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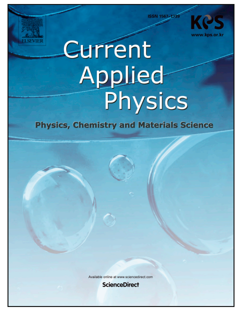

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Andreev tunneling and Josephson current in light irradiated graphene

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Abstract

We investigate the Andreev tunneling and Josephson current in graphene irradiated with high-frequency linearly polarized light. The corresponding stroboscopic dynamics can be solved using Floquet mechanism which results in an effective stationary theory to the problem exhibiting an anisotropic Dirac spectrum and modified pseudospin-momentum locking. When applied to an irradiated normal graphene - superconductor (NS) interface, such analysis reveal Andreev reflection (AR) to become an oscillatory function of the optical strength. Specifically we find that, by varying the polarization direction we can both suppress AR considerably or cause the Andreev transport to remain maximum at sub-gap excitation energies even in the presence of Fermi level mismatch. Furthermore, we study the optical effect on the Andreev bound states (ABS) within a short normal-graphene sheet, sandwiched between two s-wave superconductors. It shows redistribution of the low energy regime in the ABS spectrum, which in turn, has major effect in shaping the Josephson super-current. Subjected to efficient tuning, such current can be sufficiently altered even at the charge neutrality point. Our observations provide useful feedback in regulating the quantum transport in Dirac-like systems, achieved via controlled off-resonant optical irradiation on them.

1. Introduction

The quantum transport in graphene[1, 2], with its low energy Dirac spectrum[1, 2, 3, 4] at the edges of the brillouin zone, has remained an engaging field of study ever since its inception in 2004[5]. Though experimental difficulties still remain in detecting its transport characteristics at the edges[6], its bulk behavior, described by the massless, chiral fermions[4] has been quite well probed by now. Tuning such system with straining or introducing gap in the Dirac spectrum witness noticeable variations in the charge transport. Particularly, graphene based superconductor—normal—superconductor (SNS) junction can be tuned to enhance supercurrent at the charge neutrality point upon straining[7] or an energy gap can enhance the pseudospin inverted Andreev conductance in a graphene-based superconductor/pseudoferromagnet junction[8]. As it turns out, such modifications can be easily implemented via optical irradiation. The transport properties of the Dirac-like systems are very much susceptible to light irradiation and produce interesting outcomes such as exciting surface plasmon polaritons[9, 10, 11] in graphene sheet, enhancing controllability of electrodynamics in graphene-based metamaterials[12, 13] or allowing photoreduction of graphene-oxide films to tune wettabiity[14] and so on.

The energetics of the charge carriers of a graphene monolayer, periodically driven via high frequency electromagnetic light waves with electrons strongly coupled to the photons, has been analyzed recently[15, 16, 17, 18, 19, 20, 21] using Floquet theory. There, the electrons get dressed by the field exhibiting drastic changes in the dispersion. For example, it is observed that the circularly polarized light create a field induced gap at the charge neutrality or Dirac point [22, 23, 24]. In contrast the energy spectrum of electrons dressed by linearly polarized light is modified by Bessel function and it remains gapless. The physical properties of dressed electrons have been studied in various condensed matter systems including quantum well [25, 26, 27], quantum rings [28] and in recently in Dirac materials like graphene [16, 24, 31], Weyl semimetals [29] and topological insulators[30]. In graphene related systems, particularly attentions paid to the transport properties of dressed electrons in $p-n$ junctions [31], magneto-transport [15] and spin transport of dressed electrons[17], optical response of dressed electrons [19] and field induced topological phase transition[31, 32, 33].

Though an effective stationary theory is constructed for stroboscopic evolution of the fermionic wavefunction under light irradiation, to the best of our knowledge, no study on transport behavior of the light irradiated superconducting graphene junctions has been performed yet. We would like to bridge this gap in the literature and study the tunneling conductance of a normal metal-superconductor (NS) junction as well as the Andreev bound state (ABS) and Josephson current of a SNS junction in a strongly irradiated graphene sheet. As a primary investigation, this paper deals with only irradiation via linearly polarized light. A graphene is a semimetal in which superconductivity can be induced via proximity effect [34]. Transport through a NS junction experiences Andreev reflection (AR) for energy-bias smaller than the superconducting gap[35]. The resulting electron-hole conversion in the Normal (N) sub-system and the cooper pair production in the superconductor (S) counterpart develops a finite conductance across the NS junction. An irradiation via linearly polarized light offers a tuning parameter α (which is a function of both intensity and frequency of the light, to be elaborated later on) to the problem. In the off-resonant

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