GRAPHENE AND 2DM VIRTUAL CONFERENCE & EXPO
10 ANNIVERSARY
Graphene online 2020
October 19-23

Gate-mediated helicity sensitive detectors of terahertz radiation with graphene-based field effect transistors

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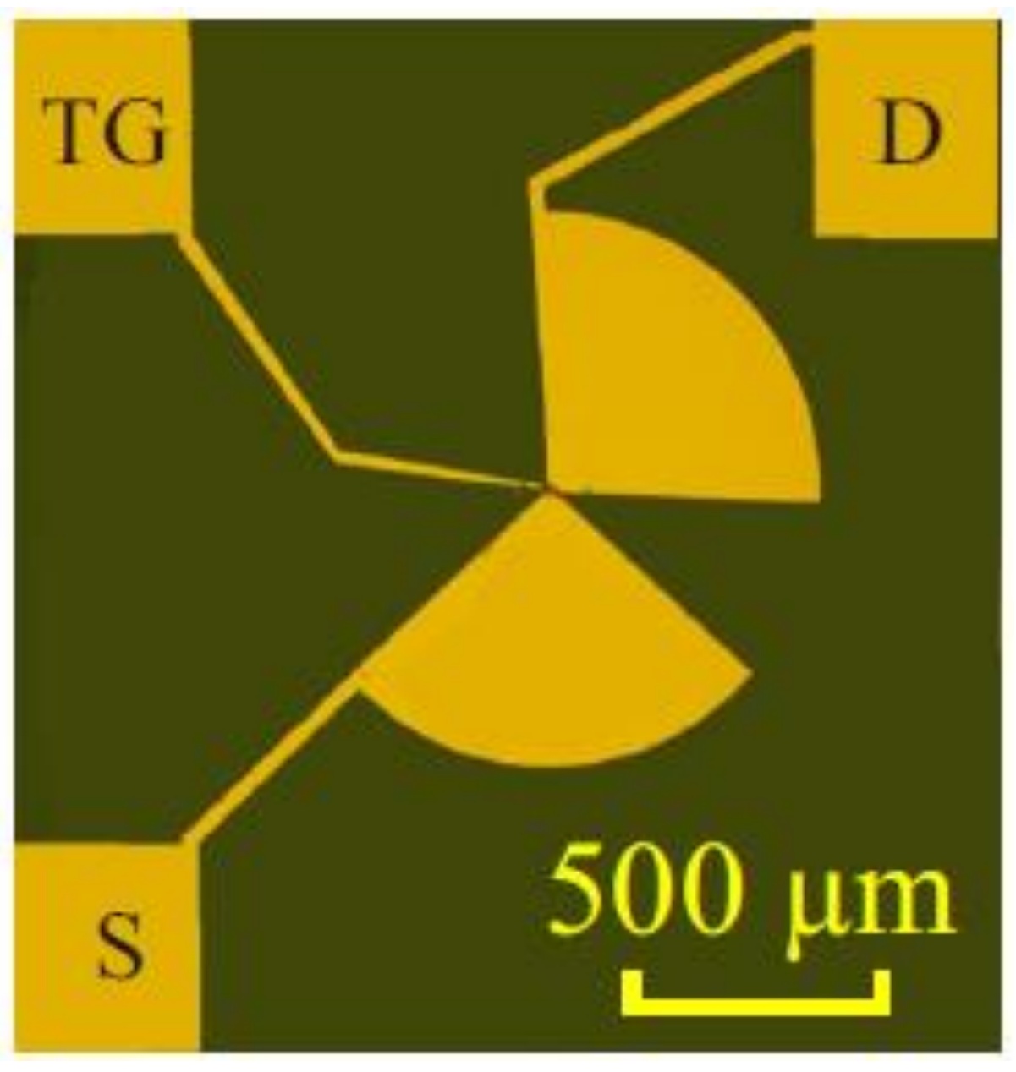
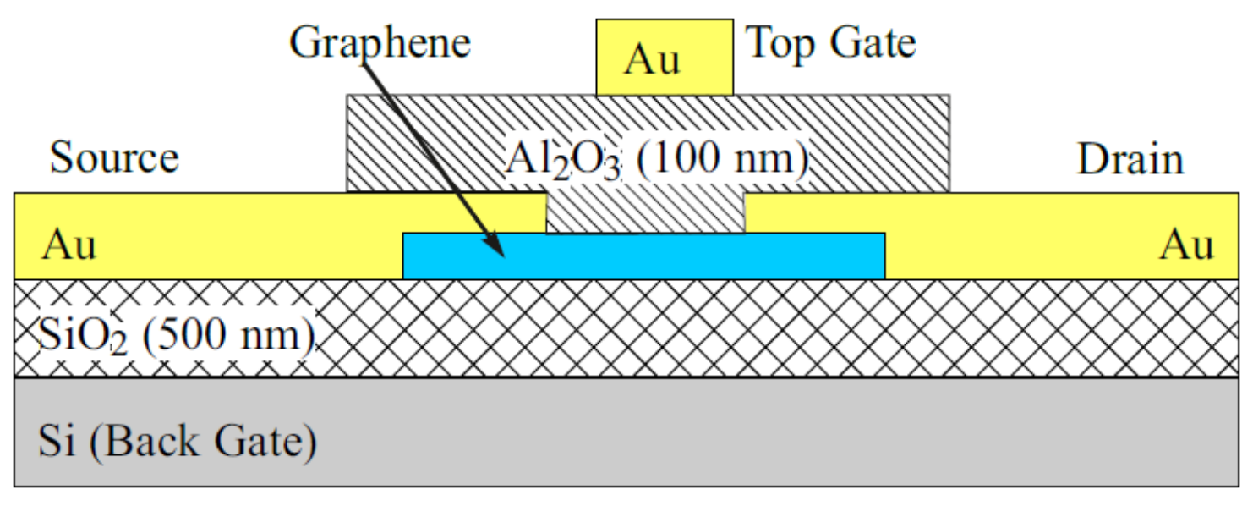
ABSTRACT: Closing of the so-called terahertz gap results in an increased demand for optoelectronic devices operating in the frequency range from 0.1 to 10 THz. Active plasmonic in field effect devices based on high-mobility two-dimensional electron gas (2DEG) opens up opportunities for creation of on-chip spectrum [1] and polarization [2] analysers. Here we show that single layer graphene (SLG) grown using CVD method can be used for an all-electric helicity sensitive polarization broad analyser of THz radiation. Our devices are made in a configuration of a field-effect transistor (FET) with a graphene channel that has a length of 2 mkm and a width of 5.5 mkm. Different response of our devices to clockwise and anticlockwise polarized radiation highlights the plasmonic nature of the response of our detectors [3]. Our approaches can be extrapolated to other 2D materials and used as a tool to characterize plasmonic excitations in them.

Device optical photograph

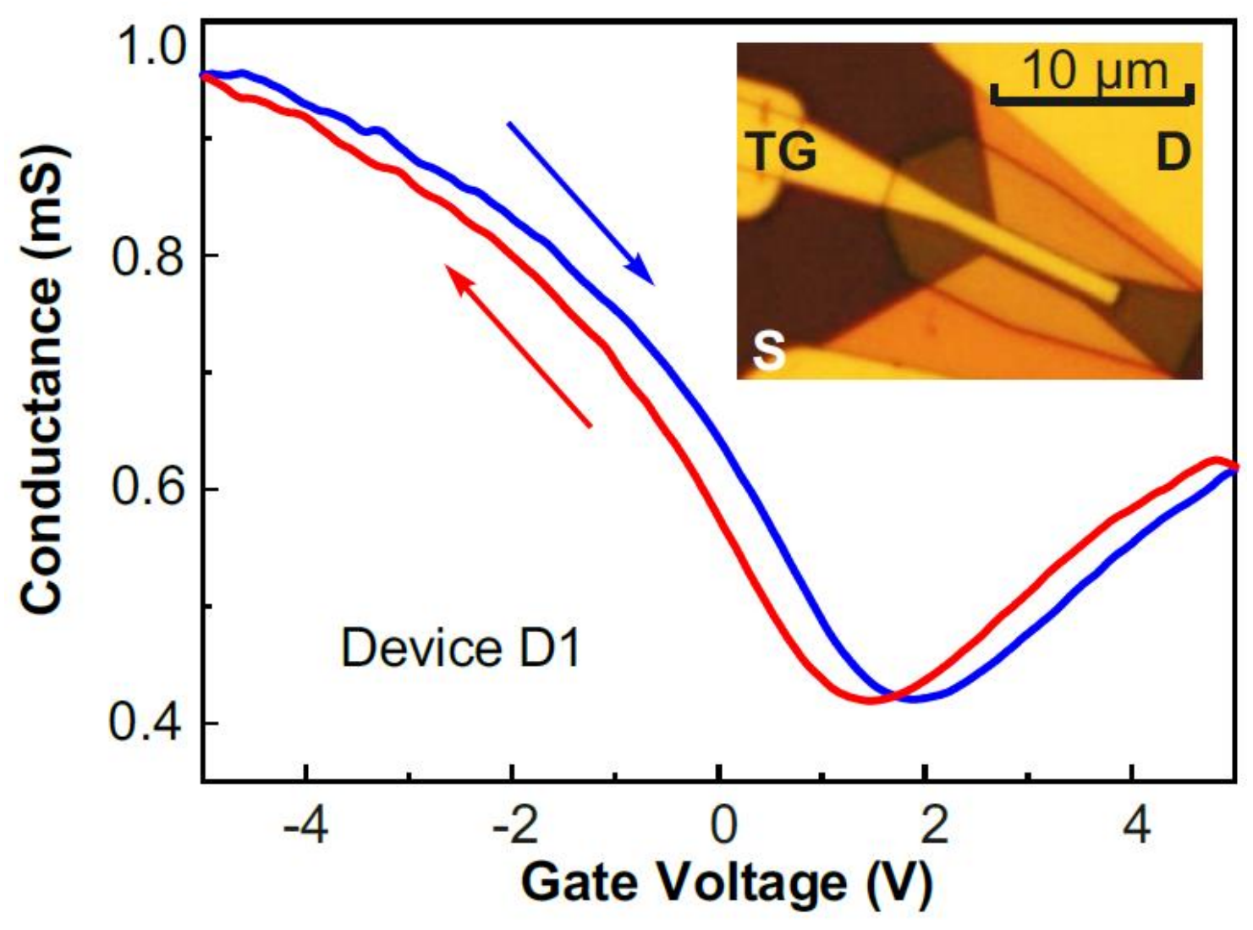


FET cross-section

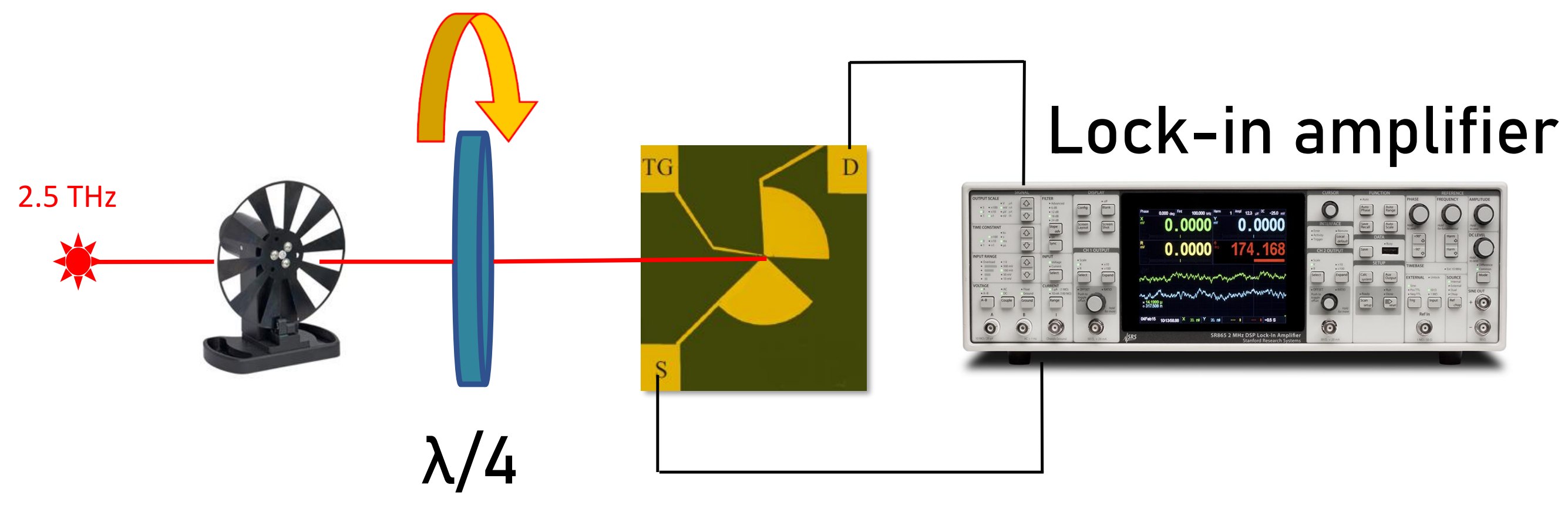


We used CVD graphene as field effect transistor (FET) channel. It was synthesized in home-made cold-water reactor on a cooper foil with a thickness 25 micrometers. FET was created with help of e-beam lithography, oxygen plasma etching and e-beam gold sputtering. Big contact pads made by optical laser lithography. As gate insulator we used e-beam sputtered amorphous aluminum oxide.

Gate-dependent conductivity



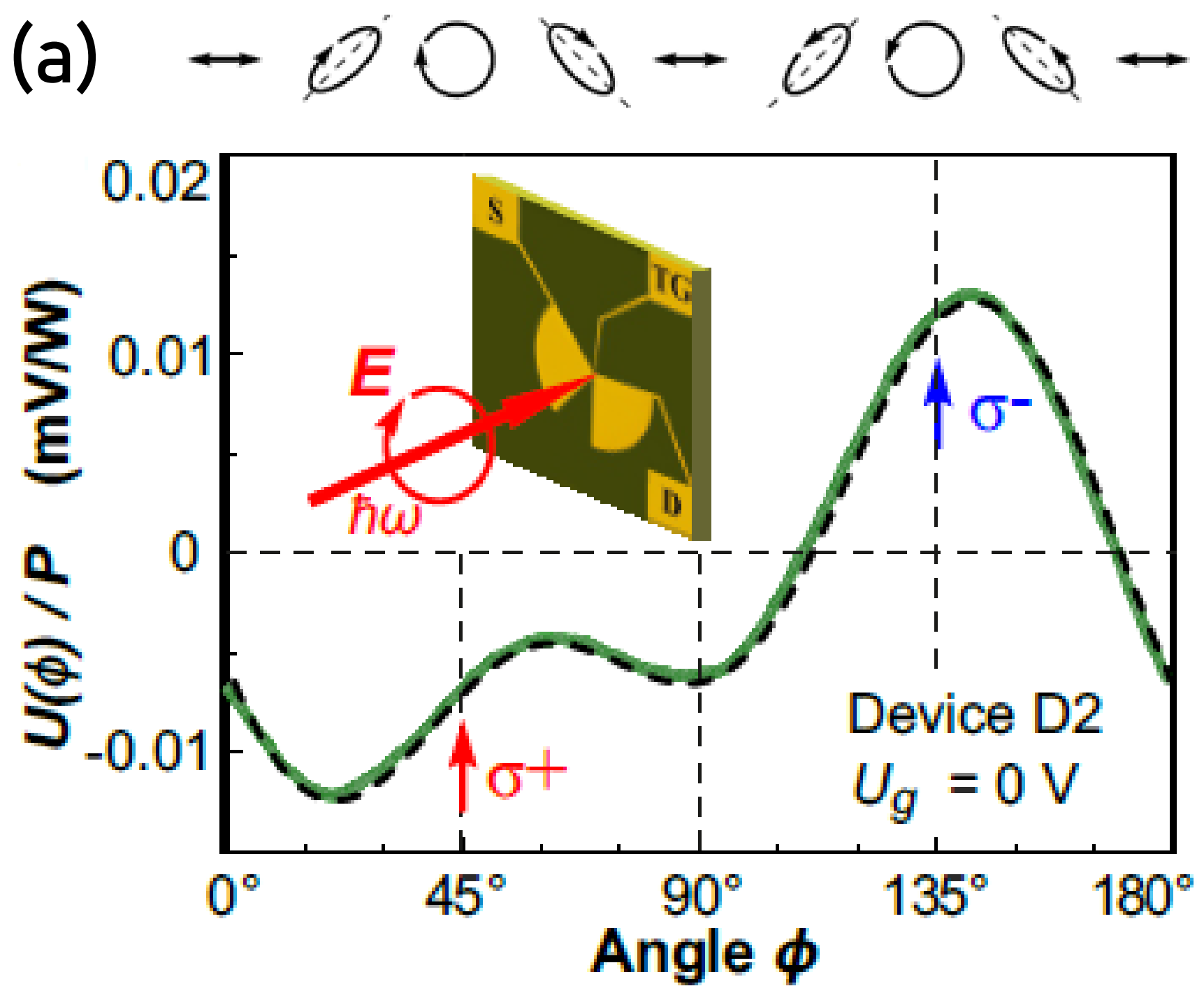
Experimental setup



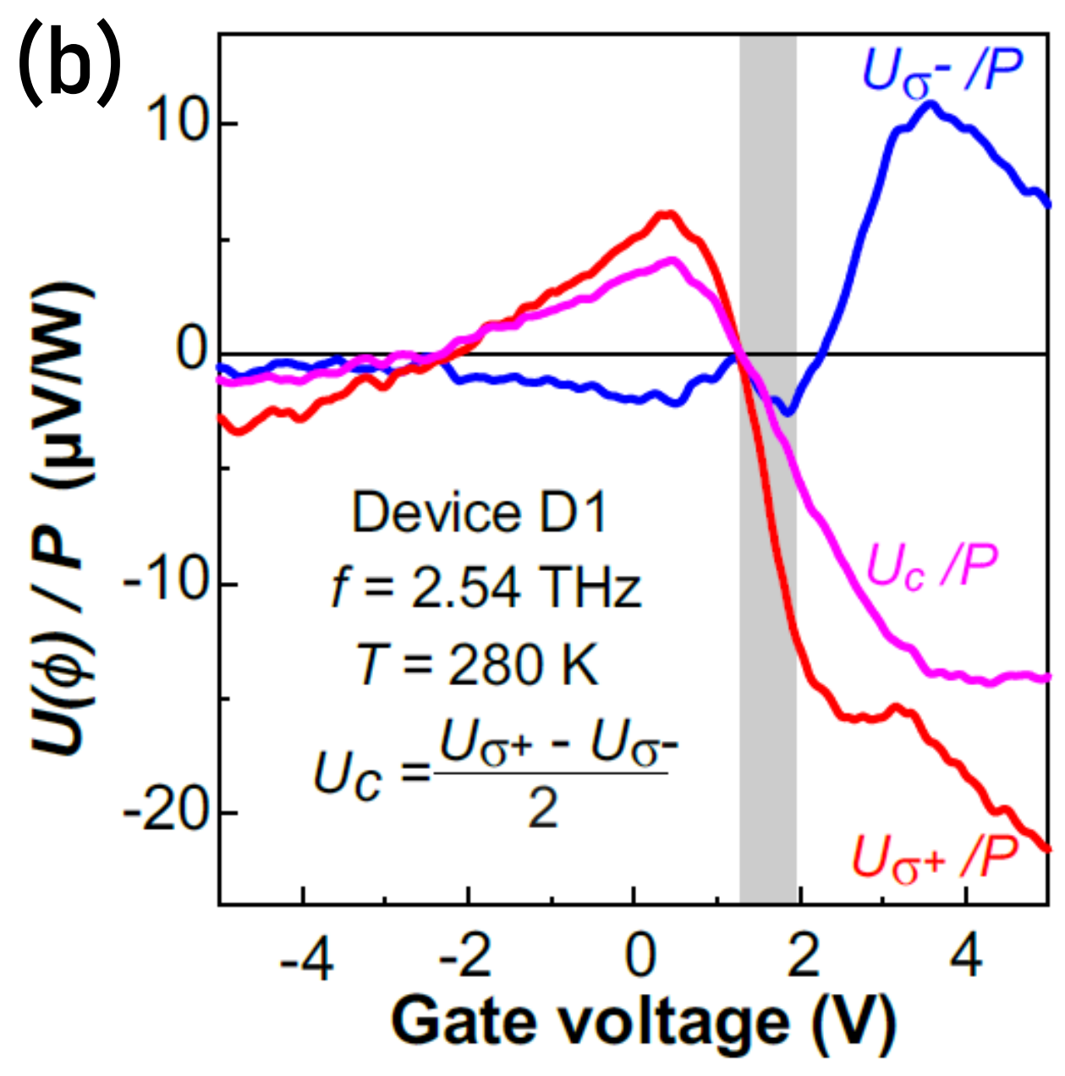
As source of THz – radiation we used methanol laser with two generation frequencies 0.7 and 2.5 THz. We used standard Lock-in amplifier technique with optomechanical chopper. Main feature of experiment is lambda-quarter phase plate. We can rotate it and measures device responsivity versus radiation polarization.

Main results

(a) Dependence of the photovoltage normalized to the laser power on the angle of rotation of the phase plate, at zero gate voltage and a temperature of 300K. In this graph, you can see that the magnitude of the photoresponse for different directions of circular polarization sigma+ and sigma- differs so much that it even has a different sign. This non obvious result can be described in plasmonic model of response.



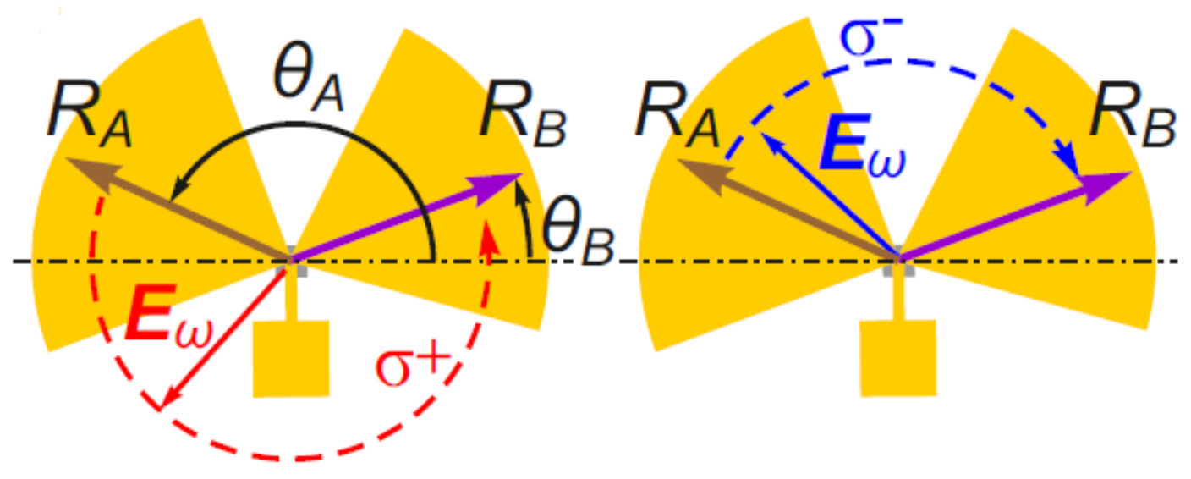
(b) Dependence of the photovoltage normalized to the laser power on top gate voltage, at +45° and -45 lambda-quarter angle. You can also see a very strong difference in response for radiation with different helicity.



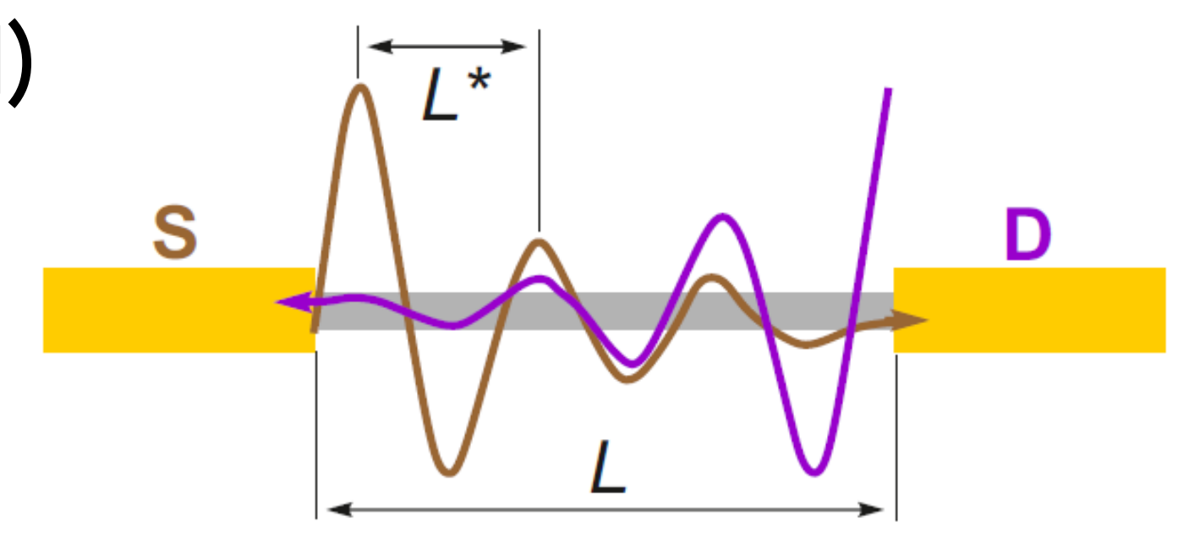
Photoresponse mechanism

$$\begin{cases} \dfrac{\partial v}{\partial t} + v\dfrac{\partial v}{\partial x} + \gamma v = -\dfrac{e}{m}\dfrac{\partial U}{\partial x} \qquad \dfrac{\partial U}{\partial t} + \dfrac{\partial (Uv)}{\partial x} = 0 \\ U(L) = U_g + V + U_b \cos \omega t \\ U(0) = U_g + U_a \cos(\omega t + \theta) \end{cases}$$

(c)



(d)



Our device can be described by one-dimensional hydrodynamic equations. Their solution in the form of plane waves for our boundary conditions is shown in the red box. It is the interference of two damped plasma waves propagating from the drain and source of the transistor (d). Figure (c) demonstrates that the last term in the main response formula will have different signs for different helicities of the radiation. This fact is confirmed by the curves (a) and (b).

$$\boxed{U = \frac{U_A^2 - U_B^2 - 16 U_A U_B e^{-L/L_*} \sin(L/L_*)(\omega/\gamma)\sin(\theta_A - \theta_B)}{4U_g}}$$

Conclusion

Device response depends on radiation polarization

There are two reasons for this experimental effect:

- Hydrodynamics of charge carriers in graphene, and as a consequence plasmons nature of response
- Special antenna geometry

We created a detector that is sensitive to polarization and phase of radiation

Acknowledgements

This work was supported by the Russian Foundation for Basic Research within Grants No. 18-29-20116 and 20-32-90224

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