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OPTICAL PROPERTIES OF DYSPROSIUM MONOANTIMONIDE THIN FILMS

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A process has been developed for the growth of thin crystalline DySb films by thermal evaporation using Dy and Sb separate sourses. The room-temperature optical spectra (reflection and absorption, the real and the imaginary part of the dielectric constant, loss function) of DySb films have been studied at photon energies from 0.05 to 5.5 eV. The behavior and energy position of features in the spectra have been analyzed.

Keywords: film, substrate, the optical spectra, reflection, absorption, dielectric constant, loss function.

ОПТИЧЕСКИЕ СВОЙСТВА ДИСПОЗИИ ТОНКИХ ПЛЕНОК МОНОАНТИМОНИДОВ

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Разработана технология приготовления тонких кристаллических плёнок моноантимонида диспрозия методом вакуумно-термического испарения из двух независимых источников Dy и Sb. При комнатной температуре в области энергии фотонов 0.05 – 5.5 эВ исследованы оптические спектры (отражение и поглощение, действительная и мнимая части диэлектрических постоянных, функция потерь) приготовленных плёнок. Проанализировано поведение и энергетическое состояние спектральных зависимостей.

Ключевые слова: плёнка, подложка, оптические спектры, отражение, поглощение, диэлектрическая постоянная, функция потерь.

ОПТИЧНІ ВЛАСТИВОСТІ ДИСПОЗІЇ ТОНКИХ ПЛІВОК МОНОАНТИМОНІДІВ

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Розроблена технологія приготування тонких кристалічних плівок моноантимоніду диспрозії методом вакуумно-термічного випару із двох незалежних джерел Dy і Sb. При кімнатній температурі в області енергії фотонів 0.05 – 5.5 еВ досліджені оптичні спектри (відбиття та поглинання, дійсна та уявна частини діелектричних постійних, функція втрат) приготовлених плівок. Проаналізовано поводження та енергетичний стан спектральних залежностей.

Ключові слова: плівка, підкладинка, оптичні спектри, відбиття, поглинання, діелектрична постійна, функція втрат.

INTRODUCTION

Rare-eart (RE) monoantimonides continue to receive a great deal of attention owing to their interesting properties which have not yet studied in sufficient detal [1 – 8]. These little-studied materials include dysprosium monoantimonide. In this work are presented the technology of preparation of DySb crystalline thin films and study of the optical properties at room temperature in the photon energy range 0.05 – 5.5 eV.

EXPERIMENT

Single-phase films DySb have been prepared by vacuum-thermal evaporation from two independent sources of Dy and Sb. As substrates we used glass-ceramic, fused silica and (111) oriented single-crystal Si plates. The sourse materials used were 99.9% DyM-1 dysprosium and 99.9999% antimony. During the growth process the vacuum in the deposition chamber was $\sim 10^{-5}$ Pa. In the all of the growth runs, the substrate temperature was maintained from 1050 to 1110 K. The axis of the Dy and Sb evaporators made an angle of ~35° with the normal to the substrate surface. The source-substrate separation was 42 mm for Dy and 56 mm for Sb. Angles evaporators Dy and Sb against the normal of the substrate are the same and composes ~35°. The thickness of the prepared films varied in the range 1.2 – 2.1 µm, the deposition rate was ~68 Å/s

The phase composition and crystallinite of the films were cheked by by X-ray diffraction (XRD). XRD pattern were taken at CuKα radiation with a nickel filter, in the mode of recording a rate of

$4\cdot10^{-2}$ deg/s and eleqtron diffraction. Electron diffraction patterns were obtained in reflection at an accelerating voltage of $(75-100)\cdot10^{2}$ V. The surface of the films was examined by X-ray fluorescence analysis (Camebax-Microbeam system). Their elemental analysis was determined by electron X-ray microanalysis.

Optical properties of dysprosium monoantimonide are studied poorly. In [9], only are researched reflection spectra of crystals and powder of DySb. In this paper, at room temperature in the photon energy of 0.05 eV – 5.5, reflection and absorption spectra are studied. By the Kramers-Kronig relations were calculated spectra of the main optical parameters such as real and imaginary parts of the dielectric constant, the loss function.

RESULTS AND DISCUSSION

By XRD and electron diffraction methods were investigated influence of temperature of a substrate in the range of 1050 to 1110 K and also the material of a substrate on crystallinity and phase structure of prefared films. Experiments have shown that the substrate material have no effect on the crystallinite and phase composition of the films. Films stay in the open air for 4 – 6 days causes change of color of films and the appearance of additional peaks on XRD pattern, not belong DySb, indicating the instability of films in air.

Fig.1 shows a typical the electronogramm and fig. 2 XRD pattern of an DySb film. Analysis of XRD and electron diffraction data indicated that the film grown at this temperature consisted DySb (cubic structure of NaCl-type) with lattice parameters 6.14 Å in good agreement with those of bulk DySb crystals 6.150 Å [9].

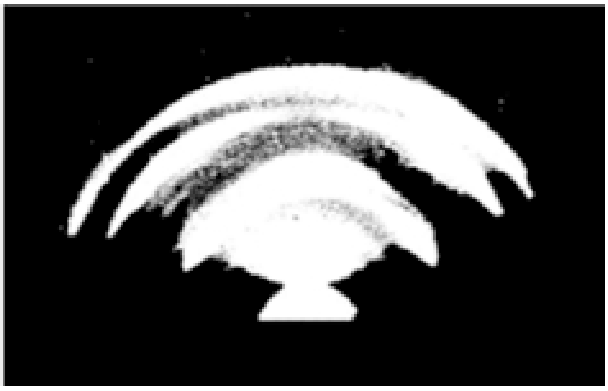

Fig. 1. Electron diffraction pattern of a thin DySb film (fused silica substrate, film thickness of 1.9 mm).

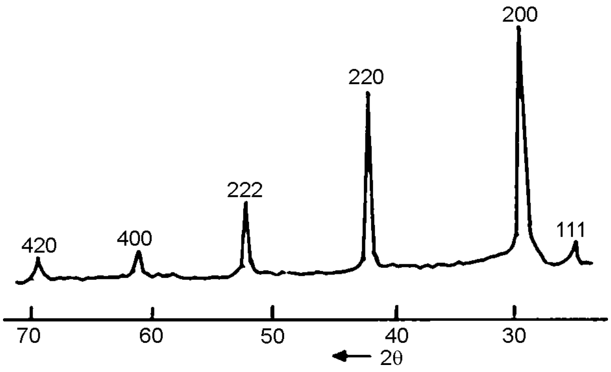

Fig. 2. XRD pattern of a thin DySb film (glass ceramic substrate, film thickness of 1.8 microns).

X-ray microanalysis showed that the film contained 49.8% Dy and 52.2% Sb.

In secondary X – rays the surface of the prepared films has been removed. The atoms of Dy and Sb are distributed on a surface of films in regular intervals enough at visible from fig. 3 (1) an (2) accordingly.

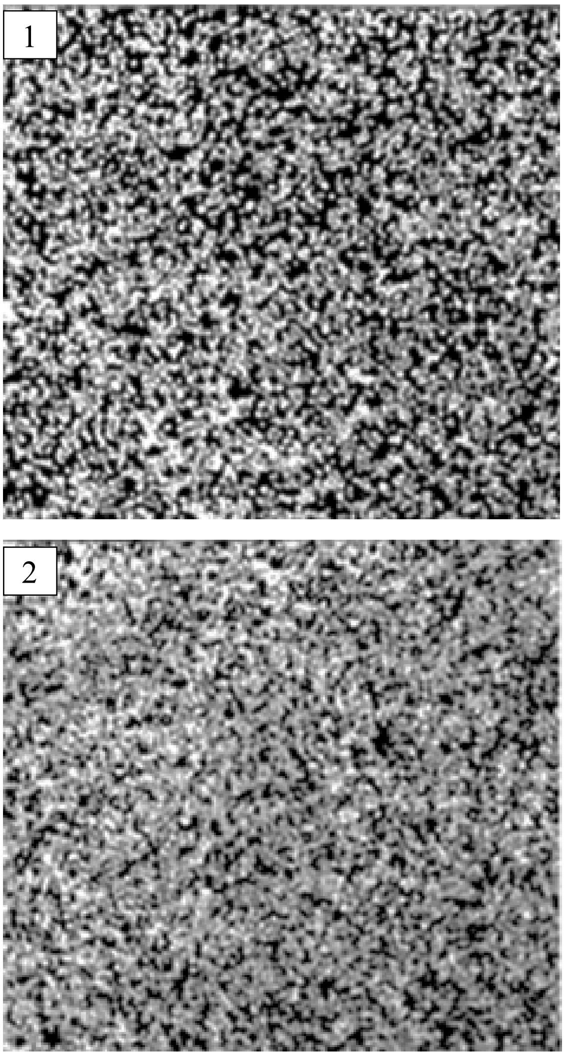

Fig. 3. The image of distribution of Dy (1) and Sb (2) atoms on a surface of a thin DySb film in secondary X-rays (×400).

On the reflection spectrum (fig. 4) are some features, such as: a deep minimum of about 0.28 eV which is accompanied with a pronounced long-wavelength edge of the reflection, well-formed reflection band with a maximum at 0.50 eV, a minimum at 0.22 eV and the structure at 1.67 eV. Depending on the spectral absorption coefficient (fig. 4.) strong absorption is observed in the region of relative transparency proximity 0.46 eV, 0.23 eV for the structure and the sharp increase in the absorption coefficient at energies below 0.12 eV.

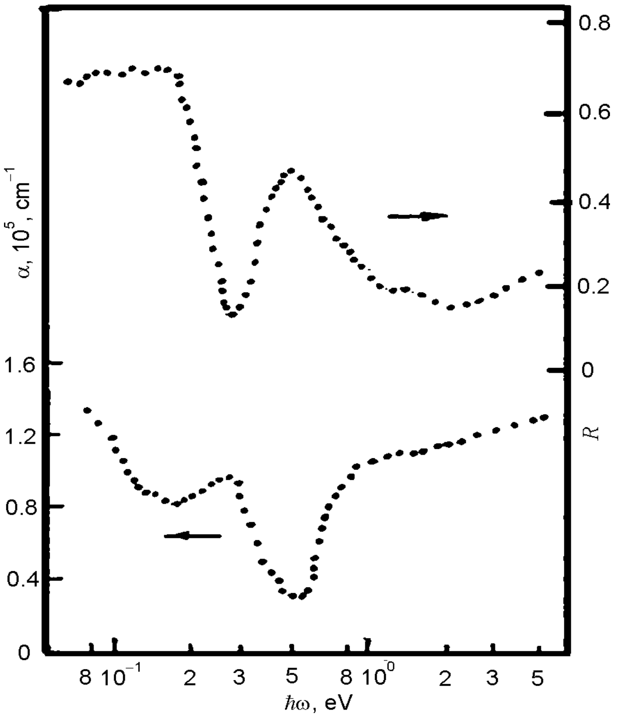

Fig. 4. Spectra of the reflection (*R*) and absorption (α) of a thin DySb film.

The interpretation of the optical spectra of DySb is difficult because there are no data on the energy band structure. It is possible to say only that a deep minimum of reflection and the associated increase in long-wave reflection is undoubtedly associated with plasma oscillations of charge carriers. Very difficult is interpret of the structural features of the spectra at energies close to 0.5 eV. On the one hand, we can assume that the same reflection spectra of crystals SmSb [10], in this region of the spectrum a decisive role plays the fundamental absorption with interband transition energy 0.50 eV. For an assessment of width of the forbidden zone it is necessary to consider the amendment connected with an arrangement of level of Fermi which corresponds to full regeneration. On the other hand, there are several objections to this explanation: when the carrier concentration is high ~$3 \cdot 10^{21}$ cm^{-3} and the effective mass of the order of the free charge carrier is m_0 (at X point of Brilyuen zone exists conduction *d* zone), the Fermi energy (0.75 eV) 1.5 times are more than energy of interzonal transitions and if in the trivalent rare earth elements compounds it is observed the reflection strip with a width few eV, in the DySb films half-width of the reflection strip which can be attributed with the electron interband transitions, is only 0.41 eV.

These remarks to some extent, may be rejected if interpretation of the optical spectra in the vicinity of the Fermi level admit the possibility of the existence of subbands *d*, *f* and *f-d* with very high density of states. In this case, apparently, the structure of the optical spectra of about 0.5 eV determined transitions of *f* and *f-d* nature.

On the basis of the spectral dependence of the coefficients of reflection and absorption spectra were calculated real μ_1 and imaginary μ_2 part of the permittivity (fig. 5) and the refractive *n* and absorption *k* index (fig. 6) and the loss function Imε^{-1} (fig. 7).

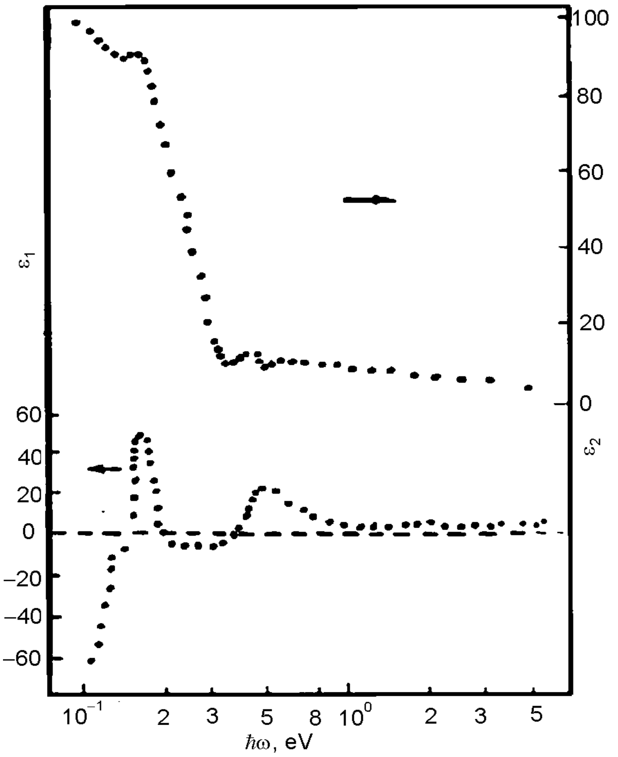

Fig. 5. Spectra of the real (ε_1) and imaginary (ε_2) part of the dielectric permitivity of a thin DySb films.

Fig. 5 shows that in the deep infrared region ε_1 aspires to very large negative values, which means that in the optical processes essential role played

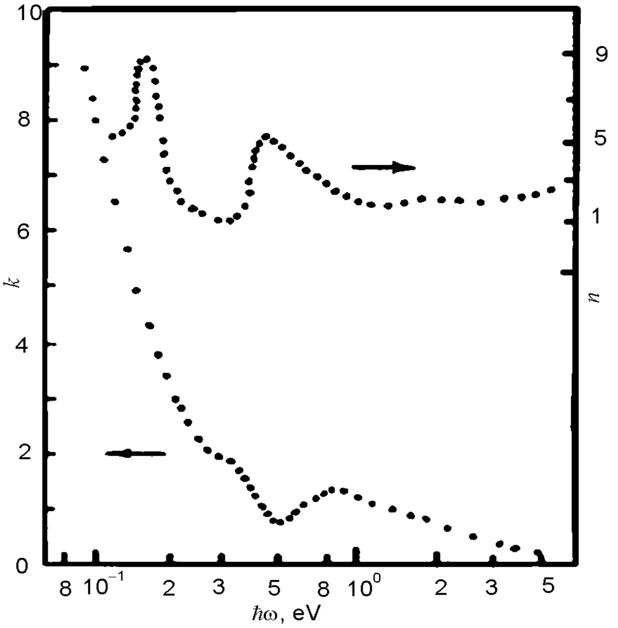

Fig. 6. Spectra of the reflectance (n) and absorption (k) of a thin DySb film.

free charge carriers. After that ε_1 changes a sign three times: twice with a positive slope ($d\varepsilon_1/d\omega > 0$) at 0.15 eV and 0.38 eV, that will well be coordinated with position of the maximum energy loss function accordingly, the energy of 0.38 eV probably corresponds to a plasma resonance. In the DySb films because of the proximity of this energy and energy of the band absorption, damping is large, excited plasma oscillations damped and the “true” plasma frequency should be higher than the estimated frequency.

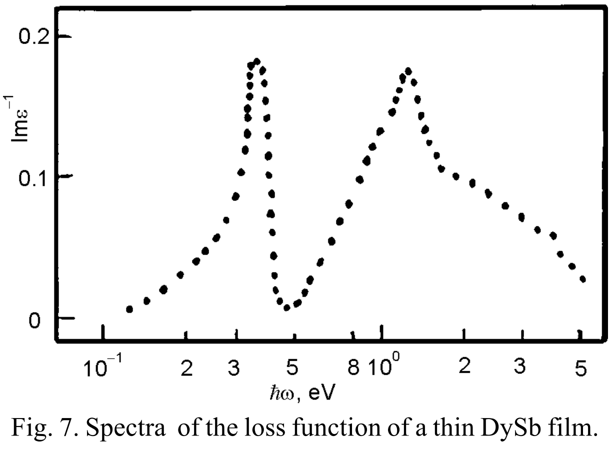

Fig. 7. Spectra of the loss function of a thin DySb film.

Characterized by relatively low-energy position of the main absorption band is clearly seen in the spectra of the absorption coefficient and the imaginary part of permittivity. In a place with that three factors: very sharp increase of the k and ε_2 in the long-wavelength part of the spectrum; the existence of a well-formed structure in spectrum of n and ε_1; the change of the sign of ε_1 with negative slope ($d\varepsilon_1/d\omega < 0$) at energy 0.18 eV suggest a significant contribution of intraband transitions and complex structure of the zone of DySb thin films.

CONCLUSION

The first process has been developed for the growth of thin crystalline DySb fiLms (cubic symmetry, NaCl structure, lattice parameters $a = 6.14$ Å) by vacuum-thermal evaporation of the two independent components. At room temperature in the photon energy range 0.05 – 5.5 eV spectra of reflection and absorption are measured. Are calculated spectra of the real and imaginary part of the dielectric constant, the loss function, the coefficient of reflection and absorption. It is shown that deep minimum on the reflection spectrum at 0.28 eV corresponds to the plasma energy minimum. It is suggested that the formation of the spectral dependence is dominated by intraband transitions.

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