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Frequency dispersion and damping mechanisms of terahertz plasmons in graphene transistor structures

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Abstract. We develop a numerical model for simulation of plasmons in graphene with grating-gate structures, based on the Boltzmann equation and self-consistent Poisson equation. Using the model, we study the effect of coupling between plasmons in gated and ungated regions on the frequency tunability by the gate voltage and the damping of plasmons due to carrier scattering and due to source and drain contacts.

1. Introduction and background

Plasmons in graphene have attracted much attention recently for applications to compact, frequency-tunable terahert (THz) sources and detectors that operate at room temperature [1]. One of the most important advantages of plasmons in graphene is the long momentum relaxation time in clean monolayer graphene and, hence, the weak damping of plasmons in the THz range. In this report, we study frequency dispersion and damping mechanisms of THz plasmons in graphene transistor structures by numerical simulation.

2. Results

We consider a graphene channel with periodic single-grating gates shown in figure 1 with electron doping concentration 10^{12} cm^{-2}. Our numerical model is based on the Boltzmann equation for electron and hole transport with the Poisson equation for self-consistent electric field. We adapt the so-called weighted essentially-nonoscillatory scheme to solve the Boltzmann equation, whereas the finite-element method is used for the Poisson equation. Figure 2 shows the gate-voltage dependence of frequency of the fundamental plasmon mode. It clearly shows that the frequency is in the THz range and is tunable by the gate voltage. The frequency is higher in the structure with L_g = 1000 nm than with L_g = 2000 nm, whereas the voltage tunability of the frequency is wider in the latter than in the former. These are related to the coupling of plsmons in the gated and ungated regions.

Figure 3 shows the dependence of the damping rates due to the acoustic-phonon scattering at room temperature on the electron concentration, as well as damping rates due to short- and finite-range disorder scattering. The damping rate in disorder-free graphene can be as low as 1.3×10^{11} s^{-1}. The damping rates due to disorder scattering can be on the the same order if the the point-defect concentration n_{DS} is as low as 10^{12} cm^{-2} and the correlation length l_{DF} for the finite-range disorder, characterizing the inhomogeneity of graphene, is longer than 100 nm. In addition to the damping caused by carrier scattering, we studied the damping caused by the presence of equilibrium source and drain contacts, which was reported for compound semiconductor two-dimensional electron systems [2]. It is demonstrated that the damping rate is proportional to v_F/L, where $v_F = 10^8$ cm/s. This damping

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is caused by the leakage of the oscillation energy of plasmons to the equilibrium electron reservoirs, i.e., source and drain contacts.

In conclusion, we have shown that the frequency of plasmons in graphene transistor structures can be widely tuned in the THz range and the damping rate can be as low as 10^{11} s^{-1} at room temperature in disorder-free graphene, suggesting the ultimate performance of graphene-based THz plasmonic devices.

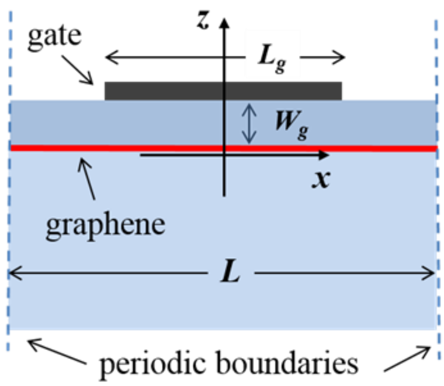

Figure 1. Schematic view of the single-grating-gate structure.

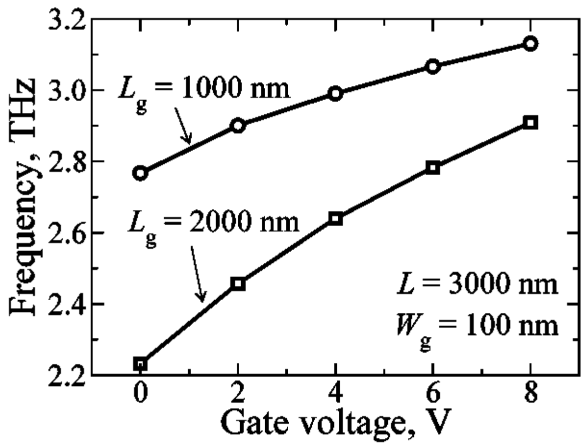

Figure 2. Gate-voltage dependence of the fundamental plasmon frequency in the structure with different gate lengths.

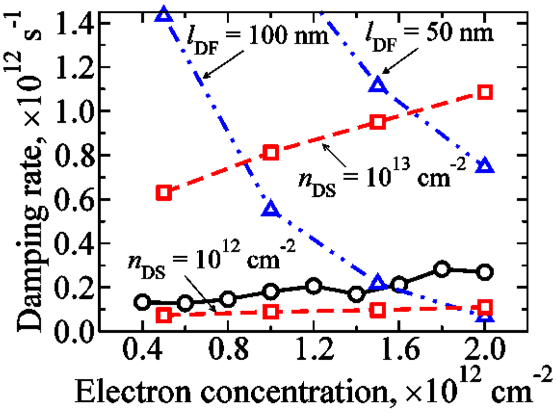

Figure 3. Damping rates caused by the acoustic-phonon, short-range disorder, and finite-range disorder scatterings (solid, dashed, and dashed-dotted lines, respectively).

References

[1] Ryzhii V 2006 *JJAP* **45** L923
[2] Satou A, Ryzhii V, Mitin V and Vagidov N 2009 *Phys. Status Solidi B* **246** 2146