

Polycrystalline bismuth films: fabrication, structure and electrophysical properties

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Thin bismuth films provide a wide range of practical applications. Owing to a high magnetoresistive effect bismuth layers can be used as components of magnetic field sensors [1]. Many of today's conventional thermoelectric materials are bismuth-based compounds, for example Bi₂Te₃ [2].

The present work is focused on establishing correlation between electrophysical properties of polycrystalline bismuth films prepared by different methods and their microstructure. The films were fabricated by melt spinning and electrochemical deposition techniques.

Electrochemical bismuth deposition was performed from aqueous electrolyte containing 0.174 mol/l Bi(ClO₄)₃ and 3 mol/l HClO₄ onto plates made of a one-sided flexible foil-coated laminate. 70 μm thick Bi films were electrodeposited at room temperature and electrolyte stirring under galvanostatic regime with a current density of 2.5 A/dm². In the melt spinning technique, bismuth (99.9999 %) was melted and then spilled on the cold surface of rotating cylinder made of a polished copper.

Grain structure analysis (electron backscatter diffraction technique) showed that relatively fine-crystalline films (grain size l_G is 0.5–1.5 μm) are formed by electrochemical deposition. Annealing of these films at 540 K for 5–6 h leads to a significant growth of the grain size (up to 10–50 μm). Melt spinning technique gives the coarse-grained Bi films ($l_G \sim 5$ –15 μm) at once.

Electrophysical characteristics such as resistivity, magnetoresistance, Seebeck coefficient and Hall coefficient of the prepared bismuth films were measured in 4–300 K temperature range under magnetic fields up to 8 T (Fig. 1). Relative magnetoresistance $\Delta\rho/\rho_0$ at 4 K under magnetic field 8 T reaches 4500 for annealed electrodeposited films, whereas $\Delta\rho/\rho_0$ does not exceed 12 for as-prepared electrodeposited films. Temperature dependence of the resistivity was found to be strongly influenced by Bi grain size. Semiconductor-like behavior is observed for the fine-grained samples and metal-like behavior – for the coarse-grained ones (Fig. 1a).

Mobilities and concentrations of electrons and holes were calculated using parabolic dispersion law for holes and Lax model, which takes into account a non-parabolicity of dispersion law for electrons [3]. Electron and hole concentrations were found to be practically independent of the film fabrication method and are around 10²⁴ m⁻³, increasing five to seven times as the temperature grows from 25 to 300 K. Mobilities for the electrochemically

deposited samples are close to $1 \text{ m}^2/(\text{V}\cdot\text{s})$ and depend only slightly on temperature in the studied range. For the other types of Bi films, mobilities are approximately $10 \text{ m}^2/(\text{V}\cdot\text{s})$ at helium temperatures and decline by an order of magnitude at room temperature.

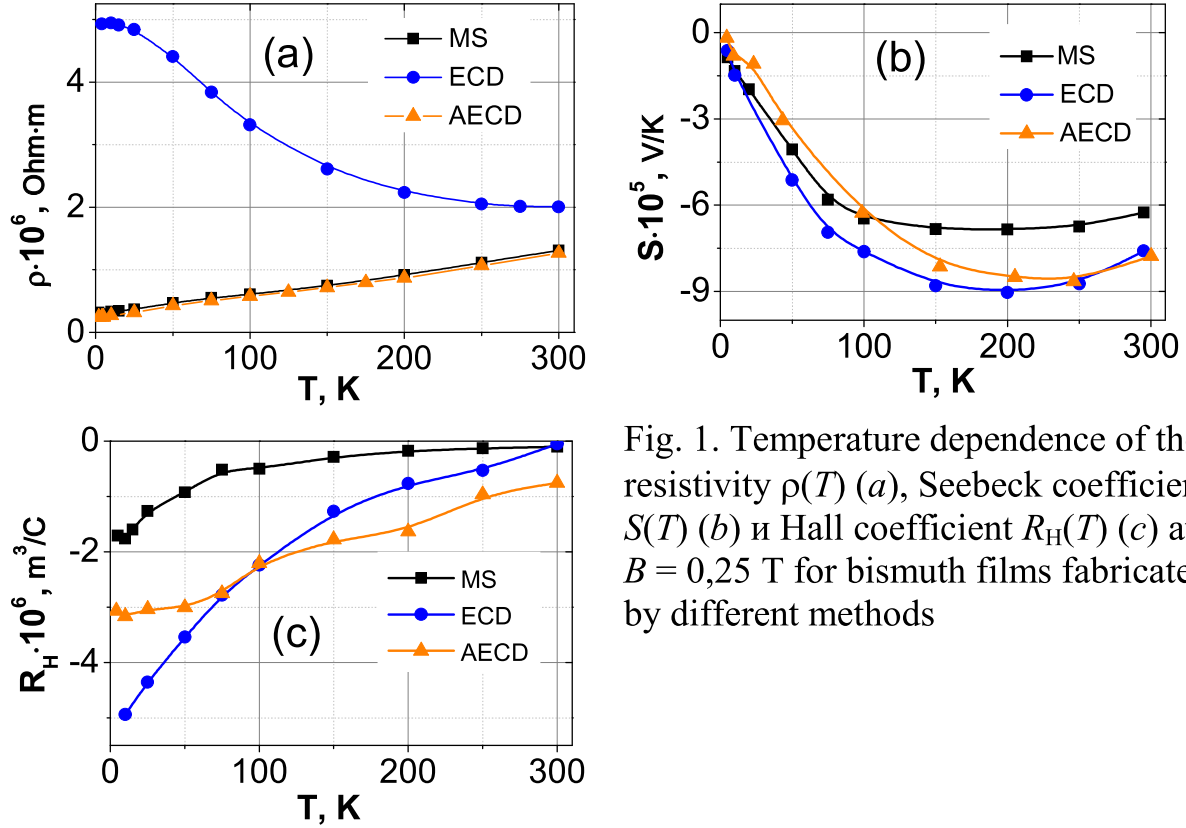


Fig. 1. Temperature dependence of the resistivity $\rho(T)$ (a), Seebeck coefficient $S(T)$ (b) и Hall coefficient $R_H(T)$ (c) at $B = 0,25 \text{ T}$ for bismuth films fabricated by different methods

The observed differences in electronic properties of the Bi films under study can be explained by a profound effect of grain boundaries on charge carriers scattering. For fine-crystalline films (as-prepared electrodeposited films, ECD) the grain-boundary scattering plays a significant role, which results in a weak temperature dependence of mobility and in a decrease of resistivity with increasing the temperature due to a rise of the charge carrier concentration. In the case of coarse-crystalline films (electrodeposited films after annealing, AECD, and films deposited by melt spinning, MS) a contribution of the temperature-dependent scattering by phonons enhances strongly. As a result, the charge carrier mobility decreases, and the resistivity monotonically rises with increasing the temperature.

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