Research Networking Programmes

Short Visit Grant ☐ or Exchange Visit Grant ☒

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online <u>within one month of the event</u>. It will be published on the ESF website.

<u>Proposal Title</u>: Few-layer graphene: towards high-temperature excitonic superfluidity

<u>Application Reference N°</u>: 4636

1) Purpose of the visit

The main purpose of the visit was to study the excitonic superfluid state properties of double-fewlayer graphene devices in order to guide the experimental research and realization of high-Tc electron-hole superfluidity.
The prediction of excitonic superfluidity in spatially separated electron and hole layers has captured the attention of the scientific community over the last few decades. The interest results mainly from the fact that double-layer electron-hole systems offer the possibility of observing a coherent superfluid up to very high temperatures.
Despite long standing theoretical predictions [1-3] and considerable experimental efforts [4,5] such excitonic superfluidity in double layered systems has never been observed in zero magnetic field.
The ability to have large r_s, i.e. the average electron-electron interaction energy to the Fermi energy, in few-layer graphene, and consequently realizing the strong electron-hole pairing regime in an experimentally accessible range of densities, motivated me to propose few-layer graphene as a promising system to observe high-temperature electron-hole superfluidity.

2) Description of the work carried out during the visit

In order to investigate the superfluid state properties of double-fewlayer graphene devices we studied two parallel few-layer graphene sheets in which the upper (lower) sheet is connected to the top (back) gate. The few-layer graphene sheets are separated by

an hexagonal boron-nitride (h-BN) insulating barrier to prevent tunneling and electron-hole recombination between the sheets.
The first step in our theoretical study was to evaluate the superfluid energy gap within a mean-field description. During the first days of my visit in University of Camerino, the mean field equations [6] were formulated for coupled fewlayer graphene sheets. We considered the influence of a static screened Coulomb interaction between the electron and holes within the random phase approximation (RPA) framework [6].
Thanks to on-going discussions with Prof. Andrea Perali and Prof. David Neilson and their enlightening comments I was abale to develop the computational code in which we obtain the superfluid gap in a self-consistent manner. In the last week of my visit we discussed on our initial results which we found them very promising.

3) Description of the main results obtained

In our study we predicted room temperature electron-hole superfluidity in double few-layers electron-hole graphene devices. The key physical mechanism is that by increasing the number of graphene layers, the electronic band dispersion is flattened making the electrons and holes acquire large non-constant effective masses. Our results show that this effect can push the graphene sheets into the strongly interacting region. Consequently double few-layer sheets result in strong electron-hole Cooper pairing.
In an experimentally accessible range of densities and spatial separations between electron and hole sheets, the enhanced density of states and effective mass determine large amplification of the maximum superfluid gap as well as an increase in the onset density for superfluidity thanks to a strong suppression of screening.

References

[1] Yu. E. Lozovik and V. I. Yudson, Pis′ma Zh. Eksp. Teor. Fiz. 22, 556 (1975).
[2] G. Vignale and A. H. MacDonald, Phys. Rev. Lett. 76, 2786 (1996).
[3] H. Min, R. Bistritzer, J. Su, and A. H. MacDonald, Phys. Rev. B 78, 121401(R) (2008).
[4] U. Sivan, P.M. Solomon, and H. Shtrikman, Phys. Rev. Lett. 68, 1196 (1992).
[5] J. A. Seamons, C.P. Morath, J.L. Reno, and M.P. Lilly, Phys. Rev. Lett. 102, 026804 (2009).
[6] A. Perali, D. Neilson, and A. R. Hamilton, Phys. Rev. Lett. 110, 146803 (2013).

4) Future collaboration with host institution (if applicable)

The observation of high temperature superfludity in two dimensional (2D) few-layer graphene sheets motivated us to continue our collaboration to investigate the excitonic superfluid state properties in other 2D materials. I am planning to visit the Physics Department of University of Camerino again during the next academic year.

5) Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)*

We are currently preparing a manuscript for publication in a high-quality peer-reviewed journal. We will also present our results at international upcoming conferences, MultiSuper2014 in Camerino and ICSM2014 in Antalya (Turkey). The ESF grant will be acknowledged in relevant publications and talks.

6) Other comments (if any)

I would like to acknowledge the hospitality of the Physics Department of University of Camerino and specifically of Prof. David Nelison and Prof. Andrea Perali. I would also like to acknowledge the support received from the European Science Foundation (ESF) under the framework Common perspectives for cold atoms, semiconductor polaritons and nanoscience (POLATOM).