Scalable Graphene Field Effect Transistors with Boron Nitride Dielectrics

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The commercial realization of graphene-based technologies is dependent on the ability both to produce large-area films of graphene with high-quality electronic properties and to maintain device characteristics while decreasing device dimensions. Furthermore, for radio frequency (RF) device performance, it is essential for graphene to demonstrate both high mobility and current saturation characteristics for devices to achieve high power gain.

While chemical vapor deposition (CVD) offers a promising method to produce large-area films of graphene, CVD-grown graphene has not yet demonstrated equivalent electronic transport properties to those of graphene derived from mechanical exfoliation.[1,2] Furthermore, trapped charges in gate dielectrics, a common problem to all oxide-based dielectric films on graphene, result in non-saturating devices as device dimensions are reduced. [3]

We demonstrate that by improving CVD graphene quality and utilizing low-disorder gate dielectric materials, we can achieve both high-quality and scalable graphene-based RF devices. By improving CVD growth conditions and device fabrication processes (Fig. 1), we demonstrate CVD graphene with field effect mobilities comparable to exfoliated graphene, up to 110,000 $cm^2V^{-1}s^{-1}$ on hexagonal boron nitride (h-BN) dielectrics (Fig 2). We eliminate the significant effects of trapped charge in the gate dielectric, preserving saturating characteristics to gate lengths of 150 nm (Fig. 3).[4] Furthermore, utilizing high-quality dielectrics, such as h-BN, enables the fabrication of RF devices exhibiting current saturation and values of f_T and f_{max} of 44 and 34 GHz, respectively, at gate lengths of only 600 nm (Fig 4).[5]

Our work demonstrates that by improving CVD graphene and dielectric quality, high-performance and scalable RF devices can be achieved.

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[1] Li, X. S. *et al*. Science **324** (5932), 1312-1314 (2009).
[2] Li, X. S. *et al*. Nano Lett. **10** (11), 4328-4334 (2010).
[3] Meric, I. *et al*. Nano Lett. **11** (3), 1093-1097 (2011).
[4] Meric, I. *et al*. IEDM, 23.2.1-23.2.4 (2010).
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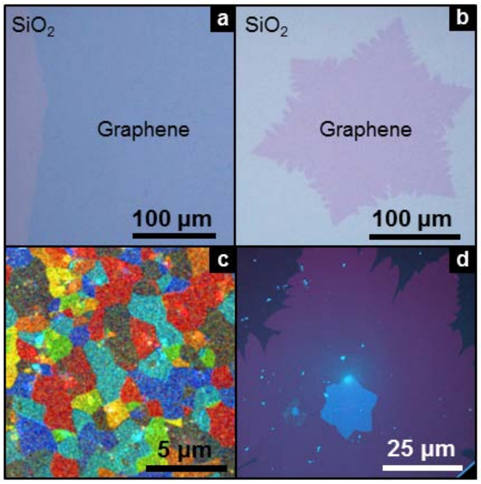

Figure 1. CVD growth of graphene: Optical (a,b) and false-colored dark-field TEM (c,d) images of CVD graphene. Varying CVD growth conditions result in either (a,c) low-quality polycrystalline films or (b,d) high-quality, single-crystalline graphene patches up to 250 microns in dimension.

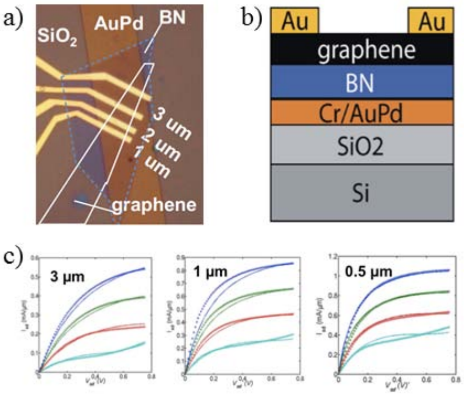

*Figure 3. Graphene FETs fabricated on h-BN dielectrics: (*a,b) Device structure of graphene FETs fabricated with high-quality h-BN dielectrics. (c) dc current-voltage measurements show that devices fabricated on h-BN dielectrics show saturating current characteristics down to gate lengths of 500 nm.

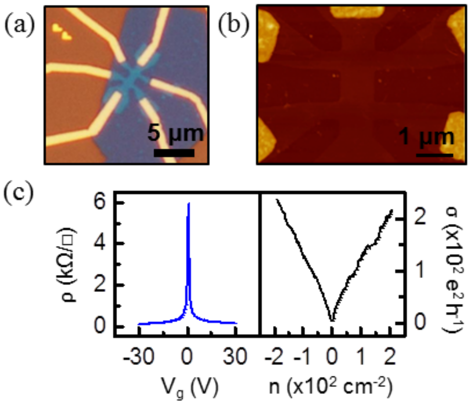

Figure 2: Graphene Hall bar and transport data: (a) Optical micrograph and (b) AFM image of Hall bar structure fabricated from large-grain CVD graphene on h-BN and (c) corresponding resistivity and conductivity data taken at 1.6 K. CVD graphene devices demonstrate field-effect mobilities up to 110,000 cm^{2}V^{-1}s^{-1} when fabricated on h-BN.

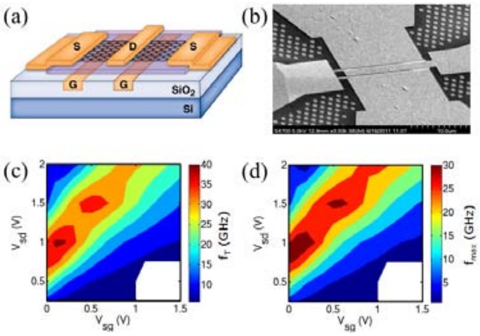

Figure 4: Graphene-based RF structures fabricated with h-BN dielectrics: Diagram (a) and scanning electron micrograph (b) of an RF device fabricated with h-BN dielectric. (c) Bias dependence of high-frequency figures-of-merit. Devices show f_T and f_{max} of 44 and 34 GHz, respectively, at 600 nm gate lengths.