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RELATIONSHIP BETWEEN ELECTRICAL RESISTIVITY AND CRYSTAL STRUCTURE OF THULIUM THIN FILMS[1]

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The high precision electrical resistance measurements in the temperature range from 4.2 K to 300 K were performed on thulium thin films, prepared in ultrahigh vacuum. "Knee-like" anomalies in thinner films or "hump-backed" anomalies in thicker films were observed near the Néel temperature. They resemble anomalies found for the basal plane or for the c-axis of Tm single crystal. X-ray diffraction study in films with thicknesses below $\sim$ 100 nm revealed that these anomalies are caused by a preferential orientation of crystallites.

1. Introduction

Rare earth /RE/ metal thin films are studied because of two reasons,at least.The first one lies in the wealth of the physical properties that imposed the source of their preparation - RE metals. The second is because of the thickness dependence of these properties. Moreover,thin films containing RE metals are studied as a promising material for technical application.This demand has been met by RE-TM films used as the data storage materials.Promising are high temperature superconducting films containing RE metals because of their high critical current density values.

Low temperature electrical and magnetic properties were studied mostly in Dy and Sm. Using X-ray diffraction various preferential crystal orientations have been observed in Dy films, prepared under high vacuum. Near magnetic phase transitions the structural changes influenced the electrical properties of Dy films, namely the temperature dependence of electrical resistance and the thickness dependence of the spin disorder resistivity [1].

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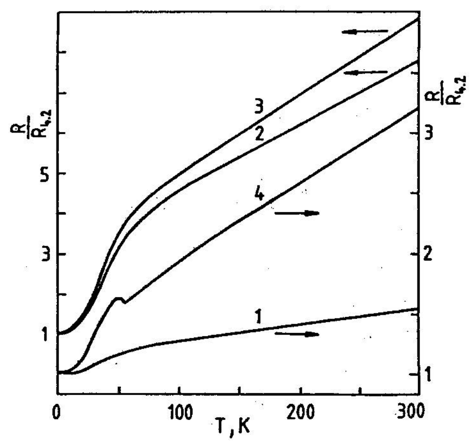

Fig. 1 Temperature dependence of the resistance ratio $R/R_{4.2}$ of Tm thin films prepared in UHV: 1 - 16 nm, 2 - 89 nm, 3 - 189 nm, 4 - 364 nm.

Our interest in this paper is devoted to the thin film study of another rare earth metal - thulium. Namely, we report on some electrical and structural properties of Tm thin films in the low temperature region.

2. Experimental

Thulium thin films were evaporated in an ultrahigh vacuum ($\sim 10^{-7}$ Pa) from a very pure Tm bulk sample (residual resistance ratio RRR = 143) onto the glass substrates pre-heated up to 250 °C. SiO layers were deposited to protect the films against a contamination by the air. Current leads and potential probes were cemented at appropriate positions using silver paint. A conventional dc arrangement was used to measure the electrical resistance (R) with an accuracy of 0.05 % in the temperature range from 4.2 up to 300 K using digital Keithley programmable source 222 and digital nanovoltmeter 181. Temperature of the films was measured using callibrated Ge and Pt thermometers. Optical Tolansky interference method was used to measure film thickness. Crystal structure was determined using X-ray diffraction technique with Bragg-Brentano focusing geometry.

3. Results and discussion

Prior to the thin film study we measured electrical resistance of Tm bulk sample as a reference in the temperature range from 4.2 to 300 K. "Hump-backed" anomaly of R.vs.T curve has been observed near the Néel temperature (T_N), as found in the c-axis of Tm single crystal [2]. Numerical analysis yielded the value of $T_N = 57.5$ K.

Thin films of Tm were prepared in the thickness range from 16 to 370 nm. Their electrical resistance was measured in the above mentioned temperature range. Size-effect of their electrical resistivity does not exhibit anomalous behaviour and is in accordance

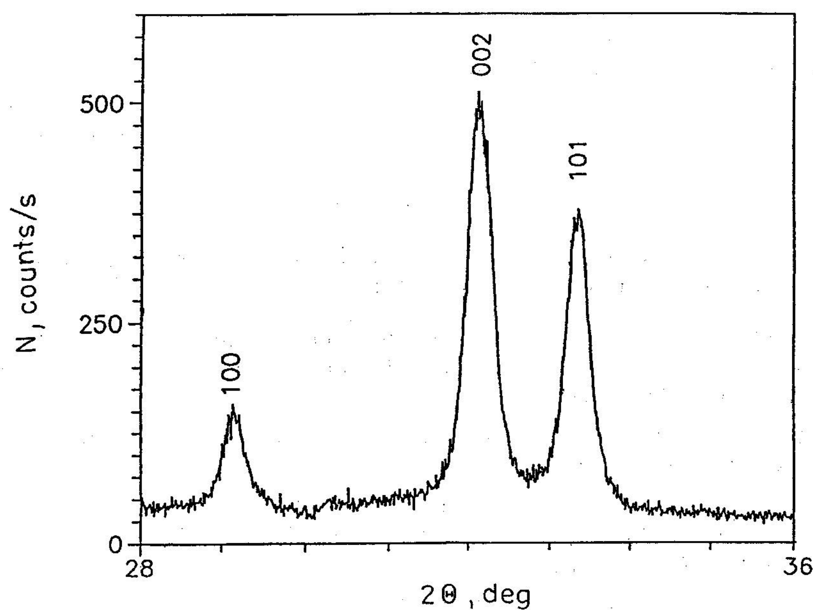

Fig. 2 X - ray diffraction pattern for 79 nm thulium film.

with the Fuchs-Sondheimer theory [3, 4]. Typical R vs. T dependences of four of these films are illustrated in Fig.1. A "knee-like" R vs. T anomaly near T_N is seen in the case of thinner films with the thickness of 16,89 and 189 nm, whereas a "hump-backed" anomaly in thicker films is represented by the 364 nm thick film.

The resemblance of the R vs. T anomaly of thinner films to that observed for Tm single crystal basal plane as well as of that of thicker films to "hump-backed" anomaly found in the c-axis single crystal suggests the idea that the thin film crystal structure has an influence on their R vs. T behaviour. We assume that the majority of crystallites in thinner films is oriented with their basal plane parallel to the substrate plane and in the direction of electrical current. The majority of crystallites in thicker films has their c-axis oriented parallel to the substrate plane or exhibit a small deviation from this direction.

This variation of crystal orientations was investigated in thinner films with thickness below $\sim$ 100 nm using X-ray diffraction. The measured number of counts N is plotted against 2Θ in Fig. 2 for the 79 nm thin film,representative of thinner films. The high intensity of the (002) reflection at the angle of 32.1° shows that the majority of the crystallites have their basal plane parallel to the substrate surface, whereas the lower intensities of the (100) and (101) reflections at 29.1 ° and 33.3°, respectively, show the other direction of crystallites.

The X-ray diffraction study of other thinner films - 15, 21 and 95 nm thick - is in accordance with the results of 79 nm thin film.

Further study is needed to confirm the influence of preferential crystal structure on

the R vs. T behaviour in thicker films.

The results of the X-ray diffraction study of Tm thin films with thicknesses of 29, 36, 47 and 117 nm, prepared in high vacuum ($\sim 10^{-4}$ Pa) are in accordance with the presented results.

Conclusions

Following conclusions could be drawn from the study of the low temperature behaviour of electrical resistance and crystal structure of thulium thin films:

[1] "Knee-like" anomaly of the electrical resistance temperature dependences near the Néel temperature in thinner films of thulium resemble that found for the Tm single crystal basal plane

[2] "Hump-backed" R vs. T anomaly near T_N in thicker films is like that for the c-axis of Tm single crystal

[3] The observed different behaviour of the electrical resistance in thinner and thicker films is caused by different preferential orientation of their crystallites which is verified by X-ray diffraction study.

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