Magnon assisted long-range superconducting proximity effect in half-metallic ferromagnets

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Recently, research of superconducting-ferromagnetic (S/F) heterostructures has developed rapidly. In conventional superconductors the Cooper pair condensate has a spin-singlet symmetry, that is decaying quickly inside a strong ferromagnet due to the presence of the exchange field acting on pairs. It is in contrast to the normal metal, where the superconducting correlations persist at distances of the order of the normal metal coherence length. However, some recent experiments demonstrate that even in the half-metallic fully-spin-polarized ferromagnets (HMF) a long-range proximity effect is possible as in normal metals [1]. It has leaded to a suggestion that an inhomogeneous magnetization close to the interface or a spin-active interface allows generation of the triplet pairs of electrons with the same spin that can penetrate the ferromagnet leading to the long-range proximity effect. However, in the previous discussions, the angular momentum conservation was poorly understood. One can realize that without additional assumption the singlet-triplet conversion process will have an inelastic character and would lead to decoherence. In order to resolve this problem we suggest an alternative approach. We consider that the charge transport in the HMF is mediated by triplet pairs of electrons accompanied by the opposite spin current transferred via coherent spin-waves (magnons) [2]. We develop a model of magnon assisted transport of Cooper pairs and study its properties. It occurs that the composite particles moving inside the ferromagnet are pairs of electrons with spin up dressed with a magnon, that surprisingly poses in total the even singlet symmetry as for normal singlet Cooper pairs. Considering the thermal Bose distribution of magnons we obtain, due to negative interference between magnons of different momentum, a short range proximity effect of the distance of the typical range of the domain-wall width of the ferromagnet. However, if there is a single mode which dominate others that can be possibly stabilized by the proximity free energy then the long-range proximity effect is possible as well. This model is able to explain pronounce magnitude of the Josephson current observed in the experiment, its dependence on the anisotropy energy, and magnetic histeretic behaviour, as well as the reduction of the magnetization due to proximity of superconductuctivity so called the inverse proximity effect. We propose also to amplify the Josephson supercurrent via nonequilibrium coherent magnons injected during the coherent precession of the magnetization by tuning the microwave frequency to the ferromagnetic resonance (FMR) frequency in a ferromagnetic Josephson junction [3].

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