

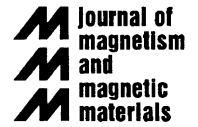


ELSEVIER

Available online at [www.sciencedirect.com](http://www.sciencedirect.com)

SCIENCE @ DIRECT®

Journal of Magnetism and Magnetic Materials 300 (2006) 83–88

[www.elsevier.com/locate/jmmm](http://www.elsevier.com/locate/jmmm)

# Decoupled superconductivity in the four- and five-layered ferromagnet–superconductor nanostructures and control devices

Yurii N. Proshin<sup>a,b,\*</sup>, Alexei P. Zimin<sup>a</sup>, Nail G. Fazleev<sup>a,c</sup>, Mansur G. Khusainov<sup>a,b,d</sup><sup>a</sup>Kazan State University, Kazan 420008, Russia<sup>b</sup>Max-Planck-Institute for the Physics of Complex Systems, Dresden 01871, Germany<sup>c</sup>University of Texas at Arlington, Arlington, Texas 76019, USA<sup>d</sup>Kazan State Tupolev Technical University, Chistopol' 422981, Russia

Available online 16 November 2005

## Abstract

The ferromagnet/superconductor (F/S) tetra- and pentalayer consisting of rather dirty metals are considered with regard for the boundary conditions. The dependences of critical temperatures  $T_c$  versus the thicknesses of the F layers are investigated. The clearest manifestation of *decoupled superconductivity* for the F'/S'/F''/S'' *tetralayer* is the rise of a *hierarchy* of transition temperature  $T_c$ , and *different S'* and *S'' layers* can have *different critical temperatures*. The same is valid for *nonsymmetrical* case of the F'/S'/F''/S''/F''' *pentalayer*. The complicated phase diagram of the tetralayer is discussed. The *inverse* action of *superconductivity on magnetism* leads to preferable mutual *antiferromagnetic* orientation of magnetizations of the F' and F'' layers, if the inner S' layer is in the *superconducting* state. Conceptual scheme of the new nanoelectronics control device, that has up to *seven* different states and combine in one sample the advantages of two different recording channels, is proposed.

© 2005 Elsevier B.V. All rights reserved.

PACS: 74.78.Fk; 85.25.-j; 74.62.-c; 85.75.-d

Keywords: Proximity effect; Superconductivity; Ferromagnetism; Multilayers; Critical temperature; Control device

## 1. Introduction

For the ferromagnet/superconductor (F/S) heterostructures consisting of alternating ferromagnetic metal (F) and superconducting (S) layers, the superconducting order parameter (OP), owing to the proximity effect, can be induced in the F layer; on the other hand, the neighbouring pair of the F layers can interact with one another via the S layer. One can control properties of such systems varying the thicknesses of the F and S layers ( $d_f$  and  $d_s$ ) or changing external magnetic field  $\mathbf{H}$ . Numerous experiments on the F/S *structures* revealed nontrivial dependences of superconducting transition temperature  $T_c$  on the thickness  $d_f$  (see reviews [1,2] and references therein).

The first solution [3,4] of the boundary value problem (BVP) for pair amplitude in the dirty F/S superlattices led to the possibility of the nonmonotonic dependence  $T_c(d_f)$  which was related to periodically switching the ground superconducting state between the 0 and  $\pi$  phases. Later the boundary conditions valid for arbitrary transparency of the F/S interface were deduced from the microscopic theory [1]. An additional mechanism of nonmonotonic dependence  $T_c(d_f)$  [1,5–8] has been revealed due to modulation of the pair amplitude flux from the S layer to the F layer by thickness  $d_f$ . The reentrant superconductivity predicted by us [1] has been recently observed in the Fe/V/Fe trilayer [9].

The superconductivity in the F/S systems [1,10] is a combination of the BCS pairing in the S layers and the Larkin–Ovchinnikov–Fulde–Ferrell (LOFF) [11] pairing with a nonzero three-dimensional (3D) momentum of pairs in the F layers. Nevertheless, usually it is assumed [3–8,12]

\*Corresponding author. Kazan State University, Kazan 420008, Russia. Tel.: +7 8432 315193; fax: +7 8432 380994.

E-mail address: [yurii.proshin@ksu.ru](mailto:yurii.proshin@ksu.ru) (Y.N. Proshin).