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SFINX

SUPERCONDUCTIVITY – FERROMAGNETISM INTERPLAY in NANOSTRUCTED HYBRID SYSTEMS

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Publishable results

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[submitted report]

Section A3 - Publishable results

i. Methods to grow and control AlO_x barriers as well as MgO barriers in ferromagnetic-normal metal and ferromagnetic superconductors structures (F/I/S junctions) have been developed and reproducible protocol has been determined. Theory of magnetisation texture and magnetisation dynamics near the interface of ferromagnetic and normal metal or interface of two ferromagnetic metals has been developed.

ii. We have created superconducting films of Nb with embedded magnetic nano-clusters, uncovered experimentally the origin and revealed the structure of sub-gap spectra of Andreev bound states on a magnetic cluster and cluster arrays embedded in a superconductor. We have assessed the influence of ferromagnetic cluster arrays on critical parameters I_c and T_c of superconducting films. We have developed a theory of magneto-transport in metals with embedded nanoclusters of a ferromagnetic metal. We have related the magnetic field dependence of resistivity of such composite materials to the polarisation state of clusters taking into account the depolarisation effect due to the non-colinearity of cluster polarisation and the distribution of cluster sizes.

iii. We developed a theoretical framework that describes the spin-dependent transport in superconducting spin valves, with the full spatial dependence of the pairing potential calculated self-consistently. We have formulated the theory of tunneling of spin-polarized quasi-particles through a thin superconducting layer in F-S-F (F-I-S-I-F) structures taking into account the contribution of resonant tunnelling via Andreev bound states, which permitted us to describe quantitatively spin-filtering by a nanometer-thin superconducting layer.

We have manufactured hybrid micro-circuits of various geometries. These includes ring-shaped structures used to study interfence effects (such as Aharonov-Bohm effect), and fork-shaped structures used to study cross-correlation in current noise caused by Andreev reflection. In particular, persistent currents in NIS and SIS'IS nanostructures with ring-shaped S electrode have been studied using tunneling experiments. Metastable states at ultra-low temperatures result in oscillations of the persistent current (~ tunnel current) with periodicity much higher than the superconducting flux quantum h/2e. It has been found that for a given diameter of the loop, the shape of tunnel current oscillations depends on the effective diameter of the line forming the ring. The effect can be associated with manifestation of quantum phase slips which remove energy level crossing at the degeneracy points. Various interference effects have been observed in fork-shaped NIS systems, which can be considered as solid-state-analogues of double-slit interferometers.

A new type of a micro-cooler has been created and its work has been demonstrated. The new device (developed at the Grenoble node) is based upon a series of SN tunnel junctions and can be used to provide on-chip cooling from 4K down to 100mK.

iv. We have developed a theory of the critical current in superconductor–ferromagnetic alloy–superconductor trilayers, which takes into account the strong spin dependence of electron scattering on compositional disorder in a diluted ferromagnetic alloy. We have shown that in such a system the critical current oscillations as a function of the thickness of the ferromagnetic layer, however, the critical current decays exponentially with a characteristic length of the order of the mean free path. We have developed a model and efficient calculation method (the circuit-theory approximation) to describe the fully developed proximity effect in superconductor-ferromagnet heterostructures. Within the circuit-theory approximation, we have evaluated the Green functions, the density of states, and the Josephson current which depend essentially on the magnetic configuration of an SFS structure and, most crucially, on its ferromagnetic texture.

On the experiemtnal side, we have demonstrated a superconducting spin-valve effect in Nb/CuNi S/F structure, although it is rather weak. We have shown, by experimentally constraining various parameters, that this is the best that can be expected from this particular materials system, the only one to have shown any effect at all at that time. This is because the proximity effect form the F layer prevents the S layer from getting sufficiently thin. We then moved our attention on to look at ways of tuning the effect of the ferromagnet on the superconductor by introducing a double proximity interlayer, Pd. We have shown that the structural quality of this layer can be affected by whether it is above or below the Nb, which affects the S proximity effect. We have also demonstrated the present of a double proximity effect in this materials system.

The obtained results have been disseminated in the following 71 **publications** in refereed journals, books and conference proceedings**.**