Gate-controlled proximity effects in superconductor/ferromagnet heterostructures

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The discovery of 2D materials opens up unprecedented opportunities to design new materials with specified properties. In many cases, the design guiding principle is based on one or another proximity effect, i.e. the nanoscale-penetration of electronic correlations from one material to another. In a few layer van der Waals (vdW) heterostructures the proximity regions occupy the entire system. In this talk we unveil the microscopic physical mechanism of the magnetic proximity effect, that is the suppression of the superconductivity by the exchange field of the adjacent ferromagnet in 2D superconductor/ferromagnet (S/F) vdW heterostructures and predict that it is determined by the degree of hybridization of electronic spectra of the individual materials [1]. The degree of hybridization can be adjusted by changing the relative filling factors by gating one of the materials allowing for high controllability of the magnetic proximity effect. We illustrate the underlying physics of the processes governing the proximity effect using a minimal tight-binding hamiltonian model on a square lattice, and then demonstrate the existence of the same effects in heterostructures based on vdW materials: a monolayer 1H-$NbSe_2$ as a superconductor and a monolayer 1T-VSe_2 as a ferromagnet. It is demonstrated that the Zeeman splitting of the DOS can be switched on/off and reversed by gating and nonmonotonic dependencies of the superconducting order parameter on the gating potential are obtained.

Also we develop a theory of dissipationless spin transport carried by a supercurrent in such $NbSe_2$/VSe_2 heterostructure due to the simultaneous presence of the Ising-type spin-orbit coupling and a Zeeman field directed in plane of the layer [2]. We analyze the spin structure of triplet Cooper pairs and conclude that the simultaneous presence of the Ising-type spin-orbit coupling and the Zeeman field causes a partial conversion of the singlet pairing into the non-unitary triplet pairing with the averaged non-zero pair spin. If the supercurrent is applied to the system, such pairs carry a superconducting spin current. Furthermore, the triplet pairs acquire an additional spin component induced by the applied supercurrent and proportional to the condensate momentum, which also participates in the spin transport. For this spin current component we predict a rectification effect unlike the charge supercurrent that generates it. Also it is shown that the value and sign of the spin polarization carried by the spin current can be controlled by gating. In addition we consider F/S/F vdW heterostructure, which is well-known as a spin-valve. For such systems we predict direct, inverse and non-monotonic valve effects. Different regimes can be switched via applying gating potential.

Bibliography

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