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

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Research of superconducting-ferromagnetic (S/F) heterostructures has recently attracted broad interest. 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 the pairs. This is in contrast to normal metals, 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]. This has led to a suggestion that an inhomogeneous magnetization close to the interface or a spin-active interface allow generation of triplet pairs of electrons, where both electrons posses the same spin. Such pairs can penetrate the ferromagnet for a long distance. However, in the previous discussions, the angular momentum conservation was poorly discussed. From the spintronics point of view, the singlet-triplet conversion process, due to conservation of the total angular momentum, has an inelastic character leading to decoherence and possible magnetic excitations inside ferromagnet.

In order to resolve this problem we suggest a model of magnon-assisted transport of Cooper pairs and study its properties. We assume that the conversion at the interface of a singlet pair into a triplet one is assisted by creation of a magnon. 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]. It occurs that the composite particles moving inside the ferromagnet are pairs of electrons with spin up dressed with a magnon carrying an angular momentum -1, which poses in total the even singlet symmetry as for normal singlet Cooper pairs. Considering the thermal Bose distribution of magnons we obtain, due to destructive interference between magnons of different momentum, a short range proximity effect of the distance of typical range of the domain-wall width in the ferromagnet. However, in the case when a single magnon mode dominates other modes, the long-range proximity effect is possible as well. We suggest two possible scenarios in order to create a single mode behavior. First, via nonequilibrium 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]. In the second scenario, we consider Bose-Einstein condensation (BEC) of magnons induced by the increase of the magnon chemical potential due to the superconducting proximity free energy. The BEC of magnons will induce a modulation of magnetic order (the inverse proximity effect) - spin superstructure presumably with a weak helical structure that allows for dissipationless spin current.

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