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The size effect in the AgO_x -type super-resolution near-field structure

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Abstract

To understand the mechanism of AgO_x -type super-resolution near-field structure (Super-RENS), the size effect is studied by using the photoacoustic measurement. The absorption spectra for AgO_x -type Super-RENS with different thickness are obtained, and the blue shift of the peak position of absorption spectra is successfully observed as the size of the silver particles or clusters in the AgO_x layer is decreased.

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1. Introduction

Since Tominaga and coworkers have proposed the super-resolution near field structure (Super-RENS) as a technology to obtain ultrahigh density storage, it is widely investigated by researchers [1–8]. Briefly, Super-RENS consists of one nonlinear optical layer sandwiched between two dielectric protection layers capped by a recording layer; and the near-field effects are produced from the nonlinear optical layer. The most important advantage for Super-RENS is the superior spatial resolution with no diffraction limit. The original Super-RENS consists of polycarbonate/SiN (170 nm)/Sb (15 nm)/SiN (20 nm)/GeSbTe (15 nm)/SiN (20

nm), in which the Sb layer serves as the nonlinear optical layer [1–3]. However, most recently, Tominaga demonstrated that AgO_x -type Super-RENS with a 15 nm AgO_x layer as the nonlinear optical layer has much stronger near-field intensity and better carrier-to-noise ratio [4]. To understand its mechanism, Tsai et al. introduced the concept of surface plasmon effect to explain the local enhancement in the center of the transmission near-field intensity profiles for AgO_x -type Super-RENS sample, and indicated that AgO_x layer is not just a simple, uniform layer, but a complicated and heterogeneous one, in which are small silver particles or clusters embedded inside [7]. The complicated material structure would give much stronger scattering effects for the incident light and enhance the surface plasmon effect.

Actually, there are a number of particles composed of Ag, AgO and Ag_2O in AgO_x layer that

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have semiconductor character [5]. These nanometer silver particles in the AgO_x layer, as same as that fabricated and utilized semiconductor nanostructures, which are small compared to the bulk exciton Bohr radius should exhibit two- or three-dimensional electron and hole confinement [9–13]. The interband absorption spectrum should change from continuous bands to a set of discrete lines as the size of the particle is decreased. And the discrete interband shifts to higher energy with smaller particle size. In this paper, the size effect of AgO_x -type Super-RENS is studied firstly. The absorption spectra for AgO_x -type Super-RENS with different thickness are obtained, and the blue shift of the peak position of absorption spectra is successfully observed as the size of the silver particles or clusters in the AgO_x layer is decreased.

2. Experiment

In our experiment, photoacoustic measurement has been used, because it is difficult to detect the absorption spectrum of AgO_x -type Super-RENS using ordinary transmission or reflection methods due to its characters of high reflection and scattering. The photoacoustic spectroscopy is a direct monitor of energy band gap and the nonradiative relaxation channel, and can detect the spectra of any type of solids whether it is crystalline, powder or gel [14–16].

The AgO_x -type Super-RENS samples were fabricated by reactive rf reactive-magnetron sputtering method. The Ag_2O layer deposited on quartz glass is sandwiched between 170-nm thick ZnS-SiO_2 and 20-nm thick ZnS-SiO_2 by magnetron sputtering. The thickness of the AgO_x layers are 5, 10, 15, 20 and 25 nm, respectively. The photoacoustic spectra (PAS) for all samples were measured on a simple-beam photoacoustic spectrometer. The excitation source was a 500 W xenon lamp. The optical system was composed of a CT-30F monochromator and a CH353 chopper at frequency of 72 Hz that was used to modulate the light source intensity. The acoustic signal was monitored with the sample placed in an indigenous photoacoustic cell equipped with an electron microphone. The output signal from the microphone

Fig. 1. PAS for the AgO_x -type Super-RENS samples with different thickness of AgO_x layer.

was amplified by a preamplifier and then fed to a lock-in amplifier with a reference signal imputed from the chopper. The PAS of all the samples were recorded at room temperature in the wavelength region 300–500 nm. The final signal was normalized for the changes in lamp intensity using a reference by carbon black.

Fig. 1 shows the PAS for the AgO_x -type Super-RENS samples. In the ultraviolet region 300–350 nm, the absorption peaks which have the fine structure with an about 10 nm interval are observed. An absorption peak is corresponding with an interband transition of the silver particles with a certain size in the AgO_x layer. For Super-RENS samples with different thick AgO_x layer, the wavelength of absorption peak is 306 nm (AgO_x – 5 nm), 318 nm (AgO_x – 10 nm), 339 nm (AgO_x – 15 nm), 304 nm (AgO_x – 20 nm) and 302 nm (AgO_x – 25 nm), respectively.

3. Discussion

The comparison of the PAS for AgO_x -type Super-RENS samples is listed in the Table 1. There is an obvious blue shift of the absorption peak for the samples with 5, 10 and 15 nm AgO_x layers as the thickness of the AgO_x layer is decreased. It is coincident with the size effect, and can be easily explained. When the thickness of AgO_x layer is thin, the clustering is the major way

Table 1

Comparison of PAS for the AgO_x -type Super-RENS samples with different thickness of AgO_x layer

Thickness of Ag_xO layer (nm)	Peak position (nm)	Internal of fine structure (nm)	Intensity (a.u.)
5	306, 317	11	1.40–1.46
10	318, 327	9	1.28–1.50
15	311, 321; 339, 348 9	1.06–1.55	
20	304, 313	9	0.87–1.14
25	302, 312	10	0.77–0.82

of Ag depositing on the dielectric protection layer. And then, the thinner the thickness of the AgO_x layer is, the smaller the silver particles in the AgO_x layer are. Therefore, the blue shift of the absorption peak is shown as the size of the silver particles

(a)

(b)

Fig. 2. Dependence of absorption peak on thickness of AgO_x layer: (a) intensity of absorption peak versus thickness of the AgO_x layer, (b) wavelength of absorption peak versus thickness of the AgO_x layer.

in the AgO_x layer is decreased. However there is an obvious red shift of the absorption peak for the samples with 20 and 25 nm AgO_x layers as the thickness of the AgO_x layer is decreased. It is not contrary with the size effect. When the thickness of AgO_x layers becomes thick, the oxidizing is the major way of Ag depositing on the dielectric protection layer. Accordingly, the thicker the thickness of the AgO_x layer is, the smaller the silver particles in the AgO_x layer are. Therefore the blue shift of the absorption peak exhibits as the size of the silver particles is decreased. The 15 nm thick of the AgO_x layer is a threshold of two ways of Ag depositing on the dielectric protection layer. It is confirmed by two absorption peaks in the PAS for the sample with the 15 nm AgO_x layer, which are corresponding with the silver particles with two different sizes. Fig. 2(a) shows the relationship between intensity of the absorption peak and thickness of the AgO_x layer. The intensity of absorption peak for the sample with 15 nm AgO_x layer is approximately equal with that for the samples with 5 and 10 nm AgO_x layers, but is more great than that for the samples with 20 and 25 nm AgO_x layers. The relationship between wavelength of the absorption peak and thickness of the AgO_x layer is shown in Fig. 2(b). The wavelength of the absorption peak for the sample with the 15 nm AgO_x layer is maximal.

4. Conclusion

In conclusion, the size effect of AgO_x -type Super-RENS is demonstrated by the PAS experiment. The blue shift of the absorption peak is shown as the size of the silver particles in the AgO_x layer is decreased. The comparison of the PAS for AgO_x -type Super-RENS samples shows that

15-nm thick of the AgO_x layer is a key value for the transition of two ways of Ag depositing on the dielectric protection layer from clustering to oxidizing as the thickness of the AgO_x layer is increased. The size effect may be the reason that AgO_x -type Super-RENS exhibit novel nonlinear optical properties not encountered in bulk materials.

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References

- [1] J. Tominaga, T. Nakano, N. Atoda, *Proc. SPIE* 3467 (1998) 282.
- [2] Tominaga, H. Fuji, A. Sato, T. Nakano, T. Fukaya, N. Atoda, *Jpn. J. Appl. Phys. Part 2* 37 (1998) L1323.
- [3] T. Nakano, A. Sato, H. Fuji, J. Tominaga, N. Atoda, *Appl. Phys. Lett.* 75 (1999) 151.
- [4] H. Fuji, J. Tominaga, L. Men, T. Nakano, H. Katayama, N. Atoda, *Jpn. J. Appl. Phys. Part 1* 39 (2000) 980.
- [5] J. Tominaga, H. Fuji, A. Sato, T. Nakano, T. Fukaya, N. Atoda, *Jpn. J. Appl. Phys. Part 39* (2000) 957.
- [6] D.P. Tsai, W.C. Lin, *Appl. Phys. Lett.* 77 (2000) 1413.
- [7] W.C. Liu, C.Y. Wen, K.H. Chen, W.C. Lin, D.P. Tsai, *Appl. Phys. Lett.* 78 (2001) 685.
- [8] F.H. Ho, W.Y. Lin, H.H. Chang, Y.H. Lin, W.C. Liu, D.P. Tsai, *Jpn. J. Appl. Phys. Part 1* 40 (2001) 4101.
- [9] S. Schmitt-Rink, D.A.B. Miller, D.D. Chemla, *Phys. Rev. B* 35 (15) (1987) 8113.
- [10] M.G. Bawendi, *Phys. Rev. Lett.* 65 (1990) 1623.
- [11] L. Brus, *IEEE J. Quantum Electron.* 22 (1986) 1909.
- [12] T. Kishishita, *J. Chem. Phys.* 72 (1980) 5343.
- [13] N. Fominykh, J. Berakdar, *Surf. Sci.* 482–485 (2001) 618.
- [14] C.S. Sunandana, *Phys. Stat. Sol. A* 105 (1988) 11.
- [15] T. Ikarl, H. Yokoyama, S. Shigetomi, *Jpn. J. Appl. Phys.* 29 (5) (1990) 887.
- [16] K.T. Ramakrishna Reddy, R.B.V. Chalapathy, M.A. Slifkin, A.W. Weiss, R.W. Miles, *Thin Solid Films* 387 (2001) 205.