Experimental and Theoretical Investigation of Highly Tunable Graphene-GaSe Field-Effect Devices with Dual Heterojunction

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Graphene transistors have recently surpassed the gigahertz limit and are expected to impact next generation radio frequency electronics. However, the performance of graphene transistors as logic components is limited by the zero bandgap. Therefore, variety of different semiconducting 2D materials have been under intense investigation. Recently, van der Waals heterojunctions between graphene and other 2D materials have also received significant attention.

Among the binary chalcogenides MoS_2 is probably the most widely investigated material. Very limited number of studies has examined GaSe although it is also a layered 2D semiconductor. Bulk GaSe is a known nonlinear material in photonics and it has a direct bandgap in the visible range (2.1 eV, 590 nm) regardless of the thickness whereas MoS_2 has a direct bandgap only in monolayer form. GaSe forms planar tetra-layer (TL) structures and one TL consists of four covalently bonded stacks in a sequence of Se–Ga–Ga–Se. Exploiting these benefits, we have recently reported on the nonlinear optical properties of GaSe by investigating second and third harmonic generation [1] using multiphoton microscopy [2].

In this work, we demonstrate highly tunable transport characteristics of a graphene–GaSe dual Schottky diode device both experimentally and theoretically [3]. As a striking difference to previous 2D material investigations, we introduce an alternative device architecture which does not rely on manual layer-by-layer stacking. Instead, the concept employs vertical monolayer CVD graphene [4] on GaSe as heterojunctions and a lateral GaSe channel allowing the utilization of multilayer 2D materials. Implementation of gate electrodes on top of the graphene contacts on GaSe enables the modulation of the Fermi energy of graphene (but not that of the GaSe channel) resulting in a controllable and switchable device. In transport measurements, a strong tunable current rectification was observed by the modulation of the Fermi level of graphene with the gate voltage. Transport measurements revealed strong current rectification and an on/off ratio as high as 10^3 underlining the importance of GaSe among other potential 2D materials. Detailed theoretical models were used to gain fundamental understanding of the operation mechanisms of the double diode device. Effective gate voltage determined by the drain-source voltage is one key factor for the device operation. Both experimental and theoretical results showed that the threshold voltage is shifted by the gate voltage enhancing the forward current modulation suggesting that dual Schottky junction device can also be exploited for various sensor applications. This device concept is expected to be useful for the progress of 2D material-based electronics making device processing compatible with conventional semiconductor technology.

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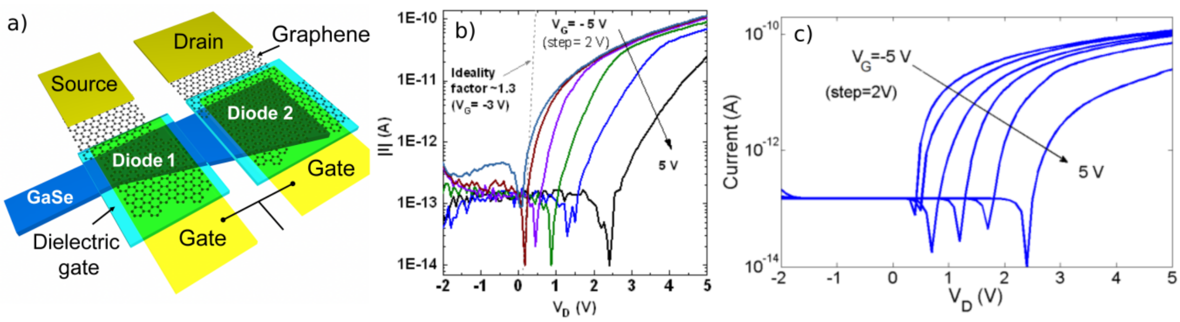

Figure 1. a) Illustration of the device structure b) measured and c) simulated I-V characteristics.