Amorphization and crystallization of GeSbTe thin films induced by a nanoscale femtosecond light source

Takashi Hira, Yuki Hongo, Kazuyuki Tajima, Takashi Honma, Nariaki Kitamura and Toshiharu Saiki

Graduate School of Science and Technology, Keio University

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. A polarization-based readout method of nanoscale recording mark is also discussed.

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

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.

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

RESULTS and DISCUSSIONS

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.

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.

We are grateful to K. Yusu (Toshiba Corporation) for providing us with GST thin film samples. This work was supported by the Strategic Information and Communications R&D Promotion Program from the Ministry of Internal Affairs and Communications.

REFERENCES

1. H. F. Hamann *et al.*: “Ultra-high-density phase-change storage and memory”, Nature Materials **5** (2006) 383.
2. M. Konishi *et al.*: “Ultrafast amorphization in $Ge_{10}Sb_2Te_{13}$ thin film induced by single femtosecond laser pulse”, Applied Optics **49** (2010) 3470.
3. T. Matsumoto *et al.*: “Writing 40 nm marks by using a beaked metallic plate near-field optical probe”, Optics Letters **31** (2006) 259.

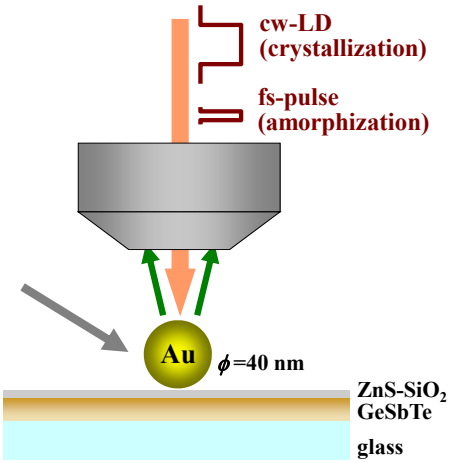

Figure 1: Schematic illustration of experimental setup for amorphization and crystallization of a GeSbTe thin film with a gold nanoparticle under femtosecond pulse irradiation.

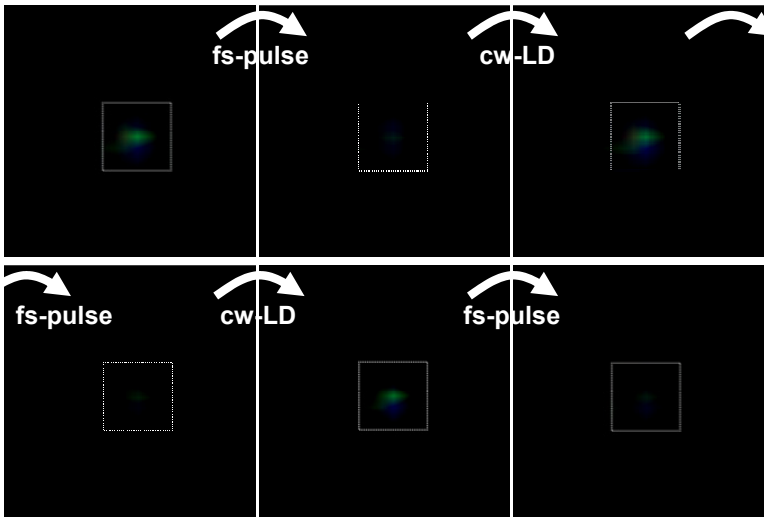

Figure 2: Sequential optical micrographs of a single Au nanoparticle on a GeSbTe film taken by alternative irradiations of femtosecond laser and cw annealing laser. When a small portion of GeSbTe film directly below the Au particle changed to amorphous, the scattered light completely vanished.