NÉEL INSTITUTE Grenoble
Topic for Master 2 Internship – Academic year 2020-2021

Yu-Shiba-Rusinov states in superconducting graphene

Graphene, an atomically thin crystal made of carbon atoms arranged into a honeycomb lattice, provides an extremely rich model-system for addressing quantum electrodynamics. Mostly, this is due to its exotic electronic band structure, hosting quasiparticles known as chiral, massless Dirac fermions. At low temperature, if contacted to another superconducting metal, graphene can be turned into a superconductor, that is, a quantum coherent state opposing no resistance to the flow of electric currents. The nature of this superconducting state in graphene, which is unique as it involves Dirac fermions, remains mysterious, however.

Isolated magnetic impurities inside a superconductor provide an exchange scattering mechanism, which is known to act as an extremely sensitive probe of the superconducting state. In particular, such impurities give rise to bound states at energies below the superconducting gap, known as Yu-Shiba-Rusinov states [1]. The observation and study of these bound states will provide deep insights into the physics of superconducting quasiparticles in graphene [2].

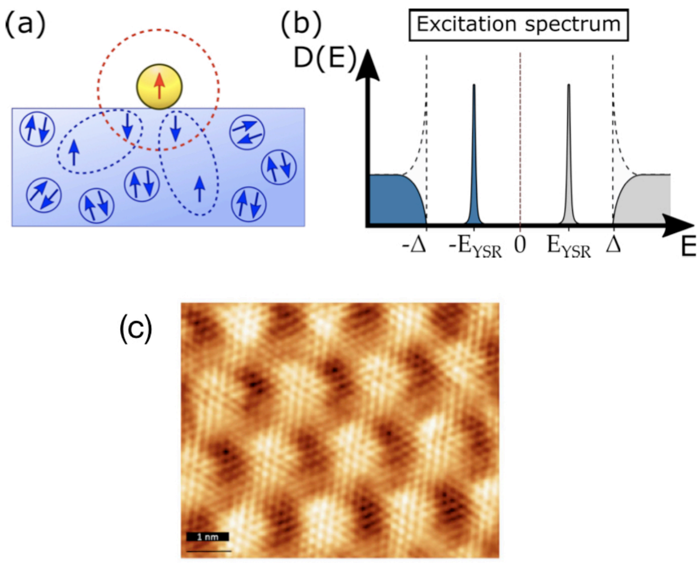

Figure 1: (a) Illustration of the competition of superconducting pairing with the magnetic exchange coupling provided by an isolated impurity. (b) Density of states at the impurity site, displaying the resulting Yu-Shiba-Rusinov bound states, at energies below the superconducting gap. (c) STM image of graphene on superconducting rhenium, in which on top of the atomic structure, a moiré superstructure is seen. This demonstrates the high structural coherence of graphene on rhenium.

The general framework of this project is about spin control and manipulation in two-dimensional materials for quantum engineering. More precisely, the aim of the present PhD project is to address the physics of Yu-Shiba-Rusinov states in graphene. For this purpose, the work will rely on graphene samples grown on superconducting rhenium (see Figure) [3,4]. Magnetic impurities will be artificially engineered by either creating point defects (vacancies known to hold a magnetic moment) or placing individual atoms/molecules on the surface. The atomically resolved structure and electronic density of states in the system will be investigated down to very low temperature (50 mK) using a scanning tunneling microscope.

The work will be performed within collaboration between two laboratories in Grenoble (CEA-IRIG and CNRS-Institut Néel). Two very-low-temperature scanning tunneling microscopes, as well as a multi-technique surface science system equipped with versatile growth and characterization facilities will be available. The project will further benefit from support from theorists from CEA-IRIG.

The candidate should possess a strong background in Condensed Matter Physics and a strong inclination to experimental works requiring complex and fine instrumentation.

Starting date: 2021

References

[1] Magnetic-Field-Induced Transition in a Quantum Dot Coupled to a Superconductor, A. García Corral, D.M.T. van Zanten, K.J. Franke, H. Courtois, S. Florens, and C.B. Winkelmann, Phys. Rev. Research 2, 012065(R) (2020)
[2] E. Cortés-del Río, J.L. Lado, V. Cherkez, P. Mallet, J-Y. Veuillen, J.C. Cuevas, J.M. Gómez-Rodríguez, J. Fernández-Rossier, I. Brihuega, Observation of Yu-Shiba-Rusinov states in superconducting graphene, arXiv:2010.10377
[3] C. Tonnoir, A. Kimouche, J. Coraux, L. Magaud, B. Delsol, B. Gilles, C. Chapelier. Induced superconductivity in graphene grown on rhenium. *Phys. Rev. Lett.* 111, p. 246805 (2013)
[4] E. Mazaleyrat, S. Vlaic, A. Artaud, L. Magaud, T. Vincent, A.C. Goméz-Herrero, S. Lisi, P. Singh, N. Bendiab, V. Guisset, P. David, S. Pons, D. Roditchev, C. Chapelier, J. Coraux, How to induce superconductivity in epitaxial graphene via remote proximity effect through an intercalated gold layer, *2D Mater.* 8, 015002 (2020)

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