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Possible Observation of Spin-triplet DC Josephson Effect in Superconductor/Ferromagnet Hybrid Structure

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Because of the fermionic nature of electrons the total wavefunction of superconducting electron pairs must be anti-symmetric. Thus, if the orbital part of the wave function is symmetric (anti-symmetric) the spin part should be anti-symmetric (symmetric). Any electronic pairing known to the present satisfies the condition so that, if the spin-part of the pair wavefunction is symmetric (spin-triplet states), its orbital part is anti-symmetric (p- or f-wave). In the above argument, however, the time was assumed to be equal. If a more general condition is considered including the time part, the pair wavefunction may possess an odd symmetry in time and an even symmetries both in momentum and in spin; characteristics of odd-triplet pairs. According to Bergeret *et al.*, these pairs may form at the interface of spin-singlet superconductor (SC)/metallic ferromagnet (FM) hybrid structures, where the FM layer is much thicker than the nano-scale coherence length (~1 nm) of the s-wave spin-singlet superconducting order inside the FM. In this study, we examined the superconducting proximity effect in a particular Nb/Py/AlO_X/Co/AlO_X/Py/Nb stacked geometry with 20-nm-thick Co layer, where the magnetization of permalloy (Py) and Co layers are not collinear. In this configuration, as proposed by Bergeret *et al.*, the m=0 spin-triplet superconducting order induced in one side of Nb/Py interface becomes long-ranged across the thick Co layer and connected to the m=1 spin-triplet superconducting order in the other side of Nb/Co interface. We observed the existence of the supercurrent-like I-V characteristics through the above-structured junction. It strongly suggests the possible formation of spin-triplet superconductivity at the interface between a spin-singlet superconductor and a ferromagnet. We also observed the Fraunhofer-like interference behavior of the critical current for an in-plane external magnetic field.

Keywords : Superconductor/ferromagnet hybrid structure, Proximity effect, Odd-triplet superconductivity