Structural properties of epitaxial $Ge_2Sb_2Te_5$ films related to optical switching

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ABSTRACT

We investigate structural properties of epitaxial films close to $Ge_2Sb_2Te_5$ composition on GaSb(001) related to the optical switching process. While the amorphization process takes place in a single or in multiple steps, the re-crystallization process (RCP) always takes place in multiple steps. Intermediate stages of the RCP are characterized by small crystalline islands within the amorphous area. The structural properties are investigated by optical microscopy and electron backscatter diffraction (EBSD). The analysis of the EBSD pattern demonstrates that the crystalline islands at intermediate stages of the RCP exhibit different orientations. We conclude that the RCP is driven by nucleation without any orientation information from the substrate.

Key words: epitaxial GST, optical switching, EBSD

Phase-change materials as exemplified by quasibinary alloys in the $(GeTe)(Sb_2Te_3)$ system, in particular $Ge_2Sb_2Te_5$ (GST), are very important materials for a variety of nonvolatile memory devices. Especially phase-change random access memory received recently intensified interest.[1,2] The storage of information is achieved by optical or electrical switching between the metastable crystalline and the amorphous state. However, the details of the structural changes during the amorphization and re-crystallization are still discussed controversially. In the conventional picture of laser switching, the amorphization occurs via super-cooling after application of a short laser pulse that melts the material, while the re-crystallization is performed using more gentle optical heating reaching the crystallization temperature. Recently, it has been shown that, in contrast to the current consensus, the switching proceeds through a photoexcited state that may trigger rupture of sacrificial bonds leading to a collapse of the ordered phase.[3]

The investigated GST film with a thickness of about 90 nm has been grown by molecular beam epitaxy on a lattice-matched GaSb(001) substrate and is completely crystalline after growth. Using reflection high-energy electron diffraction, the investigated film was shown to exhibit a cubic crystal structure. For the optical switching experiments, we use a high-power Nd:YAG laser (Continuum Leopard SV-20) operating at a wavelength of 532 nm, providing pulses of 60 ps duration with a maximum repetition rate of 20 Hz. Individual laser pulses of an energy up to 60 mJ are used for the switching experiments. The laser-induced change of the reflectance of a specific area on the GST film is synchronously monitored by reflecting the light of a diode laser with a wavelength of 635 nm, which is detected using a photodiode and lock-in technique. In order to investigate the crystal structure of the GST film, we used an electron backscatter diffraction (EBSD) system (EDAX DigiView IV EBSD Detector) attached to a scanning electron microscope (Zeiss ULTRA 55) in combination with an evaluation software (EDAX OIM V5.3) to analyze the EBSD patterns.

For the amorphization process (AP), we found that the crystalline film is amorphized in a step-like fashion by selecting the appropriate energy flux ρ_E in the range of 12 mJ/cm^2 < ρ_E < 25 mJ/cm^2. For smaller values of ρ_E, no AP is induced, while for much higher values of ρ_E the exposed area will be damaged. Furthermore for a value of ρ_E close to 25 mJ/cm^2, a single laser pulse can be used to amorphize the exposed area, while for a value of ρ_E close to 12 mJ/cm^2 ten and more laser pulses are necessary to complete the AP. Figures 1(a) and 1(b) show optical micrographs of the sample surface after a complete AP and complete re-crystallization process (RCP), respectively. The absence of the Kikuchi lines in the EBSD pattern in Fig. 1(c) clearly demonstrates the amorphous nature of the GST film after a complete AP, while Kikuchi lines are clearly visible in Fig. 1(d) indicating the crystalline nature of the GST film after a complete RCP. The RCP is performed by exposing the GTS film to a chain of laser pulses with the full repetition

rate and values of ρ_E of about 15 mJ/cm^2. We observed that each individual laser pulse of the chain yields a single step-like increment of the reflectance, until the film is totally re-crystallized. In Figs. 2(a), 2(b), and 2(c), the RCP was interupted directly after the beginning, after 50% of re-crystallization, and shortly before the RCP was completed, respectively. The optical micrographs demonstrate that during the RCP more and more small islands (with comparable diameter) appear, which finally cover the whole exposed area. The investigation of these islands with EBSD demonstrates that each island is crystalline and has a different crystal orientation as indicated by the different colors in Fig. 2(d). These observations suggest that the RCP is driven by nucleation without any orientational information from the substrate.[4] After the RCP is completed, the crystal orientation is uniform over the whole exposed area.

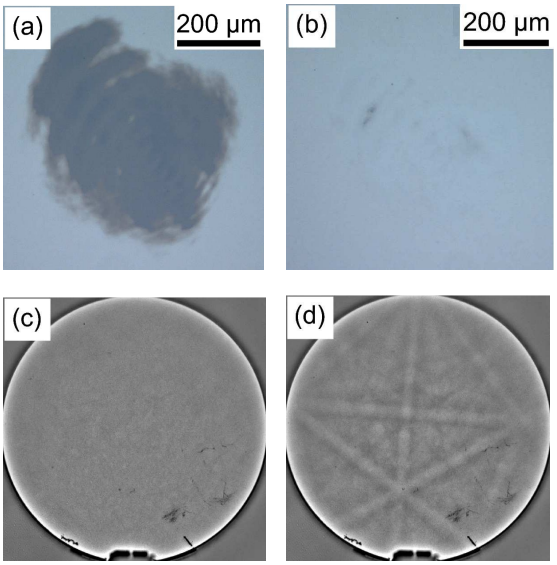

Fig 1: Optical microscope images of two areas on the sample surface after (a) a complete AP and (b) a complete RCP. (c) and (d) EBSD patterns recorded for representative spots inside the areas in (a) and (b), respectively.

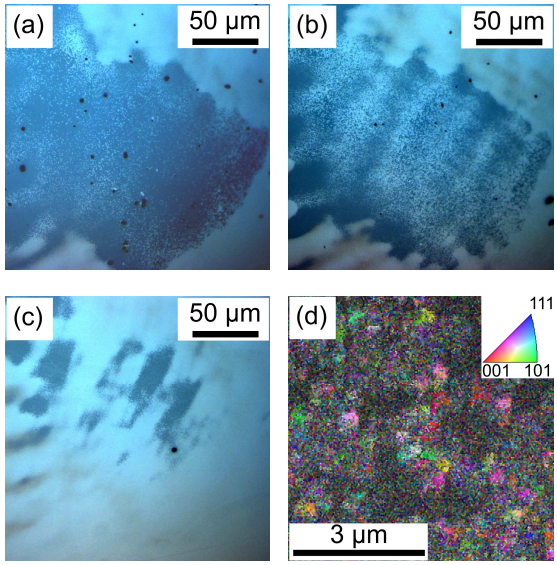

Fig 2: (a)-(c) Optical microscope images of the GST film for different stages of the RCP. (d) EBSD out-of-plane orientation map recorded within the partially re-crystallized area shown in (b) indicating the presence of small crystalline islands on an amorphous background.

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Biographies

Timur Flissikowski graduated from the Humboldt Universität zu Berlin in 2004 writing his thesis on coherent properties of semiconductor quantum dots. Subsequently, he joined the Paul-Drude-Institut where he investigates mainly time-resolved properties of semiconductors.