Nanoscale writing and erasing of amorphous marks in a GeSbTe thin film with a gold nanoparticle by femtosecond laser irradiation

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ABSTRACT

Writing of amorphous marks in a GeSbTe thin film with a femtosecond localized electric field generated on an Au nanoparticle was demonstrated. A drastic modification (depletion) of plasmon scattering accompanied the amorphization of the underlying GeSbTe film. The amorphous mark was erased and the plasmon scattering recovered by irradiation of annealing laser. The repeatability of the writing and erasing processes was confirmed.

Key words: femtosecond laser, localized surface plasmon, gold nanoparticle

1. INTRODUCTION

The demand for high density optical data storage with fast recording and retrieval rates is still growing ever faster. Also, to meet the explosive growth in data volume to be stored, drastic improvement in storage capacity is strongly required. Toward ultra high density storage over hard disk magnetic recording, Hamann *et al*. demonstrated phase-change (crystallization) recording at a storage density of 3.3 Tb/inch^2 by using a heated atomic force microscope tip[1]. In actual device operation, however, heat transfer through a tip-surface point contact is not appropriate in the sense of mechanical damage to the tip. More importantly, lateral heat spreading in the thermal recording process inherently limits the recording density. The problem is more serious in the amorphization process, where a higher temperature gradient is required compared to the crystallization process.

Recently we have demonstrated sub-picosecond nonthermal amorphization of a GeSbTe thin film with femtosecond laser pulse excitation[2]. In the process high density carrier excitation on a femtosecond time scale makes a significant contribution to the amorphization that is completed without the formation of a liquid phase. This nonthermal amorphization could solve the essential problem of the heat flow in the writing and erasing process.

For recording and retrieving small marks much beyond the diffraction limit of light, localized surface plasmon on a metal nanoparticle or nanostructure provides an ideal nanoscale light source[3]. In addition to this, electric field enhancement due to the plasmon resonance enables a reduction of threshold fluence for both amorphization and crystallization.

In this presentation, amorphization of a GeSbTe thin film with a femtosecond localized electric field generated on an Au nanoparticle is demonstrated. As a mechanism for reading of nanoscale recording marks, modification of plasmon resonance associated with the phase change of the underlying substrate is also discussed.

2. EXPERIMENTS

The sample investigated was a $Ge_{10}Sb_2Te_{13}$ (GST) film with a thickness of 20 nm sputtered on a glass substrate. The GST film is covered with 10-nm thick ZnS-SiO_2. The thin film was annealed at 280 °C to obtain the crystalline phase. Au nanoparticles with a diameter of 40 nm were uniformly dispersed on the film.

A schematic of the experimental setup is illustrated in Fig. 1. Surface plasmon resonance scattering from individual Au nanoparticles was observed with an optical microscope under white light illumination using a color CCD camera. For amorphization of the GST film a single femtosecond pulse (λ=800 nm) was delivered through a microscope objective and was focused on an Au nanopaticle. A continuous

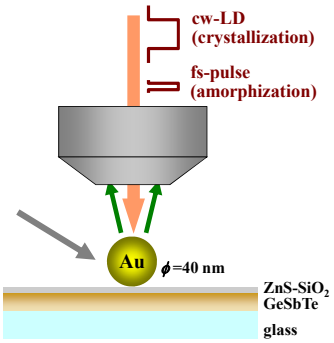

Figure 1

wave (cw) laser diode (λ=830 nm) was used to erase the amorphous region by thermal annealing crystallization.

3. RESULTS & DISCUSSION

Figure 2 shows sequential optical micrographs of a single Au nanoparticle taken during repeated amorphization and crystallization of the underlying GST film by alternative irradiations of femtosecond laser and cw annealing laser. We found that the amorphization of GST substrate leads to a drastic reduction of scattered light of the nanoparticle. Also by the irradiation of annealing laser the scattered light recovers the initial intensity. A good repeatability in phase transformation was confirmed.

In order to understand the mechanism of the significant modification of plasmon resonance of the Au nanoparticle, we performed FDTD simulation and calculated the difference in plasmon resonance for the amorphous and crystal states of GST substrate. Although a small resonance shift and broadening is expected, the drastic change obtained experimentally could not be reproduced. One possible explanation is that a strong electric field originating from localized spatial charges generated by the photoexcitation may attribute to the modification of plasmon oscillation.

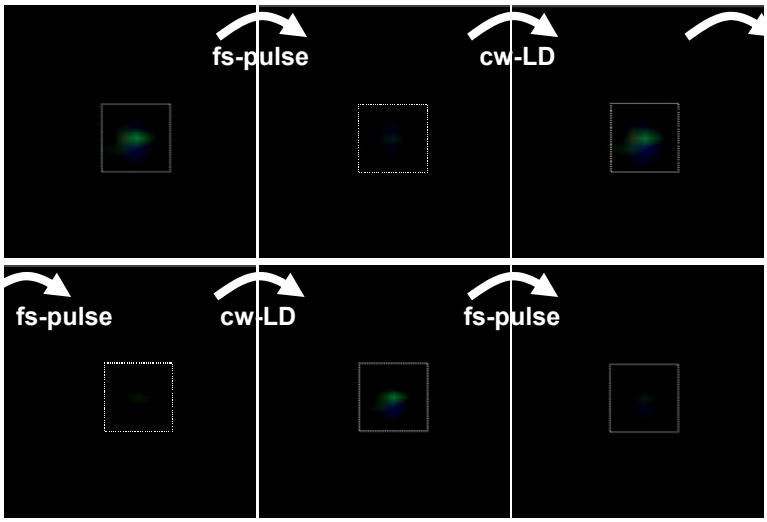

Figure 2

4. CONCLUSION

Femtosecond local surface plasmon assisted recording and erasing of amorphous marks and their repeatability was demonstrated. A significant switching contrast of plasmon resonant scattering is promising as a mechanism of reading out of nanoscale recording marks.

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Biographies

Toshiharu Saiki was born in Tokyo, Japan in 1965. He received the B.S. and M.S. degrees in physics, and the Ph.D degree in applied physics from the University of Tokyo. In 1993, he joined the Kanagawa Academy of Science and Technology (KAST), where he later became a project leader. He had been an Associate Professor in the Department of Electronics and Electrical Engineering at Keio University since 2002 and Professor since 2009.

His current research interests include near-field optical microscopy and spectroscopy in semiconductor quantum-confined systems and nanoparticles and biomolecules in solution, and ultrafast spectroscopy of phase change materials. He has developed a highly sensitive near-field scanning optical microscope (NSOM) with a spatial resolution of 10 nm and has demonstrated real-space mapping of exciton wavefunctions confined in a quantum dot.