Abstract

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Title: Long-range proximity effect on the structures superconductor/ferromagnet

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Superconducting spintronics, which emerged on the border between traditional spintronics and superconducting science brings significant improvement to the traditional spintronic devices. In particular, the challenging problem of spintronics, namely the creation of the high-efficient net spin current generators could be solved using the hybrid structures based on the conventional superconductor and ferromagnet. Further investigation of such structures requires a significant fundamental study, which should characterize electron transport in such structures. This type of structures often presents unusual electron-transport behavior. Subsequently untypical results are commonly considered as an anomaly and are discarded from further analysis. In the presented work we deal with the study of electron transport at the superconductor-ferromagnet interface and the possibility of long-range proximity effect on these heterostructures as well as the analysis of anomalies in differential conductivity measured by point contact Andreev reflection spectroscopy. Such anomalies are commonly referred to as "zero-bias anomalies", and in our case, similar increased zero-voltage conductivity was measured on structures consisting of an NbN superconductor and a weakly spin-polarized NiCu ferromagnet. In this work we have shown a theoretical explanation of this phenomenon based on the induced superconductivity in the ferromagnet as well as experimental verification of the measured differential conductivities of these heterostructures.

The presented PhD thesis consists of the preface, state of knowledge, 4 main parts and conclusions.

The theoretical background concerning the studied problem is given in Chapter 1. The chapter begins with the consideration of the main experimental facts and theories, which leads to the

establishment of the modern view on conventional superconductivity. The chapter continues by considering of the main points of the microscopic theory of superconductivity developed by Bardin, Cooper and Schrieffer. Afterwards, the physics of proximity effect in the structures based on conventional superconductor (S) and normal metal (N) is discused. The basics of Blonder-Tinkham-Klapwijk theory are presented on contact the superconductor with normal metal. Subsequently, a theoretical model describing the possible formation of anomalies in the conductance spectra based on proximity-induced superconductivity was developed. The chapter ends with a discussion of the phenomenon of proximity in structures based on a classical superconductor and a ferromagnet, as well as a brief introduction to ferromagnetism.

The properties of the studied materials are discussed in Chapter 2. At the beginning of the chapter, the crystalline phases and the electronic structure of the stoichiometric fcc-NbN are presented. The chapter ends with an overview of the mechanical, electrical and magnetic properties of nickel-copper alloys depending on the mutual concentrations of Ni and Cu.

The methods and techniques, which were used for the production and studying of samples are presented in Chapter 3. In the beginning, the pulsed laser deposition, magnetron sputtering and shaping of the samples using optical lithography and ion etching are briefly considered. The continuing of the chapter includes consideration of the techniques, which were used for measurement of the electron-transport properties of studied samples. They are presented by point-contact spectroscopy (PCS, PCARS), the resistive-temperature (RT) and current-voltage (IV) measurements. The chapter ends by consideration of techniques, which were used for the analysis of morphology, crystal structure, chemical and phase composition of studied materials. The morphology was studied using the scanning electron and atomic force microscopies, crystal structure and phase composition were determined by the X-ray diffraction techniques and high-resolution transmission electron microscopy, chemical composition was estimated using the energy-dispersive X-ray spectroscopy and X-ray photoelectron spectroscopy wherein thickness of samples was estimated using X-ray reflection technique.

In the chapter “Experimental results” we demonstrate the study of the transport properties of the heterostructures based on NbN and NiCu. In the current study, we have estimated the superconducting density of states in measured structures by the point-contact Andreev reflection spectroscopy. The research is focused on the changes in the superconducting density of states (DOS), which are caused by the presence of a weakly-polarized ferromagnet layer in the proximity of a conventional superconductor. By the consistent increase of the NiCu thickness, we have observed the possible occurrence of the proximity-induced order parameter in the NiCu layer. Anomalies at zero voltage were observed in some of the measured conductivity characteristics, where the measured

differential conductivity was greater than twice that of the conductivity measured at voltages above the energy gap. By providing additional experiments and using our approach from Chapter 1, we were able to verify and provide a possible explanation of the zero-bias anomaly, which occurred in our case. This study is supplemented by the enhanced research of crystalline and phase structure, electron-transport, magnetic (in case of NiCu) properties of single NbN and NiCu.