Graphene terahertz injection lasers: Concepts and feasibility of realization

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The gapless energy spectrum of electrons and holes in single graphene layers (SGLs), graphene bilayers (GBLs), and non-Bernal stacked multiple graphene layers (MGLs) opens up prospects of creating graphene-based terahertz (THz) and infrared (IR) lasers. The interband population inversion in such lasers can be achieved, for instance, by optical pumping [1]. However, the excess energy received by electrons and photons generated due to the absorption of optical (pumping) photon can lead to a significant heating of the photogenerated electron-hole plasma. In such a case, apart from the electron-hole plasma heating, a significant heating of the optical phonon system can occur. The latter two effects hinder the population inversion. If the pumping is provided by radiation with the photon energy less that the energy of optical phonon in graphene (0.2 eV), say CO_2 laser radiation, the situation becomes more favorable. Moreover, even the electron-hole cooling can be achieved [2].

In this regard, injection pumping in graphene structures with a *p*-*i*-*n* junction [3] (apart from being a fairly convenient pumping method) can provide much better conditions for realization of interband population inversion and lasing because of the injection of carriers with rather low energy [4].

As we demonstrate, even in the latter case, the accumulation of optical phonons can substantially affect the values of the quasi-Fermi energies of electrons and holes and their effective temperature. This gives rise to nontrivial (in particular, multi-valued) dependences of these quantities on the injection conditions, although the injection pumping appears to be an effective pumping method.

To realize THz or IR lasing in graphene structures, apart from the interband population inversion, one needs to suppress the intraband (Drude) absorption of THz or IR photons generated due to the interband transition. This, as we show, requires a careful optimization.

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