# Terahertz free electron laser induced periodic surface structures on $Ge_2Sb_2Te_5$

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Ablation phenomena in the terahertz (THz) region have not been well studied due to the lack of high-power THz sources. Recent advances in laser light sources have made it possible to use high-intensity THz sources, making it possible to achieve microfabrication by ablation [1] and high-intensity induced nonlinear phenomena [2]. Recently, our group reported THz laser-induced periodic surface structures (LIPSS) using a THz free electron laser (FEL) [3]. LIPSS formation provides a simple method for surface nanostructuring. LIPSS can be classified as low spatial frequency LIPSS (LSFL) or high spatial frequency LIPSS (HSFL) depending on its periodicity. The great flexibility and tunability of LIPSS allows the mechanical, biological, or optical properties of the surface to be customized. In this study, we used high-intensity pulses generated from a THz-FEL to cause laser ablation on $Ge_2Sb_2Te_5$ (GST) as a phase-change recording material and observed the formation of two LIPSS patterns.

We used the THz-FEL at the Institute of Scientific and Industrial Research, Osaka University, to generate extremely strong THz pulses (macropulse energy of about 40 mJ) at 4 THz. The experimental setup is as shown in Fig. 1. The maximum energy density of the irradiated area is 35 J/cm$^2$. The 100-nm GST thin film was deposited on a 500-μm thick $Al_2O_3$ substrate by DC magnetron sputtering at room temperature. A 20-nm $SiO_2$ protective layer was deposited on the sample to prevent oxidation. The results of 10-shot irradiation are shown in Fig. 2. The incident polarization *E* is indicated by the vertical red arrow. A periodic structure parallel to the polarization direction was generated with an average periodicity of 19.6 μm, which was 1/4 of the incident wavelength. This structure is classified as LSFL-II, which is induced by the excitation with a smaller energy than the bandgap. Furthermore, the HSFL structure with a spacing of 4 μm (1/18 of the wavelength) perpendicular to the polarization direction was observed around the ablation mark. We will discuss the generation process of two types of LIPSS at the conference.

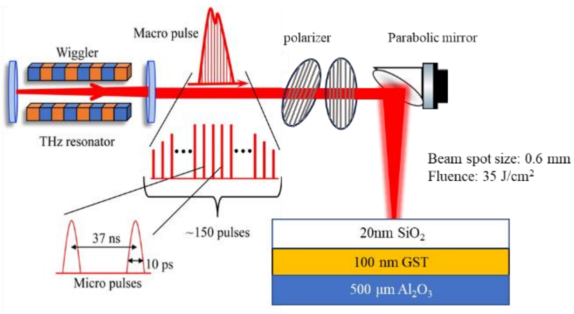


Fig.1: Schematic diagram of the experimental configuration for sample irradiation with THz beam.

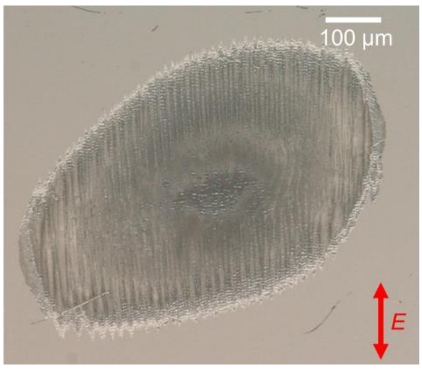


Fig.2: Microscope image of the GST film after 10-shots THz pulse irradiation.

**References**: [1] Y.W. Wang, S. Segawa, T. Shimizu, V. C. Agulto, V. K. Mag-usara, et al., *Appl. Phys. A* **128**, 836 (2022). [2] T. N. K. Phan, S. Tomoki, Y. W. Wang, K. Kato, V. C. Agulto, et al., *Opt. Lett.* **49**, 1073-1076 (2024). [3] K. Makino, K. Kato, K. Takano, Y. Saito, J. Tominaga, et al. *Sci Rep* **8**, 2914 (2018).