

Graphene/4H-SiC Schottky photodetector operating in the visible spectrum range

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Abstract. In this work, we present the first experimental results on a Schottky photodetector based on Silicon Carbide (SiC) and Graphene (Gr) designed to operate in the visible spectral range. While SiC has been extensively investigated for various applications in the ultraviolet domain, there are only a few works in the visible range, where SiC exhibits negligible optical absorption. To overcome such intrinsic limit of SiC, we exploit the properties of a single layer of Gr to enhance, significantly, the photodetection performance of the device operating, in our experiments, at the wavelength of $\lambda=633$ nm. From the current-voltage (I-V) characteristics, a series resistance of 3.7 k Ω , an ideality factor of 8.4, and the zero-bias Schottky barrier height of 0.755 eV have been calculated. Finally, the internal responsivity, as function of the reverse bias applied to the device, has been measured demonstrating a maximum value exceeding 1 mA/W at -5V.

1 Introduction

In recent years, silicon carbide (SiC) has gained significant attention as a potential semiconductor material for the development of advanced optoelectronic devices for several applications [1]. SiC is particularly well-suited for ultraviolet (UV) detection in high-temperature and high-power environments [2,3], thanks to its wide and direct bandgap. However, the bandgap of SiC, which is around 3.2 eV, limits its ability to detect photons with wavelengths longer than approximately 380 nm.

To overcome this limitation and enable detection in the visible range, alternative device structures need to be explored. Currently, the investigation of SiC photodetectors optical response in the visible range is limited. One promising approach to address this challenge involves incorporating a two-dimensional material, such as graphene, into the device structure [4]. The integration of a single layer of graphene (SLG) on a SiC substrate enables the formation of a Schottky junction that can be exploited for sub-bandgap photodetection through the internal photoemission effect (IPE). The IPE involves the emission of photo-excited carriers from the metal contact into the semiconductor by overcoming the Schottky barrier. In our case, since SLG behaves as the metal component of the Schottky junction, this effect allows for detection in a wavelength range corresponding to an energy lower than the SiC bandgap, as long as it is higher than the SLG/4H-SiC Schottky barrier.

In this work, we present the fabrication and the electro-optic characterization of a Schottky photodetector based on SLG/4H-SiC operating at $\lambda=633$ nm.

2 Device structure

The Schottky photodetector (PD) is fabricated starting from a highly-doped 250 μm thick 4H-SiC substrate. After a standard RCA cleaning of the substrate, a 200 nm-layer of SiO₂ is deposited by sputtering process. The pattern for the ohmic contact on the 4H-SiC substrate is defined using a bilayer photolithography technique and the excess SiO₂ is removed through buffered oxide etching (BOE). Subsequently, a 200 nm-thick layer of Nickel is deposited on the substrate using a thermal evaporator followed by a rapid thermal annealing to achieve a non-rectifying behaviour. To form the Schottky contact, a circular active area (7.85 \cdot 10⁻⁵ cm²) is defined, and the corresponding portion of SiO₂ is selectively etched using BOE. The SLG is then transferred onto the SiO₂/SiC substrate. Finally, the Gr contact is created by depositing a stack of Cr/Au (5 nm/50 nm) using thermal evaporation. Additional information on the fabrication process is reported in our previous work [5].

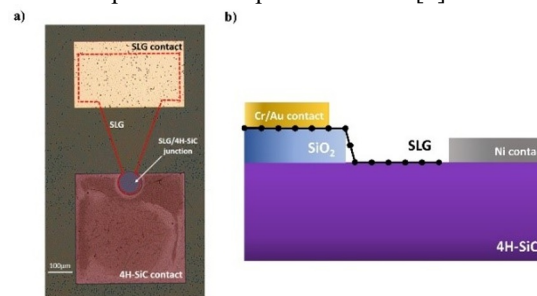


Fig. 1. Optical microscope image (a) and schematic cross-section (b) of the Schottky SLG/4H-SiC photodetector.

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The schematic cross-section and the optical microscope image of the PD are shown in Fig.1.

3 Experimental results

To electrically characterize the Schottky PD, we performed current-voltage (I-V) measurements on the SLG/4H-SiC junction under dark conditions. The SLG was biased while the 4H-SiC electrode remained grounded. In Fig. 2 the experimental results in a range -3 to 3 V using a source meter (Keithley, 2410) are shown.

The proposed Schottky PD exhibits a typical rectifying behavior which can be analyzed using the thermionic emission (TE) model:

$$I = I_s (e^{q(V - R_s I) / \eta k_B T} - 1) \quad (1)$$

$$I_s = A A^* T^2 e^{-q\Phi_B / k_B T} \quad (2)$$

where, A is the active area, A^* is the Richardson constant, $k_B T / q$ is about 26 meV at room temperature, η is the ideality factor, R_s the series resistance, V is the applied voltage, and $\Phi_B = \Phi_{B0} + \Delta\Phi_B(V)$, Φ_{B0} is the Schottky barrier height (SBH) at zero voltage, $\Delta\Phi_B(V)$ is the SBH change due to applied voltage.

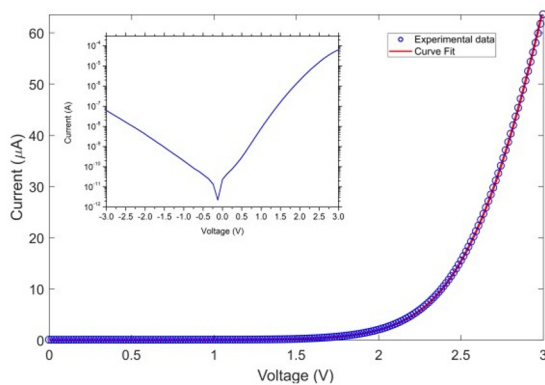


Fig. 2. I-V characteristic of PD in linear and logarithmic scale.

From the TE model, a fitting procedure was applied to the experimental data, shown in Fig. 2, allowing to extract the fundamental parameters of the electrical SLG/SiC junction including $\Phi_{B0} = 0.755$ eV, $R_s = 3.7$ k Ω and $\eta = 8.4$.

Concerning the optoelectronic characterization, the optical response measurement was performed using a visible laser at $\lambda = 633$ nm which has been modulated and sent onto the active area of the PD. To apply a bias voltage to the PD, a transimpedance amplifier was employed. The corresponding photogenerated current was collected and amplified using the same amplifier and measured using a lock-in technique. Then, the incident optical power was evaluated using a power meter (Newport 1931).

The internal responsivity (R_{int}), namely the ratio of the photocurrent (I_{ph}) to the absorbed optical power (P_{abs}), was finally measured. It is worth noting that the P_{abs} corresponds to the fraction of the incident optical power that is absorbed by the active material. For our Schottky PD, as well reported in literature [6], a SLG absorbs approximately only the 2.3% of the incident optical power. The R_{int} , measured as a function of the reverse bias applied to the device, up to -5 V, is shown in Fig. 3.

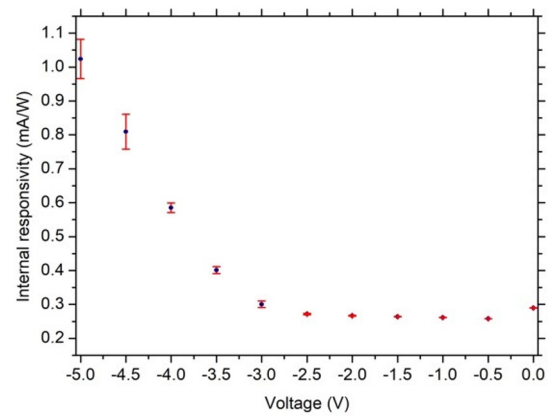


Fig. 3. Internal responsivity as function of applied voltage.

The internal responsivity of the Schottky photodetector exhibits an increasing trend as the reverse applied voltage is increased. At a reverse bias of -5 V, the internal responsivity reaches its maximum value of 1.02 mA/W, while at zero-bias, it is measured to be 0.29 mA/W. This behaviour can be attributed to the lowering of the SBH. As the reverse bias is increased, the SBH becomes more pronounced, leading to an upward shift of the Fermi level of the SLG. This shift allows for improved charge transport and enhanced photoresponse, resulting in a higher internal responsivity. By applying a reverse bias, the energy barrier for the photo-excited carriers must overcome to be collected at the electrode is reduced, leading to a more efficient photodetection process.

4 Conclusions

In conclusion, this work presents a preliminary study on the fabrication and electro-optic characterization of a Schottky photodetector based on SLG/4H-SiC exploiting the internal photoemission effect at a wavelength of $\lambda = 633$ nm. By incorporating graphene into the device structure, the detection capability of SiC in the visible spectrum range has been demonstrated. The internal responsivity of the photodetector has been evaluated as a function of reverse bias, reaching a maximum value of 1.02 mA/W at -5V. Further investigations are currently underway to provide a comprehensive understanding of the underlying physics behind the detection mechanism and to explore the optical response of the photodetector at different wavelengths expanding its applications.

References

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