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COMMUNICATIONS

INFLUENCE OF MAGNETIC FIELD ON ELECTRICAL RESISTANCE AND MAGNETIC ORDERING TEMPERATURES IN HOLMIUM THIN FILMS

Ján Dudáš [*] — **Slavomír Gabáni** [**] —
Viktor Kavečanský [**] — **Jozef Bagi** [***]

The influence of magnetic field on the electrical resistance and magnetic ordering temperature T_N in Ho thin films is reported. X-ray diffraction investigation of these films revealed two phases composition consisting of the prevailing hexagonal Ho (space group $P6_3/mmc$) and small but inessential content of cubic holmium dihydride HoH_2 ($Fm3m$) with preferential crystal orientation in these films. Electrical resistance measurements on Ho films in the thickness range from 98 nm to 215 nm showed a "knee-like" resistance anomaly near the T_N. Magnetic field applied parallel to the thin film plane caused an increasing suppression of the T_N value up to 5 K with increasing flux density value up to 5 T.

K e y w o r d s: electrical resistivity, Neél temperature, holmium thin films, X-ray diffraction

1 INTRODUCTION

Magnetic and transport properties of magnetic metallic 3d and 4f films exhibit a considerable renascence since the discovery of the spin polarized transport in multilayered ferromagnetic/nonmagnetic structures. Observation of new magnetic phenomena such as the giant magnetoresistance is attractive for technical utilizations. The intense activity in this area is driven, in part, by needs of magnetic recording and other applications [1]. Sophisticated thin-film deposition techniques transformed the discovery of the spin polarized transport (GMR) in a billion-dollar business within a decade of its discovery.

Size effects may produce relevant modifications in the known magnetic phases of rare earth (RE) elements because of non-uniform magnetic structure induced by the lower coordination near the surface. It has been demonstrated that RE films may have not only the regular bulk RE behaviour but also surface features rather similar to antiferromagnetic multilayers [2].

Unexpected anomalies of physical properties were observed in RE thin films at low temperatures (see *eg* the review monograph [3, 4]). The intricate world of rare earth thin films is connected with the reactivity of the lanthanides. They are excellent getters for hydrogen and can absorb (OH) - radicals. Thus thin RE films could contain hydrides or hydroxides causing problems in interpretation of the experimental data.

We concentrated in this paper on Ho thin films. Being paramagnetic at room temperature, holmium orders antiferromagnetically below the Neél temperature $T_N = 130$ K into the basal-plane spiral. At $T_C = 20$ K the spiral changes to a cone-shaped structure [5]. As for Ho films, thickness effects on magnetism, on magnetic ordering temperatures, on magnetoelastic stresses and electric charge transport anomalies were studied in the last time [6-9]. The influence of magnetic field on the electric charge transport and on magnetic ordering temperature T_N in Ho films is presented in this paper.

2 EXPERIMETAL DETAILS

Thin films of Ho with thickness of 98, 116, 147, 196 and 215 nm were evaporated onto the glass substrates in vacuum (10^{-7} Pa). The conventional four-point dc arrangement was used to measure the electrical resistance of bulk and thin film samples of holmium in helium cryostat in the temperature range from 4.2 K up to room temperature using a digital Keithly programmable current source K 220 and a Keithly digital nanovoltmeter K181. Magnetic field with flux density values from 0 T up to 5 T was applied parallel to the thin film surface. The temperature of the bulk and thin film samples was measured using calibrated Ge (from 4.2 K to 80 K) and Pt (from 80 K up to 300 K) thermometers. Film thickness was measured using the optical interference Tolansky method. The crystal structure of Ho films was investigated by means of X-ray diffractometry (in the Bragg-Brentano focusing geometry) with $Co_{K\alpha 12}$ β-filtered radiation ($\lambda = 0.17902$ nm).

[*] Department of Theoretical Electrotechnics and Electrical Measurement, Technical University, Park Komenského 3, 043 89 Košice, Slovakia; Jan.Dudas@tuke.sk, [**] Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 45, 043 53 Košice, Slovakia; Stanislav.Gabani@saske.sk, Viktor.Kavecansky@saske.sk, [***] Húskova 61, 041 11 Košice, Slovakia

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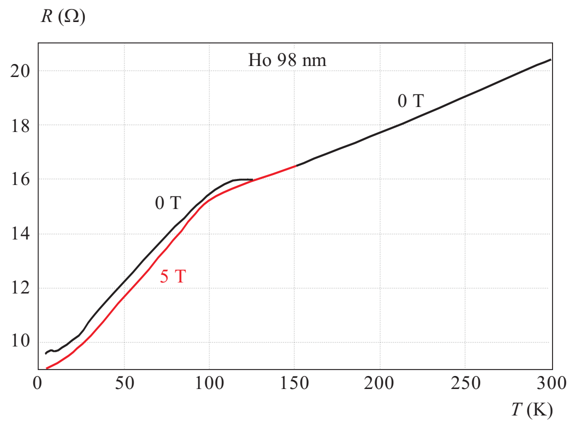

Fig. 1. The R *vs* T dependence of the 98 nm thin Ho film in the temperature range from 4.2 K up to 300 K in zero field and in magnetic field of 5 T below 150 K

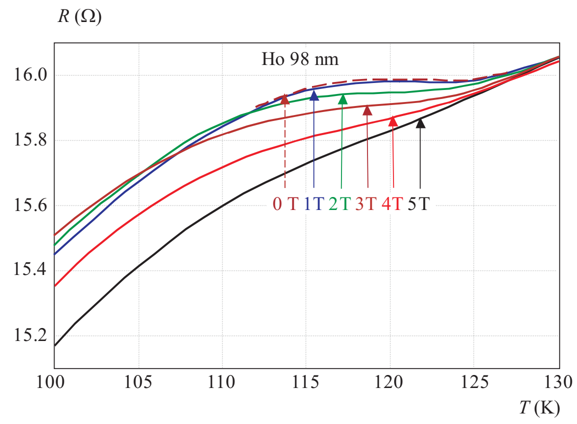

Fig. 2. The influence of magnetic field on R *vs* T anomaly in 98 nm thin Ho film near T_N and in fields with increasing flux density value from 1 T up to 5 T

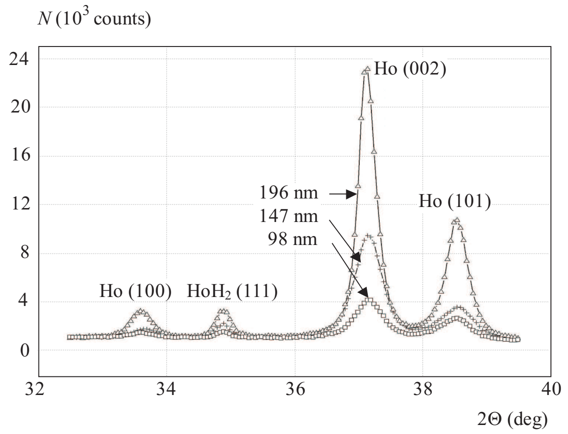

Fig. 3. X-ray diffraction pattern for thin Ho films with thickness of 98, 147 and 196 nm

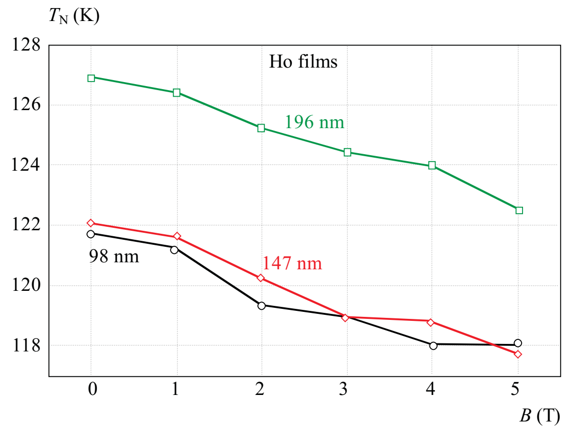

Fig. 4. The decrease of T_N value with increasing flux density B in Ho films with thickness 98, 147 and 196 nm

3 RESULTS AND DISCUSSION

The electrical resistance of the reference Ho bulk sample was measured prior to the Ho thin film study [9]. The "knee-like" resistance anomaly was clearly seen near 130 K. Numerical analysis of the resistance *vs*temperature data yielded the Neél temperature value $T_N = 128.90$ K and the transition from spiral spin structure to cone one was found at Curie temperature $T_C = 19$ K.

The influence of magnetic field on the electrical resistance of Ho thin films was investigated in the temperature range from 4.2 K up to the room temperature in zero magnetic field and in the field with flux density from 1 T up to 5 T. The result of these investigations is illustrated for one of them with a thickness of 98 nm in Fig. 1.

The observed R *vs* T anomaly in this film is caused by the magnetic structure and exhibits a change from a small "hump-backed" anomaly near T_N in zero magnetic field to a "knee-like" anomaly in a magnetic field of 5 T. The gradual change of the R *vs* T anomaly in increasing magnetic field with flux density values 0, 1, 2 , 3, 4, 5 T is illustrated in Fig. 2.

The R *vs* T curves of other Ho films exhibit similar resistance anomalies in the low temperature region.

The observed R *vs* T dependence of Ho films under influence of magnetic field is the result of superposition of two temperature dependent conduction electron scattering mechanisms-the electron-phonon mechanism and the electron-spin one. According to Bloch-Grüneisen equation the electron-phonon interaction leads to resistance decrease with the change from T^1 dependence at higher temperatures to a T^5 one at low temperatures.

The magnetic spin scattering is influenced by the decrease of the spin turn angle below T_N . The majority of the hcp crystallites of Ho is oriented with their basal plane parallel to the substrate (see Fig. 3) and with their c-axis perpendicular to the thin film plane. It was shown that in the absence of an external magnetic field the helical spin structure of Ho film was deformed only in the two monolayers near the surfaces [2]. On the other hand, in the presence of an applied field of 2T, only a small fraction of spins, near the middle of the film, preserved the helix character. The fan phase was produced near the surfaces, while near the other surface a few spins were aligned with the applied field. Upon further increase of the applied field the fan phase covered the whole film.

We assume that in lower applied fields oriented in the film surface and in basal plane of Ho crystallites the magnetic helix is slightly distorted. Helifan phase appears, spins are more oriented in the direction of the applied field and spin scattering of the conduction electrons decreases. Upon further increase of the applied field the volume of the fan phase increases with the result that the fan phase covers the entire part of the film in the field of 5T and the spins are oriented parallel to the applied field. Spin scattering decreases with the increasing magnetic ordering and thus spin contribution to resistivity decreases. A decrease of the resistivity value with increasing applied field is clearly seen in Fig. 2.

We have observed a decrease of the T_N value with increasing magnetic flux density. The applied magnetic field caused a suppression of the T_N value – *eg* it decreased from 126.90 K (0 T) to 122.50 K (5 T) in 196 nm film and from 121.70 K (0 T) to 118.00 K (5 T) in 98 nm film. The decrease of T_N value with increasing flux density is illustrated in Fig. 4 for Ho films with thickness of 98, 147 and 196 nm.

We assume, the decrease of the T_N value in dc magnetic field is connected with non-uniform distortion of helix [2] which could lead to the decrease of the total magnetic exchange energy.

The crystal structure was investigated in all Ho films. The two phases structure model (Ho and HoH_2) of the studied films was refined by the Rietveld method using FullProf software package The result of the study for the 98, 147 and 196 nm thin films is shown in Fig. 3. The dominant phase (of the weight fraction about 98 %) is represented by hexagonal Ho ($P6_3$/mmc and refined values of the lattice parameters $a = 0.35691(4)$ and $c = 0.56112(5)$ nm) and minority cubic phase of HoH_2 ($Fm3m$, $a = 0.51635(8)$ nm). The crystal structure of Ho-phase shows significant in-plane texture characterized by the basal plane (002) of the unit cell preferentially oriented parallel to the thin film surface.

However, comparing the R *vs* T curves of our Ho bulk sample [9] with that of 98, 147 and 196 nm thin films we can see that the amount of HoH2 did not influence qualitatively the observed R *vs* T dependence of these films.

5 CONCLUSIONS

The following conclusions could be made from this study:

- The X-ray diffraction studies of thin Ho films revealed prevailing the (002) textured hcp Ho phase as well as the presence of the second but minority inessential phase of fcc HoH_2
- The R *vs* T dependences of Ho films exhibit anomalies caused by magnetic structure similar to those observed in the Ho bulk sample
- The resistivity value of Ho films decreased with increasing flux density for the temperatures below T_N values
- Increasing magnetic field up to 5 T caused increasing suppression of the T_N value by about 5 K.

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Jozef Bagi (RNDr) was born on 1960. After graduation in solid state physics at Faculty of Science, Šafárik University in Košice in 1985 he was with the Research Institute of Radioecology in Košice and after 1990 he is on private business. He is in external form of PhD. study in Theoretical Electrotechnics since 2004 and he is co-author of two papers in electrical and magnetic properties of holmium thin films at low temperatures.

Ján Dudáš (Assoc Prof, Ing, DrSc), born in 1946, graduated with honour in solid state physics at the Faculty of Electrical Engineering, Slovak University of Technology, Bratislava, in 1969 . After the study stay in the Institute of Physical Metallurgy, Czech-Slovak Academy of Sciences in Brno 1969-72 he changed for the Department of Theoretical and Experimental Electrotechnics, Technical University, Košice. His research interests changed to the low temperature electrical, magnetic and structural properties of rare earth metals and their thin films. Defending the thesis Study of the

conduction electron scattering processes in bulk and thin film samples of dysprosium at low temperatures at the šafrik University in Košice, in 1985 he gained the CSc. degree in Solid State Physics. After 1989 he was allowed to habilitate and after the defence of habilitation dissertation in 1990 he was appointed as Associate Professor in Theoretical Electrotechnics at TU in Košice. His second habilitation dissertation Influence of the magnetic structure on the electric charge transport in thin films of dysprosium and samarium at low temperatures was defended in 2000 at Technical University in Žilina in Theoretical Electrotechnics.

In 1999 he defended the doctoral thesis Electric charge transport in bulk and thin film samples of dysprosium, thulium and samarium at low temperatures at Technical University in Košice and received the DrSc degree in Theoretical Electrotechnics.

He took part at short study stays at 8 Universities in Great Britain in 1980, at Technical University of Wismar, Germany in 1989, at the Institue of Inorganic Chemistry of the Siberian Branch of the Academy of Sciences of USSR in Novosibirsk, in 1990, at Donetsk Physical-Technical Institute of the Academy of Sciences of USSR, in 1990, at Technical University of Darmstadt, Germany in 1997, at Institue of Physics, A.M.University in Poznań, Poland in 1994, 1996, 2003, 2008 and at the Institue of Molecular Physics, Polish Academy of Sciences in Pozna in 1994, 1996, 2003, 2008. He is author and co-author of 92 papers with 19 papers in Current Contents journals, with 35 citations mainly abroad (30) and 24 in SCI. In 2001 he issued scientific monograph Intricate behaviour of rare earth metal thin films at low temperatures. He is author of three textbooks in Theoretical Electrotechnics and one historical-cultural monograph. His research interests also include searching of the personalities from Orava region creative in science, technics, literature and in other branches of culture.

At present he is with the Department of Theoretical Electrotechnics and Electrical Measurement, Technical University, Košice and he gives lectures and leads tutorials in the Theoretical Electrotechnics. More informations could be found on http://www.tuke.sk/dudas/

Slavomír Gabáni (RNDr, PhD) born in 1974 in Košice, graduated in physics at Faculty of Science, P. J. šafrik University, Košice in 1997. Being postgraduate student at this Faculty in 1997-2000 he concentrated to solid state physics and acoustic with specialization in low temperature physics and technique. The PhD thesis Study of the properties of metallic 4f-electron systems in chosen borids of lanthanides at low temperatures he defended at Faculty of Science, P. J. šafrik University in 2001.

He is author and co-author of 35 CC papers in journals and conference proceedings abroad and home with 45 SCI citations.He took part at postdoctoral states at TU WIEN, 2001, in 3He cryostat laboratory and at TU WIEN, 2002 in Transport phenomena laboratory, at HMI BERLIN, 2003-2004, 2006, 2007, at Kobe University, 2005, in NMR laboratory of Dept. of Physics, at CEA Grenoble, 2008, in INAC / SPSMS / IMAPEC laboratory and at GPI Moscow, in Low temperature laboratory.

Now he is as scientific coworker-physicist with Centre of Low Temperature Physics, Institute of Experimental Physics, SAS, Košice. His research interests are devoted to the investigation of the electric, magnetic and thermal properties of solid states at low temperatures.

Viktor Kavečanský (RNDr, CSc) born in 1952 in Košice, graduated in experimental physics at Faculty of Sciences, P. J. Šafarik University, Košice in 1975. Defending the PhD thesis at Technical University in Košice (1984) he has become a scientist at the Institute of Experimental Physics, Slovak Academy of Sciences in Košice. His research is focused mainly to the crystal structure investigation using diffraction techniques. He is author and co-author of 30 CC indexed scientific papers with more then 60 SCI citations. He has been lecturing at P. J. Šafarik University in Košice and J.Kepler University in Linz. He has organized and co-organized more scientific conferences devoted to the crystal structure investigation.

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