Materials Issues Impacting GHz Devices from Epitaxial Graphene on SiC

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The advent of the world's first graphene RF field effect transistors (FETs) fabricated on epitaxial graphene (EG) grown on 50.8 mm SiC semi-insulating wafers has given rise to a new electronic device technology. The EG RF FETs had f_{max} of 14 GHz at 5 Vds for 2 μm gate widths [1] and results are expected to improve as gate widths are scaled down. Performance metrics on wafer scale EG electronic devices will improve as key materials issues are addressed. Some of these key materials issues are morphology and thickness control, enhanced mobility, uniformity of sheet carrier density and resistivity. In this presentation, we provide details on our approach using Si sublimation from SiC substrates for growing EG on 50.8 mm diameter SiC wafers and discuss the impact of key material issues on RF device performance. A commercial Aixtron VP508 SiC epitaxial growth reactor was use to form epitaxial graphene on the Si- and C-faces of 4H- and 6H-SiC semi-insulating 0° oriented substrates at temperatures from approximately 1225 to 1700°C and for times ranging from 10 to 300 min. Substrates were 16 x 16 mm^2 coupons and 50.8 mm diameter wafers. Synthesis conditions were an improvement on the work presented at the 7th ECSCRM 2008 [2] and used both the *in-vacuo* (10^{-6} to 10^{-4} mbar) and Ar ambient (50-200 mbar) Si sublimation process. EG was characterized by a wide array of tools including atomic force, scanning electron, Nomarksi and scanning tunneling microscopies, Raman spectroscopy, x-ray photoelectron spectroscopy, Hall effect, and Lehighton contactless resistivity and mobility wafer probe. Optimization of EG growth on 50 mm Si-face wafers using the *in-vacuo* process resulted in an excellent relative resistivity uniformity of 2.8% and record 300 K Hall mobilities up to 2700 $cm^2V^{-1}s^{-1}$ were found. Using Raman spectroscopy mapping of the 2D peak, it was determined that: (1) the majority of the film was monolayer EG, (2) two layers of EG could be found at step edges and (3) the EG was continuous across the wafer. RF FETs fabricated using photolithography on the latest optimized wafer-scale EG exhibited state-of-the-art ambipolar behavior, Ion/Ioff ratios and peak transconductances. Frequency performance metrics were established for these devices such as fT●Lg products of 10 GHz●μm and fmax of 14 GHz. Most encouragingly, gate delay was 2 pm $μm^{-1}$. We will discuss the impact of key material parameters associated with EG for these record results as well as the impact of Ar ambient controlled graphenization on future RF devices.

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References

[1] Press Release, HRL Laboratories, LLC, http://www.hrl.com/, Dec. 5, 2008
[2] B.L.VanMil, R.L.Myers-Ward, J.L.Tedesco, C.R.Eddy, Jr., G.G.Jernigan, J.C.Culbertson, P.M.Campbell, J.M.McCrate, S.A.Kitt, and D.K.Gaskill, Materials Science Forum, Vol. 615-617 (2009), p.211.