Highlights

Advanced materials and techniques for organic electronics, biomedical and sensing applications - 2018

Quantum Interference in Single-Molecule Superconducting Field Effect Transistors

Ciro Nappi[1,2], Francesco Romeo[3], Loredana Parlato[1,2,4], Francesco Di Capua [2,4] , Alberto Aloisio[1,2,4]
and Ettore Sarnelli[1,2]

[1]CNR-SPIN, c/o Complesso di Monte S. Angelo, via Cinthia - 80126 - Napoli, Italy
[2]INFN, Naples Division, Naples 80126, Italy
[3]Physics Department " E. R. Caianiello" , University of Salerno, Fisciano 84084, Salerno, Italy
[4] Physics Department "E. Pancini", University of Naples Federico II, Naples 80126, Italy

JOURNAL OF CHEMICAL PHYSICS C 122 (2018) 11498

Single molecules can be coupled to metallic electrodes when the latter are in the superconducting state. In such emerging hybrid molecular devices, the possibility of a molecular Josephson effect arises. From the practical point of view, one of the obstacles hampering the realization of a working molecular transistor is the relatively large contact resistance associated with a single conduction channel in such a type of device. The contact resistance, a concept borrowed from ordinary electronics, is nature-imposed and cannot be lower than the quantum limit $h/2e^2$ = 12.9 kΩ. Under this condition, the Joule loss is an issue affecting the transistor operation efficiency. One way to overcome this drawback is the introduction of superconducting electrodes. In the presence of superconducting electrodes, Cooper-paired electrons flow in principle without resistance through the junction owing to the Josephson effect. In this theoretical study, we explore the possibility that a junction formed by two superconductors linked by a ring molecule, of which benzene (phenylene group) is a prototype, sustains a supercurrent and acts as a "single molecule superconducting field-effect transistor (SMoSFET)". In this device, Cooper-paired electrons are transmitted via a twofold branch molecule in the presence of quantum interference. We show that the critical currents, likewise the conductances, do not add classically as is the case for standard dimensions devices in a parallel setup. We also show that in such a device the resonant nontrivial modulation of the critical current with an external gate voltage is determined by the quantum interference associated to the different length paths of the electrons crossing the junction. To illustrate this latter point we choose a para-coupled, a meta-coupled, or an ortho-coupled ring molecule junction configuration. In the case of meta coupling with the electrodes (in practice choosing 1,3-Benzenedithiol instead of 1,4-Benzenedithiol), complete destructive interference is obtained and no supercurrent can flow unless a finite gate voltage Vg is applied.

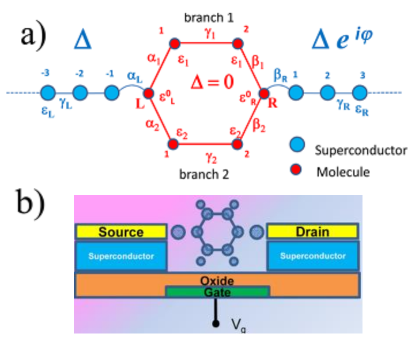

Fig. 1: a) A tight binding representation of the system studied in this paper: a superconductor-six atom ring molecule - superconductor structure (S-mol-S). The structure of the molecule is close to that of Benzene-1,4-dithiol $C_6H_6S_2$. b) A pictorical view of a SMoSFET realization.

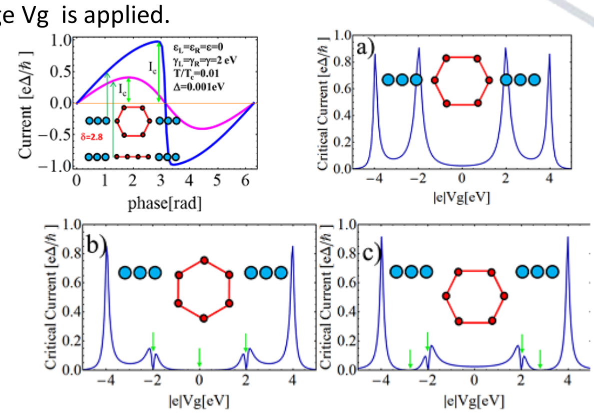

Fig. 2: Upper left. Current phase characteristic of a ring molecule junction and a chain molecule junction. (a–c) Josephson critical current as a function of the gate voltage V_g in a six-atom ring molecule between superconducting electrodes. The curves in (a–c) correspond to para-, meta-, and ortho-type coupling, respectively.