Uspekhi Fizicheskikh Nauk 2002 vol.172 N2, pages 152-154

Competition between superconductivity and magnetism in ferromagnet/superconductor heterostructures

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Abstract

The mutual influence of superconductivity and magnetism in FS systems, i.e. systems of alternating ferromagnetic (F) and super-conducting (S) layers, is comprehensively reviewed. For systems with ferromagnetic metal (FM) layers, a theory of the proximity effect in the dirty limit is constructed based on the Usadel equations. For a FM/S bilayer and a FM/S superlattice, a boundary-value problem involving finite FM/S boundary transparency and the diffusion and wave modes of quasi-particle motion is formulated; and the critical temperature Tc is calculated as a function of FM- and S-layer thicknesses. A detailed analysis of a large amount of experimental data amply confirms the proposed theory. It is shown that the superconducting state of an FM/S system is a superposition of two pairing mechanisms, Bardin - Cooper - Schrieffer's in S layers and Larkin - Ovchinnikov - Fulde - Ferrell's in FM ones. The competition between ferromagnetic and antiferromagnetic spontaneous moment orientations in FM layers is explored for the 0- and π-phase superconductivity in FM/S systems. For FI/S structures, where FI is a ferromagnetic insulator, a model for exchange interactions is proposed, which, along with direct exchange inside FI layers, includes indirect Ruderman - Kittel - Kasuya - Yosida exchange between localized spins via S-layer conduction electrons. Within this framework, possible mutual accommodation scenarios for superconducting and magnetic order parameters are found, the corresponding phase diagrams are plotted, and experimental results explained. The results of the theory of the Josephson effect for S/F/S-contacts are presented and the application of the theory of spin-depending transport to F/S/F contacts is discussed. Application aspects of the subject are examined.