Coexistence of superconductivity and ferromagnetism at low-dimensional heterostructures

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Abstract

Investigation of superconducting / ferromagnetic low-dimensional heterostructures by polarized neutron reflectometry with secondary radiation registration.

Introduction

Interest in multi-layer magnetic structures is motivated by their numerous applications – both realized and those being developed – in magnetic and spin electronics: for example, highly sensitive magnetic field sensors, magnetic recording and storage devices, etc. Much interest is shown to phase transitions, spin structure, scaling (qualitative change of properties), and proximity effects related to decreasing the material dimensions. Special attention is drawn by the following properties of such structures: exchange bias, giant magnetoresistance, induced and suppressed magnetism, artificial magnetic semiconductivity and superconductivity, etc. Such structures are widely used in different areas. For example, car brake anti-blocking is based on detecting the magnetic field associated with wheel rotation. Another application of magnetic nanosystems is using them in magnetic carriers of information. Thus, one can see that studying magnetic nanosystems is an important task of modern science.

One of more intriguing multi-layer magnetic structures: with superconducting and ferromagnetic properties [1,2]. The magnetic properties of superconductors (S) and ferromagnets (F) are antagonistic. If in a ferromagnet the magnetic moments of atoms line up collinearly to the external magnetic field, then the superconductor completely displaces the magnetic field, since superconducting electron pairs have antiparallel ordering of spins. On the other hand, proximity effects at the physics of superconductivity are known. The classic proximity effect appears as penetration of superconductivity to ferromagnet in case of their contact. Low-dimensional heterostructures with alternating ferromagnetic and superconducting layers are in focus of view, because proximity effect realizes at them.

Polarized neutron reflectometry (PNR) is irreplaceable for studying magnetic nanosystems. The method is based on the interaction between the neutron's magnetic momentum and magnetic moments within the structure. At the fig.1 shown classical schema of PNR. With grazing angles of 3÷30 mrad and neutron wavelength of several Angstroms – parameters typical for neutron reflectometry – the transmitted impulse is 10^{-3}÷10^{-1} Å^{-1}, which provides spatial resolution of 1÷100 nm in determining magnetization. The students performing this project will get the idea of the polarized neutron reflectometry, learn to handle spectra, and do data processing and analysis. The results of data processing are presented as quantitative information on magnetic structure: magnetic moment magnitude and direction, domain size, etc. For practical work, used will be spectra of scattering by real samples obtained at the REMUR facility [3].

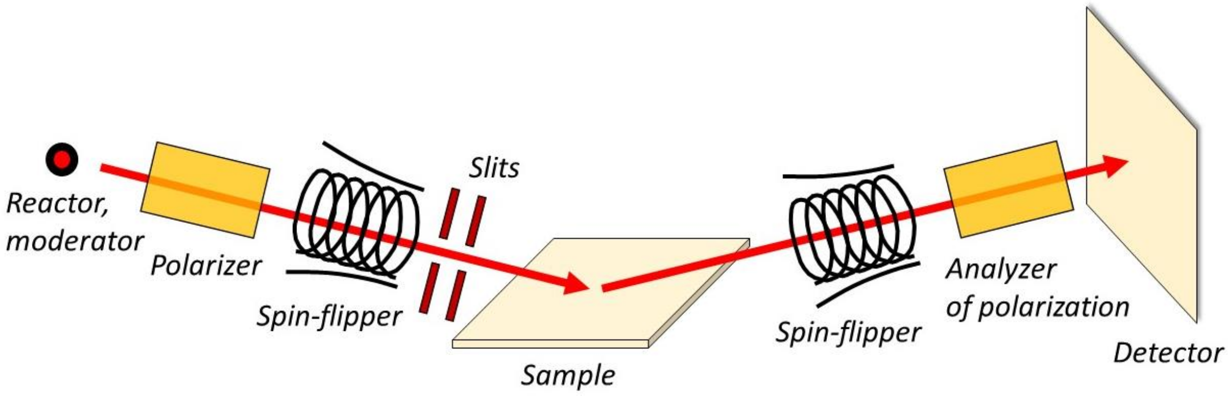

Fig.1. Layout of a polarized neutron reflectometer

Tasks

1. Understanding of scientific problem
2. Processing of raw-data spectra with Spectra_Viewer software
3. Data fitting with physical model by Matlab software
4. Calculation of modeling reflectivity curve depending on different parameters

Preliminary schedule by topics/tasks

The duration of this project is 4 weeks.
Week 1 – introduction lecture, reading the articles
Week 2 – lecture with task explanation
Week 3 - task completion
Week 4 – preparing of the report

Required skills

1. Condensed matter physics: basic knowledge of magnetism / superconductivity
2. Neutron physics: basic knowledge of polarized neutron reflectometry
3. Computer skills: Matlab

Acquired skills and experience

1. Understanding the problems of coexistence superconductivity / ferromagnetism at low-dimensional heterostructures
2. Skills at polarized neutron reflectometry (PNR)
3. Understanding of possible directions of PNR development: isotope-identifying neutron reflectometry, etc.
4. Experience at data processing and fitting of data with physical model.

Recommended literature

1. A.I. Buzdin // Reviews of Modern Physics, vol. 77, № 3, P. 935, 2005.
2. Yu N Khaydukov, et al. // Physical Review B, Vol. 99, No. 14, pp. 140503, 2019.
3. V.L. Aksenov, et al. // JINR Communications D13-2004-47 (2004).