RELATIVE MECHANICAL STRENGTH OF SOME RARE EARTH ELEMENTS COMPOUNDS THIN FILMS

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Accepted 2020 October 23

Abstract

The study of rare-earth elements compounds' mechanical properties is an essential task because even though their electro-physical properties have been studied quite thoroughly data on their mechanical properties are not available. The purpose of this work is to study the relative mechanical strength of gadolinium diantimonide, terbium monoantimonide, and thulium monotelluride thin films.

Relative mechanical strength (RMS) of thin films of gadolinium diantimonide $GdSb_2$, terbium monoantimonide TbSb, and thulium monotelluride TmTe prepared by the method of vacuum-thermal evaporation from two independent sources of components has been studied at different substrates – quartz, single-crystalline silicon, glass-ceramic sitall, and sapphire coated tapes. During the study, a particular load is applied to the surface and counted the number of passes for complete abrasion. For comparison, all studied films' initial thickness was the same on all substrates: 1.2 μm. And the load on the films was same: 300 g. The grinding surface was a suede layer with a thickness of ~ 0.8 mm, on which diamond paste was applied.

RMS was studied immediately after removing the film from the vacuum camera and completing the procedure for measuring its thickness using an interference microscope. We studied 5 – 6 films of each cast. **Table 1** shows the average values of the measurement results.

Table 1. Relative mechanical strength of $GdSb_2$, TbSb, and TmTe tapes.

Film composition	Number of passes required or complete grinding			
	Substrate material			
	Quartz	Silicon	Sitall	Sapphire
$GdSb_2$	13 – 15	32 – 35	41 – 42	51 – 54
TbSb	20 – 21	40 – 42	47 – 49	62 – 65
TmTe	25 – 27	47 – 50	58 – 61	77 – 79

As we can see from the **Table 1** and **Figures 1** and **2**, the RMP of the film strictly depends on both: the composition of the film and the substrates material. In particular, the RMS of films applied on the different substrates of the same composition is increased by the following

https://doi.org/10.52340/ns.2020.19

sequence of substrate materials: quartz, single-crystalline silicon, sitall, sapphire. The lowest RMS has films grown on quartz substrates, the highest – on sapphire substrates. Average values are obtained for films on single-crystalline silicon and sitall substrates, respectively.

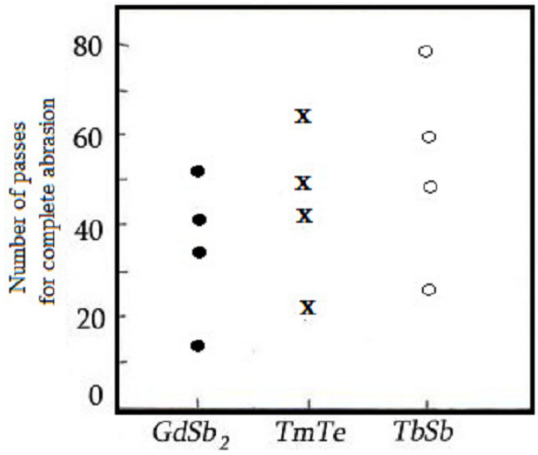

Figure 1. Dependence of RMS of films of same composition on substrate material.

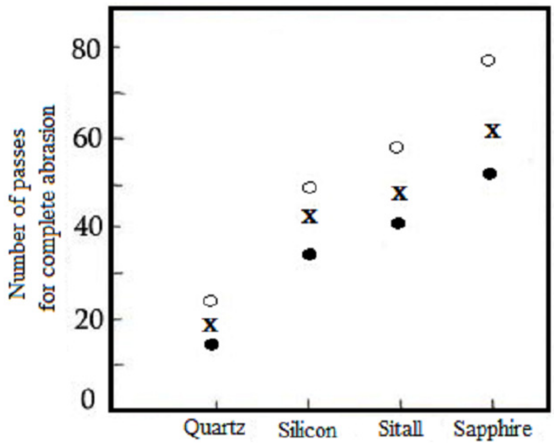

Figure 2. Dependence of RMS of films grown on substrates of same composition on their composition: o – TbSb, **x** – TmTe, and ● – $GdSb_2$.

Data show that TbSb films have the highest RMS for all substrate materials, and $GdSb_2$ films have the lowest values for all substrate materials, while TmTe films have an intermediate value. The films on sapphire substrate have the highest RMS values followed by films on the silicon substrate and then – sitall. The lowest RMS has films prepared on quartz substrates.

Table 2 shows the values of obtained and studied films and substrates thermal expansion coefficients (TEC). We can see that quartz has the lowest TEC among the materials used as a substrate, which is almost 130 times less than that of sapphire and 80 and 50 times less than the TEC of sitall and silicon, respectively. In terms of film materials, gadolinium diatimonide has the highest TEC followed by thulium telluride and finally terbium antimonide.

If we compare our experimentally obtained data with each other, we can assume that the material's RMS is influenced by the difference between the TEC of the substrate from the grown films TEC. The greater the difference, the lower the RMS. This may be related to the

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well-known fact that cooling the film from the deposition temperature to room temperature causes more mechanical stresses in the film than the greater the difference between the TEC of the substrate and the TEC of the film material.

These mechanical stresses cause various distortions of the film's crystalline lattice: point, circular, volumetric defects, which ultimately reduce the RMS.

Table 2. Thermal expansion coefficient of thin films and their substrates.

Film / substrate composition	CTE, 10^{-6} / K	Temperature range, K	References
$GdSb_2$	12.8	300 – 890	[1]
TbSb	11.8	300 – 890	[2]
TmTe	10.9	300 – 980	[1]
Quartz	0.055	320 – 600	[3]
Silicon	2.54	300 – 1050	[3]
Sitall	4.1	298 – 573	[3]
Sapphire	8.1	298 – 573	[3]

Studies have shown that a similar picture is observed for films obtained by single-source evaporation. The difference in RMS of films obtained by discrete evaporation is about 8 – 10 % higher than that for films obtained by evaporation of components from two independent sources.

It is known that materials suffer from so-called aging. Aging is the process of changing the properties of a material over time. The aging process of antimonides and tellurides of rare earth elements, especially, thin films has not been studied. One of the objectives of this work was to study the RMS's dependence for the TbSb film obtained by us on the film's storage time under ambient conditions.

It is known that rare earth antimonides suffer specific changes after an inevitable delay in the atmospheric air. In particular, they change color. Additional maxima appear on the X-ray diffraction pattern corresponding to oxides and compounds of different compositions.

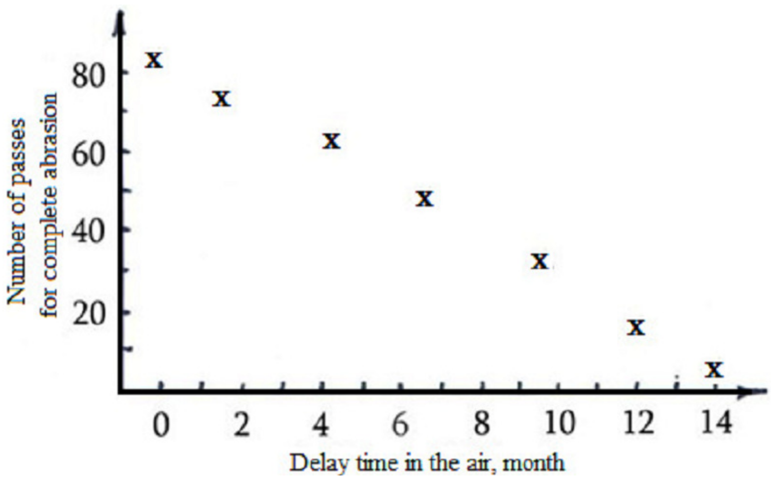

Figure 3. Dependence of RMS of TbSb film grown on sapphire substrate on delay time on air.

To determine how the ambient air retention time affects the RMS of the film, the RMS of the TbSb film grown on the sitall substrate was measured as a function of the ambient air retention time. Six TbSb films of the same thickness, 1.3 μm, were deposited on sitall substrate by the method of vacuum thermal evaporation of components from two independent sources. Next, the RMS was measured for the prepared films under a load of 350 g at the end of the applied completing grinding process and then periodically after keeping the films under ambient conditions for a certain period. In particular, the second measurement was carried out after the film surface has significantly changed its color (delay time was ~ 1000 h, i.e. 1.5 month). The other four films were measured at approximately 1.5 month intervals. The measurement results are shown in **Figure 3**.

As can be seen from the **Figure 3**, RMS decreases almost proportionally to the increase in heat retention. Retention of the film on the air for about fourteen months reduces the mechanical strength by almost 20 times.

As the analysis of scientific reference data [**4 – 6**] show, many factors can cause the aging. The films' aging process depends on the film material's chemical stability. And the aging rate, in turn, depends on the rate of change of various chemical and physical properties of the film. The leading cause of aging is oxygen in the atmospheric air enhanced by light, heat, and water vapor. Aging can also be caused by the recrystallization of the film material, decrease and disappearance of adhesion between the substrates and the film material, a decrease in the film surface smoothness, etc. A detailed determination of the causes of RMS rigidity requires additional complex studies.

References

[1] M. N. Abdusaliamova. Antimonides and bismuthides of rare earth elements (Doctoral Dissertation in Chemical Sciences), 1987, Sverdlovsk, 385 pp. – *in Russian*

[2] E. I. Iarembash, A. A. Eliseev. Chalcogenides of Rare Earth Elements, 1975, Moscow, Nauka, 258 pp. – *in Russian*

[3] S. I. Novikova. Thermal Expansion of Solids, 1974, Moscow, Nauka, 198 pp. – *in Russian*

[4] G. P. Nikolaychuk. Structure of Metal Films Obtained by Pulsed Laser Deposition (Autoreferat of Candidate Dissertation in Physical and Mathematical Sciences), 1990, Kharkiv, 20 pp. – *in Russian*

[5] A. G. Bagmut. Formation, natural aging, and annealing of amorphous and crystalline laser gold condensates. Surface, X-Ray, Synchrotron, and Neutron Studies, 2008, 6, 65-69. – *in Russian*

[6] Yu. A. Skakov. Aging of metal alloys. In: Mater. Symp. Metallurgy, 1971, Moscow, 136-136. – *in Russian*

 https://doi.org/10.52340/ns.2020.19