TECHNOLOGY OF TERBIUM MONOTELLURIDE NANOFILMS AND ELECTROPHYSICAL AND MECHANICAL PROPERTIES

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Accepted 2021 November 2

Abstract

Rare earth chalcogenides possess interesting electrophysical, magnetic, optical, thermal, mechanical, etc. properties. Work aims to develop the terbium monotelluride TbTe nanofilms deposition technology on various substrates and study some of their electrophysical and mechanical properties. 0.2 – 0.8 μm thick films are prepared by vacuum-thermal evaporation from two independent sources of Tb and Te. Deposition temperatures of terbium and tellurium evaporators are ~ 1600 and ~ 780 K, respectively. And distances from Tb and Te evaporators to a substrate are 23 and 49 mm, respectively. Deposition rate is of 55 Å/s. Substrate temperature changes within the range of 720 – 1150 K. Fused silica (sitall), sapphire and (111)-oriented single-crystalline silicon plates are used for substrates. Substrate optimal temperature is shown to be in the range 980 – 1100 K. According to the X-ray diffraction and microanalysis, any of obtained films has the NaCl-type structure with lattice constant of 6.10 Å and contain Tb and Te, respectively, around 50.1 and 49.9 at.%. With the increase in the substrate temperature from 980 to 1100 K the film grain size increases from 23 to 49 nm. With an increase in particle size, the resistivity decreases from $4.0 \cdot 10^{-6}$ to $3.2 \cdot 10^{-6}$ Ohm·m. All investigated films have n-type conductivity. The relative mechanical strength is investigated by the complete abrasion method on films with same thickness (of ~ 0.7 μm), load (of 180 g) and deposition temperature, but prepared on different substrates. Relative strength decreases in the sequence: sapphire–sitall–silicon, which is consistent with data that the greater difference between thermal expansion coefficients of film and substrate materials, the less relative strength of the film.

Monochalcogenides of rare-earth elements have interesting electrophysical, magnetic, optical, thermal, mechanical, and other properties [1 – 4]. But, not all the compounds of this class are fully studied. Terbium monotelluride TbTe belongs to such little-studied materials. The purpose of this work is to develop the technology of TbTe nanofilms formation on various substrates and study their electrical resistivity dependence on the size of nanoparticles constituting the obtained films. 0.2 – 0.8 μm thick films are prepared by vacuum-thermal evaporation from two independent sources of Tb and Te. **Figure 1** shows the scheme of the corresponding installation and **Figure 2** – its photo-image.

https://doi.org/10.52340/ns.2022.13

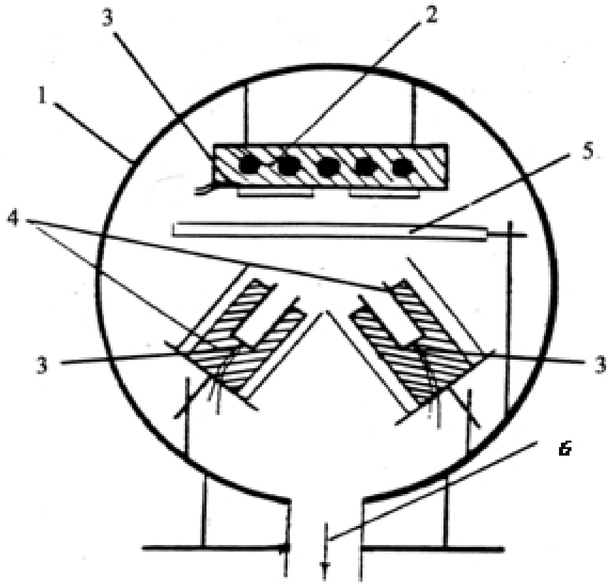

Figure 1. Principal scheme of installation for film preparation by vacuum-thermal evaporation from two independent sources. 1 – vacuum chamber, 2 – substrate heater, 3 – thermocouples, 4 – component evaporators, 5 – gate and 6 – direction to vacuum system.

Figure 2. Spraying installation.

Evaporation of terbium is carried out electronically by electron-beam evaporation and tellurium – by the Joule evaporator. The source materials are: terbium of the brand TbM-1 with the basic element of 99.9 at.% (with total content of controlled impurities ≤ 0.1, Fe ≤ 0.01, Cu ≤ 0.03 and Ta ≤ 0.02 at.%) and tellurium of 99.9999 at.% purity. At films spraying, terbium and tellurium evaporators temperature equal ~ 1600 and ~ 780 K, respectively. Distances from Tb and Te evaporators to a substrate make, respectively, 23 and 49 mm. Films deposition rate equals to 55 Å/s. Substrate temperature changes within the interval 720 – 1150 K.

Fused silica or sitall, sapphire and (111)-oriented single-crystalline silicon plates are used as substrates. During the film grown process, the residual pressure in the deposition chamber was ~ 10^{-5} Pa. The phase composition and structural perfection of the films are determined by X-ray and electron diffraction techniques. The surface of the films is examined using the X-ray mapping approach.

Figure 3 shows the images of films prepared on different substrates. Note that in color all these films are black.

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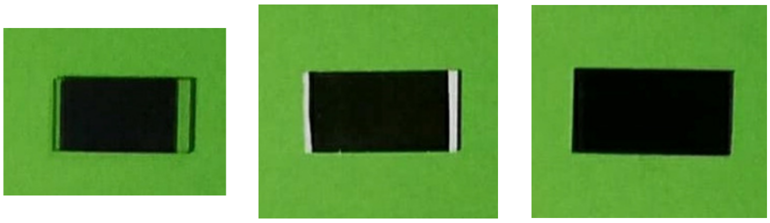


(a) (b) (c)

Figure 3. TbTe films prepared on different substrates:
(a) sapphire, **(b)** glass-ceramic and **(c)** silicon.

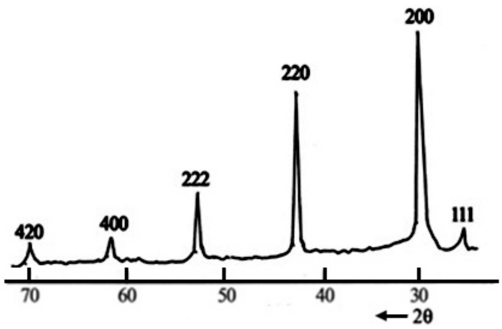


Figure 4. X-ray diffractogram of terbium monotelluride film. Substrate: glass-ceramic.

It is shown that optimum temperature of a substrate is 980 – 1100 K: above this temperature the besieged atoms come off a substrate, and below the temperature the adsorbed atoms create islands of various thicknesses. According to the X-ray analysis (**Figure 4**) a film had structure of NaCl-type with lattice constant 6.10 Å and according to the X-ray microanalysis films contained 50.1 at.% of Tb and 49.9 at.% Te.

The image of the TbTe surface (**Figure 5**) has been obtained by the electronic-scanning microscopy. It has shown that the film contains characteristic elements in the size range 24 – 49 nm allowingto draw conclusion that it is a nanodimensional object, ~80% grains of which have a diameter of 32 nm.

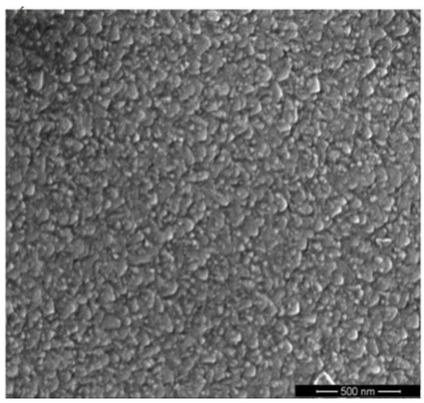
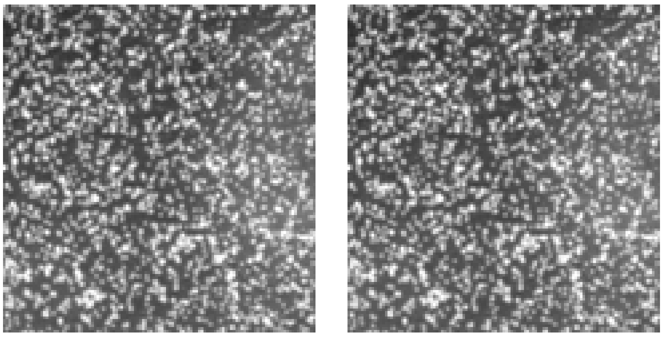


Figure 5. Scanning electron microscopy image of TbTe film surface.

Images of processed film surfaces obtained by electron microscopy experiments show that with an increase in the substrate temperature from 980 to 1100 K the grain size increases from 23 to 49 nm, but this dependency is not linear and there is a peak of 49 nm at about 1050 K. **Figure 6** shows the components distribution on the terbium telluride films surface. As can be seen from this figure, the components are distributed fairly evenly.



(a) (b)

Figure 6. Distribution of terbium **(a)** and tellurium **(b)** atoms on TbTe film surface.

At room temperature, the dependence of electrical resistivity on the nanoparticles size is measured. Measurements show that with an increase in particle size, the resistivity decreases from $4.0 \cdot 10^{-6}$ to $3.2 \cdot 10^{-6}$ Ohm·m.

All investigated films have n-type conductivity.

By the method of complete abrasion [**5**] it is investigated the relative mechanical strength of the prepared films. Experiments are carried out on films prepared on substrates such as sapphire, sitall and single-crystalline silicon. All films have the same thickness of ~ 0.7 μm, and the load during the experiment for all films is also the same and consists of 180 g. The experiment shows that the relative strength depends on the substrate material and decreases in the following sequence: sapphire–sitall–silicon. Note that the spraying temperature of the substrate is the same for all experiments. Observed dependence of TbTe nanofilms relative strength from the substrate material is well consistent with the data obtained in [**6**] for TbSb films: the greater difference between thermal expansion coefficients for film and substrate materials, the less the relative mechanical strength of the film.

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