Free-Charge Carrier Properties of Graphene Layers on SiC

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P2-37

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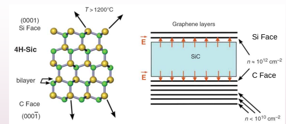
Our Message

- A rotating analyzer-type ellipsometer employing a frequency-tunable backward wave oscillator source was used for Mueller matrix measurements in the THz frequency range.
- High mobility few layer graphene (d~1 nm) is observed as a distinct damping of Fabry-Pérot interferences originating from the SiC substrate.
- The combination of THz and MIR ellipsometry allows the identification of high and low mobility graphene layers grown on C-face SiC.
- THz optical-Hall effect data are successfully used for the determination of the free electron effective mass in epitaxial graphene.
- THz ellipsometry is found to be a very useful tool for the investigation of the electrical properties of epitaxial graphene deposited on SiC substrates.

Epitaxial Graphene for THz Electronics

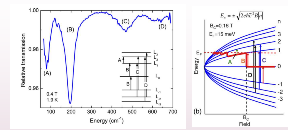
Epitaxial Graphene on SiC Substrates



- few graphene layers are formed on the Si-terminated face (top), with substantially more on the C-terminated face (bottom).
- electron doped effects due to the interface electric field close to the SiC interface

P. N. First, *et al.*, *MRS Bull.* **35**, 296-305 (2010).

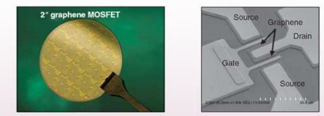
Dirac Particle Properties



- Infrared transmission spectroscopy of epitaxial graphene revealing Landau level structure
- absorption maxima positions as a function of field is characteristic for a chiral "massless" Dirac particle

W. A. de Heer, *et al.*, *Solid State Commun.* **143**, 92 (2007).

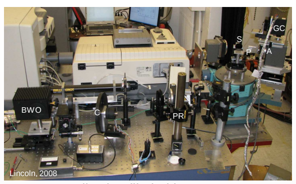
Wafer-Scale THz Field-Effect Transistors



- 50 mm graphene wafer was processed by standard lithographic techniques
- Graphene based field-effect transistors have been demonstrated to operate in the 100 GHz range

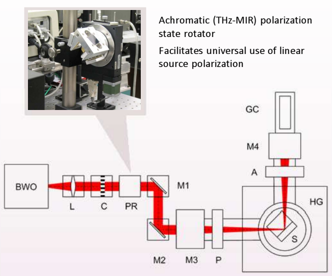
P. N. First, *et al.*, *MRS Bull.* **35**, 296-305 (2010).

THz Ellipsometry Setup



Patent application filed with UNL, Sept. 2008

- polarizer (P) sample (S) rotating analyzer (A) configuration
- Golay detector (GC)
- Backward wave oscillator (BWO) source:



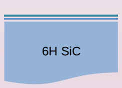
Backward wave oscillator (BWO) source:

- base resonator frequency 107 to 177 GHz, bandwidth 2 MHz (!), peak power 0.1-0.01 W (!)
- linearly polarized light
- full spectral range (with Schottky diode multipliers): 0.1 to 1.5 THz

Sample Preparation

Sublimation of Si from SiC substrates at temperatures >1200°C results in the formation of epitaxial graphene at the SiC interface.

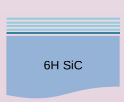
Si-Face (0001)



- step bunching results in bi-layer formation on a $6\sqrt{3}\times 6\sqrt{3}$ R30° reconstructed surface
- low sheet charge density, mobility graphene

The morphology, growth rate, and roughness of epitaxial graphene are different between C- and Si-face

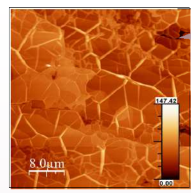
C-Face (000-1)



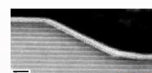
- high sheet charge density, mobility graphene
- graphene layer is covered with "graphitic" layers with lower carrier concentration and mobility

THz and MIR Ellipsometry

C-Face (000-1)

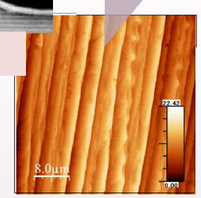


AFM topography of graphene on C-face, showing typical "giraffe pattern"



TEM micrograph showing graphene over a step bunch

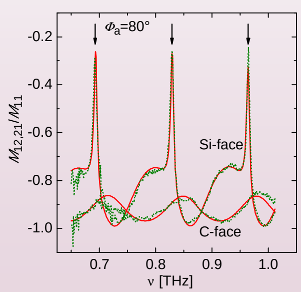
AFM topography of graphene on Si-face, showing step bunches



Si-Face (0001)

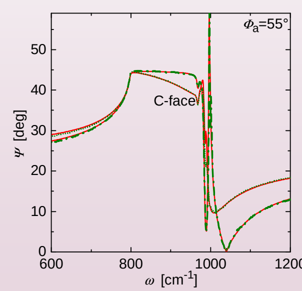
- morphology, growth rate, and roughness are different between C- and Si-face
- graphene on Si-face has transition layer, graphene on C-face does not
- for a given sheet charge density, mobility of EG on Si-face less than EG on C-face

THz Ellipsometry



Fabry-Pérot interferences (arrows) originating from the SiC substrate are damped out for C-face grown graphene

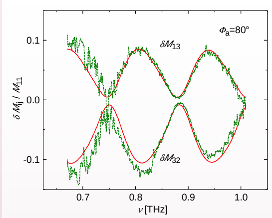
MIR Ellipsometry



Fingerprint of graphene at the reststrahlenband of SiC – more dominant for C-face grown graphene

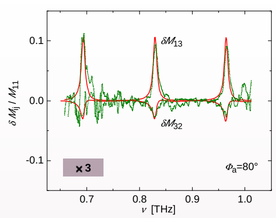
THz Optical-Hall Effect

C-Face (000-1)

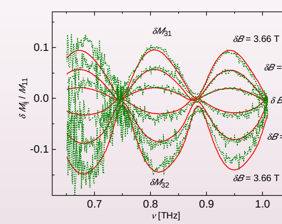


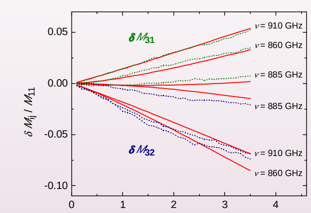
Non-zero Mueller matrix $M_{13,32}$ difference spectra for δB=3.4 T in the THz region allow the determination of the graphene free-charge carrier effective mass

Si-Face (0001)



Field-dependent Optical-Hall Effect: C-Face Grown Graphene

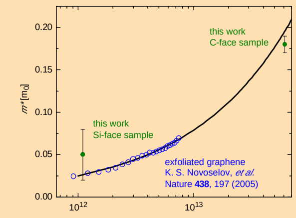




- OHE at THz frequencies allows determination of graphene effective mass consistent with Shubnikov-de Haas measurements on exfoliated graphene
- Simultaneous analysis of THz and MIR data requires two layer model for graphene (low and high mobility)
- C-Face graphene shows a field dependence of effective mass:

$$m^*(B) = m_a - m_b\sqrt{B}$$

m_a=0.18 and m_b=0.07 for δB<3.7T



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