Akinobu Kanda
Katsuhide Yarimizu[1], Daisuke Yabe[1], Kenji Watanabe[2], Takashi Taniguchi[2], Hikari Tomori[1,3]
[1] Division of Physics and TIMS, University of Tsukuba, Tsukuba, Japan
[2] National Institute for Materials Science (NIMS), Tsukuba, Japan
[3] PRESTO, Japan Science and Technology Agency, Kawaguchi, Japan

kanda.akinobu.gm@u.tsukuba.ac.jp

Search for Unusual Andreev Reflection in a Bilayer Graphene/Layered Superconductor $NbSe_2$ Junction

At a superconductor/normal metal interface, an incident electron (-*e*) from the normal metal enters into the superconductor as a Cooper pair (-2*e*) and a hole (+*e*) is reflected into the normal metal due to the charge conservation. This process is called the Andreev reflection. Usually, because both the incident electron and the reflected hole belong to the conduction band of the normal metal, the reflected hole goes back along the same path of the incident electron satisfying the momentum conservation (retro-reflection). On the other hand, in the case that graphene is used as the normal metal, the reflected hole is in the valence band when the Fermi level is close to the Dirac point, leading the novel *specular* Andreev reflection. Early theory [1] tells that when the Fermi level of graphene is swept across the Dirac point, the transitions between retro- and specular reflections cause an anomalous behavior in the current-voltage (*I*-*V*) characteristics. This can be used as an easy proof of the existence of the specular reflection. In experiments, the specular Andreev reflection has not been confirmed for a long time, mainly due to spatial variation of the carrier density (electron/hole puddles) in graphene caused by charged impurities, which allows the retro- and specular reflections to coexist. Besides, due to the difference in the work functions between graphene and the superconductor, charge carriers (electrons or holes) are doped to graphene in the vicinity of the interface, the effect of which was not taken into account in Ref. [1]. Recently, Efetov *et al*. in Columbia University claims the observation of the anomalous *I*-*V* characteristics due to the transition between specular and retro-reflections.[2] They decreased the number of the charged impurities by encapsulating the device with hBN. Besides, they reduced the spatial variation of the Dirac point by using bilayer graphene (BLG). It is noted, however, that in their analysis, the spatial variation of the Dirac point due to the difference of the work functions was not taken into account. In this study, to clarify the details of the previous experiment of Ref. [2], we fabricated similar superconductor/BLG devices, and analyzed the data in the same manner. In the experiment, using the van der Waals dry transfer technique [3], we fabricated a $NbSe_2$/BLG junction and encapsulated it with hBN. Here, $NbSe_2$ is a layered superconductor with the critical temperature of 7.1 K. The device structure is shown in Fig. 1. The BLG is rectangular-shaped with several side arms for the four terminal measurement. We measured the voltage V_1 across the junction (the distance between the junction and the contact in BLG is d_1), and voltage V_2 across the side arms in the BLG (the distance between the side arms is d_2) simultaneously in the four terminal configuration. We derived the voltage across the junction, V_{NS}, by subtracting the voltage difference in BLG from V_1 ($V_{NS} = V_1 - (d_1/d_2)V_2$) and calculated the differential conductance of the junction, $G_{NS} = V_{NS}/I$, as a function of the gate voltage V_g and the junction voltage V_{NS}, as was done in Ref. [2]. We found that in the ratio of G_{NS} at the superconducting state (4 K) to G_{NS} at the normal state (10K) plotted in the V_{NS}-V_g plane exhibits an anomalous behavior around the charge neutrality point (CNP), which is similar to that in Ref.[2]. However, we note that at the anomaly region, the sign of the junction voltage V_{NS} is opposite to that of the bias voltage, which is physically incorrect. This occurs because the CNP at the junction is shifted by the carrier doping from the superconductor due to the difference in the work functions of BLG and $NbSe_2$. We speculate that the anomalous behavior in Ref. [2] also might originate from such CNP shift. On the other hand, we find that the differential conductance dV_1/dI also exhibits anomalous behavior around the CNP. This result agrees qualitatively with the theoretical result which takes into account the effect of the difference in the work functions[4]. Thus, our result might indicate the existence of the specular Andreev reflection.

References

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Figures

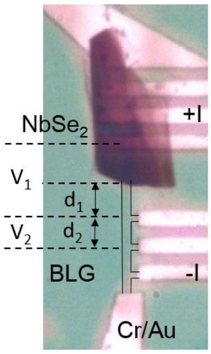

Figure 1: Device structure.