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Reentrance phenomenon in superconductor/ferromagnet nanostructures and their application in superconducting spin valves for superconducting electronics

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In superconductor/ferromagnet layered structures, a Fulde–Ferrell–Larkin–Ovchinnikov-like inhomogeneous superconducting pairing give rise. The singlet and zero-projection triplet components of the pairing oscillate in space, and the presence of interfaces causes interference phenomena. As the result of the interference, the superconducting critical temperature T_c oscillates as a function of the ferromagnetic layer thicknesses or, even more spectacular, reentrant superconductivity appears. Two ferromagnetic layers can be combined with a superconducting layer into a superconducting spin valve. Proper design and choice of the material parameters give possibility to control superconducting T_c manipulating with magnetic configurations in the system. The conditions to get large spin-valve effect, i.e., a large shift in the critical temperature, are reviewed in the article.

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1. Introduction

Superconductivity (S) and ferromagnetism (F) are antagonistic long-range orders which cannot coexist in a homogeneous material [1] (see, however, reviews on coexistence and interaction of superconductivity and magnetism in Chevrel phases and ternary rhodium borides [2], borocarbides [3] and ruthenates [4]). Heterostructures comprising nanometer-scale layers of superconducting and ferromagnetic layers offer new physical picture of the interaction of superconductivity and magnetism, in which the superconducting pairing function penetrates in the ferromagnetic layers in an oscillating manner. If the oscillation scale and the pairing function decay length are comparable with the ferromagnetic layers thickness, as well as the superconducting layer thickness is comparable with the superconducting coherence length, various interference effects can be expected. In this review we focus on mesoscopic oscillations of the superconducting transition temperature T_c which arise as a result of modulation of the coupling between the superconducting and ferromagnetic layers when varying the ferromagnetic layer thickness. One superconducting layer and two ferromagnetic layers already offer functionality determined by mutual alignment of magnetic moments of the ferromagnetic layers. This functionality can be utilized to build a superconducting spin valve discussed at the end of the article.

2. Oscillations of superconducting T_c in S/F bilayers

In this section we consider plane contact of a superconducting film with a ferromagnetic metal film. At an S/F interface the quasi-one-dimensional Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) like state can be generated in the F material [5–10]. Due to exchange splitting of the conduction band (Fig. 1) the singlet Cooper pairs acquire finite pairing momentum $\hbar Q_F = E_{\text{ex}}/v_F$ because wave vectors of