Dielectric Function Method applied to single layer graphene

D. Elst,[1] S. N. Klimin,[1,3] and J. Tempere[1,2]

[1] TQC, Universiteit Antwerpen, Universiteitsplein 1, B-2610 Antwerpen, Belgium
[2] On leave of absence from the Department of Theoretical Physics, State University of Moldova, str. a. Mateevici 60, MD-2009 Kishinev, Republic of Moldova
[3] Lyman Laboratory of Physics, Harvard University, Cambridge, MA 02138, USA

The dielectric function method (DFM), which uses a non-adiabatic approach to calculate the critical temperatures for superconductivity, has been quite succesful in describing superconductors at low carrier densities. We investigate the application of DFM to the linear dispersion of a monolayer of graphene. We derive the DFM gap equation for a Dirac cone and calculate the critical temperature as a function of carrier density. This is done using an interaction potential that uses the Random Phase Approximation dielectric function and thus allows for plasmonic interactions.

Introduction

The two-dimensional honeycomb structure of a single layer of graphene has raised substantial interest since its experimental realisation [1]. Several unusual electronic properties are supported by the symmetry of graphene's two-dimensional electron gas [2, 3]. For undoped graphene, Kopnin and Sonin [4] demonstrated Cooper pairing is be possible for finite carrier doping. The work of Uchoa and Neto [5] shows plasmon mediated Cooper pairing is favorable at low doping. To treat the regime of low carrier doping, we use the Dielectric Function Method (DFM) [6, 7]. DFM uses the dielectric function to describe screening effects in the weak coupling regime. This way, a general form of the electron-electron interaction can be used that is not limited to a small interaction window around the Fermi level. This technique has already proven its worth in systems like $SrTiO_3$ [8, 9] and the 2DEG in the $LaAlO_3$-$SrTiO_3$ interface [10, 8].

Results

To calculate the critical temperature for a superconducting state, we derived the DFM gap equation for graphene. In this treatment, we write the electron-electron interaction potential in the Random phase Approximation, only including plasmon mediated pairing. The dielectric constant κ is used as a parameter that demonstrates the influence of the environment on the graphene layer. Figure 1 shows the critical temperature as a function of carrier doping for a small range of dielectric constants. For low carrier doping, the critical temperature is greatly suppressed, due to the low density of states around the Dirac point. Also, for a small change in dielectric constant, the critical temperature drops significantly as the plasmon. Keeping in mind these critical temperatures are an upper limit for the Berezinskii-Kosterlitz-Thouless mechanism of superconductivity in 2D materials, it is clear why superconductivity in single layer graphene remains unpractical.

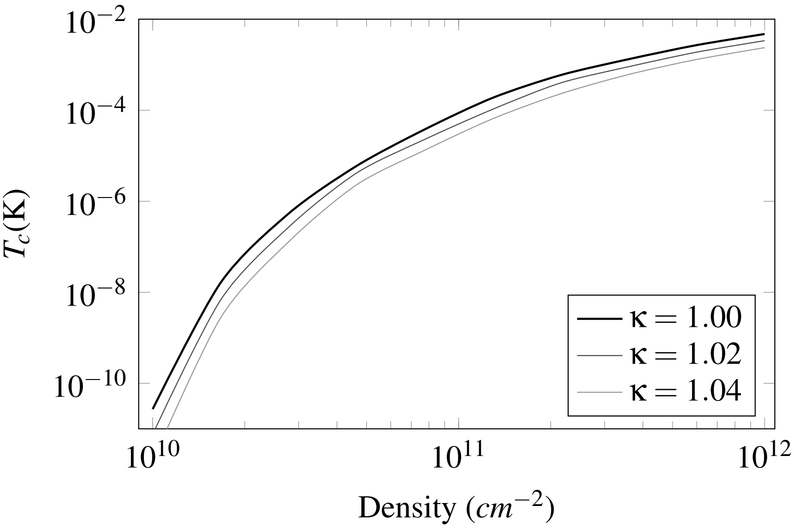

Figure 1: The critical temperature T_c as a function of carrier density plotted for a small range of dielectric constants κ.

References

[1] K.S. Novoselov, A.K. Geim, S.V. Morozov, D. Jiang, Y. Zhang, S.V. Dubonos, I.V. Grigorieva, and A.A. Firsov. Electric field effect in atomically thin carbon films. *Science*, 306(666), 2004.

[2] K.S. Novoselov, A.K. Geim, S.V. Morozov, D. Jiang, I.V. Grigorieva, S.V. Dubonos, and A.A. Firsov. Two-dimensional gas of massless dirac fermions in graphene. *Nature*, 438, 2005.

[3] Y. Zhang, Tan Yan-wen, Horst L. Stormer, and Philip Kim. Experimental observation of the quantim hall effect and berry's phase in graphene. *Nature*, 438, 2005.

[4] N. B. Kopnin and E. B. Sonin. BCS superconductivity of Dirac electrons in graphene layers. *Physical Review Letters*, 100, 2008.

[5] Bruno Uchoa and A. H. Castro Neto. Superconducting state of pure and doped graphene. *Physical Review Letters*, 98(146801), 2007.

[6] D. A. Kirzhnits, E. G. Maksimov, and D. I. Khomskii. The description of superconductivity in terms of dielectric response function. *Journal of Low Temperature Physics*, 10(1), 1973.

[7] Yasutami Takada. Plasmon mechanism of superconductivity in two- and three-dimensional electron systems. *Journal of the Physical Society of Japan*, 45(3), 1978.

[8] S. N. Klimin, J. Tempere, J. T. Devreese, and D. van der Marel. Multiband superconductivity due to the electron-LO-phonon interaction in strontium titanate and on a SrTiO3/LaAlO3 interface. *Journal of Superconductivity and Novel Magnetism*, 30(3), 2017.

[9] S. N. Klimin, J. Tempere, J. T. Devreese, J. He, C. Franchini, and G. Kresse. Superconductivity in SrTiO3: Dielectric function method for non-parabolic bands. *Journal of Superconductivity and Novel Magnetism*, 2019.

[10] S. N. Klimin, J. Tempere, and J. T. Devreese. Interface superconductivity in LaAlO3-SrTiO3 heterostructures. *Physical Review B*, 89(184514), 2014.