Towards Graphene Adjustable-Barriers Phototransistors: p-type Schottky contacts between silicon, germanium and graphene

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Abstract: The graphene (Gr) adjustable-barriers phototransistor is an attractive novel device for potential high speed and high responsivity dual-band photodetection. In this device graphene is embedded between the semiconductors silicon and germanium. It requires both n-type and p-type Schottky contacts between graphene and the semiconductors. While n-type Schottky contacts are widely investigated, reports about p-type Schottky contacts between graphene and the two involved semiconductors are scarce. In this study we demonstrate a p-type Schottky contact between graphene and p-germanium. A clear rectification with on-off ratios of approximately 10^3 (± 5V) is achieved. Further, p-type silicon is transferred to or deposited on graphene and we also observe rectification for these kind of p-Schottky junctions. The Schottky barrier heights and photo response of the various p-type Schottky junctions are investigated in detail.

The graphene adjustable-barriers transistor (GABT) was proposed in 2022 [1]. The device can best be used as an amplifier, power semiconductor switch or phototransistor [2]. In the latter application scenario, ultra-high responsivities of larger than 10^8 A W^{-1} and a high speed with cutoff frequencies of more than 1 GHz are predicted [2]. Two device designs are conceivable. The first is a n-Si/Gr/p-Ge structure while the second is a p-Si/Gr/n-Ge composition. With the first design the speed of the device is maximized at telecommunication wavelengths of 1550 nm, while the second design allows for highest speeds at shorter wavelengths below 700 nm. The simplified band scheme of the first design is shown in Figure 1 a and b. In this configuration, an inverse band bending with a Schottky barrier $q\Phi_G$ in the valence band forms between the gate semiconductor p-Ge and graphene (Figure 1a). Thus, this junction represents a p-type Schottky contact. In the OFF-state, the large drain Schottky barrier $q\Phi_D$ restricts the current across the source-drain junction as indicated by the small red arrow. The ON-state (Figure 1 b) is triggered by SWIR illumination. The light of e.g. 1550 nm wavelength is transmitted through the n-Si with a wider bandgap and then absorbed in the p-Ge gate semiconductor with a smaller bandgap. Within the graphene/p-Ge space charge region the absorbed light generates electron-hole pairs, which are separated by the potential gradient of the Schottky junction. Thus, electrons move towards and accumulate in graphene and also shift the graphene Fermi energy level towards the conduction band E_C. This leads to a decreasing drain Schottky barrier $q\Phi_D$ and the current across the source-drain junction increases (big red arrow, Figure 1 b).

The p-Ge/graphene Schottky junction is essential for the device operation. It is often argued that due to the orientation of the graphene and p-Ge work functions, there could be no rectification at such a junction. This hypothesis seems to be confirmed by a study from Song et al. [3]. On the contrary, a significant p-type Schottky junction behaviour was found even between n-Ge and graphene when Gr is grown directly on Ge [4]. However, in this case the area of the junction was in the nanometer scale which limits the current density and application scenarios. In the present study we demonstrate for the first time a p-type Schottky junction between Gr and p-Ge with Gr transferred to the semiconductor. Rectification was observed for much larger device dimensions of up to 100x100 µm². Figure 1 c shows the IV curve of such a Gr/p-Ge p-type Schottky diode. On-off ratios of 6x10^2 and a significant photo response at 1550 nm telecommunication wavelength are achieved.

For the inverse device configuration of the photo-GABT with a p-Si/Gr/n-Ge structure, a p-type Schottky junction between Gr and p-Si is required. While such p-type Schottky diodes were realized with Gr transferred on top of p-Si [5], investigations on devices with p-Si transferred or deposited on top of Gr are missing. This is also addressed in the present study. We will show IV curves in the dark and under illumination for such silicon-on-graphene Schottky diodes. A clear rectification and photo response is observed. The Schottky barrier heights are deduced from IV-T measurements. These results are an important step towards a functional graphene adjustable-barriers phototransistor.

References

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Figures

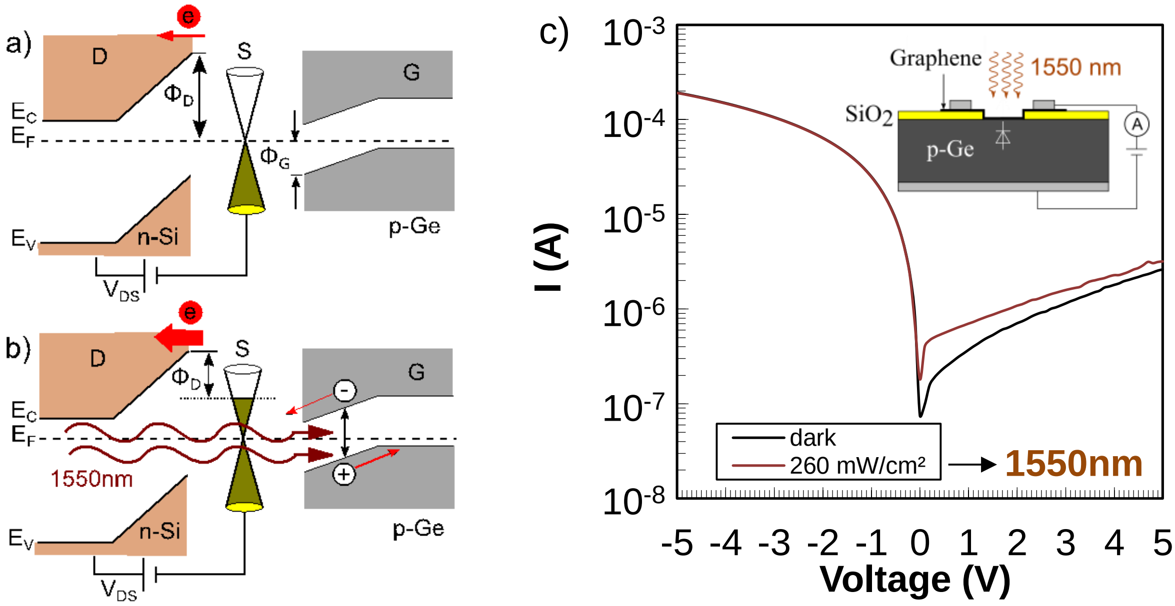

Figure 1: a) Simplified band diagram of the photo-GABT in the OFF-state with the Schottky barriers Φ_G and Φ_D. b) Simplified band diagram of the photo-GABT in the ON-state. c) IV-curve of a graphene/p-Ge Schottky junction in the dark (black curve) and under illumination with 1550 nm (red curve).