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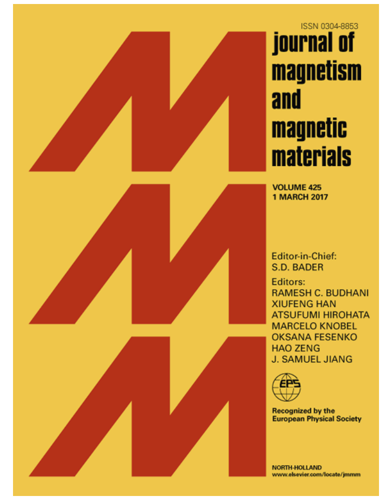

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PII: S0304-8853(17)32120-0
DOI: http://dx.doi.org/10.1016/j.jmmm.2017.08.021
Reference: MAGMA 63055

To appear in: *Journal of Magnetism and Magnetic Materials*

Please cite this article as: Yu.N. Proshin, M.V. Avdeev, The theory of long-range Josephson current through a single-crystal ferromagnet nanowire, *Journal of Magnetism and Magnetic Materials* (2017), doi: http://dx.doi.org/10.1016/j.jmmm.2017.08.021

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The theory of long-range Josephson current through a single-crystal ferromagnet nanowire

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Abstract

Theoretical model of the singlet long-range Josephson transport is proposed. Taking into account the mismatch of the electron effective masses of majority and minority spin subbands the Eilenberger-like equations are obtained with renormalized effective exchange interaction. The critical Josephson current is calculated through ferromagnet nanowire. It is shown that the effective exchange field can be completely compensated and thereby the long-range spatial supercurrent arises. Within the proposed theoretical model, the long-range proximity effect observed in the Co single-crystalline nanowire [Wang, M. *et al.* Nat. Phys. **6**, 389 (2010)] can be qualitatively understood.

Keywords: Josephson current; long-range proximity effect; singlet; superconductivity; ferromagnetism

1. Introduction

Due to the proximity effect [1] in artificial superconductor (S) - ferromagnet (F) structures the induced singlet superconducting correlations can penetrate into the F region, strongly exponentially decays and oscillates at length $\xi_h = \sqrt{D/h}$ for dirty limit, where D is diffusion constant and h is exchange field in ferromagnet. For conventional ferromagnets such as Co, Fe, Ni, *etc.* this decay length is very small, $\xi_h \sim 1 \div 10\,\text{nm}$. The corresponding penetration depth for the non ferromagnet (N) metal, $\xi_N = \sqrt{D/2\pi T}$ (T is temperature), is much greater than in F metal, and ξ_N can reach $0.1 \div 1\,\mu\text{m}$. The strong suppression of induced superconductivity in F metals is caused by relatively large value of the exchange field $h \gg T$. This field tends to parallel electron spins, destroying superconducting spin-singlet Cooper pairs with antiparallel spins. It is well-known as pair breaking effect of the exchange field, this effect is clearly seen experimentally and it corresponds to the simple picture of the destruction of the singlet superconductivity by the exchange field [2, 3, 4]. An oscillatory part

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