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ELECTRIC CONDUCTIVITY OF Sb/Se THIN FILM MICRO-SCALE STRUCTURES

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Research into the phase change transition (PCT) from amorphous to crystalline state in chalcogenide glass semiconductors is often more associated with large-scale samples. The authors present a micro-scale structural model of the Sb/Se thin films. They have also extended the investigations of photo- and thermo-stimulated inter-diffusion and PCT effects between two adjacent layers. The results show that the optical and electrical characteristics of such a film change simultaneously. It has been found that the electric conductivity of the films increases 3 times during a PCT process.

1. INTRODUCTION

Se–Sb glasses have been proved to be attractive candidates in optical and electronic communications, switching & memory devices, and photovoltaic applications [1–6]. Apart from that, a Se–Sb glassy system can be considered consisting of the basic a-Se network with Sb added as impurity. The addition of antimony to chalcogenide glasses is generally accompanied by a marked change in their electrical and photoelectrical properties. To this issue a series of works are devoted [7–11].

The application of Sb-containing glasses has generally been limited because of their strong tendency for crystallization, especially when the Sb content is substantial. The effect of Sb alloying on the electrographic properties of a-Se and laser-induced amorphous-to-crystalline phase transition in glassy Se–Sb alloys is reported by Mikla [12–13]. The Se–Sb system was also widely studied as a suitable medium both for erasable and WORM applications (Tokushuku *et al*. [14]).

Modern studies in the PRAM (phase change random access memory) field are focused on the chalcogenide materials used for rewritable optical recording disks [15–17]. In this field, the GST (GeSbTe, Germanium–Antimony–Tellurium) material is widely used; however, owing to its high melting temperature and low resistivity a high reset current (> 1 mA) is needed, which leads to increased power consumption of the memory device. To reduce it, some attempts have been made (see, e.g. [18–20]). In our experiments, we investigated Sb–Se bilayer structures as phase change materials with a lower melting temperature than that of GST.

A number of research works have been done with Sb–Se alloys to investigate these materials for application in rewritable optical disks [21–23]. However, little attention was paid to the photo-electrical properties of these glasses in micro- and nano-scale structures.

In the present work, we report the experimental results of research into the electric conductivity of Sb–Se bilayered micro-scale structures (10×30 μm) prepared by the conventional thermal evaporation technique. The structural characteristics were changed by laser irradiation and direct current.

2. EXPERIMENTAL

A Sb–Se bilayered thin film was prepared by thermal evaporation from high-purity Sb and Se, in the vacuum of 10-5 Torr onto BK-7 glass substrates at room temperature (RT). In the formation of micro-scale structures, photolithographic techniques were used to illuminate and then to pattern the photoresist. In this manner, rectangular bilayered structures (10×30 μm bridges) with lead electrodes were produced (Fig. 1).

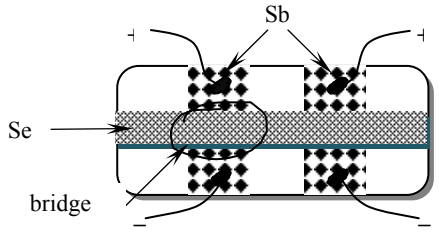


Fig. 1. Sb/Se bilayered micro-scale structures.

During the evaporation, the film thickness was controlled applying the interference technique at a wavelength of 890 nm (as shown in [24]). In the experiments, 100 nm thick Se films were used. The thickness of metal layers on the selenium surface was ~ 300 nm. The composition and structure of the deposed layers were analyzed using an INCA X-act detector and an X-ray diffractometer (SmartLab Rigaku).

To study the light-induced inter-diffusion, we irradiated the sample at RT by a He–Ne laser ($\lambda = 633$ nm) with the intensity of 15 mW. The Sb–Se bilayered thin film was irradiated both on the Sb and Se surfaces. It was found that the light-induced changes in such a film occured at a faster rate when it was irradiated from the Se side.

The electrical conductivity measurements were carried out using a conventional circuit with a digital DVF 1100 multielectrometer and a Tekstronix Digital Phosphor Oscilloscope TDS3054B. For the contacts silver paste was taken.

A confocal laser-scanning microscope (Leica TCS-SPECIFIC) and a scanning electron microscope (TESCAN VEGA) were employed to study the surface modifications induced by the light or heat treatment of the Sb/Se bilayered thin films.

3. RESULTS

Figure 2*a* (the as-deposed films) clearly shows several Sb crystalline peaks that appear in the amorphous background.

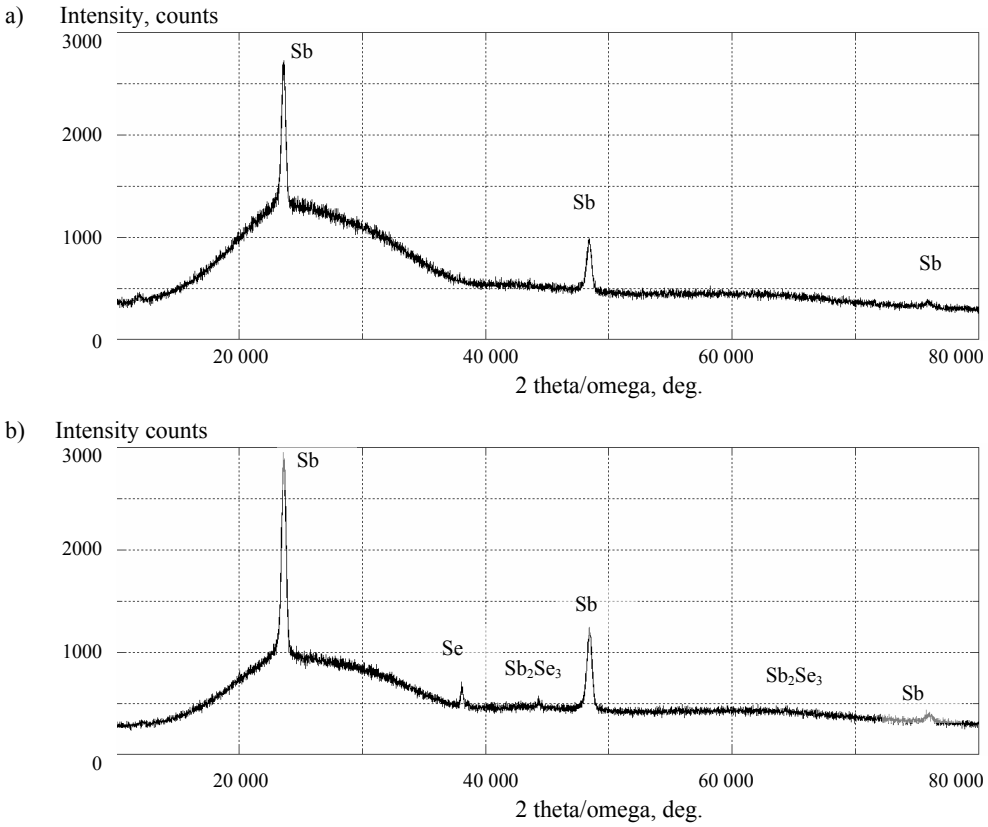


Fig. 2. X-ray diffraction picture of Sb–Se films:
as-deposed (*a*); after laser illumination (*b*).

Light stimulation (λ = 633 nm) of the Sb–Se system is found to change its optical parameters because of inter-diffusion between Sb and Se and further crystallization. At the beginning of illumination, the crystallization process cannot develop owing to the fast inter-diffusion which creates a solid solution resistant to crystallization. The process of bleaching (A-band in Fig. 3*a*) transforms to that of darkening (B-band) caused by crystallization. The photo-bleaching in Sb/Se samples is most likely associated with the light-stimulated inter-diffusion, i.e., antimony diffuses in selenium, so the optical transmission (T) of the structure increases while its reflection (R) decreases. The photo-darkening is caused by appearance of small crystallites in the amorphous matrix, which also causes an increase in the reflection and a decrease in the transmission. Figure 2*b* confirms the crystalline substance growth in the Sb–Se sample: the Sb crystalline peaks are much higher than those in Fig. 2*a*; the Se and Sb_2Se_3 peaks appear, whereas the amorphous background level of the Sb–Se sample steadily decreases.

Figure 4 shows the images of surface evolution in the Sb-Se sample under irradiation. In Fig. 4*a*, a chaotic mix of light and dark spots on the as-deposed film surface is seen. After the light stimulation, 50–100 nm clusters appear on the sample (Fig. 4*b*). The cluster is composed of crystallized Sb, Se and Sb_2Se_3.

The electrical properties of Sb–Se were studied on rectangular 10×30 μm bridges with lead electrodes to the Sb layer.

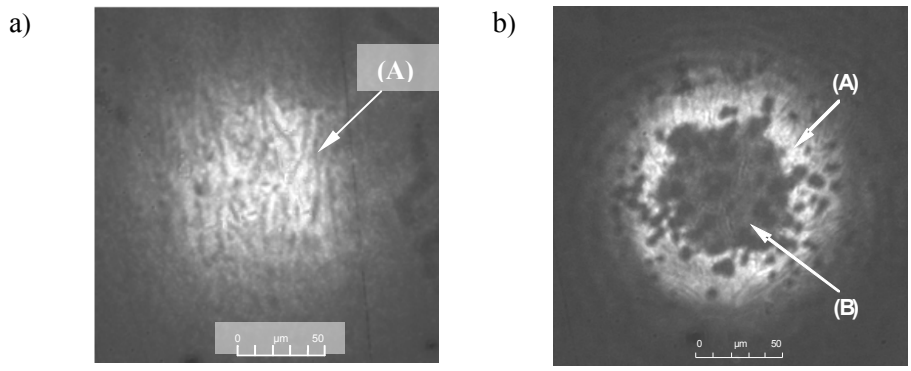
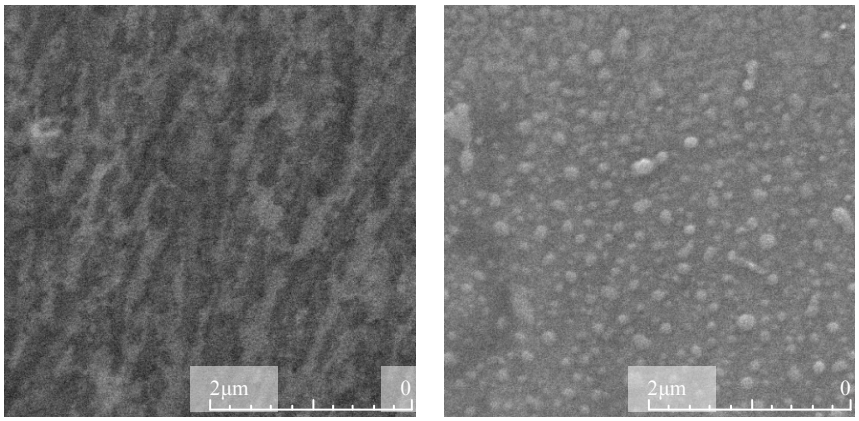


Fig. 3. Sb/Se bilayered film surface after 10 min (*a*) and 30 min (*b*) laser stimulation (λ=633 nm). Transmitted light image: (A) – interdiffusion band, (B) – crystallization band.



a) b)

Fig. 4. SEM- image of Sb–Se sample surface:
(*a*) – as-deposed sample; (*b*) – sample after irradiation.

The volt-ampere characteristic of such a bridge obtained in simple non-destructive measurements is linear, which means that direct current flows through the Sb layer surface. When electric potential difference is applied across the film, irradiation of the bridge sharply reduces the electrical conductivity of the sample (from $10^{2.5}$ to 10^{1} Ohm/cm, see Fig. 5), which is followed by a 38% reduction in reflectance (from 45% to 7%). This can be explained by the inter-diffusion process between Sb and Se.

The system's reflectance decreases up to point A (Fig. 5, curve *2*). After that, the process of system crystallization is accompanied with a slight increase in the reflectance. If we assume that there is a disordered system at point A and an ordered system at point B, this would mean that the system's crystallization enhances the electrical conductivity 3 times. A reverse transfer of the bridge in the disordered state can be realized with short light or current pulse. As we suppose, improvement of the lead electrodes would allow increase in the conductivity by the factor of ten.

The direct current flowing through the bridge in the crystalline state causes the initial increase in the electrical conductivity from 11.4 to 11.8 Ohm·cm^{-1}, with further saturation of the process (Fig. 6).

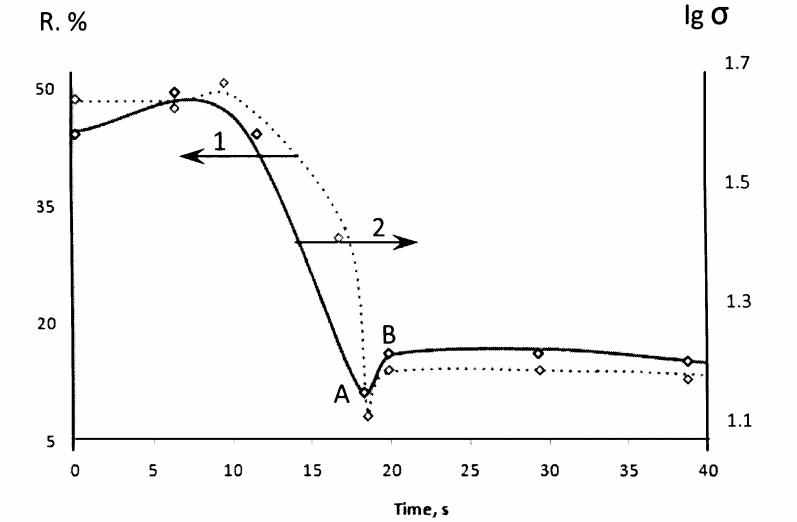


Fig. 5. Time dependences of reflectivity and electrical conductivity for a Sb–Se bilayered film (λ = 633 nm, U = 0.5 V).

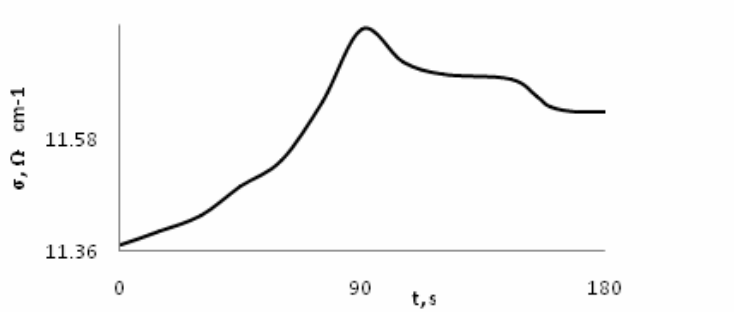


Fig. 6. Time dependence of the electrical conductivity for a Sb–Se bilayered film.

4. CONCLUSIONS

1. Sb–Se bilayer micro-scale structures (10×30 μm) have been obtained in which light-stimulated Sb and Se inter-diffusion with further crystallization occur.
2. Transition of disordered microstructures to the ordered state results in a three-fold increase in the electrical conductivity.

ACKNOWLEDGEMENT

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Sb–Se DIVSLĀŅU MIKROSTRUKTŪRU ELEKTROVADĪTSPĒJA

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K o p s a v i l k u m s

Fāzu pārejas no amorfā stāvokļa kristāliskajā stāvoklī parasti tiek pētītas lielos HSP apjomos pie relatīvi nelielām temperatūras izmaiņām. Tiek pētītas arī fāzu pārejas, kas noris īsā laikā mazos apjomos, struktūrīpatnības. Pēdējie pētījumos iegūtie dati par fāzu pārejām HSP norāda uz to, ka zibatmiņu nomaina fāzu inversā atmiņa (phase change RAM, PCRAM). Par darba materiālu PCRAM izmantojām arī Sb–Se sastāvus, tādējādi to izpēte rada noteiktu interesi. Šis darbs ir veltīts procesu, kas noris Sb–Se plānajās kārtiņās robežvirsmas mikrotilpumos termo un foto iedarbības rezultātā: difūzijai un fāzu pārejai. Tika noteikts, ka mikrostruktūrai, pārejot no nesakārtota stāvokļa sakārtotā stāvoklī, elektrovadītspēja var palielināties 3 reizes.

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