Surface Plasmon Resonance Switching of Gold Nanoparticles Based on Ultrafast Phase Change of GeSbTe

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Abstract

We demonstrated localized surface plasmon resonance (LSPR) switching of Au nanoparticles (AuNPs) with a phase change of a GeSbTe (GST) material. We observed difference in the magnitude of LSPR shift and damping depending on the degree of interaction between AuNPs and the GST film. In a static measurement, LSPR spectra of AuNPs on a crystalline GST were significantly different from those on amorphous GST, which result is almost consistent with numerical simulation. In a dynamic measurement, for appropriate degree of interaction, we obtained giant switching of LSPR, spectral shift and reduction of scattering intensity, upon repeated amorphization and crystallization by alternate irradiations of femtosecond laser and cw annealing laser.

1. Introduction

Phase change materials such as GeSbTe (GST) compounds are commonly used for rewritable memory devices due to high contrast between the amorphous and the crystalline phase in refractive index and resistance, fast write and erase speeds as well as non-volatility, and low energy consumption. Regarding the write speed, recently we demonstrated sub-picosecond nonthermal amorphization of a GeSbTe thin film with femtosecond laser pulse excitation [1]. Also in the process of erasing, we have found that for nonthermally amorphized phase, crystallization proceeds more efficiently than for the melt-quenched amorphous phase.

Localized surface plasmon resonance (LSPR) of noble metal nanoparticle such as Au and Ag provides us with a strong and highly confined electromagnetic field. The resonance can be modulated by the change of refractive index of the surrounding medium. By combining this unique property of LSPR with the femtosecond phase change, we can achieve ultrahigh density storage, ultrafast switching devices and, more interestingly, neuron-inspired devices by using plasticity and threshold responses of phase change materials.

In this presentation, we demonstrated LSPR switching of Au nanoparticles (AuNPs) on a GST thin film upon phase change between crystalline and amorphous phase.

2. Experiments

Figure 1 shows the sample structure used in this experiment. AuNPs with a diameter of 85 nm was embedded in a polymer (polyvinyl alcohol; PVA) thin film and was partially covered with a $Ge_2Sb_2Te_5$ (GST) film. The thickness of GST film was 30 nm. By changing the thickness d of the polymer film, we can control the degree of interaction (contact area) between an AuNP and the GST film. For $d > 85$ nm, AuNPs were not in contact with the GST film. We also investigated LSPR behavior of AuNPs directly dispersed on a GST (20 nm)/SiO_2 (10 nm) thin film (Fig. 1(b)).

LSPR scattering from individual AuNPs was observed with a dark-field optical microscope setup under white light illumination. Single-particle scattering spectra were measured by using a liquid-nitrogen-cooled multi-channel CCD spectrometer. For amorphization of the GST film a single femtosecond pulse (λ=800 nm) was delivered through a microscope objective and was focused on an AuNP and the underlying GST film. A continuous wave laser diode (λ=830 nm) was used to erase the amorphous region (recrystallization) by thermal annealing.

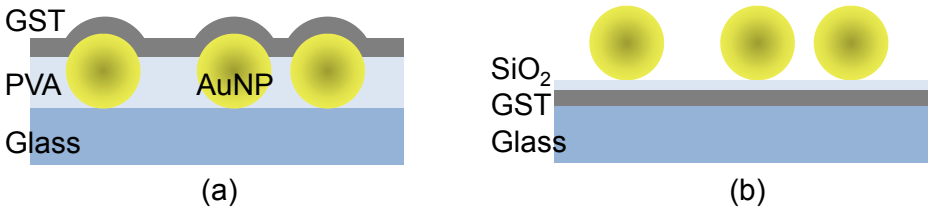

FIG. 1: Schematic of sample structure

3. Results and discussions

Figures 2(a) and (b) are dark-field optical micrographs for d =100 nm and 30 nm, respectively. In both images left half part is as-deposited amorphous phase and right half part is crystalline phase prepared by laser annealing. In the case of polymer thickness d =100 nm, where there was a 15 nm average gap between AuNPs and the GST film, AuNPs exhibit various colors depending on their LSPR frequency. We do not see visible difference in color distribution between the amorphous and crystalline area. In the case of d =30 nm, on the other hand, AuNPs do not exhibit specific colors and look almost white (broad spectrum) as shown in Fig. 2(b). Large contact area with the GST film probably causes strong damping of LSPR due to a significant large imaginary part Imε of dielectric constant of GST. Brighter scattering in the amorphous area implies less LSPR damping, which corresponds to smaller Imε (for $Ge_2Sb_2Te_5$ Imε (cry)> Imε (amo) in visible wavelength).

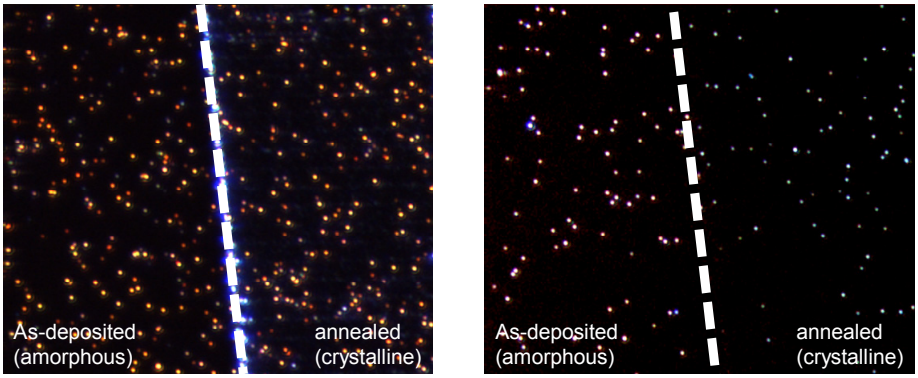

FIG. 2: Dark-field optical micrographs of AuNPs partially covered with a GST film for PVA thickness of (a) 100 nm and (b) 30 nm.

For appropriate d, at which AuNPs undergoes less LSPR damping compared to the case in Fig. 2(b), we expect a peak shift of LSPR (change in color of scattered light) upon phase change of the GST film. Figure 3 shows sequential dark-field optical micrographs of a single AuNP (encircled) taken during repeated amorphization and crystallization of the underlying GST film by alternate irradiations of femtosecond laser and cw annealing laser. A drastic and dynamic change in color of AuNP was observed. In particular a large blue shift cannot be accounted for even qualitatively in the context of optical

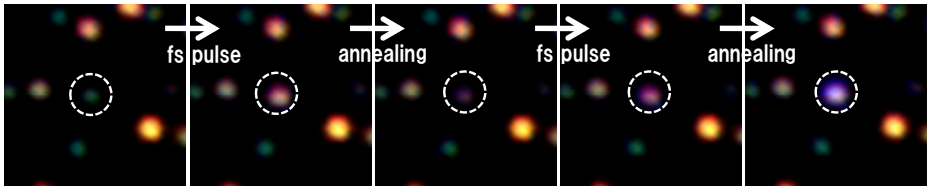

FIG. 3: LSPR switching of a single AuNP partially covered with a GST film upon phase change. The AuNP was irradiated with a femtosecond laser pulse and annealing laser alternately.

interaction between AuNP and GST. Transformation of the polymer film, such as melting and resolidification, might be responsible for the LSPR switching.

We also investigated LSPR switching of AuNPs directly dispersed on a GST/SiO_2 film (Fig. 1(b)). Figures 4(a) and 4(b) are micrographs and scattering spectra of two different single AuNPs. In some cases, as shown in Fig. 4(a), AuNPs exhibit a LSPR peak shift as large as 25 nm. In other cases we obtained LSPR switching just with a change of its scattering cross section and not accompanied by a change in spectral shape. In all measurements we confirmed repeatability of the switching process.

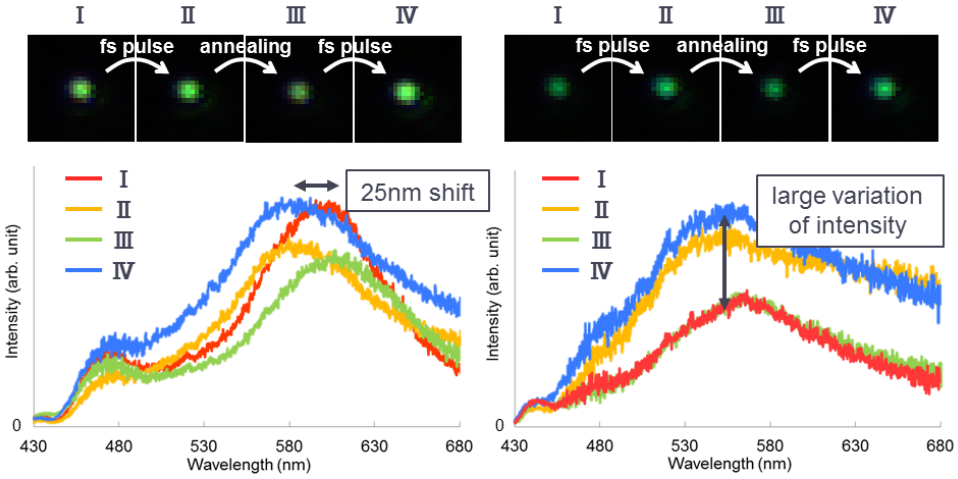

FIG. 4: LSPR switching of single AuNP dispersed on a GST thin film upon phase change. The AuNP was irradiated with a femtosecond laser pulse and annealing laser alternately.

4. Conclusion

We demonstrated LSPR switching of Au nanoparticles through the interaction with a phase-change GeSbTe thin film. In dynamic measurements, where alternate irradiations of femtosecond laser and cw annealing laser was given, giant LSPR shift and damping was observed with good repeatability. The ultrafast and high contrast switching mechanism will be implemented in future active nanophotonic devices.

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References

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