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Experimental and theoretical analysis of the upper critical field in ferromagnet–superconductor–ferromagnet trilayers

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Abstract

The upper critical magnetic field H_{c2} in thin film ferromagnet–superconductor–ferromagnet trilayer spin-valve cores is studied experimentally and theoretically in geometries perpendicular and parallel to the heterostructure surface. The series of samples with variable thicknesses d_{F1} of the bottom and d_{F2} of the top $Cu_{41}Ni_{59}$ ferromagnet (F) layers are prepared in a single run, utilizing a wedge deposition technique. The critical field H_{c2} is measured in the temperature range 0.4–8 K and for magnetic fields up to 9 T. A transition from oscillatory to reentrant behavior of the superconducting transition temperature versus F-layer thickness, induced by an external magnetic field, has been observed for the first time. In order to properly interpret the experimental data, we develop a quasiclassical theory, enabling one to evaluate the temperature dependence of the critical field and the superconducting transition temperature for an arbitrary set of system parameters. A fairly good agreement between our experimental data and theoretical predictions is demonstrated for all samples, using a single set of fit parameters. This confirms the adequacy of the Fulde–Ferrell–Larkin–Ovchinnikov (FFLO) physics in determining the unusual superconducting properties of the studied $Cu_{41}Ni_{59}/Nb/Cu_{41}Ni_{59}$ spin-valve core trilayers.

(Some figures may appear in colour only in the online journal)

1. Introduction

The upper critical magnetic field H_{c2} of an isotropic type-II superconductor generally obeys a linear temperature dependence in the vicinity of the superconducting transition temperature T_c [1]. Deviations from the linear T-dependence of $H_{c2}(T)$ are usually ascribed to inhomogeneities distributed in the sample, which can broaden the resistive transitions $R(T)$ and $R(H)$ [2, 3]. The temperature dependence of H_{c2} is also known to be sensitive to the orientation of the magnetic field, if the size of the superconducting nucleus becomes comparable to the characteristic dimensions of the structure (see, for example, [4, 5]). In particular, artificially prepared metallic multilayers (ML) consisting of alternating superconducting (S) and normal metal (N), or of S and insulating (I) layers, or even of two different superconductors, S and S′, show nonlinear $H_{c2}(T)$ dependences (see, for example, an early review [6]).

Among a variety of layered superconducting systems, superconductor–ferromagnet (S/F) metallic hybrids attract

