Development of infrared radiation sensor for household electronic applications

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Abstract. Infrared (IR) detector is became an integral part for daily used electronic applications such as TV remote, night vision camera, remote temperature monitoring. Due to the importance of these devices, we developed an ultrasensitive IR sensor based on reduced graphene oxide (rGO). The synthesis of our sensing material (rGO) is very cheap and easy to fabricate for mass production. Flexibility and stability of rGO makes it more interesting for IR sensing applications. As developed IR sensor shows best balance in linearity, sensitivity and performance reproducibility as compare to other existing IR sensors. Furthermore, rGO has insulating layer on the surface, so, it is unaffected by surrounding environmental gases and humidity. It provides more stability to IR detector. In this work, the use of structures based rGO as sensors is presented. The response of the rGO film under the influence of infrared radiation from a CO_2 laser in the form of a change in its resistance was experimentally obtained. The dynamic characteristics of a sensor based on a rGO film when exposed to radiation at a wavelength of 10.6 μm are determined.

1. Introduction

Even before the creation of nanomaterials, i.e. materials whose properties are determined by their structure at the nanoscale level, their application in various applications was predicted [1]. Up to day, a number of rapidly developing areas of their practical use have stood out. One of these areas is sensorics. In particular, gas sensors [2], broadband absorbers [3], temperature sensors [4] and radiation sensors of the optical [5–7] and terahertz [8, 9] ranges are fabricated on the basis of nanomaterials. Infrared detectors have become an integral part of daily used electronic devices such as remote controls for household electronics, night vision cameras, pyrometers, etc.

In modern electronics, two-dimensional materials (graphene, transition metal dichalcogenides, their hybrid systems) have huge advantages over conventional semiconductors [10]. Their advantages are: high mechanical flexibility, better electronic and optical properties [11], high-quality integration and the ability to achieve maximal miniaturization [12]. Heterojunction photodiodes in 2D materials provide ultrafast and wideband response within the range from visible to far infrared. Phototransistors based on two-dimensional hybrid systems in combination with other material platforms (quantum dots, perovskites, organic materials, or plasmon nanostructures) provide ultra-sensitive and broadband radiation detection taking into account polarization [13].

One of the most widely used materials in optoelectronics and photonics today is reduced graphene oxide (rGO) [14–18]. Large-scale production of graphene-based devices requires the separation of graphite into individual graphene sheets in large quantities, so it is convenient to use graphene oxide, which can subsequently be converted to rGO. Recent studies show that rGO obtained by chemical

stratification from graphite has a natural energy gap without complex bandgap creating processes. The width of this natural energy gap can be adjusted by tuning the graphene oxide reduction degree. Theoretical calculations indicate that the graphene band gap changing can expand the working spectrum of graphene photodetectors to the far infrared and even to the terahertz range [16]. The band gap of rGO can be easily tuned by annealing rGO in argon atmosphere. By tuning bandgap of rGO, we can use it for broadband photodetector i.e. visible to terahertz range.

The aim of this work is to create the infrared radiation sensor based on reduced graphene oxide, which demonstrates a response in the form of a resistance change when exposed to monochromatic radiation, and to study its operating parameters.

2. Film fabrication technology

Films from reduced graphene oxide were fabricated using the Hummers method described in detail in Refs. [19, 20]. The mixture of flake graphite/$NaNO_3$ was prepared in weight ratio of 2:1. The mixture was added into a beaker with a certain amount of 98 wt. % H_2SO_4 at 15 °C and a suspension was obtained. Then, $KMnO_4$ powder which acted as an oxidation agent was gradually added into the suspension with continuous stirring. The weight of the $KMnO_4$ powder is 3 times as much as the one of the mixture. There were 3 steps for the following process. First of all, it is the low temperature reaction. The temperature of the mixture was controlled below 20 °C for 2 hours; at the same time, the suspension should be stirred continuously. The second step is the mid temperature reaction. The temperature of the mixture was maintained at 35 °C for 30 minutes after $KMnO_4$ was totally dissolved. Finally, it is the high temperature reaction. A certain amount of deionized water was added into the mixture slowly; therefore a large amount of heat was released when concentrated H_2SO_4 was diluted. 15 minutes later, certain amounts of hot water and 30% H_2O_2 aqueous were added into the mixture, respectively, with continuously stirring. The bright yellow resulted suspension was filtered by the qualitative filter paper when it was still hot, and the solid mixture was washed with dilute HCl aqueous and distilled water and dried in vacuum oven at 70 °C for 24 h.

3. Measurement of the graphene film electro-optical response

The experiments were carried out on the setup which scheme is shown in figure 1. The radiation of a CO_2-laser *1* at a wavelength of 10.6 μm with a Gaussian intensity distribution was applied to the rGO film. Its fabrication technology is described in Section 2. A laser beam with a diameter of 5 mm was directed exactly between the electrodes deposited on the rGO film by the rotary mirror *2*. The power of laser radiation was measured with a portable analog power meter LPM-407A with the error of ± 3% (position *3* in the figure). The electrodes of the sample *4* were connected to the spring copper electrodes of the auxiliary device. The last were joint to the contacts of the multimeter. Resistance was measured in real time through the UNI-T UT803 digital multimeter (it is not shown in the figure).

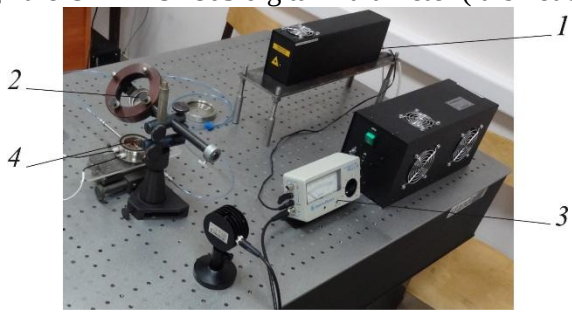

Figure 1. Measuring system: *1* – CO_2-laser, *2* – rotary mirror, *3* – power meter, *4* – sample (rGO film).

In the experiments, the LCD-1A laser was used. RGO films were studied in two power ranges: up to 1 W and from 2 to 3 W. Figures 2 and 3 show the resistance change cycles of the rGO film at the various incident beam power levels. The areas of decline on the graphs correspond to the radiation presence, the areas of growth correspond to resistance restoration in the absence of laser exposure.

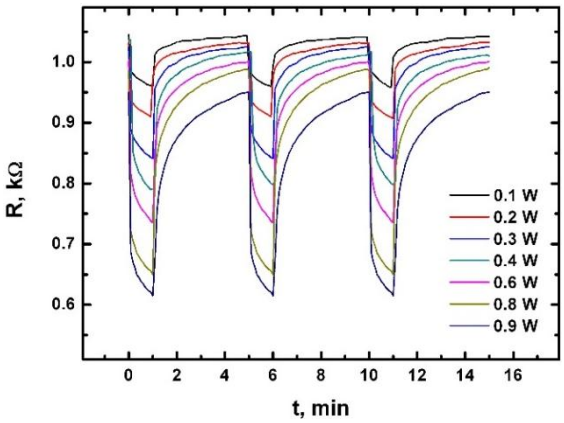

Figure 2. Cycles "response – recovery" of the rGO sample resistance at various values of laser radiation power (range up to 1 W).

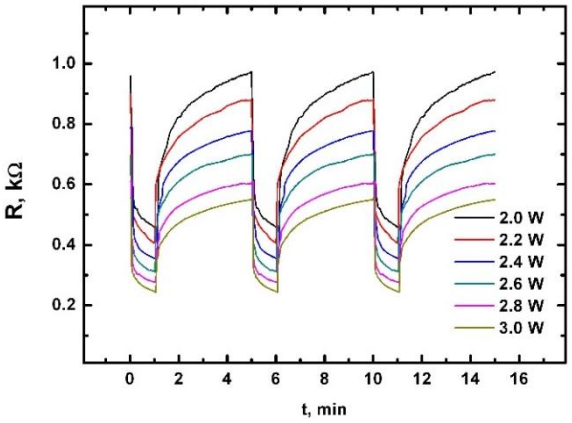

Figure 3. Cycles **"**response – recovery" of the rGO sample resistance at various values of laser radiation power (range from 2 to 3 W).

At the initial rGO film resistance of the 1 kΩ order in the absence of radiation, observed relative change in the resistance increases from 10 to 70 % (at 3 W) with the incident beam power growth. The obtained dependences are characterized by a sharp, almost instantaneous (less than 0.1 s) resistance drop and much more gentle recovery curves. The plots clearly show the results reproducibility.

The response speed or operation speed of the detector sensitive element, defined as the period of time when the maximum resistance drop occurs at the given acting beam power, was 1 min. The characteristic resistance recovery time to the initial value was more than 4 min.

4. Conclusion

A brief literature review, where the results of the two-dimensional materials properties studies and the areas of nanomaterials practical use are presented, has given. The reduced graphene oxide electro-optical properties of and the prospects for controlling them have been considered from the point of view of using rGO films as the IR-radiation sensors.

The conventional chemical technology of the two-dimensional rGO film fabrication (Hummers method) has been reproduced with the subsequent electrodes deposition on its surface. The experiments devoted to the determination of the rGO film response depending on the infrared laser radiation exposure intensity make it possible to observe a significant (10–70 %) decrease in the electrical resistance when the incident beam power is in the range from 0.1 to 3 W. The characteristic response time of the rGO films is very short (less than 1 min), and the recovery time is more than 4 min. The research results discover the possibility of rGO films using as the far-infrared radiation sensors.

The main future goal of our work is develop a THz detector by modify the rGO for suitable bandgap.

5. Acknowledgement

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6. References

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