PROXIMITY EFFECT IN SINGLE AND MULTI-LAYER STRAINED GRAPHENE

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Although graphene was not yet found to sustain intrinsic superconductivity (neither experimentally or theoretically), there is experimental evidence [1] that when in proximity with a conventional superconductor graphene becomes superconducting. This is the conventional proximity effect which describes how Cooper pairs diffuse from the superconducting material into graphene. Because of its peculiar lattice structure, graphene shows another remarkable property. Any strain (due to phonons, substrate, corrugation) existing in graphene will induce a pseudo-vector potential. It was recently shown [2] that it is possible to engineer strain such that the induced pseudo-magnetic field is slowly varying. Even though in contrast to regular magnetic fields, the time-reversal symmetry is not broken and there are no circulating currents, quantized Landau levels still exist. The pseudo-magnetic field has opposite sign for electrons in different valleys, thus allowing circulating orbits in opposite directions for each valley while the overall current vanishes.

The problem of interest here is to see the interplay between strain and the proximity induced superconducting order parameter. In other materials, superconductivity and large magnetic fields are complementary but inducing pseudo-Landau levels through strain is one fortunate situation which allows the interplay between these two scenarios. For this purpose we use a recently developed method (Chebyshev-BdG [3]) which solves self-consistently the mean-field inhomogeneous Bogoliubov-de Gennes equation for graphene. This method calculates the Green's function at each spatial location, while the superconducting order parameter is obtained self-consistently. It is efficient numerically mainly because of its parallel nature, which allows for straightforward use of parallel computing: each spatial location can be solved independently. Moreover our method is amenable to large scale computations on graphical processing units (GPUs).

We consider a tight-binding approach which includes only the low energy pi-bands of graphene. We consider a junction-type geometry such that superconductivity is induced on the sides of a rectangular flake. As shown previously, strain will induce a pseudo-magnetic field in this system. We calculate selfconsistently the order parameters, the local density of states and the current profile as a function of strain. By applying inhomogeneous strain a gap is induced in the electronic spectrum, but since the time-reversal symmetry is conserved, the sub-lattice symmetry will be broken. We show that this is manifested in the density of states of the zero pseudo-Landau level which is present only in one sublattice.

The breaking of this symmetry has profound effects on the diffusion of Cooper pairs in the graphene flake; one sub-lattice has a long leaking distance while the other one has a very short one. If one considers the next-nearest neighbor coupling, we observe that Josephson currents will flow mainly through one sub-lattice We also study the formation of Andreev bounds states for energies below the superconducting gap. We show that due to interference at the superconducting/graphene interfaces, the broken symmetry survives even at higher energies and that the zero-energy Landau level is spatially modulated due to Andreev scattering/interference.

References

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