BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Proximity effect in [Nb(1.5 nm)/Fe(x)]$_{10}$/Nb(50 nm) superconductor/ferromagnet heterostructures

Yury Khaydukov*[1,2,3], Sabine Pütter[4], Laura Guasco[1,2], Roman Morari[5], Gideok Kim[1], Thomas Keller[1,2], Anatolie Sidorenko[5] and Bernhard Keimer[1]

Full Research Paper

Open Access

Address:
[1]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, D-70569 Stuttgart, Germany, [2]Max Planck Society Outstation at the Heinz Maier-Leibnitz Zentrum (MLZ), D-85748 Garching, Germany, [3]Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow 119991, Russia, [4]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ), Lichtenbergstr. 1, D-85747 Garching, Germany and [5]Institute of Electronic Engineering and Nanotechnologies ASM, MD2028 Kishinev, Moldova

Email:
Yury Khaydukov* - y.khaydukov@fkf.mpg.de

* Corresponding author

Keywords:
ferromagnet; iron (Fe); mixed state; neutron reflectometry; niobium (Nb); proximity effects; superconductor

Beilstein J. Nanotechnol. **2020,** *11,* 1254–1263.
https://doi.org/10.3762/bjnano.11.109

Received: 26 November 2019
Accepted: 28 July 2020
Published: 21 August 2020

This article is part of the thematic issue "Functional nanostructures for electronics, spintronics and sensors".

Associate Editor: J. M. van Ruitenbeek

Abstract

We have investigated the structural, magnetic and superconduction properties of [Nb(1.5 nm)/Fe(x)]$_{10}$ superlattices deposited on a thick Nb(50 nm) layer. Our investigation showed that the Nb(50 nm) layer grows epitaxially at 800 °C on the Al_2O_3(1−102) substrate. Samples grown at this condition possess a high residual resistivity ratio of 15–20. By using neutron reflectometry we show that Fe/Nb superlattices with x < 4 nm form a depth-modulated FeNb alloy with concentration of iron varying between 60% and 90%. This alloy has weak ferromagnetic properties. The proximity of this weak ferromagnetic layer to a thick superconductor leads to an intermediate phase that is characterized by a suppressed but still finite resistance of structure in a temperature interval of about 1 K below the superconducting transition of thick Nb. By increasing the thickness of the Fe layer to x = 4 nm the intermediate phase disappears. We attribute the intermediate state to proximity induced non-homogeneous superconductivity in the structure.

Introduction

Superconductor(S)/ferromagnet(F) heterostructures are intensively studied systems, which are interesting for fundamental physics due to a big number of predicted and detected phenomena such as the appearance of non-uniform superconducting states (see reviews [1-3]). Among these phenomena are π–Josephson junctions [4-7] with a π-phase difference of super-