The development of graphene-based terahertz bolometers using the noise-thermometry method

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ABSTRACT: The paper investigates a new approach for the development of graphene-based terahertz bolometers using the noise thermometry method. Graphene, due to its record low electron heat capacity and weak electron-phonon coupling at low temperatures, is considered as a promising material for creating terahertz bolometers on hot electrons. The main obstacle to the development of such devices is the weak dependence of graphene resistance on temperature. Here we are trying to solve this problem by directly measuring the electron temperature in graphene using noise thermometry. Our first data demonstrate a strong heating of the graphene electronic system under the influence of direct current (up to 10 K at a current of 500 nA). An analysis of the results shows that the internal electrical sensitivity of the devices under study is 100,000 V/W, which allows them to be considered as the basis for creating sensitive terahertz detectors.

Graphene-based terahertz (THz) detectors are promising for medical diagnostics and other fields. However, the weak dependence of graphene resistance on temperature makes it difficult to implement them. In this paper, we propose to use the method of noise thermometry to measure the temperature of electrons in graphene, which changes under the action of THz radiation. This makes it possible to detect sub-terahertz radiation in a wide temperature range (3.5–300 K). The data obtained can be used to optimize and develop graphene THz detectors.

Our samples are field-effect transistor devices in which graphene serves as a conduction channel. There is also a gate electrode that controls the concentration of charge carriers in the device. We have manufactured two types of devices: those based on graphene synthesized using chemical vapor deposition (CVD), which is the most industrially viable method for producing graphene, and those based on split graphene encapsulated in hBN, a method for obtaining the highest-quality graphene.

Summary

The electron temperature was measured in graphene samples encapsulated in boron nitride at a cryostat temperature of 4.2 K. An analysis of the results shows that the internal electrical sensitivity of the devices under study is 100,000 V/W, which allows them to be considered as the basis for creating sensitive terahertz detectors.

The transport properties of the manufactured devices were characterized. The field mobility of the CVD graphene-based device was 1500 $cm^2V^{-1}s^{-1}$, which is typical for graphene on a Si02 substrate. The field mobility estimates for devices based on encapsulated graphene, obtained from the dependence of the resistance of manufactured structures on the concentration of charge carriers (Fig. 1), gives from 10000 $cm^2V^{-1}s^{-1}$ at 300 K to 100,000 $cm^2V^{-1}s^{-1}$ at 4.2 K, which corresponds to the best graphene samples known from the literature.

The obtained data demonstrate that at a low concentration of charge carriers, electrons heat up sharply with an increase in the modulus of the transmitted current. According to the results of the experiment, the maximum temperature of the electron gas was about 18 K with a current strength of 30 μA. It can be seen that at a low concentration of charge carriers, the electrons heat up asymmetrically, the reason for this is also the differences in the materials of the contacts.

Based on measurements of the dependence of the differential resistance and spectral density of noise on the current through the sample, the dependence of the temperature of the graphene electron gas on the value of the transmitted current was determined (Fig. 2).

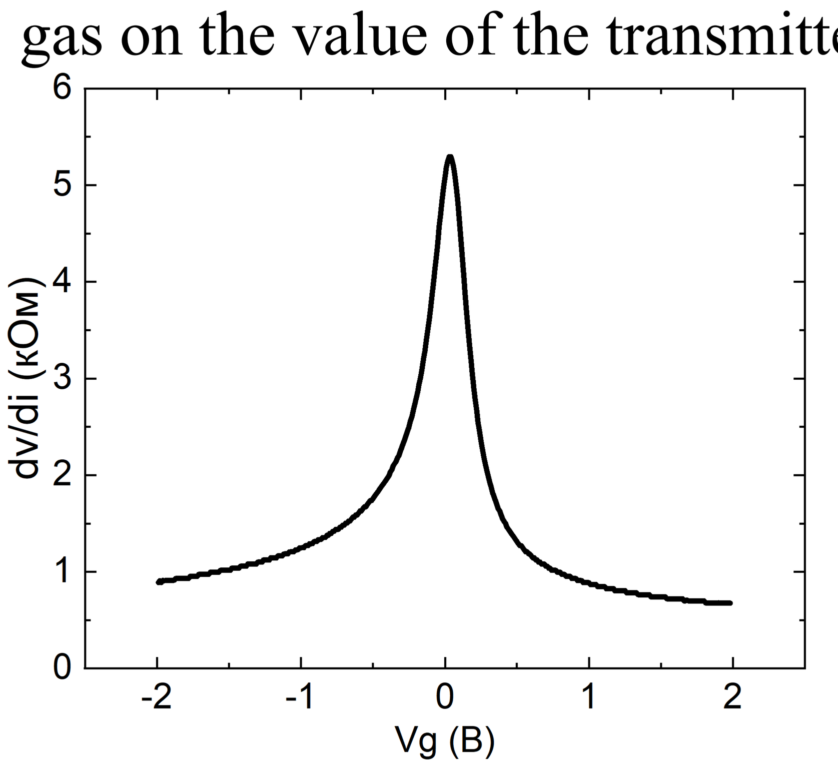

Fig. 1 - Typical dependence of the two-point resistance on the gate voltage. Measured at T = 300 K .

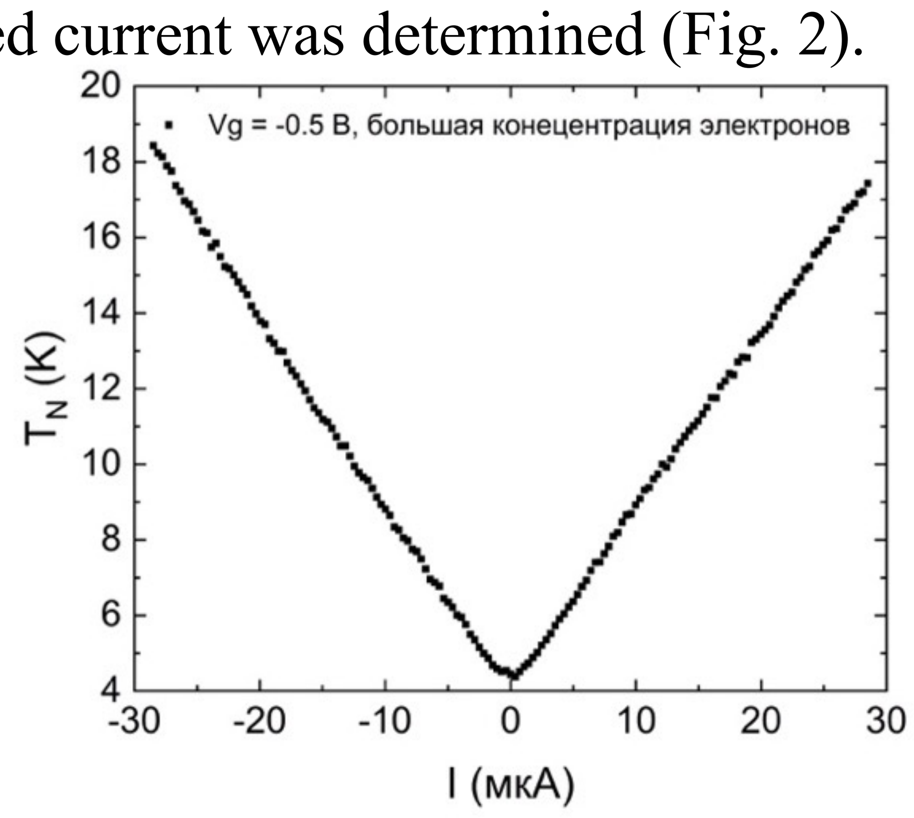

Fig. 2 - Dependence of the electron temperature on the current passed through graphene. The cryostat temperature is 4.2 K .

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