Spin orbit coupling effects in a graphene Josephson junction

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Abstract: We study a graphene Josephson Junction with spin-orbit coupling induced via proximity effect, and focus on its consequences on the critical current, revealing bulk supercurrent suppression or enhancement and edge supercurrent robustness to disorder.

We study a graphene Josephson junction where the inner graphene layer is subjected to a strong Spin-Orbit Coupling (SOC) by proximity effect. This could be achieved, for example, by growing the graphene layer on top of a transition metal dichalcogenide, such as WS_2. This setup is experimentally relevant in all Josephson junctions applications since it was shown that it can host superconducting current for magnetic fields of up to 10 T [1]. Indeed, the SOC terms heavily modify the band structure of the inner graphene layer, inducing different topological phases with associated helical (on all graphene edge terminations) or quasi-helical edge modes (only on zigzag edge terminations) [2,3]. In our work, we focus on the ballistic and short junction limits and study the effects of the SOC interaction on the supercurrent. For the bulk contribution, we follow an analytical approach based on the continuum model. We find that there are combinations of spin-orbit couplings that, by opening a gap (topological or not) in the system, drastically suppress the bulk supercurrent, while there are other combinations that enhance it, effectively acting as chemical potential. To analyze the edge contribution, instead, we made us of a tight-binding procedure based on the Kwant python package. We find that there is no difference in intensity between the supercurrent carried by topological helical edge modes and non-topological dispersive quasi-helical ones: they both contribute as (almost) ballistic modes. By including localized magnetic impurities along the edges we are also able to analyse their degree of topological protection. Because of the different localization properties, the supercurrent carried along the zigzag edge termination was found to be very sensitive to even a single impurity while, remarkably, the supercurrent carried along the armchair one showed an extreme resilience. Finally, we analyse the robustness of the quasi-helical edge modes against the roughening of different graphene edge terminations. We find their supercurrent contribution to be very robust on all graphene terminations, even showing some disorder-induced transport on previously insulating armchair edge termination. In the figure below we plot the critical current against magnetic flux for an experimentally relevant SOC combination for different edge termination, both clean and roughened. The residual critical current at high magnetic flux is given by $I_{Edge}|cos(\pi\phi/\phi_0)+f|,\ f\lesssim 1,$ and provides the intensity of the edge carried supercurrent in the system [4].

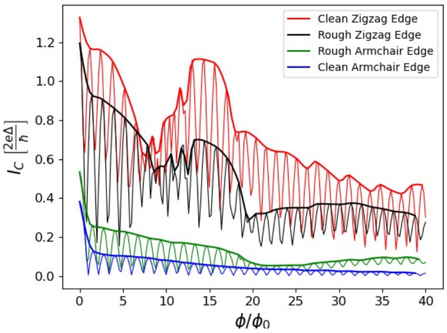

Fig. 1. Critical current against magnetic flux for a high Rashba SOC with a smaller valley-Zeeman one [2,3].

References

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