# Influence of superconducting mixed state on Ni nanowire magnetoresistance

S.N. Kozlov,[1,2,3,a)] O.V. Skryabina,[1,3] S.V. Egorov,[1] A.A. Klimenko,[4,5] V.V. Ryazanov,[1,6,7,8] S.V. Bakurskiy,[9,3,7] M.Yu. Kupriyanov,[9,3,8,7] N.V. Klenov,[9] I. I. Soloviev,[9] A.A. Golubov,[3,10] K.S. Napolskii,[4,11] I.A. Golovchansky,[3,7] and V.S. Stolyarov[3,1,2,8,b)]

[1)] *Institute of Solid State Physics RAS, 142432 Chernogolovka, Russia*
[2)] *Fundamental Physical and Chemical Engineering dep., MSU, 119991 Moscow, Russia*
[3)] *Moscow Institute of Physics and Technology, 141700 Dolgoprudny, Russia*
[4)] *Department of Materials Science, MSU, 119991 Moscow, Russia*
[5)] *Institute of Nanotechnology of Microelectronics RAS, 119991 Moscow, Russia*
[6)] *Faculty of Physics, National Research University Higher School of Economics, Moscow, Russia*
[7)] *National University of Science and Technology MISIS, 119049 Moscow, Russia*
[8)] *Solid State Physics Department, KFU, 420008 Kazan, Russia*
[9)] *Skobeltsyn Institute of Nuclear Physics, MSU, 119991 Moscow, Russia*
[10)] *Faculty of Science and Technology and MESA+ Institute of Nanotechnology, 7500 AE Enschede, The Netherlands*
[11)] *Department of Chemistry, MSU, 119991 Moscow, Russia*

We have fabricated and studied the structures consisted of Ni nanowire and Nb electrodes having high-quality interface resistance. Transport measurements of the nanowire (NW) revealed the anisotropic magnetoresistance behavior characterized by low resistivity and particularly large coercive field of the NW. Investigation of magnetization reversal process with micromagnetic simulations showed that large coercive field is justified by the polycrystalline structure of the studied nanowire where both magnetocrystalline anisotropy of randomly oriented grains and effective uniaxial anisotropy at the grain boundaries contribute to the enhanced coercive field as compared to the ideal structure. The magnetization reversal of the grained NW occurs via the curling mode when the vortices are formed and propagate in the NW and the propagation is inhibited at grain boundaries. In addition to the conventional anisotropic magnetoresistance, the effect of the superconducting mixed state of the Nb electrodes on the Ni-nanowire based structure magnetoresistance has been experimentally observed and studied. The effect is related to superconducting Nb electrodes that operate as superconducting shunts. As the result, the conventional anisotropic magneto-resistance of the ferromagnetic nanowires remains, but is accompanied by a strong growing, hysteresis, and saw-like dependence of the resistance of the shunt on a magnetic field. This phenomenon is associated with distribution and penetration/escape of individual Abrikosov vortices and their influence on nonequilibrium processes close Ni-nanowire/Nb-interface. These effects should be taken into account when designing novel cryogenic hybrid magnetoresistive nanodevices which comprise both anisotropic magnetoresistance of NW and complex superconducting magnetoresistance of a superconducting shunt.

[a)] Electronic mail: sergeikozlov24@yandex.ru

[b)] Electronic mail: vasiliy.stoliarov@gmail.com