Graphene Field Effect Transistors for Microwave and mm-Wave Applications

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Abstract—In order to operate at microwave frequencies and higher, the channel length of a field effect transistor must be made very short (~25nm at 1THz) to minimize input capacitance and the drift time of carriers through the channel. This scaling cannot continue indefinitely however, as short channel effects limit FET transconductance at very short gate lengths. These effects are largely due to a degradation in the ability of the gate to electrostatically control channel doping as the gate-to-channel distance and the finite thickness of the 2DEG channel become comparable to the channel length. This degradation can be avoided by utilizing graphene, a zero-bandgap two-dimensional material consisting of carbon atoms on a hexagonal lattice, as a channel material due to its high carrier mobility, truly atomic thickness and ability to be integrated with other Van der Waals materials for ultra-thin gate dielectrics. Presently however, the difficulty of producing low-resistance electrical contacts to graphene and the absence of saturating behavior in graphene transistors lead to poor RF performance especially for short channel devices. By utilizing current annealing to reduce contact resistance and biasing in a high-field regime with saturated carrier velocities, graphene field effect transistors (GFETs) with improved RF performance can be realized. Here, we present fabrication techniques to create edge-contacted, exfoliated, hexagonal Boron-Nitride encapsulated graphene field effect transistors (GFET), including self-aligned processes for producing ultra-short gate lengths scalable to dimensions enabling THz and higher transistors. We discuss measurements of the DC and AC linear response of several GFETs of gate lengths between 1um and 100nm, as well as potential for future improvements. Notably an f_{max} of 59GHz is achieved in a 1µm gate length transistor with softly saturating DC characteristics. In contrast to the high-field operation of GFET amplifiers, when biased near the zero density of states Dirac point, the low field conductivity of graphene exhibits a distinctly non-linear behavior with respect to gate voltage. Utilizing this non-linearity to rectify incident voltage waves, a GFET can be made to be a very broadband power detector. In a 1µm gate length GFET at 30K, a responsivity from 1-20GHz of 55V/W is achieved with a noise equivalent power limited by the room temperature readout to 1nW/√Hz.