Theory of plasma excitations in graphene counterflow superconductors

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Double layer graphene systems are considered as promising candidates for a realization of the counterflow superconductivity [1]. Nondissipative transport in counterflow superconductors is caused by pairing of electrons and holes from adjacent layers.

We report the influence of the electron-hole pairing on collective mode properties of double layer graphene systems [2,3]. We show that plasma excitations in counterflow superconductors demonstrate a number of specific features. We find that the optical as well as the acoustic plasma mode splits into two branches. The lower branches belong to the frequency domain $\hbar\omega < 2\Delta$, where 2Δ is the gap caused by electron-hole pairing in the quasiparticle spectrum. The spectrum of the lower optical mode is very sensitive to the temperature: under decrease in temperature the frequency of this mode decreases and at low temperature this mode disappears completely. The lower acoustic mode can be interpreted as an analog of the Carlson-Goldman (CG) mode (plasma oscillations coupled to the order parameter fluctuations). It is shown that the CG mode in counterflow superconductors exists at all temperatures below the critical one (T_c), in contrast with common superconductors, where it appears only in a very narrow temperature range close T_c. The lower optical and acoustic modes are weakly damped ones, while the upper optical and acoustic modes suffer a strong Landau damping. It is also established the existence of the Anderson-Bogolyubov mode in counterflow superconductors (fluctuations of the phase of the order parameter uncoupled from plasma excitations) The latter appears due to the presence of two species of electron-hole pairs in such systems and connected with out-of-phase oscillations of two order parameters.

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