TECHNICAL SCIENCES

PREPARATION AND ELECTRICAL PROPERTIES OF ERS FILMS

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Abstract

Thin polycrystalline ErS films have been grown by thermal evaporation in vacuum from two separate sources on glass-ceramic, sapphire, and single-crystal silicon substrates. It has been shown that the substrate material does not significantly affect the phase composition and crystallinity of the prepared films. Films have cubic structure of NaCl type with lattice parameter a = 5.46 Å. The optimal temperature of the substrate is 820-870 K. The resistivity, Hall coefficient, and thermoelectric power of the films have been measured as functions of temperature in the temperature range 95-750 K. It has been shown that with increasing temperature the resistivity of the films linearly increases. The Hall coefficient is negative, and doesn't depend on temperature. The thermoelectric power is positive. its absolute value in the range of temperatures ~ 95 – 180 K slightly increases from $\sim 11.3 \times 10^{-6}$ to $\sim 12.5 \times 10^{-6}$ V/K and then in the area ~ 180 – 750 K decreases from $\sim 12.5 \times 10^{-6}$ to $\sim 1.2 \times 10^{-6}$ V/K. According to electrical measurements, ErS is a metal.

Keywords: vacuum evaporation, film, electrical resistance, Hall coefficient, thermoelectric power, metal

Introduction

Rare earth monosulfides (REE) are intensively studied in connection with the valuable physical properties found in them and represent both scientific and practical significance [1-10], especially for thin films. However, not all of them compounds in this family have been studied in sufficient detail. One such compound is erbium monosulfide.

The objectives of this work were to develop a process for producing thin crystalline ErS films on various substrates by the vacuum - thermal evaporation method and study the temperature dependencies of the main electrophysical parameters: resistivity, Hall coefficient and thermoelectric power.

Experimental

Erbium monosulfide films with a thickness of 0.4-1.5 μm, a length of 4 mm and a width of 7 mm were prepared by vacuum-thermal evaporation from two separate sources of components Er and S. Erbies of ЭрМ-1 grade (99.99%) and sulfur of ОСЧ 16-5 grade (99.99999%) were used as source materials. During the film growth process, the residual pressure in the deposition chamber was $\sim 10^{-5}$ Pa. The Er evaporation using an electron beam evaporator, and the S source, by Joule heating. The Er evaporation temperature was ~ 1560 K, and the S evaporation temperature was 370 K. The film growth rate was $\sim 15 \times 10^{-10}$ m/s, and the substrate temperature in our experiments was varied from 720 to 1150 K (±0.05 K). The evaporator-substrate separation was ~ 85 and ~ 110 mm, respectively, and the axes of the evaporators were tilted $\sim 25^0$ and $\sim 35^0$ about the normal to the substrate. The preparation of ErS films was carried out on substrates having the shape of a rectangular parallelepiped 15×8×5 mm made of leucosapphire, glass-ceramic, and single-crystal silicon. After chemical cleaning, the substrate was transferred to a vacuum chamber and annealed at a temperature of ~ 1000 K for one hour in a vacuum of about $\sim 10^{-5}$ Pa.

The phase composition and crystallinity of the resulting films were determined by X-ray and electron diffraction techniques. X-ray diffraction patterns were collected on a DRON-2 diffractometer nickel-filtered CuK_{α} radiation, continuous scan mode. Electron diffraction patterns were obtained in reflection on a UEMV-100K electron diffraction apparatus at an accelerating voltage of $(75 - 100) \times 10^3$ V. The surface of the films was examined using X-ray mapping (Camebax-Microbeam system). Their composition was determined by electron probe X-ray microanalyses, using the Camebax-Microbeam and a PDP-11/73 computer, and by Auger electron spectroscopy (Riber LAS-200 spectrometer).

The resistivity, Hall coefficient, and thermoelectric power of the films were measured as functions of temperature in the range 95-750 K. In all of the measurements, we used the same single-phase films grown on leucosapphire substrates. Their resistivity was measured by a compensation method. The Hall coefficient of the films was determined at a direct current (dc) in a static magnetic field of 16×10^5 A/m. Their thermoelectric power was assessed using an absolute method, with correction for the thermoelectric power of copper. The accuracy in our resistivity and thermoelectric power measurements was 3-4% or better, and the Hall coefficient was determined with an accuracy of 8-10% or better.

Results and discussion

To examine the effects of substrate temperature and substrate material on the crystallinity and phase composition of the films, we carried out experiments in which the substrate temperature was varied from 700 to 1100±3 K. The results indicated that the substrate material had no significant effect on the phase composition and crystallinity of the films. In the temperature range of substrate 820-870, all films were single phase and had a composition corresponding to ErS. The films grown at substrate temperatures under 820 K contained both ErS and metallic erbium inclusions as a separate phase. The films grown at substrate temperatures above 870 K were two-phase: they consisted of ErS and Er_2S_3. Only the films grown at substrate temperatures in the range 820-870 K were single-phase, and their composition corresponded to ErS. In subsequent measurements, we used the films grown at substrate temperatures in this range.

Analysis of X-ray diffraction and electron diffraction patterns leads us to conclude that the films grown at substrate temperatures in the range 820-870 K consist of ErS are formed on all used substrates with a cubic (NaCl) structure. The lattice parameter evaluated from X-ray diffraction patterns of the films is $a = 6.16$ Å, in good agreement with previously reported date for bulk crystals [11]. All films were purple.

According to X-ray microanalysis data, the composition of the films is 49.9±0.1 at % Er + 50.1±0.1 at % S.

The Auger electron spectrum in Fig.1. characterizes the composition of the films across their thickness to within the present experimental uncertainty, ±0.05 at %.

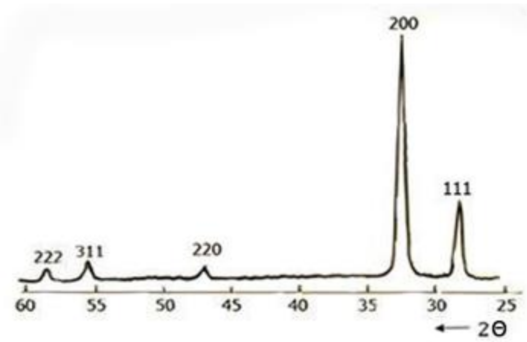

Fig.1. X-ray diffraction pattern of the Ers film

Figures 2,3 show the results of measuring the temperature dependencies of electrical resistivity and Hall coefficient in the temperature range 95-750 K. As can be seen from Fig. 2. specific resistance linearly increases from $4{,}8 \times 10^{-7}$ to $14{,}2 \times 10^{-7}$ Ωm, it will well be coordinated with similar data for REE monosulfides which specific resistance in direct ratio to temperature is higher than Debye's temperature, and is defined by dispersion of electrons of conductivity fluctuations of a lattice [12].

The Hall coefficient is negative, and doesn't depend on temperature (fig. 3.) and it is also equal $\sim 3 \times 10^{-10}$ m^3/K. The Electron Concentrations $\sim 2.6 \times 10^{28}$ m^{-3} obtained from the experimental data match well with the value obtained on the assumption that there is one electron for each formula unit of ErS.

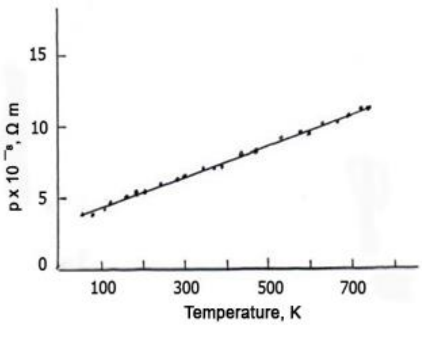

Fig.2. Temperature dependence of resistivity

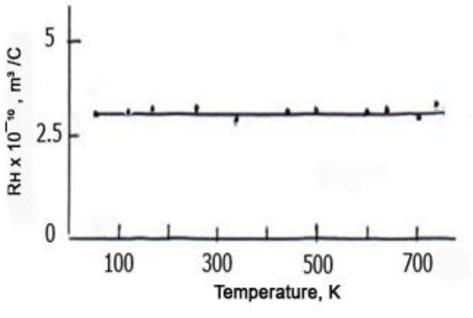

Fig.3. Temperature dependence of Hall coefficient

Temperature dependence of thermoelectric power (Fig. 4.) is quite complex. In all explored temperature area she has the positive sign, in the temperature range $\sim 95 - 180$ K its absolute value increases from $\sim 11.3 \times 10^{-6}$ to $\sim 12.5 \times 10^{-6}$ V/K a little and then in the temperatures range $\sim 180 - 750$ decreases to $\sim 1.2 \times 10^{-6}$ V/K and tends to change the sign. It is known from the scientific literature that when Hall coefficient, such monovalent metals as Au and Ag have a positive sign [12]. Some authors explain this fact by the fact that the thermoelectric power formula consists of two terms, one of which depends on the mechanism of dissipation of charge carriers, and the second on the structure of the Brillouin zone. Ultimately, the sign of the thermoelectric power depends on which factor of these two is dominant.

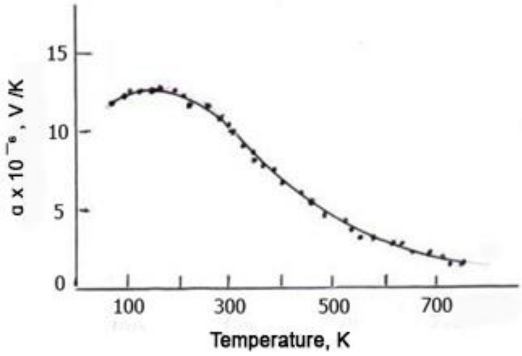

Fig.4. Temperature dependence of the thermoelectric power

Based on the measurement of temperature dependencies of resistivity and Hall coefficient, calculated the mobility of charge carriers in the temperature rage of 95-750 K. With increasing temperature, the mobility decreases from $\sim 6.2 \times 10^{-6}$ to $\sim 2.1 \times 10^{-6}$ $m^2/(V \cdot s)$. The values of electrophysical parameters and the nature of their change depending on temperature suggest that erbium monosulfide films are a metal.

Conclusion

A process has been developed for the growth of thin crystalline ErS films by thermal evaporation in vacuum from two separate sources (Er end S) on various substrates (leucosapphire, glass-ceramic, single-crystal silicon). The results demonstrate that the optimal substrate temperature is 820-870 K and that the substrate material has no effect on the crystallinity and phase composition of the films. The films have a stoichiometric composition and cubic crystal structure of the NaCl type with lattice parameter a = 5.46 Å.

The electrophysical parameters of the films and their temperature dependences lead us to conclude that ErS is a metal.

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