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Evolution of non-collinear magnetic state of exchange biased ferromagnet/normal metal/ ferromagnet/superconductor heterostructure in magnetic field studied by polarized neutron reflectometry

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By using waveguide enhanced polarized neutron reflectometry we have characterized the magnetic state of exchange biased CoO_x(20 nm)/Co(4 nm)/Nb(5 nm)/Co(2 nm)/Nb(25 nm)/Al_2O_3 system. Measurement allowed to determine the dependence of the inclination angles of magnetic moment of the both Co layers as a function of applied field. According to the measurement the soft Co(2 nm) layer magnetization turns towards external field in magnetic fields as small as 20 Oe. In contrast direction of magnetic moment of Co(4 nm) layer can not be altered in magnetic fields as high as 2 kOe.

PACS: 75.70.Cn Magnetic properties of interfaces (multilayers, superlattices, heterostructures);
75.25.–j Spin arrangements in magnetically ordered materials (including neutron and spin-polarized electron studies, synchrotron-source x-ray scattering, etc.);
61.05.fj Neutron reflectometry.

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Superconductor–feromagnet (SF) heterostructures are in the focus of current investigations, and reveal in the last years several experimental findings at nanoscale, based on development of unconventional correlations of superconducting pairs [1]. Quasi-one-dimensional Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) superconducting state describes oscillating in space superconducting order parameter and related phenomena [2–4]. The appearance of the component with spin triplet symmetry in superconducting condensate is the base of another group of effects [5–8] and is favored by the presence of inhomogeneous, noncollinear magnetization. The spin polarized superconducting currents may flow in these systems and are of especial interest of superconducting spintronic [9,10]. The understanding of underlying physics and reliable control over experimentally measurable superconducting properties in SF layered heterostructures is based on possibility of unambiguous determination of the value and magnetization directions in F-layers.

For the direct control of non-collinear magnetic state of SF structures polarized neutron reflectometry (PNR) can be used [11,12]. In PNR, the intensities of specularly reflected neutron beams with different polarization $R^{\mu\eta}(Q)$ are measured. Here $Q = 4\pi \sin(\theta)/\lambda$ is the momentum transfer, and θ and λ are the grazing-incidence angle and the neutron wavelength, respectively. The indices μ and η take values «+» or «–» and correspond to the projection of the neutron spin parallel to H before and after the scattering process, respectively. The non-spin-flip (NSF) reflectivities R^{++} and R^{-} are sensitive to the depth profiles of sum and difference of nuclear scattering length density (SLD) and collinear component of the magnetization: