Complementary hot carrier transistor with vertical graphene base electrode for THz applications

W. Mehr, J. Dabrowski, Ch. Scheytt, G. Lippert, Y.-H. Xie*, M.C. Lemme[#], S. Vaziri[#], G. Lupina

IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany
mehr@ihp-microelectronics.com

* Department of Materials Science and Engineering, University of California at Los Angeles, USA

[#]KTH Royal Institute of Technology, Isafjordsgatan 22, 16440 Kista, Sweden

The ultimate thinness and low resistivity of graphene can be exploited to realize ultra-fast electronic devices. Here, we analyze a novel vertical concept of a graphene transistor called graphene base transistor (GBT). Figure 1 illustrates the difference between a graphene field-effect transistor (GFET) and a GBT [1]. In a GFET, the output current flows inside of the graphene sheet that forms a channel connecting the source to drain and that has its conductivity controlled by the gate electrode. In a GBT, the output current flows from the emitter to the collector perpendicularly to the graphene sheet that is contacted to the base electrode and that controls the amount of carriers ejected from the emitter. The carriers are injected from the emitter by Fowler-Nordheim tunneling through the emitter-base insulator (EBI) into the conduction band of the base-collector insulator (BCI) and further into the collector, traversing the graphene base. Due to monatomic thickness of graphene, the transport across the base is ballistic. Assuming that only electrons scattered within the base contribute to the base current I_B, this may reduce I_B even by two orders of magnitude compared to a similar design with a metal base. In addition, graphene is chemically inert, potentially reducing problems with interface reactions.

A GBT has advantages over a GFET. In particular, it is designed to have a very high I_{ON}/I_{OFF} ratio, a natural current saturation, and high power operation. For that reason, GBT is useable for analog radio frequency applications and as complementary transistors for ultra-high speed logic applications [2]. In addition, the BCI can be designed to sustain output voltages well above 10 V without compromising the transfer characteristics or the frequency response, so that a GBT can work also a high power transistor.

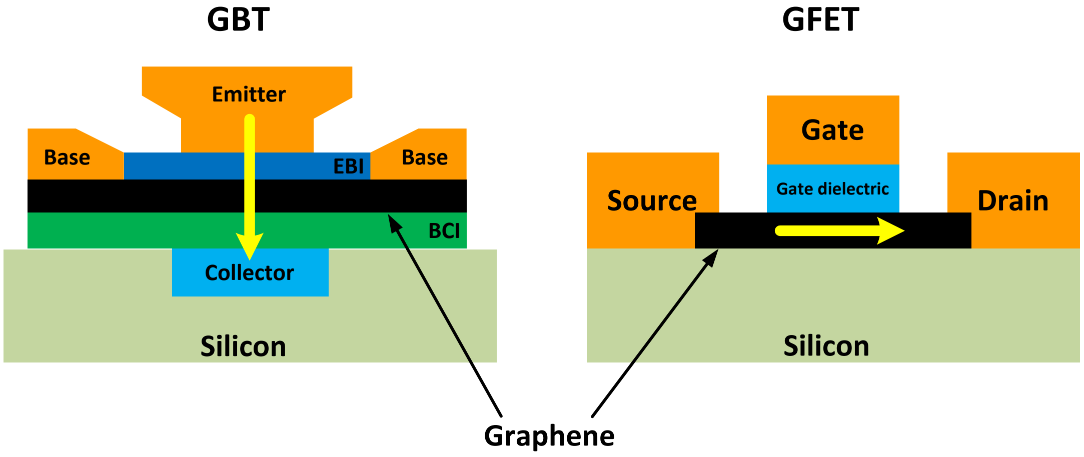
Results of conservative simulations suggest that transition frequencies up to 2 THz can be achieved (Fig. 2). The simulations assume a simple one-band effective potential for which Schrödinger equation with open boundary conditions is solved. The parameters correspond to n-GBT with Er_2Ge_3 emitter, Ge EBI, and a graded TiSiO/SiO_2 BCI. Graphene is considered to be a tunneling barrier, as indicated by the results of ab initio calculation of self-consistent tunneling spectra in equilibrium. The quantum capacitance of graphene, C_Q, is an important factor. Its role depends also on the tunneling properties of graphene, which at the moment can only be estimated. Assuming that the tunneling barrier is defined by the graphene band structure at Γ, we expect that THz operation is possible when the EBI thickness is in the range of 3-5 nm and the EBI tunneling barrier height is about 0.2-0.4 eV.

References

[1] W. Mehr et al., arXiv:1112.4520v1

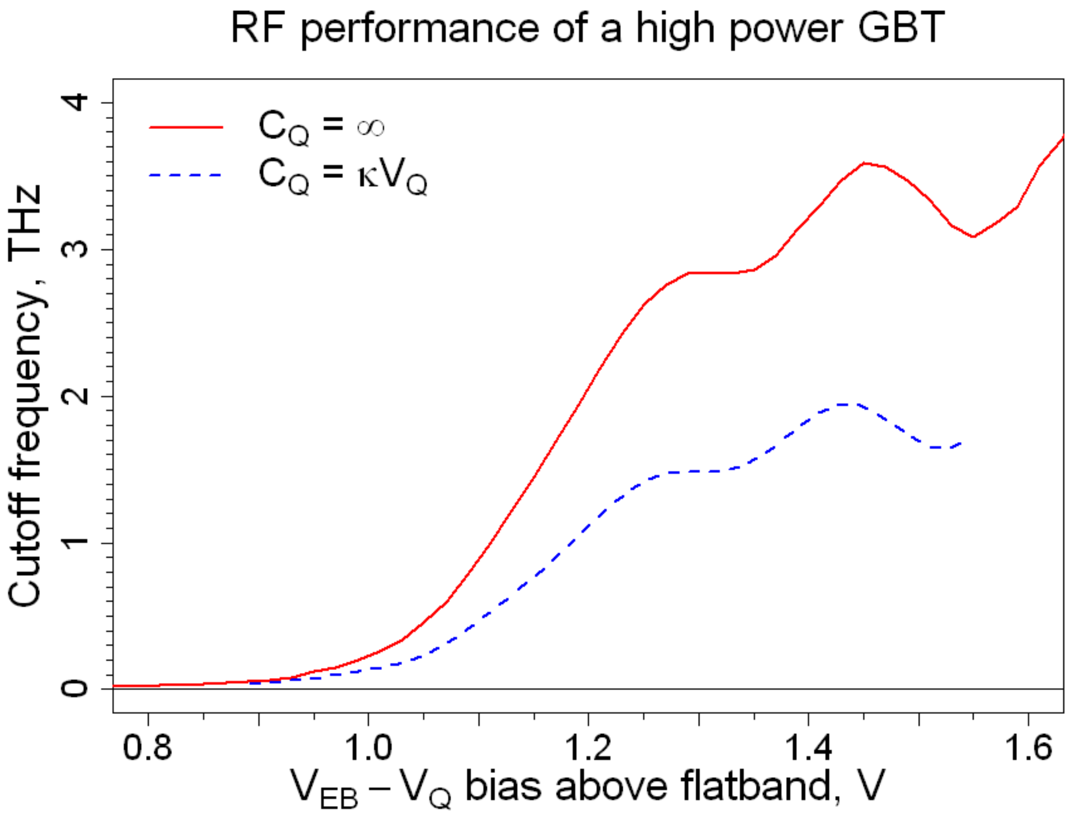
[2] W. Mehr et al., accepted for publication in IEEE Electron Device Letters, (2012)

Figure 1



Schematic cross-section of a graphene base transistor (GBT) and a graphene field-effect transistor (GFET).

Figure 2



Simulated transition (cut-off) frequency f_T of a high power GBT. Solid line: no quantum capacitance effects are accounted for ($C_Q = \infty$). Broken line: with quantum capacitance effects ($C_Q = \kappa V_Q$). $V = V_{EB} - V_Q$ defines the EBI electric field. V_Q is the voltage drop on C_Q and corresponds to the position of the Fermi level in graphene, measured with respect to the Dirac point, and is determined by the applied voltages and the EBI and BCI plate capacitances. For this particular design, $V_Q \approx 0.3$ V at $V \approx 1.3$ V. Above 1.2 eV, quantum oscillations in f_T begin.