Graphene-Based Advanced Detector Concepts

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INTRODUCTION

Within the last few years graphene, a material consisting of a single layer of carbon atoms, has demonstrated exceptional electrical properties that we are using to develop novel semiconductor-based radiation detectors. Our prototype device is an electrically biased graphene field effect transistor (GFET) on a semiconductor substrate which served as radiation absorber. The resistance of graphene changes with induced charge in the semiconductor substrate below graphene, which produces a local change in the electric field near graphene. Our detection technique is sensitive to the presence of the charge even prior to charge collection, and thus bypasses the traditional approach taken by current radiation detection systems. This approach presents a few potential advantages over traditional detectors such as faster response, lower noise, and higher sensitivity to the electron charge without needing to collect the associated holes. In this paper we discuss three novel radiation detection applications of graphene FETs.

APPLICATIONS

We are currently investigating three approaches to utilizing graphene FETs as a component of semiconductor radiation detectors. They are (1) gamma/X-ray detector with graphene integrated into the detector, (2) neutron detectors with integrated graphene, and (3) graphene as an external pre-amplifier. We are also examining the effects of radiation damage of graphene.

Gamma and X-Ray Detector

The primary focus of our studies is the use of graphene in a gamma/X-ray detector which utilizes semiconductor absorbers such as undoped SiC The SiC acts as the basis for the GFET and the graphene acts as the gate. The GFET is biased via a back gate and small current flows through the two outer electrodes attached to graphene. The resistance change is measured between the two inner electrodes by using four-probe measurement technique. For this application, the SiC also acts as the active detector volume. We have experimentally demonstrated sensitivity of our device to both visible light and X-rays and are currently studying the gamma sensitivity[1]. A conceptual schematic of a typical graphene-based radiation detector is shown in Figure 1.

Neutron Detector

A neutron detector utilizing graphene is very similar in its design to a gamma-ray detector. A boron layer will be deposited on the bottom of the SiC wafer to act as a neutron-sensitive converter, with the alpha particle or Li ion being absorbed and detected in the SiC. This approach, as with most neutron detectors, requires detectors on the order of a few μm thick, which severely limits the intrinsic efficiency. Our approach which uses graphene as the pre-amplifier, combined with recent advances in graphene production, could allow for the mass production of inexpensive neutron detectors with integrated pre-amplifiers. These devices could then be used in a large variety of applications ranging from discrete single detectors to large arrayed configurations. As an intermediate step, we are working on using graphene as an alpha detector.

External Pre-amplifier

The third approach to the utilization of graphene in radiation detection systems is to substitute a traditional external charge-sensitive preamplifier with a GFET. While not as novel as our other approaches, GFETs have the potential be inexpensive and easy to manufacture, while retaining their fast response with low noise.

Radiation Damage

We have already investigated the sensitivity of GFETs to electron and ion irradiation, and we intend to use the Penn State nuclear reactor to study the effects of radiation damage on GFETs. This data would be relevant to potential space, nuclear power, and other high radiation applications.

CONCLUSIONS

Preliminary results have been obtained with our fist batches of graphene FET-based radiation detectors. We observed sensitivity to both gamma-rays and X-rays and are currently working on detecting alpha particles. Present challenges include fabricating larger graphene devices, increasing the speed of charge collection, and improving our general understanding of the properties of graphene FETs. Our plan is to continue to improve our fabricating techniques, build and test neutron sensitive detectors, study the use of graphene in an external pre-amplifier, and study the effects of radiation damage.

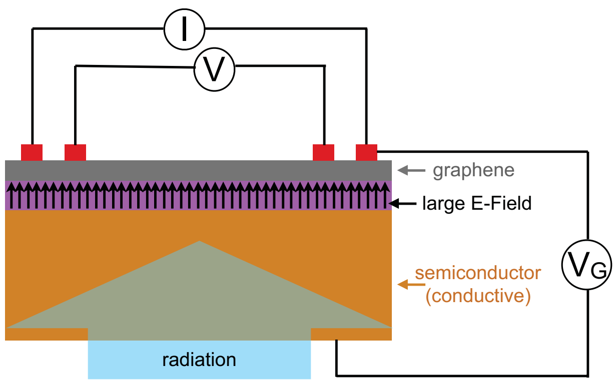

Figure 1: Schematic drawing of a typical graphene-based radiation detector.

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