High-performance graphene electronics on standard SiO_2/Si substrates enabled by new synthesis and transfer methods

Li Tao,[1,*] Xiaohan Wang,[2] Haiyu Huang,[1] Huifeng Li,[2] Richard D. Piner,[2] Rodney S. Ruoff,[2,3] and Deji Akinwande[1]

[1]*Microelectronics Research Center,,* [2]*Dept of Mechanical Engineering and the Materials Science Program, The University of Texas at Austin, TX, USA*

[3]*Director, Center for Multidimensional Carbon Materials, Ulsan National Institute of Science and Technology, Ulsan, South Korea*

[*]*Email: tao@utexas.edu;*

In graphene-based analog and radio-frequency nanoelectronics, the electronic performance (i.e., gain or bandwidth), is often commensurate with the transistor carrier transport properties such as charge mobility and velocity saturation.[1, 2] Despite extensive study on selection of the dielectric material for the graphene/dielectric interface, the effect of this interface on the carrier transport properties warrants further studies. We have recent progress on the synthesis, transfer, and device characterization to better understand the electronic properties of CVD graphene on standard SiO_2/Si substrates.

We recently developed a magnetic inductive heating CVD furnace,[3] which allows rapid heating and cooling between R.T. and 1000 ^oC in a few minutes. Transistors made from this synthesized graphene on SiO_2/Si yield average mobilities of 8,000-10,000 (maximum at 17,800) cm^2/V-s, 2-3 times higher than comparable devices made by identical transfer and fabrication but with graphene synthesized using typical low or atmospheric pressure CVD (Figure 1a). Typical I_d-V_d output curves exhibit intrinsic three-region response with current-saturation at ambient condition (V_g=20 and 30 V in Figure 1b) on back-gated CVD graphene transistors reported for the first time. Drift-diffusive transport modeling indicates a saturation velocity of 2.3×10^7 cm/s (Figure 2a), which is close to the theoretical estimate for charge carriers in graphene on SiO_2/Si.[4] This high saturation velocity (a fraction of the Fermi velocity in graphene) further supports the fast carrier properties of 'inductively heated' CVD graphene on SiO_2/Si. We measured the minimum quantum capacitance of graphene as 7.8 $fF/\mu m^2$(Figure 2b), in agreement with theoretical calculation of that property at the Dirac point.

Transfer/integration is also critical to the device performance of CVD graphene. We developed a direct electrochemical delamination process (Figure 3, top)[5] to transfer residue-free and continuous graphene showing low-sheet resistance (~50 Ω/□ for 6-layer) and high transmittance competitive with conventional transparent electrodes (Figure 3, bottom). This transfer method physically detaches graphene from copper by H_2 bubbles, preserving copper for reuse in subsequent growth[6, 7] unlike traditional transfer involving copper etching. In addition, by coating the supporting polymer layer onto both sides of the copper foil, graphene films on each side can be delaminated simultaneously doubling the output.

High-performance and thus 'pristine graphene' is essential to certain applications such as gas sensing (Figure 4) that requires high sensitivity to detect the small change in signal. With our new synthesis and transfer methods plus device characterization, the true electronic potential of CVD graphene on SiO_2/Si under ambient conditions is experimentally determined to be promising and comparable to other graphene devices made on ideal gate dielectrics such as *h*-BN.

Reference:

1. F. Schwierz, Nat Nano 5 (7), (2010). 2. S.-J. Han, et al., Nano Letters 11 (9), (2011). 3. R. Piner, et al., ACS Nano 7 (9), (2013). 4. V. Perebeinos and P. Avouris, Physical Review B 81 (19), (2010). 5. X. Wang, et al., Small, (2013). 6. Y. Wang, et al., ACS Nano 5 (12), (2011). 7. L. Gao, et al., Nat Commun 3, (2012).

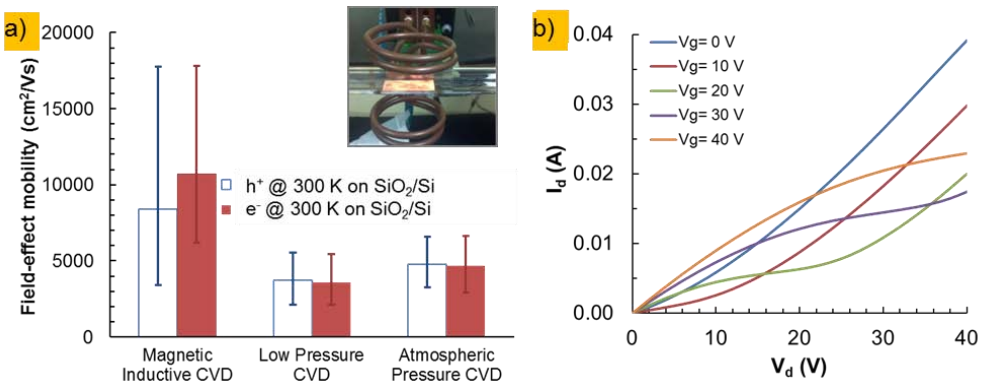

Figure 1: Electrical measurement on a) room-temperature mobility statistics of magnetic inductive heating CVD (inset is the setup) graphene compared to conventional CVD methods; b) current saturation with a second linear region in I_d-V_d curve at different gate bias.

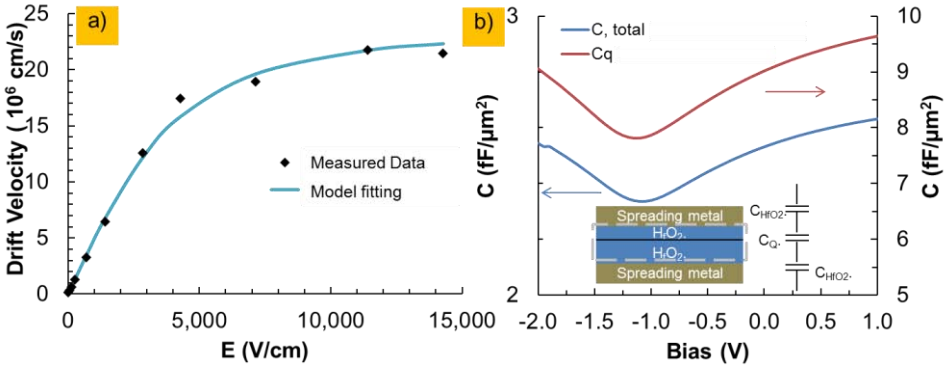

Figure 2: Magnetic inductive heating CVD graphene with intrinsic property close to theoretical prediction: a) velocity saturation at 2.3×10^7 cm/s fitted to measured drift velocity versus electrical field, b) quantum capacitance, C_q, measurement of graphene from HfO_2/graphene/HfO_2 stack.

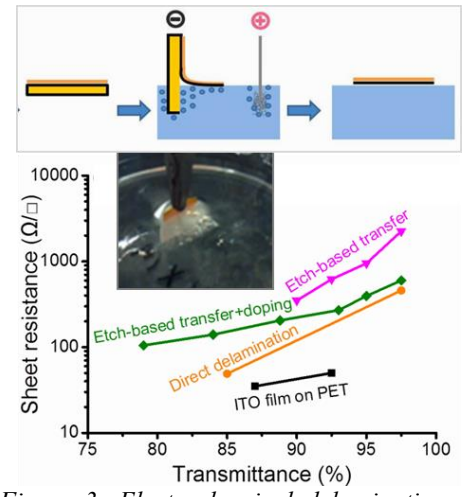

Figure 3: Electrochemical delamination of graphene from copper substrate: this transfer method yields transferred graphene with lower sheet resistance (orange) at the same transmittance compared to conventional transfer (magenta or green), approaching ITO film as a transparent conducting film.

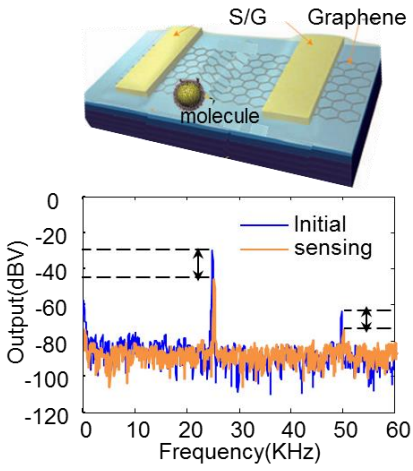

Figure 4: Demonstration of a graphene RF sensor: initial output (blue) experience drops at both fundamental tone 25 kHz and the second harmonic tone at 50 kHz when exposed to sensing molecules after 2 min (orange). The sensor can be reset by an ethanol-based electrochemical treatment for another round of sensing.