Detection of modulated terahertz radiation using combined plasma and mechanical resonances in torsion oscillating graphene nanoribbons

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There is a strong need in effective detectors of terahertz (THz) radiation with high spectral selectivity. Recently [1], a resonant detector of modulated THz radiation in a micromachined high-electron mobility transistor (HEMT) with a microcantilever serving as the HEMT gate was proposed and evaluated. This detector utilizes the plasma resonance in the HEMT channel (with the frequency Ω in the THz range) at the carrier frequency of incoming THz radiation and the mechanical resonance (with the frequency Ω_m) at the radiation modulation frequency (usually in the MHz range). The combination of these resonances can lead to a huge response. To extend the THz radiation to the GHz range of modulation frequencies, the carbon nanotube or graphene nanoribbon mechanical oscillator might be used [2, 3].

We propose a novel detector of modulated THz radiation based on section two paralleled clamped elastic graphene nanoribbons (GNR) executing torsional oscillations and evaluate its performance using the developed device model. Device model is schematically shown in Fig. 1.

Symmetrical mode of mechanical oscillator and nonsymmetrical mode of plasma oscillation in two paralleled elastic GNRs are exited in proposed construction. Between these oscillators there is a parametric relation. Plasma oscillations are investigated by means of the transmission line model [3] that developed under satisfaction of quasi-one-dimensional requirement, which hold true for sufficiently narrow graphene ribbons. Mechanical oscillation are appeared due to the variation of electromagnetic energy stored in the system:

$$U = \int \frac{C_{\mathrm{E}} v^2}{2}\, dz,$$

where C_E is capacity of unit length, $v = v(z)$ is length distribution of voltage amplitude. Angular dependence of capacity of two GNR for typical dimensions of the system (length of ribbon 1 µm, their width 10 nm, distance between centers of GNRs 15 nm) is shown in Fig. 2. The output signal is associated with the variations of the displacement current, ΔJ , at the modulation frequency.

It was estimated that resonant frequency of such torsional oscillations is in GHz range [4,5]:

$$\omega_{\mathrm{tors}} = \sqrt{\frac{C}{I}} \approx 1\ \mathrm{GHz},$$

where C is torsional stiffness of clamped GNR and I is their moment of inertia.

So for typical dimensions of given system and bias voltage of 1V the responsivity in resonance can be estimated:

$$R = \frac{\Delta J}{P} \sim 10^{-4} \alpha Q^2 Q_{\mathrm{M}} \left[\frac{\mathrm{A}}{\mathrm{W}}\right],$$

where α is the modulation depth, Q_{M} and Q are the quality factors of the mechanical and plasma oscillations, and P is the power of THz radiation incident to the detector.

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Poster

References

[1] V. Ryzhii, M. Ryzhii, Y. Hu, I. Hagiwara and M. S. Shur // *Appl. Phys. Lettl.* **90** (2007) 203503.

[2] V.G.. Leiman, M. Ryzhii, A. Satou, N. Ryabova, V. Ryzhii, T. Otsuji and M.S. Shur // *J. Appl. Phys* **104** (2008) 024514.

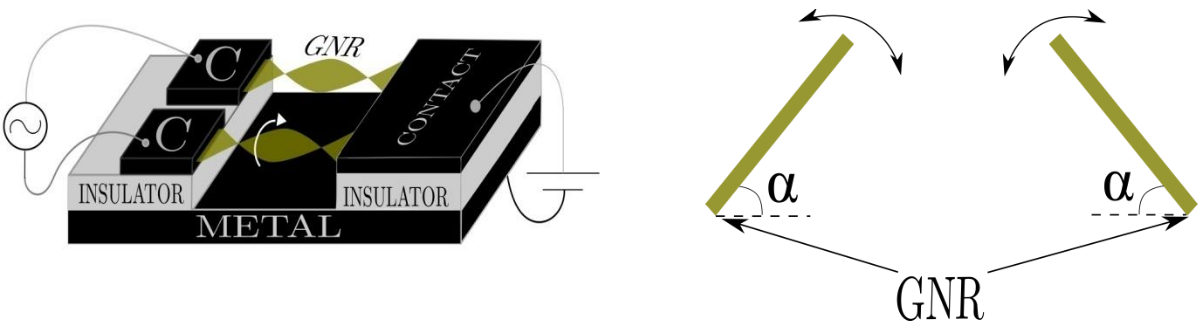
[3] V.G. Leiman, A.V. Arsenin, A.D. Gladun, V.L. Semenenko, Y.V. Stebunov, V. Ryzhii // The 2nd International Symposium on Graphene Devices: Technology, Physics, and Modeling, Oct. 27-29, 2010, Tohoku University, Sendai, Japan.

[4] A. Maffucci, G. Miano, F. Villone // *Int. J. Circ. Theor. Appl.* V. 36 (2008).

[5] A. Sakhaee-Pour et al // *Nanotechnology 19 (2008) 085702.*

[6] L.D. Landau and E.M. Lifshitz, Theory of Elasticity, 3rd ed. (Pergamon, Oxford, 1981).

Figures



(a) (b)

Figure 1. Device model: (a) schematic view of proposed detector and (b) capacitor based on two oscillating GNRs.

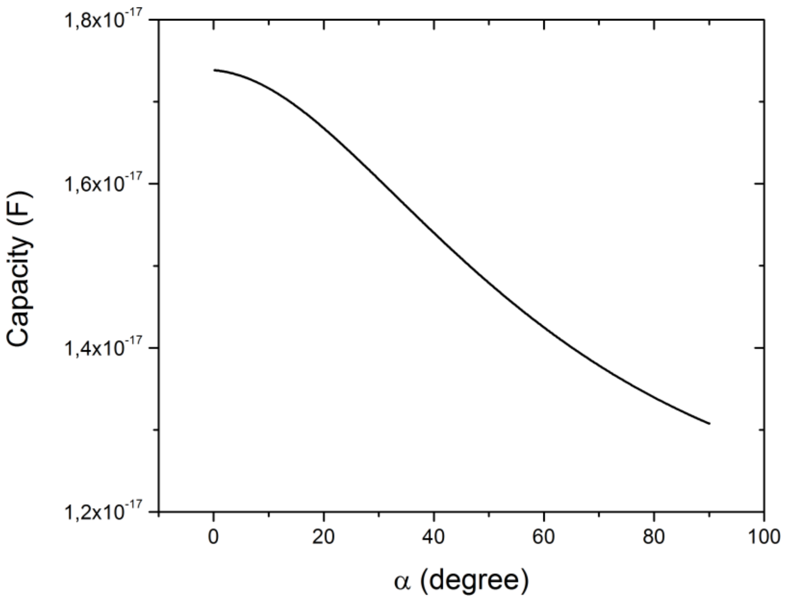


Figure 2. Angular dependence of capacity of two oscillating GNRs.