Potential Applications for Graphene Devices in Nanoelectronics

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Abstract

While benchmarking figures for graphene show remarkable properties like ballistic conductance over several hundred nanometers or charge carrier mobilities of several 100.000 cm2/Vs, integrated graphene devices are limited by defects in graphene and its dielectric environment. Furthermore, the lack of a band gap limits the applicability of graphene field effect transistors (GFETs) for logic applications. This talk will compare the expected RF performance of realistic GFETs with current silicon CMOS technology. In particular, a systematic model-based comparison of RF performance metrics between 65nm GFETs and silicon MOSFETs was performed. We show that GFETs slightly lag behind in fT and require at least a carrier mobility of μ = 3000 cm2/Vs in order to achieve similar RF performance. While a strongly nonlinear voltage-dependent gate capacitance inherently limits performance, other parasitics such as contact resistance are expected to be optimized as GFET process technology improves. Finally, we quantify the μ values, which would allow future GFETs to match and exceed CMOS, potentially up to THz operation.

In addition, a novel graphene-based hot electron transistor will be introduced: the graphene-base transistor (GBT) [2]. The GBT combines the concept of hot electron transistors with the unique properties of graphene to potentially overcome the difficulties faced by graphene RF FETs, such as the very high off current (Ioff) and the lack of current saturation. Instead of the lateral transport along the graphene in the GFET, the GBT concept is based on a vertical arrangement of emitter, base, and collector, just like a hot electron transistor or .recently suggested graphene tunnel FETs [3]. In the off-state, charge carriers face a dielectric barrier. In the on-state, the emitter-base diode injects hot electrons across the base (here: graphene) into the conducting band of the insulator separating the base from the collector (base-collector insulator, BCI). Electrons leave the emitter by Fowler–Nordheim quantum tunnelling through the emiter-base insulator (EBI). In the GBT, graphene acts as the control electrode (similar to the grid in a vacuum tube). In contrast to ultrathin metal films, graphene is far superior, because it has no pinholes, which leads to very low resistivity, while its monatomic thickness guarantees ballistic transport across the base. This, in turn, results in a high gain, low base resistance, and low base current. In addition, the GBT allows minimizing Ioff by proper BCI design and shows current saturation when the output voltage exceeds the value necessary to remove the tunneling barrier in the ballistic transport across the BCI. With the right choice of materials and device geometry, we conclude that the GBT should be capable of THz operation. The GBT may also have potential for logic integration.

Finally, graphene is an optoelectronic material and its application as a broadband photodetector will be discussed [4]. By tuning both single-layer and bilayer gated graphene devices from bipolar to unipolar, we demonstrate a gate-activated photoresponse. Our results can be explained with a model of the photothermal effect, where elevated temperatures at the p-n-junction induce thermoelectric currents. We anticipate that the responsivity can be further increased by converting incoming light more efficiently by integration with metallic plasmonic structures or by reducing the device size, using transparent top gates, and by optimizing device technology to enable p-n devices in the ballistic regime. With the possible extension into far-IR / terahertz radiation and the high conductivity of graphene, we envision broad band bolometers with submicrometer pixilation.

References

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