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A Spin Valve Core Structure based on the Fulde-Ferrell Larkin-Ovchinnikov Like State: Studies on Bilayers and Trilayers of Superconductors and Ferromagnets

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Abstract. Interference effects of the superconducting pairing wave function in thin film bilayers of Nb as a superconductor (S) and $Cu_{41}Ni_{59}$ as ferromagnetic (F) material lead to critical temperature oscillations and reentrant superconductivity for increasing F-layer thickness. The phenomenon is generated by the Fulde-Ferrell Larkin-Ovchinnikov (FFLO) like state establishing in these geometries. So far detailed investigations were performed on S/F bilayers. Recently, we could also realize the phenomena in F/S bilayers where the S-metal now is grown on top of the F-material. Combining both building blocks yields an F/S/F trilayer, representing the core structure of the superconducting spin valve. Also for this geometry we observed deep critical temperature oscillations and reentrant superconductivity, which is the basis to obtain a large spin switching effect, i.e. a large shift in the critical temperature, if the relative orientation of the magnetizations of the F-layers is changed from parallel to antiparallel.

1. Introduction

The superconducting spin-valve consists of a superconducting thin film (S) sandwiched by two ferromagnetic layers (F). The magnetization direction of one F-layer is pinned by an antiferromagnet (AF) against the rotation of the magnetization direction in an external magnetic field. Theory predicts a dependence of the superconducting transition temperature, T_c, on the relative magnetization direction of the F-layers in this AF-F/S/F structure [1]. For a parallel alignment of the magnetizations, T_c is lower than for the antiparallel one. Thus, one should be able to switch the superconducting state off and on by changing the magnetization direction of one of the layers relative to the other one.

The underlying physics is the S/F proximity effect, in which, contrary to the well-studied S/N case (with N a normal conducting, non-magnetic material), the superconducting pairing wave function does not simply decay into the ferromagnet, but oscillates in addition. The reason is that a quasi-one dimensional Fulde-Ferrell Larkin-Ovchinnikov (FFLO) [2,3] like state is generated in the ferromagnetic layer [4,5].

While the FFLO state in bulk material is restricted to a very narrow range of extreme parameters [7] and is hard to realize [8,9], it is induced from the superconductor into the ferromagnetic film in layers of superconducting and ferromagnetic material. In this state, the Cooper pairing occurs by combining electrons with antiparallel spin as in the BCS theory [10]. However, their momenta, although being in opposite directions, do not have the same absolute value. This yields the oscillating pairing wave function mentioned above.

The oscillation of the superconducting pairing wave function leads to interference phenomena, if the thickness of the F-material has a limited value and the superconducting pairing wave function is reflected at the outer border of the F-material of a (e.g.) F/S bilayer [11]. Depending on the thickness of the F-layer this interference may be constructive or destructive. Thus, by acting back on the S-layer,