Vol 18 No 7, July 2009
1674-1056/2009/18(07)/2785-03

Chinese Physics B

© 2009 Chin. Phys. Soc.
and IOP Publishing Ltd

The transmission enhancement of a THz pulse through an Ag/Ag_2O layer detected by terahertz time-domain spectroscopy

Chen Hua(陈 华)[a)†] and Wang Li(汪 力)[b)]

[a)] *Department of Physics, Southeast University, Nanjing* 210096, *China*
[b)] *Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing* 100190, *China*

(Received 27 October 2008; revised manuscript received 30 December 2008)

This paper reports a new way to detect the enhanced transmission of a THz electromagnetic wave through an Ag/Ag_2O layer by THz-TDS (time-domain spectroscopy). As the THz beam illuminates the sub-wavelength Ag particles gained by Ag_2O thermal decomposition, the evanescent wave is generated. The evanescent wave is coupled by a 500μm-GaAs substrate, which attaches behind the Ag/Ag_2O layer, and then it transmits to the far field to be detected. The experimental results indicate that the transmitting amplitude is enhanced, as well as the frequent shifting and spectra broadening.

Keywords: terahertz time-domain spectroscopy, Ag_2O, Ag, evanescent wave, frequent spectra
PACC: 4225B, 7830

1. Introduction

Silver oxides decompose into oxygen and small metallic silver particles, and this characteristic has been applied to many areas of technological importance, e.g, in organic solar cells and in chemical sensors,[1,2] as well as in ultrahigh-density optical data storage.[3] Among them, a super-resolution near-field structure (Super-RENS)[4−6] is one of the promising techniques, which was first proposed by Tominaga *et al*,[4] it has been studied and developed as a new technique for ultra-high-density optical data storage.[5,6] When the silver oxides layer is heated with a laser, the layer's material changes its optical properties in such a way that its transmission increases in the region over which the material has become sufficiently hot, which generally occurs only in the vicinity of the centre of the focused laser beam. Since this region can be substantially smaller in diameter than the focused light spot itself, it effectively becomes a small (relative to the diameter of the focused playback spot) aperture in the layer. Further, because the spot's diameter is already very near its diffraction limit, the aperture is sub-wavelength in size. Thus, only the evanescent light appearing at the bottom of this aperture will be coupled out of the layer. This phenomenon has been observed by the tapping-mode tuning-fork near-field scanning optical microscope[7] as well as by the transmission electron microscope[8] and demonstrated by numerical calculations using a finite difference time domain modeling tool.[9] Here, we report a way to observe this effect in terahertz (THz) time-domain spectroscopy (TDS). When the THz beam illuminates the colloidal silver particles which are formed in the Ag_2O layer, the silver particles act as local scattering centres which increase the local electric field amplitude and therefore can effectively form a small transmission aperture. As the evanescent wave does not couple directly with propagating photons, it is necessary to introduce a certain coupling mechanism to measure the energy in the far field. By using a 500 μm-thicked GaAs substrate attached to the layer, the evanescent light was coupled to the far field and then was detected.

2. Sample preparation

In our experiment, a sub-wavelengh Ag particles layer is gained from Ag_2O thermal decomposition. The Ag_2O used by us were purchased from Alfa Aesar and were used without further purification. The

†Corresponding author. E-mail: chenhua@seu.edu.cn

sample was pressed into a 70-μm-thick disk. All procedures were carried out well in a dry condition. Subwavelengh Ag particles are formed in the Ag_2O thin layers when they are heated near the threshold temperature by the beam of the fs-laser. Figure 1 shows the particle size and distribution of Ag_2O and Ag gained by a scanning electron microscope (SEM). It is clearly seen from the images that the particle size of Ag is around 600 nm, and the distribution is uniform.

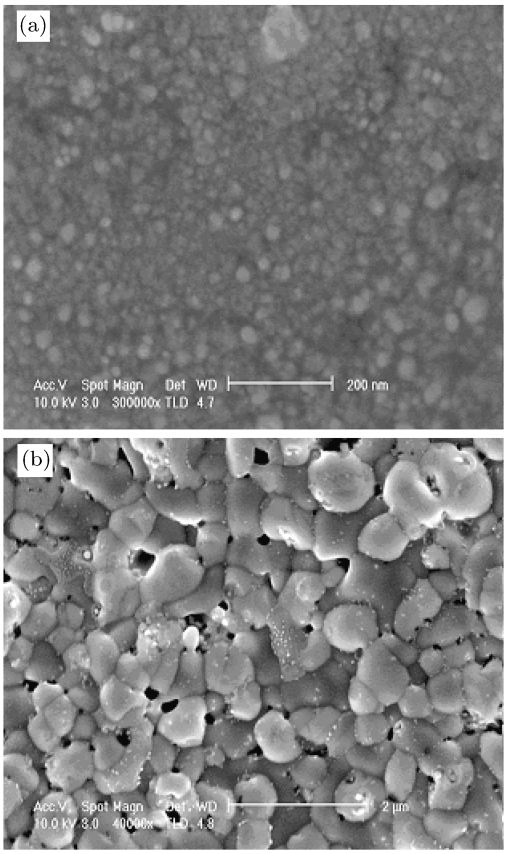


Fig.1. Images of a scanning electron microscope (SEM). (a) An Ag_2O image is collected at the magnification of 300000 and (b) an Ag image is collected at 40000, the particle size of Ag is around 400 nm.

3. Experiments and analysis

A standard terahertz TDS apparatus for transmission measures is used. The setup and corresponding experimental data analysis method have been discussed in detail in our previous reports.[10,11] In brief, the THz-ray is generated by the (1 0 0)-oriented InAs wafer, which was excited by optical pulses from a mode-locked Ti-sapphire laser ($\lambda = 800$ nm, $\tau_{\mathrm{FWHM}} =$ 100 fs). The repetition rate of the laser is 82 MHz. The THz radiation from the InAs is collimated and focused onto the sample layer by means of the off-axis parabolic mirrors. By using another parabolic mirror, the transmitted THz pulses through the sample were again collimated and focused onto the detector, which is an electric-optic (EO) crystal ZnTe.[12,13] A probe beam, derived from the same optical source by a half mirror is employed to gate the detector. In the incidence plane ahead of the sample layer, a metallic hole with 1 mm diameter is put over to ensure that the THz beam waist in the layer plane is 1 mm. A laser beam, derived from the same optical source is employed to heat the Ag_2O layer for 5 min, and the laser power is 120 mW. The spot size of the laser in the layer plane is $\sim$2 mm, so the THz beam transmitting through the sample layer can be considered uniform. In order to get rid of the influence of water vapour on the THz spectra, the experiment is conducted in the vacuum ambience.

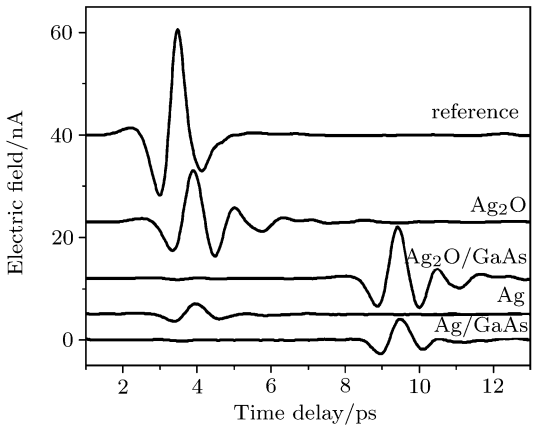


Fig.2. THz waveforms measured in the domain for the four kinds of samples.

In the process of the experiment, we first measured the Ag_2O layer in the THz-TDS system, and then attached it directly to the GaAs substrate by van der Waals force. Next, we heated the Ag_2O layer until Ag_2O changed to Ag completely. Lastly, we took out the GaAs substrate, and detected the Ag layer directly. That is to say there are four kinds of samples: Ag_2O, Ag_2O/GaAs, Ag/GaAs and Ag, which are investigated in the THz-TDS. The THz waveforms measured in the time domain for the four kinds of samples are shown in Fig.2. For clarity, a vertical offset is introduced in the data of Fig.2. The acquired sample and reference waveforms were converted to their Fourier transforms $E_{\mathrm{s}}(\omega)$ and $E_{\mathrm{r}}(\omega)$, respectively, and the transmission spectra were obtained as a ratio of their Fourier spectra, which is $E_{\mathrm{s}}(\omega)/E_{\mathrm{r}}(\omega)$. Because of the clear separation in the time domain between the

transmitted and the first reflected pulses, the multiple reflection effect of the sandwich samples is ignored in the data analysis.

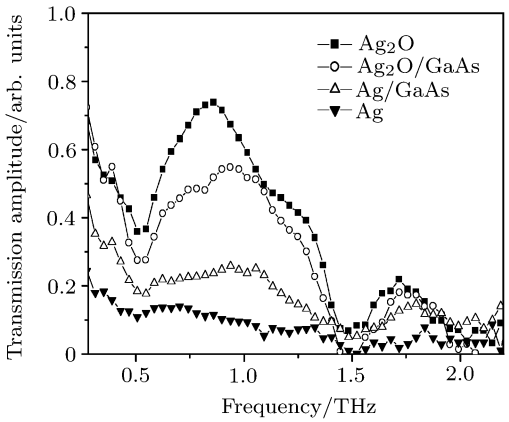


Fig.3. THz transmitting spectra of the four samples.

As usual, the transmittance amplitude of Ag/GaAs in the THz band is smaller than the sample Ag, according to the accessorial absorbance by GaAs. That is to say, the amplitude of THz electromagnetic wave transmitting through the Ag layer should be higher than the Ag/GaAs layer. But in Fig.3, the amplitude of the Ag/GaAs layer is much higher. The thin layer of particle materials Ag resonate with a band of evanescent waves of the near-field object and transfers them to the furthest side. As the permittivity of the material matches with the surrounding medium GaAs, it is possible to couple a wide band of evanescent modes to the far-field. So the transmitted amplitude is enhanced. Then we compare the normalized frequency spectra of incident THz pulse through the Ag and Ag/GaAs layer. In Fig.4, the spectra content of the transmitted pulse from the Ag/GaAs layer shifts to higher frequencies compared to the Ag layer, as well as the spectrum effectively broadening. Here, both radiating and evanescent modes exist, the evanescent waves of the high-frequency component tunnel through the interface,[14−16] enter into the EO crystal and thence are detected. The results above are induced by the embedded silver particles, which form very strong scattering centres.

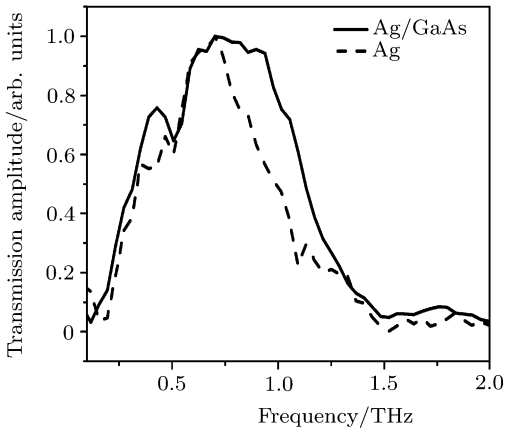


Fig.4. Fourier transform spectra of the time-domain THz waveforms from Ag_2O and Ag.

4. Conclusion

In conclusion, an experiment was conducted to study the enhanced transmission of a THz electromagnetic wave through an Ag/Ag_2O layer by THz-TDS. The layer of particle materials Ag generates evanescent waves and transfers them to the furthest side, and thence are coupled by GaAs substrate to the far-field. The experimental results show that the transmitting amplitude is enhanced. And in frequent domain, the coupled evanescent waves induce the shift and broadening of transmission peaks in the far field.

References

[1] Westphalen M, Kreibig U, Rostalski J, Lüth H and Meissner D 2000 *Sol. Energy Mater. Sol. Cells.* **61** 97
[2] Kellner R, Mizaikoff B, Jakusch M, Wanzenbock H D and Weissenbacher N 1997 *Appl. Spectrosc.* **51** 495
[3] Fuji H, Tominaga J, Men L, Nakano T, Katayama H and Atoda N 2000 *Jpn. J. Appl. Phys.* **39** 980
[4] Tominaga J, Nakano T and Atoda N 1998 *Appl. Phys. Lett.* **73** 2078
[5] Tominaga J, Fuji H, Sato A, Nakano T, Fukaya T and Atoda N 1998 *Jpn. J. Appl. Phys.* **37** 1323
[6] Nakano T, Sato A, Fuji H, Tominaga J and Atoda N 1999 *Appl. Phys. Lett.* **75** 151
[7] Liu W C, Wen C Y, Chen K H, Lin W C and Tsai D P 2001 *Appl. Phys. Lett.* **78** 685
[8] Waterhouse G I N, Bowmaker G A and Metson J B 2001 *Phys. Chem. Chem. Phys.* **3** 3838
[9] Kataja K, Olkkonen J, Aikio J and Howe D 2004 *Jpn. J. Appl. Phys.* **43** 160
[10] Chen H, Qu Y G, Peng W X, Kuang T Y, Li L B and Wang L 2007 *J. Appl. Phys.* **102** 074701
[11] Chen H, Qu Y G, Peng W X, Kuang T Y, Li L B and Wang L 2007 *Chin. Phys. Lett.* **24** 2131
[12] Wynne K and Jaroszynski D 1999 *Opt. Lett.* **24** 25
[13] Jiang Z, Xu G and Zhang X C 2000 *Appl. Opt.* **39** 2982
[14] Kretschmann E 1971 *J. Phys.* B **241** 313
[15] Kroeger E and Kretschmann E 1970 *Z. Physik* **237** 1
[16] Azad A K, Zhao Y G and Zhang W L 2006 *Opts. Letts.* **31** 2637