Percolating nature of the metal-to-insulator transition in epitaxial films of neodymium nickelate

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Perovskite rare-earth nickelates $ReNiO_3$, where Re = La, Pr, Nd, Sm, etc, exhibit a rich scale of structural and physical properties including strong electron-lattice coupling, low-temperature magnetic ordering and opposite signs of the Hall and the Seebeck coefficients. However, a principal functional feature of these materials is a sharp metal-to-insulator transition (MIT), which is governed by a tiny tilting of the Ni-O-Ni bond angle under cooling/pressure. Because of extreme synthesis conditions, there is still a lack of bulky single crystals of the nickelates. Therefore, uniform epitaxial films of tens-nm thickness present the best nowadays approach to study the intriguing physics of these materials and its application potential for innovative electronics devices [1].

Neodymium nickelate with a chemical composition $NdNiO_3$ (NNO) is the best studied representative of the $ReNiO_3$ family. High-quality epitaxial films of NNO can be routinely prepared by modern deposition techniques. The films subjected to a tensile in-plane strain (positive substrate-film misfit) demonstrate a pronounced MIT at T_{MI} = 170 K, below which the electrical resistivity abruptly increases by several orders of magnitude [1]. Therefore, controlling the MIT by external stimuli with an aim to increase T_{MI} up to the room temperature holds potential for novel micro-electronics applications including resistive switching.

In this presentation, I consider effects of percolating nature of the MIT in the thin NNO films, which have been overlooked or assigned to a concomitant antiferromagnetic transition. Recently, a hypothesis of two-phase coexistence in a hysteresis region of the MIT at T = 20-170 K has been proved experimentally. Effective-medium analysis of the resistivity dependencies on temperature in both phases, the insulator phase below 20 K and the metallic phase above 200 K, gives a phase volume ratio in the transitional region T = 20-200 K (Bruggeman-Landauer equations estimating transport properties of inhomogeneous materials). Knowing the phase ratio, non-monotonic dependencies of Seebeck/Hall coefficients in the transitional MIT region is fitted by a proportional combination of the thermal/magnetic voltages induced in the separate phases. Following a universality principle of critical exponents, percolation threshold in these films occurs at T_p = 120 K. At this critical point, a long-range connectivity between fractions of a growing phase (a large component of the order of system size) is formed. Our study reveals a significant drop of thermal conductivity and a small burst of negative magnetoresistance at the percolation threshold.

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[1] S. Catalano, M. Gibert, J. Fowlie, J. Iniguez, J.-M. Triscone, J. Kreisel, Rare-earth nickelates RNiO3: thin films and heterostructures (review), Rep. Prog. Phys. 81 (2018) 046501.