All-Graphene T-Branch Thin-Film Field-Effect Rectifiers

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Abstract

Charge carrier transport in a two-dimensional electron gas (2-DEG) has been widely studied for the past decades to exploit its nonlinear properties arising in the ballistic regime for nanoelectronics. For example, T-branch (three-terminal junction) devices fabricated on 2-DEG exhibit electrical rectification as predicted by theoretical models. Whereas III-V compound semiconductors are well known materials for 2DEG devices, graphene has recently attracted attention as a 2-DEG material because it has exceptional electronic properties. The lack of band gap in graphene does not set similar limitations for the device performance as in the case of graphene field-effect transistors (GFETs). Consequently, nonlinear behavior of three-terminal graphene nanojunctions have been studied using mechanically exfoliated [1] and silicon carbide [2] graphene. However, these nanoscale graphene three-terminal junctions with ballistic (or quasi-ballistic) operation have shown rectifications with relatively low efficiency. Large-scale graphene prepared by chemical vapor deposition (CVD) has the potential to deliver true monolithic integrated circuits (ICs) as one continuous monolayer graphene film can be utilized as a channel, gate, interconnect, and even as passive components such as resistors.

Here, all-graphene thin-film devices are realized as T-branch channels and gate electrodes are both fabricated utilizing graphene synthesized by photo-thermal CVD (PTCVD) [3] as depicted in Figure 1a. The top gate electrode is deposited on a 30-nm-thick Al2O3 by atomic layer deposited (ALD). It is intriguing to note that Raman fingerprint of high quality graphene and high mobility (~ 4700 cm^2/Vs) is achieved on PTCVD grown graphene despite the fact the graphene grain size is relatively small (2-3 μm) compared to typical CVD graphene. Moreover, small grain size is generally considered detrimental to the electronic transport characteristics. We note that PTCVD is an interesting alternative for graphene mass-production as a monolayer film can be deposited only in ~30 s on copper.

For the microscale T-branch devices, we present highly tunable and switchable room temperature full-wave rectification for 100 kHz of AC (Figure 1b). Instead of ballistic theory, we explain the rectification characteristics through an electric field capacitive model based on self-gating in the high drain-source bias regime. The model and experimental results are shown in Figure 1c. These findings open new possibilities for practical applications, as ballistic operation is impractical for flexible and transparent application due to nanoscale size requirements. The device architecture introduced here is not dependent on the substrate and therefore the concept can be utilized for transparent and flexible electronics. By comparing with invasive metal center probe structures, we demonstrate that graphene itself acts also an excellent electrode for the signal detection. Finally, examining devices with varying channel dimensions, we find the relation of the micrometer-size scaling to the device performance.

References
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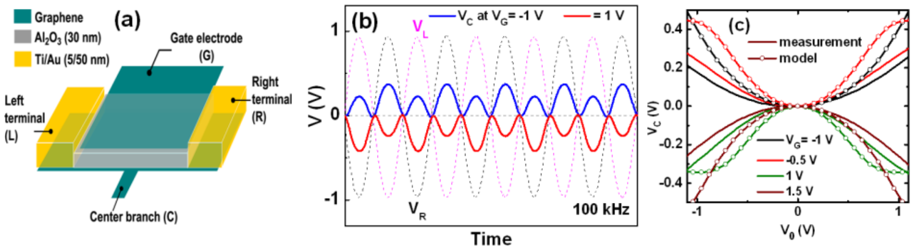

Figure 1. (a) Illustration of the all-graphene T-branch junction device. (b) Rectifier characteristics for the 100 kHz push-pull inputs (for left and right terminals) under two different DC gate fields. Solid lines are the center branch outputs for hole (V_G= -1V) and electron region (V_G= 1 V), respectively. (c) Comparison of measured and calculated rectification curves.