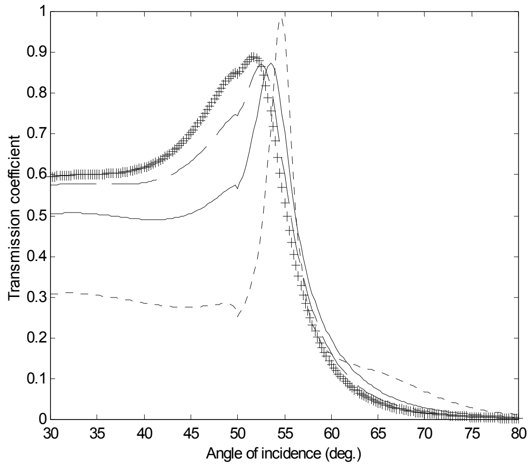

Figure 4. The plot of the transmission coefficient versus incident angle with four different dielectric constants of the metal film. The parameters used are ε_1 =8.27, ε_2 =4.84, d_2 =170 nm, d_3 =35 nm, ε_3 =–22.36 +5.21i (dotted line), –22.36+15.21i (solid line), –22.36+25.21i (dashed line), and –22.36+35.21i (pluses), respectively.

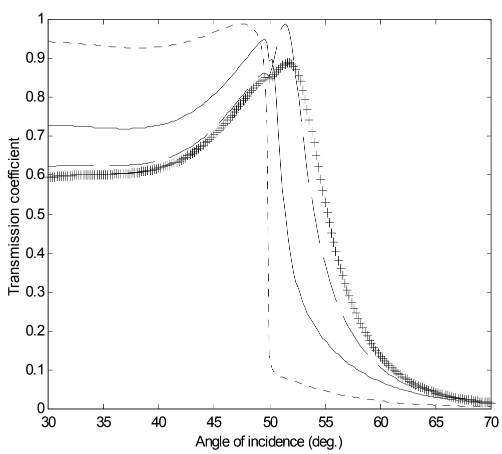

Figure 5. The plot of the transmission coefficient versus incident angle with four different thicknesses of the metal film. The parameters used are ε_1 =8.27, ε_2 =4.84, ε_3 =–22.36+35.21i, d_2 =170 nm, d_3 =5 nm (dotted line), 15 nm (solid line), 25 nm (dashed line), and 35 nm (pluses), respectively.

Conclusion

Conclusively, the enhanced filed intensity increases for a system using a metal film that has smaller loss tangent. The resonant angle decreases when the dielectric constant of the prism increases and the dielectric constant of the intermediate layer decreases and the optimum resonant condition in Super-RENS being made by proper selection of parameters.

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References

1. A. Otto: Z. Phys. **216** (1968) 398.
2. C. M. Lee, C. H. Liao, L. B. Chang and T. L. Chiao: Jpn. J. Appl. Phys. **35** (1996) 5448.
3. D. L. Chiao and C. M. Lee: J. Appl. Phys. **65** (1989) 3344.
4. J. S. Schildkraut: Appl. Opt. **27** (1988) 4587.
5. G. T. Sincerbox and J. C. Gordon: Appl. Opt. **20** (1981) 1491.
6. K. Matsubara, S. Kawata and S. Minami: Opt. Lett. **15** (1990) 7.
7. K. Matsubara, S. Kawata and S. Minami: Appl. Opt. **27** (1988) 1160.
8. I. R. Tamm, P. Dawson, A. Sellai, M.A.Pate, R. Grey and G. Hill: J. Appl. Phys. **74** (1993) 7481.
9. C. Daboo, M. J. Baird, H. P. Hughes, N. Apsley and M. T. Emeny: Thin Solid Films **201** (1991) 9.
10. E. Fontana, R. H. Pantell and M.Moslehi: Appl. Opt. **27** (1988) 3334.
11. E. Betzig and J. Trautman: Science **257** (1992) 189.
12. E. Betzig and J. Trautman, and R. wolfe: Appl. Phys. Lett. **61** (1992) 142.
13. R. T. Deck, D. Sarid, Grieg A. Olson and J. M. Elson: Appl. Opt. **22** (1983) 3397.
14. H. Kitajima, K. Hieda and Y. Suematsu: Appl. Opt. **19** (1980) 3106.
15. G. I. Stegeman, J. J. Burke and D. G. Hall: Appl. Phys. Lett. **41** (1982) 906.
16. J. Tominaga, T. Nakano, and N. Atoda: Appl. Phys. Lett. **73** (1998) 2078.
17. D. P. Tsai and W. C. Lin: Appl. Phys. Lett. **77** (2000) 1413.
18. Y. C. Hera, Y.C. Lan, W.C. Hsu and S.Y. Tsai: Appl. Phys. Lett. **83** (2003) 2138.