Transfer-free Bilayer Graphene FETs: Application as Memory Devices

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Introduction
In this paper we report on the application of in-situ CCVD grown bilayer graphene transistors (BiLGFTs) as memory devices. By means of catalytic chemical vapor deposition (CCVD) the BiLGFTs are realized directly on oxidized silicon substrate without transfer. These BiLGFTs possess unipolar p-type device characteristics with a high on/off-current ratio between $1 \times 10^{-5}$ and $1 \times 10^{7}$ at room temperature [1, 2]. The hysteresis in BiLGFTs depends on the cycling range of the applied backgate voltage $V_{BG}$, while the sub-threshold slope is uniform for varied temperatures and varied cycling ranges of the backgate voltage [3]. Based on the observed properties of BiLGFTs it is possible to use BiLGFTs as memory devices.

Fabrication of BiLGFTs
In preparation for CCVD a silicon wafer is oxidized in dry $O_2$ in order to obtain a 100 nm thick SiO$_2$ film. Afterwards several lithography steps follow and a structured lift-off system remains on the wafer surface. Thin aluminum and nickel layers are evaporated over the whole substrate surface and are structured via lift-off. By annealing the wafer the aluminum transforms into an insulating aluminumoxide (Al$_2$O$_3$) while the nickel layer generates several nickel nanoclusters at the perimeter of the catalyst system [1, 2]. In the subsequent methane-based CCVD process, graphene layers are growing while the number of the stacked graphene layers depends on the adjusted process parameters like time, temperature and gas mixture [3].

Results and Discussion
The electrical characterization of the transistors is performed using a Keithley SCS 4200 semiconductor characterization system. The catalyst pads are used as source and drain contacts. Figure 1 shows the current voltage characteristic of a BiLGFT as a function of the applied backgate voltage ($V_{BG}$) showing an on/off-current ratio of $1 \times 10^7$ at room temperature. $V_{BG}$ is swept from -10 V to 10 V and reverse. In this case the hysteresis of the BiLGFT is $\Delta V_{BG} = 11$ V and is most likely based on the trapping and detrapping of oxide charges from the backgate oxide [3].

The band structure of BiLG is known to be sensitive to interfacial interactions [5], and does not originate from an asymmetric double layer, an energy gap forms at the former Dirac crossing points [4]. Accordingly, the bandgap of an asymmetric double layer can be further enhanced by means of graphene/substrate interfacial interactions [5], and does not originate from an applied electrical field in this case. Since there is a permanent bandgap, the Schottky-barriers at the graphene/metal contact needs to be taken into account. The applied backgate voltage is used to affect the Schottky-barrier at the source/drain to graphene contacts, thereby switching the BiLGFT on and off.

To store a logical “1” a backgate voltage of $V_{BG} = 10$ V is applied. In contrast to this a logical “0” is written by applying a backgate voltage of $V_{BG} = -10$ V. The stored information can be read at $V_{BG} = 0$ V. Figure 2 shows a cycle of writing and reading. At first a logical “0” is written. Reading at $V_{BG} = 0$ V results in a S/D current of $I_{DS} = 10^{-12}$ A. Ongoing a logical “1” is written and the subsequent reading provides a current value of $I_{DS} = 10^{-12}$ A. The storage of a logical “0” or “1” is repeatable and reproducible (Fig 2). Several cycles of writing and reading have been realized without any observable degradation of the device performance.

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References

Figure 1: Current-voltage characteristics of a bilayer graphene transistor with hysteresis as a function of the applied backgate voltage $V_{BG}$, showing an on/off-current ratio of $1 \times 10^7$ at room temperature. $V_{BG}$ is swept from -10 V to 10 V and reverse.

Figure 2: Repeatable and reproducible storage of logical “0” and “1” current levels as a function of time. By applying $V_{BG} = -10$ V (+10 V) a logical “0” (“1”) is written. When measuring $I_{DS}$ at $V_{BG} = 0$ V yields the information if a logical “0” or “1” has been stored.