Epi-gra-phic

December 4th-7th Catania (Italy)

Book of Abstracts

National Research Council of Italy

4-7/12/2012

Open joint workshop of the EPIGRAT and Graphic-RF projects

Motivation

The Graphene synthesis and the demonstration its exceptional properties bring revolutionary new concepts in different research branches (from solid state physics to the applied biology). Moreover, graphene can be seen as the parent of a new class of materials (like BN or MoS_2), which are characterized by a truly two dimensional (2D) lattice. As a consequence, contrary to other kinds of atomic/molecular monolayers, these materials can be manipulated and studied in suspended planar configurations. Moreover, even when they are deposited or grown on bulk supporting substrates, they essentially maintain the properties of the suspended configuration, since their inner bonding character is not significantly altered from the contact with the substrate. Another related aspect of the intrinsic 2D character of graphene is the possibility to realize a strict hetero-epitaxy between a three-dimensional (3D) crystal and an one-atom-thick film. Epitaxial graphene can be directly grown on the surface of the 3D system (e.g. in the case of metal substrates like Cu, Ni etc.), or obtained by the thermal decomposition of SiC surfaces and subsequent Si sublimation.

The graphene/SiC epitaxial system in one of the best candidate for the nanoelectronics and other derivate applications, since Gr is synthesized directly on semiconductor (o semi-insulating) material with a good reproducible yield and on a wafer scale. For example Gr on SiC can be quite interesting for possible applications in RF devices since SiC is considered to date the most probable candidate to substitute Si for power applications. Power saving and zero loss devices is the most relevant task for power devices. Gr can contribute to that either by the fabrication of enhanced devices and circuits in Gr on SiC or by the joint synergy of devices (power) in SiC and devices in Gr (for logic or analog control circuits or even as power supply due to photovoltaic or thermoelectric properties) in the same chip using a smart configuration. Other Gr properties, for example thermoelectric (Gr has the best performance due to the high electron density) can allow to integrate in chips systems to recover the energy dispersed in heat allowing at the same time chip cooling. Sensors in Gr can be easily integrated in SiC electronics for high temperature, harsh environment applications since this interface is formed by a C-monolayer (mC).

Objectives

The EPIGRAPHIC workshop brings together engineers and scientists from around the world to

discuss recent progress and future trends in the rapidly developing science and technology of epitaxial graphene on silicon carbide. The workshop will allow researchers from the two similar Eurographene projects EPIGRAT and RF-Graphic to discuss their results and ideas in detail, which will facilitate future collaborations also after the end of the Eurographene programme. A few top graphene scientists outside the two Eurographene projects will be invited to present their research. The participation of theorists, experimentalists and engineers form industrial R&D teams will aim to facilitate: the understanding of the key features of these systems, the dissemination of the recent research results, and the analysis of possible exploitation of the research outcomes. The main topics that will be discussed are

1) Surface science and growth of EpiGr on SiC;
2) Electronic structure, phonons and electronic transport;
3) Optical properties;
4) Impurities, point and extended defects
5) Role of interface and polytype;
6) Devices and other application
7) Theory and Simulation.

Chairs

Antonino La Magna (Graphic-RF Project Leader)

&

Erik Janzén (EPIGRAT Project leader)

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LOCATION

Diocesan Museum

P.zza Duomo – Via Etnea 8

95124 Catania

CONTACTS

mail: epigraphic@imm.cnr.it

web page: http://epigraphic.imm.cnr.it

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ORAL CONTRIBUTIONS - ABSTRACTS

Tuesday 4 Dec, morning

GRAPHIC-RF Overview

Antonino La Magna

CNR-IMM, Catania, ITALY

EPIGRAT Overview

Erik Janzen

Institutionen för Fysik, Kemi och Biologi – Linköping, SWEDEN

Back gated graphene grown on SiC

Nicolas Camara

Uniformity of epitaxial graphene

J.M.Baranowski
Institute of Electronic Materials Technology, Warsaw, Poland
Faculty of Physics, University of Warsaw, Poland

The uniformity of epitaxial graphene is crucial in view of its future application in electronics. Two ways of obtaining large area epitaxial graphene, grown on metals and on silicon carbide, are presented and discussed. It is argued that both the polycrystalline character and the unavailability of atomically flat substrates lead to a relatively poor quality of epitaxial graphene on metals. On the other hand, epitaxial graphene grown on SiC(0001) is much more uniform. However, the presence of macro-steps on the surface of SiC(0001) proves harmful and is the main obstacle to growing uniform graphene layers. It is shown that epitaxial graphene obtained on terraces and step edges of the SiC(0001) surface has different carrier concentration, which results in electrically non-uniform layers. The role of hydrogen intercalation in improving the uniformity of epitaxial graphene is presented and elaborated on.

Infrared magneto-spectroscopy of grapheme-based systems

*M. Orlita**
Laboratoire National des Champs Magnétiques Intenses
CNRS-UJF-UPS-INSA, Grenoble, France
* E-mail: milan.orlita@lncmi.cnrs.fr

The results of infrared magneto-spectroscopy measurements performed in LNCMI-Grenoble, CNRS, on various graphene-based materials will be reviewed [1]. These systems involve multi- and mono-layers of epitaxial graphene, decoupled graphene flakes on the surface of graphite as well as bulk graphite. The magneto-optical methods, which mostly serve us as a tool of the Landau level spectroscopy, are employed to study the characteristic response due to massless or massive Dirac-type particles and, e.g., to distinguish materials with graphene layers exhibiting the rotational or Bernal stacking. The emphasis will be put on selected recent results, which are related to the following areas: the elastic and inelastic scattering of massless Dirac fermions in multilayer graphene [2,3], the vicinity of the Lifhitz transition at the K point of bulk graphite [4], electron-phonon interaction in epitaxial graphene [5] as well as the electron-electron sensitive Drude weight of massless Dirac particles [6].

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Graphene layers on different SiC polytypes: theoretical study

O. Pankratov , S. Hensel, P. Götzfried, and M. Bockstedte*
University of Erlangen-Nürnberg, Staudtstraße 7 B2, 91058 Erlangen, Germany
* E-mail: Oleg.Pankratov@physik.uni-erlangen.de

Epitaxial graphene grows on different SiC polytypes. To date, most experimental studies are performed on hexagonal 6H and 4H polytypes [1] but also a cubic 3C polytype attracts an increasing attention [2]. Generally, one expects that due to a weak graphene-substrate coupling the influence of a particular polytype on graphene electronic structure is marginal. The similar geometric structure of the surface of various polytypes suggests a similar electronic structure of the graphene-SiC interface and a similar Fermi level pinning mechanism. However, the band structures of the polytypes themselves differ substantially as reflected by a notable band gap variation from 3.33 eV for 2H-SiC to 2.39 for 3C-SiC. This means that the alignment of the graphene Dirac bands with the energy bands of a substrate differs substantially.

In this work, we systematically investigate the influence of polytypes on the graphene electronic spectrum [3]. We employ *ab-initio* density functional theory calculations with local-density approximation (LDA) as well as with the Heyd-Scuseria-Ernzerhof (HSE06) hybrid functional [4] to correct the LDA band gap error. We perform calculations for 2H, 4H, 6H and 3C polytypes and consider different buffer layer - graphene layer stackings on two (Si-terminated and C-terminated) SiC surfaces. We find a systematic variation of the Dirac point position with respect to the valence band edge as a function of the polytype hexagonality. HSE values are in good agreement with recent experimental results, while LDA corroborates the trends. Since the Dirac point, the interface-related electron states, and the Fermi level follow similar polytype-induced shifts the doping of the epilayer stays practically the same for different polytypes. For the *AB* stacked buffer-graphene on a Si-terminated substrate the graphene Dirac spectrum exhibits an energy gap which ranges between 25 meV and 40 meV for different polytypes [3,5]. On the contrary, for the *AA* stacking the Dirac cone remains intact. We suggest a symmetry-based analytical model which explains the origin of the gap and its absence for the *AA* geometry and provides a direct connection between the Dirac cone splitting and the buffer-epilayer interaction potential.

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The effect of graphene layer thickness on environmental gating sensitivity

*R.E.Pearce**(1) J.Eriksson (2), T.Burnett (3), R.Yakimova (2), A.Lloyd Spetz (2), O.Kazakova (1)*
1 National Physical Laboratory, Teddington, London TW11 0WL U.K.
2 Linköping University, Linköping, 58232, Sweden
3 University of Manchester, Manchester, M1 7HS U.K.
* ruth.pearce@npl.co.uk

We demonstrate increasing sensitivitity to environmental gating with decreasing graphene layer thickness. Scanning Kelvin Probe Microscopy (SKPM) enables the identification of areas of epitaxial graphene of different thicknesses and allows measurement of surface potential (SP) whilst changing the gas environment. A significantly larger change in the SP was observed for one layer graphene (1LG) in the presence of electron donating (NH_3) and withdrawing (NO_2) gases than for two layer graphene (2LG) [1]. Moreover, resistance measurements show that a 1LG gas sensor demonstrates a larger change in resistance than a multi layer (MLG) graphene sensor on exposure to NO_2 [2][3]. We calculate that the measured gating sensitivity difference between 1LG and 2LG is not fully accounted for by the difference in density of states, linear for 1LG and parabolic for 2LG.
The adsorption of water vapour is observed to change the SP of 1LG dramatically, whereas the SP of 2LG changes relatively little over a wide range of humidities. We use peak force mapping to show the change in adhesion of graphene domains of different thicknesses and demonstrate that hydrophobicity increases with epitaxial graphene layer thickness. The preferential adsorption of water vapour on 1LG rather than 2LG could explain the relatively small changes in SP observed for 2LG with increasing humidity.
Knowledge of the affinity of environmental asorbates to graphene and the effect they have on graphene's electronic properties is required for producing environmentally stable devices as well as accurate and precisely calibrated environmental sensors. We demonstate a combination of effects leads to the increasing environmental gating sensitivity of graphene with reducing layer number.

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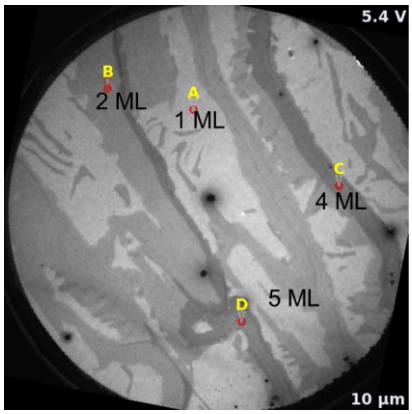
ORAL CONTRIBUTIONS - ABSTRACTS

Tuesday 4 Dec, afternoon

Low-energy electron microscopy study of graphene growth and intercalation on silicon carbide

J. I. Flege (1), A. Meyer (1), C. Virojanadara (2), J. ul Hassan (2), S. Watcharinyanon (2), L. Johansson (2), E. Janzén (2), W. Strupinski (3), J. Falta (1)*
(1) Institute of Solid State Physics, University of Bremen, Bremen, Germany
(2) Department of Physics, Chemistry and Biology, Linköping University, Linköping, Sweden
(3) Institute of Electronic Materials Technology, Warsaw, Poland
* E-mail: flege@ifp.uni-bremen.de

Graphene films on SiC(0001), grown by either sublimation driven processes or chemical vapor deposition (CVD), are promising candidates for applications such as novel electronic or high speed devices. For this purpose, however, the graphene film morphology and its interface structure are crucial as these determine the electronic properties. We have performed low-energy electron microscopy studies using intensity-voltage spectroscopy for the determination of graphene film grain sizes and thickness. The samples were grown by Si sublimation or CVD and after preparation show epitaxial graphene films with thicknesses mainly ranging from 1 to 4 monolayers (ML) within individual graphene islands. An intrinsic problem of these graphene synthesis schemes is the unavoidable presence of a strongly-bonded carbon layer ("zero-layer graphene") at the graphene-substrate interface, which results in disappointing electronic characteristics. Successful lifting of this C layer from the substrate and its conversion to graphene has been demonstrated by means of, e.g., hydrogen and oxygen intercalation [1, 2]. We have studied the effect of H intercalation applied directly after growth inside the growth reactor and find graphene of 2 ML minimum thickness along with the removal of the $6\sqrt{3}x6\sqrt{3}$ reconstruction of the buffer layer, as also evidenced by micro-LEED. In addition to these results, we will present details of the intercalation by the use of Yb [3], which has been studied in situ and is found to be successful as well.



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Quasi-freestanding graphene on SiC(0001) via oxidation in water vapor

M. Ostler (1), F. Fromm (1), R.J. Koch (1), P. Wehrfritz (1), F. Speck (1), H. Vita (2), K. Horn (2), Th. Seyller (1,3)*
(1) Technische Physik, Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
(2) Fritz-Haber-Institut, der Max-Planck-Gesellschaft, Faradayweg 4–6, 14195 Berlin, Germany (3) Institut für Physik, Technische Universität Chemnitz, Reichenhainer Str. 70, 09107 Chemnitz, Germany
* E-mail: markus.ostler@physik.uni-erlangen.de

Epitaxial graphene of high quality can easily be grown in argon on SiC(0001) by thermal decomposition. However, the carrier mobility at room temperature of about 1000 cm^2/Vs is rather poor. Responsible for this low value is the high carrier concentration in the order of 10^{13} cm^{-2} and the strong temperature dependence of the mobility [1]. Both effects can be attributed to the graphene – SiC interface, the so-called buffer layer. A buffer layer free graphene sheet on SiC(0001) can be obtained by intercalating hydrogen in order to passivate the substrate [2]. This decouples the buffer layer and transforms it into graphene. Decoupling the buffer layer can also be accomplished by oxidizing the substrate [3]. However, a closer inspection of the obtained graphene sheet by Raman spectroscopy reveals that an oxygen treatment at elevated temperatures introduces high defect densities [4].
In this contribution, oxidation of the substrate beneath the buffer layer is carried out in a more gentle way by annealing in water vapor. X-ray induced photoelectron spectra (XPS) show the oxidation of the substrate and the decoupling of the buffer layer. The transformation of the buffer layer into graphene is evident from angle-resolved photoelectron spectroscopy (ARPES) and low energy electron microscopy (LEEM). The quality of the decoupled graphene is checked by Raman spectroscopy showing possible defects introduced by the water treatment.

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Interaction of epitaxial graphene with the SiC substrate studied by Raman spectroscopy

K. Grodecki (1,2), 2 R. Bożek (1) A. Wysmołek (1) , A. Drabińska (1), W. Strupiński (2), R. Stępniewski (1) and J. M. Baranowski(1,2)*
1. Institute of Experimental Physics, Faculty of Physics, University of Warsaw, Poland
2. Institute of Electronic Materials Technology, Warsaw, Poland
* E-mail: Andrzej.Wysmolek@fuw.edu.pl

Epitaxial growth of graphene on SiC is one of emerging alternatives to the exfoliation of graphite crystals. The mainstream technology, suitable for a large area fabrication of graphene is based on Si sublimation from SiC. Recently, another graphene growth method, referred to as the chemical vapor deposition (CVD) technique, has been demonstrated. [1] In this presentation the micro-Raman spectroscopy and atomic force microscopy (AFM) results are employed to discuss the influence of the interaction with the SiC substrate on the properties of the layers grown by standard Si sublimation and CVD methods.

Epigraphene layers were grown using a commercial horizontal CVD hot-wall reactor (Aixtron VP508), which is inductively heated with an RF generator. Epitaxial films were deposited on the Si face of semi-insulating on-axis 4 H-SiC(0001) substrate by the CVD and the Si sublimation method. The growth temperature was set at 1600^0C in both cases. Argon gas pressure and flow velocity were used to control both the growth mode and the growth rate. In the case of the CVD growth, propane gas served as the carbon precursor. AFM experiments revealed that irrespective of the growth method, graphene structures formed on 4H-SiC(0001) on-axis substrates show a stepped morphology. Micro-Raman experiments revealed that graphene present on terraces is uniform, and shows relatively small thickness and strain fluctuations. On the other hand, graphene on step edges shows large thickness and strain variations. A careful analysis of micro-Raman spatial maps led us to the conclusion that the carrier concentration on step edge regions is lowered when compared with terrace regions. [2] The measurements of thermal shift rate of 2D line allowed us to determine notable differences in the pinning of graphene with SiC substrate for the sublimated and CVD grown graphene. It is found that graphene layers grown by Si sublimation of 4H-SiC(0001) surface are pinned strongly to the substrate. In contrast, the layers of graphene grown on 4H-SiC(0001) substrates by CVD method showed much weaker pinning.[3] The obtained results are discussed in terms of basic growth mechanism differences between graphene growth by Si sublimation, which is a “bottom-up” process and by CVD - a “top-down” process.

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Electronic transport in epitaxial graphene and at epitaxial graphene/SiC(0001) interface probed at nanoscale

F.Giannazzo (1), I. Deretzis(1), A. La Magna(1), G. Nicotra(1), C. Spinella(1), F.Roccaforte(1), Q.M.Ramasse(2) R.Yakimova (3)*
(1) CNR-IMM, Catania, Italy
(2) SuperSTEM Laboratory, STFC Daresbury Campus, Daresbury WA4 4AD, UK
(3) IFM, Linkoping University, Linkoping, Sweden
* E-mail: filippo.giannazzo@imm.cnr.it

Epitaxial graphene (EG) grown by controlled graphitisation of hexagonal SiC is one of the major candidates for novel graphene-based electronics. The interface with the substrate strongly influences EG electronic properties. As an example, EG grown on a SiC (0001) surface is subjected to a high electron-doping (~10^{13} cm^{-2}) originating from the interfacial C buffer layer with a partially covalent bond to the substrate [1]. As a matter of fact, EG grows on a structured substrate, which exhibits steps or facets with different size and orientations depending on the wafer off-cut angle. Recently, many interesting effects related to the local electronic properties of graphene over these substrate features are emerging, like a local conductance degradation [2] and a reduced carrier density [3] of EG at the nanostep-edges. Furthermore, novel metal-semiconductor-metal nanostructures entirely made from graphene, based on the peculiar interaction between EG and patterned SiC steps, have been envisaged [4].
In this work, the electronic transport in EG grown on SiC (0001) substrates with different miscut angles (on-axis and 8°-off axis) has been investigated both at microscale (on properly designed device structures) and at nanoscale (by scanning probe microscopy) [5,6], focusing in particular on the impact of substrate nanosteps or facets on local graphene conductance. In particular, the results of nanoscale electrical measurements, combined with atomic-resolution structural and spectroscopic characterization techniques (i.e. scanning transmission electron microscopy (STEM) and electron energy loss spectroscopy (EELS)) shed light into the properties of EG over the steps of off-axis silicon carbide (0001) substrates. The STEM analysis, obtained at an energy below the knock-on threshold for the C atoms, evidences that the buffer layer present on the planar (0001) face gets detached from the substrate on the (11-2n) facets of the steps, turning into a quasi-freestanding graphene film. Simultaneously, high energy resolution atomic scanned EELS reveals that this layer has the same electronic configuration as a purely sp^2-hybridized graphene layer. This aspect fully explains the observed local increase of EG resistance over SiC facets, due to a significantly lower substrate-induced doping.

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Silicon nitride as top gate dielectric for epitaxial graphene

P. Wehrfritz (1), F. Fromm (1), S. Malzer (2), Th. Seyller (1,3)*
(1) FAU Erlangen, Technische Physik, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany
(2) FAU Erlangen, Angewandte Physik, Staudtstr. 7, 91058 Erlangen, Germany
(3) TU Chemnitz, Institut für Physik, Reichenhainer Straße 70, 09126 Chemnitz, Germany
*E-mail: peter.wehrfritz@fau.de

Epitaxial graphene grown under atmospheric pressure offers an opportunity for large scale electronic device fabrication [1]. A suitable top gate dielectric, however, is still to be found. Most research is done on Al_2O_3 and HfO_2 grown by atomic layer deposition, which provides high quality dielectrics. Unfortunately, the films formed directly on pristine graphene are not closed due to poor adhesion of the precursors on graphene. This can be circumvented by modifying the surface with ozone or by thermally depositing a seed layer at the cost of damaging the graphene or degrading the electronic properties of the insulating layer [2-3].
We have investigated silicon nitride (SiN) grown by plasma enhanced chemical vapor deposition (PECVD) as top gate material on epitaxial graphene on 6H-SiC(0001). The NH_3 and SiH_4 flow rate ratio was optimized on the basis of x-ray photoelectron spectroscopy (XPS) measurements. The formed SiN layer is closed and has a RMS roughness of around 1 nm measured by the means of atomic force microscopy (AFM). Raman spectroscopy and transport measurements which were performed before and after the SiN deposition revealed that the plasma process leads only to a minor degradation of the graphene. The SiN layer induces strong n-type doping proven by Hall measurements, transfer characteristic and XPS measurements. For a limited gate voltage range the neutrality point was reached and the transfer characteristic was reproducible with a small hysteresis of 0.2 V.

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ORAL CONTRIBUTIONS - ABSTRACTS

Wednesday 5 Dec, morning

Resonant modes in strain-induced graphene superlattices

F. M. D. Pellegrino (1,2), G. G. N. Angilella (1,2,3,4), R. Pucci (1,2)*
(1) Dipartimento di Fisica e Astronomia, Università di Catania, Via S. Sofia, 64, I-95123 Catania, Italy. (2) CNISM, UdR Catania, Italy. (3) Scuola Superiore di Catania, Università di Catania, Via Valdisavoia, 9, I-95123 Catania, Italy. (4) INFN, Sez. Catania, Italy(es)
* E-mail: giuseppe.angilella@ct.infn.it

After reviewing electronic transport across a strained graphene sheet [1,2], we consider tunneling across a strain-induced superlattice in graphene. In studying the effect of applied strain on the low-lying Dirac-like spectrum, both a shift of the Dirac points in reciprocal space, and a deformation of the Dirac cones is explicitly considered. The latter corresponds to an anisotropic, possibly non-uniform, Fermi velocity. Along with the modes with unit transmission usually found across a single barrier, we analytically find additional resonant modes when considering a periodic structure of several strain-induced barriers. We also study the band-like spectrum of bound states, as a function of conserved energy and transverse momentum [3]. Such a strain-induced superlattice may thus effectively work as a mode filter for transport in graphene.

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Structured epitaxial graphene on SiC

Claire Berger (1, 2), Ming Ruan (2), Yike Hu (2), John Hankinson (2), James Palmer (2), Zelei Guo (2), Rui Dong (2), Jan Kunc (2), Walt A. de Heer (2)*
(1) CNRS – Institut Néel, Grenoble, France
(2) Georgia Institute of Technology, School of Physics, Atlanta, USA
* E-mail: claire.berger@physics.gatech.edu

Epitaxial graphene's importance as a new electronic material, is now being recognized. Epitaxial graphene is being developed on single crystal SiC for the same reason Silicon electronics is based on single crystal substrate, that is to allows reliable patterning on the nanoscale. We have developed a technique [1-4] to directly grow graphene nanoribbons at high temperature. This nanopattened graphene is produced by etching the silicon carbide before annealing, so that the graphene structures are produced in their final shapes on the SiC substrate sidewall. This avoids post-annealing patterning that is known to greatly affect transport properties on the nanoscale. We present new results on structured graphene that is an elegant method to avoid pervasive patterning problems.

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Homogeneous, High-Quality Epitaxial Graphene Grown on SiC(0001) using Infrared Lasers

S. N. Yannopoulos (1),(2), A. Siokou(1), N. K. Nasikas (1), V. Dracopoulos (1), F. Ravani (1), N. Bouropoulos (1), (2), and G. N. Papatheodorou (1)*
(1) Foundation for Research and Technology – Hellas, Institute of Chemical Engineering Sciences, (FORTH/ICE–HT), P.O. Box 1414, GR-26504, Rio-Patras, Greece
(2) Department of Materials Science, University of Patras, GR-26504, Rio-Patras, Greece
sny@iceht.forth.gr

One of the most promising methods for large area, high quality graphene production is the thermal decomposition of SiC, which leads to the growth of epitaxial graphene (EG). The predominant approach used to obtain EG on SiC is thermal annealing of SiC wafers (at T>1500 K) either in high vacuum or under controlled Ar atmosphere [1]. Few works have appeared so far aimed at fabricating graphene using focused laser beams, resulting in graphene with poor quality. In the current work, we present a novel facile method for the single-step, fast production of large area, homogeneous EG on SiC(0001) using a continuous wave infrared CO_2 laser (10.6 μm) as a heating source [2]. The process does not require high vacuum or strict sample-chamber conditions; it takes place under Ar gas flow at atmospheric pressure and temperature. Scalability of this method to industrial level of this method appears to be realistic, in view of the high rate of CO_2-laser induced graphene growth, the lack of strict sample–environment conditions, and the possibility for *in situ* patterning. The characteristics of few layer EG on SiC are studied by SEM, XPS, and Raman scattering. Finally, preliminary results will be presented on the fabrication of spherical, multi-shell graphene-like structures fabricated by illumination of SiC with pulsed near-infrared lasers. Details about the decoration of such graphene-like nanostructures with Si nanocrystals (3-4 nm size), during the SiC decomposition, will be discussed.

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Molecular Doping of Epitaxial Graphene on SiC with flouro-fullerenes

M. Wanke (1,2), A. Tadich (3), M.T. Edmonds (4), Y. Smets (4), C.B. Stark, C.I. Pakes (4), and Th. Seyller (1,2)*

(1) Institut für Physik, Technische Universität Chemnitz, Reichenhainer Str.70, 09126 Chemnitz, Germany

(2) Lehrstuhl für Technische Physik, Friedrich-Alexander-Universität Erlangen, Erwin-Rommel-Str.1, 91058 Erlangen, Germany

(3) Soft-XRay-Beamline, Australian Synchrotron, 800 Blackburn Rd, Clayton, VIC 3168, Australia

(4) School of Physics, La Trobe University, Physical Sciences1, Bundoora, VIC 3086, Australia

* E-mail: martina.wanke@physik.tu-chemnitz.de

Epitaxial graphene on SiC(0001) is known to have a strong intrinsic n-type doping [1] which is detrimental for the charge carrier mobility [2]. Charge transfer doping with F4TCNQ has been demonstrated to reduce the carrier concentration [2-4] and increase carrier mobility [2] but the stability of the molecular layer is still debatable. In our investigations we used the effect of surface transfer doping with fluorinated fullerenes on epitaxial graphene and quasi-freestanding graphene. The mechanism of transfer doping using C60F48 on diamond is well characterized and understood [5, 6]. C60F48 molecules have a sufficiently high electron affinity to show a surface transfer doping effect on graphene.

The molecular doping was studied with fluoro-fullerenes deposited onto epitaxial graphene using angular-resolved photoemission spectroscopy. The doping level of graphene was observed by the direct measurement of the Dirac point and its position relative to the Femi level, with the amount of doping determined from the Fermi surface [4, 7]. In the experiments charge neutral epitaxial graphene could be obtained and a reduction in the charge-carrier density was achieved. For higher coverages of the fluorinated fullerenes a net p-type doping could be achieved.

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Progress in graphene growth on cubic SiC

R.Yakimova, G.R.Yazdi, T.Iakimov, J. Eriksson, V. Darakchieva*
Linkoping University, IFM, SE-58183 Linköping, Sweden
* E-mail: roy@ifm.liu.se

The hexagonal structure of 4H- and 6H-SiC is a natural substrate for graphene on which it can grow epitaxially due to the formation of a C rich buffer layer. However in such graphene strong charge transfer can exist resulting in a high level of doping. The anisotropic crystallography of cubic SiC does not assume internal polarization and thus graphene with lower charge carrier concentration is expected. Another advantage of using 3C-SiC as a substrate for graphene is the absence of energetically driven step bunching.

In this talk we are going to discuss some main features of epitaxial graphene produced by high temperature sublimation [1]. We will show surface morphology and thickness uniformity of graphene grown on 3C-SiC (111) in comparison with hexagonal polytypes of similar orientation. The effect of the substrate surface restructuring on topology and doping will be illustrated [2]. Mapping of thickness and carrier scattering time by spectroscopic ellipsometry will demonstrate not only the material quality but also the capability of this technique for large scale characterization. Finally we will present recent results of graphene growth on 3C-SiC (001) confirming the hypothesis of buffer free material.

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Epitaxial graphene quality dependence on hydrogen etching of silicon carbide (0001) substrate

R.J.Buda (1), L.Pietrobon (2) and C.H.Marrows (1)*
(1) School of Physics and Astronomy, University of Leeds, LS2 9JT Leeds, United Kingdom
(2) CIC nanoGUNE Consolider, Tolosa Hiribidea, 76 E-20018 Donostia-San Sebastián Spain
* pyrjb@leeds.ac.uk

Among methods of growing graphene, confinement controlled sublimation of silicon carbide seems to be one of the most promising. With this method it is possible to obtain high quality, large area graphene [1,2]. However, apart from growth conditions, preparation of the substrate plays an important role in the growth process. Previous studies suggest a close relationship between hydrogen etching and properties of graphene on the C-terminated face of SiC [3]. In this study, we show the relationship between the quality of grown graphene on the Si-terminated face of SiC and the pretreatment of the substrate. We used three types of sample preparation to study the relationship between substrate treatment and graphene quality, namely etching in 85% Ar – 15% H2 atmosphere at 1500°C for 20 min, followed directly by annealing at 1690°C; etching in 85% Ar – 15% H2 atmosphere at 1500°C for 20 min, followed by cooling the samples down to 1000°C and annealing at 1690°C; simple annealing at 1690°C without the etching step.
After growth, samples were examined with atomic force microscopy, Raman spectroscopy and scanning electron microscopy in order to check the quality of grown material.
Substrates prepared using hydrogen etching resulted in better-quality graphene, and the improvement over unetched substrates was greater when there was no cooling step between etch and anneal.

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ORAL CONTRIBUTIONS - ABSTRACTS

Wednesday 5 Dec, afternoon

An analysis of electron transport in as-Grown and H-Intercalated epi-graphenes on SiC

M. Winters, N. Rorsman, H. Zirath
Chalmers Microwave Electronics Group: MC2
Kemiv□agen 9 412 58 G□oteborg, Sweden
micwinte@chalmers.se

Here is presented an essential overview of our research e_orts on graphene. Measurements and data analysis have been directed speci_cally with respect to the assessment of as-Grown and H-intercalated epi-graphene for use in high frequency electronics applications. Central to such assessment is the survey of the physical and electronic properties of both materials.
The work begins with an introductory uniformity study.[1] Hall measurements are taken on 100_mx100_m Van der Pauw structures in order to extract the Hall mobility, sheet carrier density, and sheet resistance. This data is used to comment on material uniformity and to develop an empirical relationship between sheet carrier density and sheet resistance. It is generally observed that Hall mobility for both materials is in the range of 1000cm2=(V _ s) with peak measured mobility reaching 1400cm2=(V _ s). However, signi_cant non-uniformity is observed in the measured mobility from structure to structure on both materials. Co-planar TLM structures also fabricated on both materials in order to evaluate the contact resistance. The contact resistance is measured to be 1:1 _ mm and 1:4 _ mm for both as-grown and H-intercalated materials respectively.
Lastly, dynamic IV measurements are performed on 10_mx10_m and 5_mx100_m microbridge structures.[2] Dynamic IV measurements are used to investigate material trapping e_ects and electron saturation velocity. It is observed that as-grown material has demonstrably more trapping and memory e_ects than H-intercalated material. Both materials though present strong non-linearity in their dynamic IV characteristics. Lastly, dynamic IV measurements are used to obtain the base IV relationship for both materials. When this is combined with TLM data, and Hall data, a velocity _eld model can be extracted. The measured electron velocity is in the range on 1:4_107cm=s in as-grown material and 2:6_107cm=s in the H-intercalated material. This discrepancy in electron velocity seems to indicate the e_cacy of H-intercalation process. The H-intercalation process tends to isolate the graphene layer from the SiC substrate thus reducing trapping e_ects and increasing carrier velocity. [3] These cited values are preliminary. Additional statistical studies are needed to con_rm these values within a margin of error.

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Graphene Growth on SiC for High-Frequency Devices

*J. Hassan** , *I. Ivanov, E. Janzén*
Department of Physics, Chemistry and Biology, IFM
Linköping University, Sweden
* E-mail: jawul@ifm.liu.se

Semi-insulating (SI) SiC is a natural choice of substrate for graphene-based high-frequency field effect transistors. Si-face of SiC is generally preferred for graphene growth due to easy control of graphene thickness. However, high temperature processes involved in graphene growth lead to surface step-bunching and defect-selective etching, native to the Si-face of SiC, and severely degrade the surface. A higher thermal evaporation rate of Si around dislocations, intersecting the surface, and surface steps leads to the nucleation of multiple graphene layers and limits the graphene thickness uniformity. The native properties of graphene are directly related to its thickness and uniformity [1]; therefore, a better control of graphene thickness uniformity is important to realize its potential in high-speed electronic devices.

We will present the surface step evolution of Si-face of SiC during graphene growth on as-received and in-situ etched substrates and comparison of the quality of graphene. The main focus has been to reduce surface degradation using different approaches including graphene growth under different ambient conditions and to achieve either only the carbon buffer layer or the buffer layer and a monolayer graphene with uniform surface morphology over large area. The uniformity and the quality of the graphene samples are estimated using micro-Raman mapping technique. Conversion of buffer layer into monolayer graphene through hydrogen intercalation, as confirmed by the Raman spectra and boosted mobility, will also be presented. The graphene growth and hydrogen intercalation processes are further optimized to enhance the charge carrier mobility, one of the most important parameters for high-frequency electronic devices. Charge carrier mobility – measured with contactless micro-wave reflectivity – and micro-Raman spectroscopy were used as feedback to optimize the graphene growth process.

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Selected electronic properties of graphene on SiC

R. Stępniewski,
Institute of Experimental Physics, Faculty of Physics, University of Warsaw,
Hoża 69, 00-681 Warsaw, Poland
* E-mail: Roman.Stepniewski@fuw.edu.pl

The selected electronic properties of graphene grown on SiC substrates will be presented.
The results obtained in far infrared spectroscopy, magnetotransport and EPR, obtained on graphene layers grown on Si and C terminated surfaces of SiC will be shown. The role of the surface polarity and morphology, as well as intra-layer interactions on electronic properties of graphene will be discussed.

The contribution of the buffer layer to the Raman spectrum of epitaxial graphene on SiC(0001)

F.Fromm (1), M.H. Oliveira Jr. (2) A. Molina-Sánchez (3, 4), M. Hundhausen (1), J. M. J. Lopes (2), H. Riechert (2), L. Wirtz (3, 4) and Th. Seyller (1, 5)*

(1) Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Erwin-Rommel-Str. 1, 91058 Erlangen, Germany

(2) Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

(3) Physics and Material Sciences Research Unit, University of Luxembourg, Campus Limpertsberg, L-1511 Luxembourg

(4) Institute for Electronics, Microelectronics, and Nanotechnology (IEMN), CNRS UMR 8520, Dept. ISEN, 59652 Villeneuve d'Ascq Cedex, France

(5) Institut für Physik, Technische Universität Chemnitz, Reichenhainer Str. 70, 09126 Chemnitz, Germany

* E-mail: felix.fromm@physik.uni-erlangen.de

The unique electronic properties of graphene suggest its application in electronic devices. For this purpose, a controllable growth of high-quality graphene on a wafer scale is required, which can be accomplished by epitaxial growth on SiC [1]. Raman spectroscopy is intensively used for the characterization of graphene, e.g. this technique is extremely useful in order to indentify the growth of monolayer graphene up to few layer graphene [2] and provides information about the structural quality [3], which is a crucial point concerning electronic applications [4].

We report on a Raman study of the so-called buffer layer [5] with $(6\sqrt{3}\times6\sqrt{3})R30°$ periodicity which forms the intrinsic interface structure between epitaxial graphene and SiC(0001). Raman spectra of buffer layer samples, epitaxial monolayer graphene (MLG) and buffer layer free monolayer graphene on SiC obtained by hydrogen intercalation (QFMLG) [6, 7] were analyzed. Whereas the Raman spectrum of QFMLG shows symmetric D- and G-lines, the spectrum of MLG shows additional broad features in the range of the D- and G-band. These broad signals are also observed in the Raman spectrum of the buffer layer itself. Therefore, we conclude that the buffer layer leads to a non-vanishing signal in the Raman spectrum at frequencies in the range of the D- and G-band of graphene. Ab-*initio* calculations of the phonons of the buffer layer reveal that these features can be traced back to the vibrational density of states.

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Suppression of quantum coherence in graphene by THz radiation

V. Eless[1,3], S. Kubatkin[2], T. Yager[2],
A. Tzalenchuk[3], R. Yakimova[4], S. Spasov[1], and V. Antonov[1]
[1]Physics Department of Royal Holloway University of London, [2] Department of Microtechnology and Nanoscience (MC2), Chalmers University of Technology,S-41296, Göteborg, Sweden, [3]National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, United Kingdom, [4]Linköping University, S-581 83, Linköping, Sweden
[*] E-mail: viktoria.eless@npl.co.uk

We present a study of the microwave suppression of weak localisation in graphene [1,3]. Weak localisation manifests itself as increased resistance seen at low temperatures. The electrons can trace closed paths due to elastic scattering, which are phase coherent and result in constructive interference, and therefore increased resistance.

EM radiation in the GHz frequency range can cause dephasing in this process either directly by introducing arbitrary phase shifts to the closed paths or indirectly by heating of the electron system, which leads to the suppression of weak localisation. Other factors that can cause suppression of the weak localisation are magnetic field and temperature.

A magnetic field causes the same localised path travelled by an electron in one direction to become inequivalent to travelling it in the opposite direction. Increasing the temperature also suppresses weak localisation by preventing closed paths from forming.

Using magnetic field and temperature as variable parameters allows us to deduce the nature of the effect of microwaves on weak localization. We suppress the weak localization by magnetic field and access the heating effect of the microwave radiation. Comparing the amplitude of the weak localisation at a particular temperature with the value at the same microwave-induced effective temperature we found that there was no additional effect due to microwaves i.e. the weak localization suppression is only bolometric. We observe the effect at the different frequencies spanning three orders of magnitude from two hundred MHz to two hundred GHz. This finding is in contrast to the suppression of weak localisation by microwaves seen in conventional 2DEGS where dynamic dephasing plays an important role [3].

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ORAL CONTRIBUTIONS - ABSTRACTS

Thursday 6 Dec, morning

Processing of graphene as HEMT: characterization, FIB-processing and optimization

T. Aschenbrenner, H. Kröncke, J. Ebeling, and D. Hommel*
University of Bremen – Institute of Solid State Physics – Semiconductor Epitaxy
Otto-Hahn-Allee NW1 – 28359 Bremen
* E-mail: tasche@ifp.uni-bremen.de

Since A. Geim and K. Novoselov made their groundbreaking experiments, graphene was considered as an exclusive domain of condensed-matter physicis regarding fundamental research. Within the last years, this picture changed to graphene being explored for electron-device application. Graphene-based transistors have developed rapidly and are now considered as an option for post-silicon electronics [1].
Using graphene as a high electron mobility transistor (HEMT) is one goal of the ongoing research activities in the working group of Prof. Hommel. The approach presented during this meeting is based on standard lithography techniques which are combined with a complex micro-processing sequence using a FEI Nova NanoLab200 dualbeam system (SEM: secondary electron microscope and FIB: focused ion beam). Besides the ion-milling it is possible to deposit materials such as platinum, gold and SiO2 on a nanometer scale using the maximum resolution of the system. In a first step the macroscopic processing is carried out by optical lithography followed by large scale dry etching and the deposition of macroscopic metal contacts. Thereafter, the remaining graphene is structured using the focused ion beam. The gate contact consist of two layers, SiO2 as insulator and platinum as contact electrode. For source and drain both gold and platinum were used as contact material. One challenge is directly correlated with this nano deposition in the dualbeam system. If the deposition is directly carried out using the ion-beam, graphene could be considerably damage during the process. Therefore, a two-step deposition sequence is applied using both the electron- and the ion-beam.
All samples are analyzed using SEM in comparison to LEEM experiments (carried out by the working group of Prof. Falta) for the surface characterization and the monitoring of the structuring process. Additionally, the electronic properties of these structures are investigated by e.g. current-voltage measurements.

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Tuning the Bands in Epitaxial Graphene on SiC:
Intercalation, Doping and Mini-Dirac Cones

*Ulrich Starke**
Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1,
D-70569 Stuttgart, Germany
* E-mail: u.starke@fkf.mpg.de

Large area epitaxial graphene can be grown on SiC(0001) by heating in Ar atmosphere [1]. However, the graphene layers are *n* doped due to the influence of a covalently bonded carbon interface layer. This influence can be completely eliminated by atomic intercalation. Hydrogen for example migrates under the interface layer, passivates the underlying SiC layer and decouples the graphene from the substrate [2]. The interface layer alone transforms into a quasi-free standing monolayer while monolayers and bilayers turn into decoupled bilayers and trilayers [3,4]. As a result, charge neutral quasi-free standing graphene layers can be obtained. By intercalation of Germanium the graphene layers can also be decoupled. In this process both *p* and *n* doping can be produced, depending on the amount of Ge material intercalated. Both phases can be prepared in coexistence on the surface. In this way, lateral *p-n* junctions can be obtained on a mesoscopic scale [5]. Intercalation of Cu induces a coincidence superstructure on top of the SiC surface, which originates from periodic regions of different bond configuration for the carbon atoms in the graphene layer. As a result, a long range periodic potential is imposed onto the graphene layer, which leads to a profound modification of its electronic spectrum. A surprisingly strong doping and the development of mini-Dirac cones are observed [6]. Detailed investigations of the □-band structure, the spatial arrangement, chemical bonding and local surface order are shown based on angle-resolved photoemission spectroscopy (ARPES), low-energy electron microscopy (LEEM), x-ray photoelectron spectroscopy (XPS), low-energy electron diffraction (LEED) and scanning tunneling microscopy (STM) experiments.

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Quasi-free standing graphene o SiC – fabrication and properties

Th. Seyller
TU Chemnitz, Institut für Physik, Reichenhainer Str. 70, 09126 Chemnitz, Germany
thomas.seyller@physik.tu-chemnitz.de

The growth of epitaxial graphene (EG) on the surfaces of silicon carbide (SiC) is considered to be one of the most promising techniques for the synthesis if large-area graphene and considerable progress has been made in the past in improving the homogeneity and structural integrity of the EG films. Nevertheless, the charge carrier mobility is still far behind what can be achieved for graphene on other substrates such as SiO_2. In particular, the charge carrier mobility in EG on SiC(0001) was shown to have a strong temperature dependence. Such an unexpected behavior must be caused by the substrate and/or the interface. It is therefore interesting to manipulate the interface. The possibility of manipulating the interface by intercalation of atoms such as hydrogen, fluorine, or oxygen [1-3] has been demonstrated recently. In my talk I will present results from intercalation of hydrogen and oxygen. Hydrogen intercalation can be used to prepare quasi-freestanding monolayer graphene on SiC(0001) [4] with almost temperature-independent charge carrier mobility. Oxygen intercalation in air [5] was recently observed to lead to high-quality bilayer graphene.

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Localisation and van Hove singularities in the graphene twist bilayer

*S. Shallcross**(1), S. Sharma (2), O. Pankratov (1)*
(1) Lehrstuhl fur Theoretische Festkorperphysik, Staudstr. 7-B2, 91058 Erlangen, Germany.
(2) Max-Planck-Institut fur Mikrostrukturphysik, Weinberg 2, D-06120 Halle, Germany.
* E-mail: phsss@ssh.tfkp.physik.uni-erlangen.de

The low energy excitations of a single graphene layer are governed by an effective Dirac-Weyl equation that describes massless particles, from which follows a host of novel material properties e.g. Klein tunneling, a novel chiral integer quantum Hall effect, and the suppression of back scattering, to name only a few. Low dimensional graphene based systems, such as the graphene bilayer, offer the possibility to explore the electronic properties of systems closely related to graphene, but nevertheless distinct in important ways. In this seminar I will focus on one of the most interesting of these, the graphene twist bilayer. This system consists of two mutually rotated graphene layers, and the electronic properties depend strongly on the value of the rotation angle [1,2,3]. While at large angles the two layers electronically decouple [1], reducing the rotation angle leads to an increasing number of high and low energy Van Hove singularities and an increasing localization of electrons at all energies [4].

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Tailoring the graphene/silicon carbide interface for monolithic wafer-scale electronics

S.Hertel (1) , D.Waldmann (1) , J.Jobst (1) , A.Albert (1) , M.Albrecht (1) , S.Reshanov (2) , A.Schöner (2) , M.Krieger (1) , H.B.Weber (1)*
(1) Chair for Applied Physics, Friedrich-Alexander University Erlangen-Nuremberg, Staudtstr. 7, 91058 Erlangen, Germany.
(2) ACREO AB, Electrum 236, Isafjordsgatan 22, 16440 Kista, Sweden.
* E-mail: Stefan.Hertel@physik.uni-erlangen.de

The vision of graphene as future material for electronic devices is derived from impressive material parameters. However, it is evident that graphene will not readily take over the role of a semiconductor. In particular, an efficient switch is lacking due to graphene's missing bandgap [1].
By focusing not only on the graphene layer, but considering the silicon carbide (SiC) substrate as an essential part of the system, we developed an easy scheme to fabricate transistors with high ON/OFF ratio – suited for logic – by tailoring the interface between SiC and the graphene layer [2]. Therefore we currently work with two graphene materials on SiC: as grown monolayer graphene (MLG) [3] and hydrogen intercalated quasi-freestanding bilayer graphene (QFBLG) [4]. We proved the high-quality ohmic contact of MLG to n-type SiC and also characterized the Schottky-like behavior of QFBLG.
Using these components we are currently able to demonstrate transistors with ON/OFF ratios exceeding 10^4 at room temperature in normally-on and normally-off operation mode. We present a concept for inverters using a resistor-transistor logic scheme.
Future work will focus on improving the single transistors away from the current proof-of-principal design in order to check for the concepts' full power. We will use this to explore the envisaged high-frequency and high-temperature capabilities of our devices and built up more complex logic circuits.

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CVD of graphene on SiC

W.Strupinski(1), K.Grodecki(1,2), R.Bozek(2), A.Meyer(3), J.I.Flege(3), A.Wysmolel(2), R.Stepniewski(2) and J.M.Baranowski(1)*

(1)*Institute of Electronic Materials Technology, Warsaw, 01-919, Poland; (2)Faculty of Physics, University of Warsaw, Hoza 69, 00-681 Warsaw, Poland; (3)Institute of Solid State Physics, University of Bremen Otto-Hahn-Allee 1, 28359 Bremen, Germany*

* E-mail: wlodek.strupinski@itme.edu.pl

Graphene deposited on a SiC has great potential for electronics applications, however, a major factor hindering the development of technology for the large-scale production of graphene-based nano-electronic devices is the lack of access to high-quality uniform graphene layers grown on large SiC substrates.

In this paper we report the further development of the chemical vapor deposition of graphene on SiC substrates which relies critically on the creation of dynamic flow conditions in the reactor that simultaneously stop Si sublimation and enable the mass transport of propane to the SiC substrate. The growth mechanism is discussed and the hydrogen intercalation results are presented. To prove high quality of CVD graphene different characterization methods were applied. The graphene growth in vicinity of atomic step edges was analyzed in details by STM, KFPM, LEEM, micro-Raman spectroscopy and transmission electron microscopy (TEM) in comparison to the samples obtained by sublimation technique. The transport parameters of graphene deposited on Si terminated SiC were measured with the van der Pauw method and microwave resonance technique at room temperature. The electron density was typically $1x10^{13}$ cm^{-2}, with a macroscopically averaged electron mobility inferred from Hall voltage in the range 3500 cm^2/Vs, demonstrating the high electronic quality of the CVD graphene layers on the wafer scale. Micro-Raman studies on step edges influence were performed for graphene grown by sublimation and CVD processes.

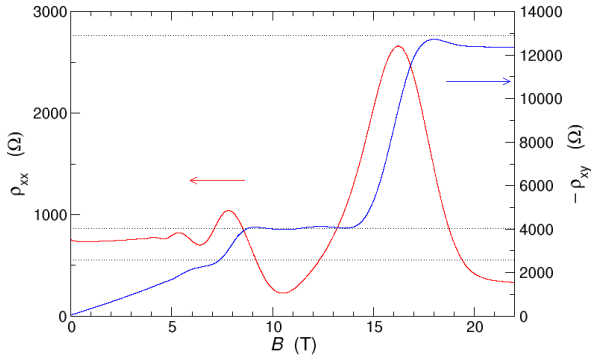
ORAL CONTRIBUTIONS - ABSTRACTS

Thursday 6 Dec, afternoon

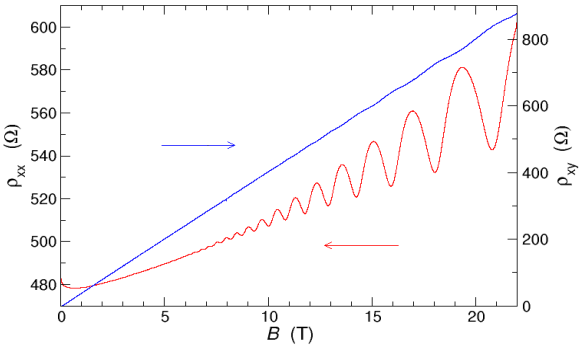
Weakly and heavily doped graphene on silicon side of SiC

V. Jurka, P. Svoboda, P. Vašek, L. Smrčka [*] *(1), Jawad-ul-Hassan, E. Janzèn (2),D. K. Maude(3)*
(1) Institute of Physics ASCR v.v.i., Prague, Czech Republic, (2) Linköping University, Sweden, (3) LNCMI CNRS, Grenoble, France
E-mail:smrcka@fzu.cz

The magnetotransport properties of as-grown and hydrogenated graphene layers on silicon side of SiC has been investigated. We have found that hydrogenation converts a weakly doped two-dimensional layer of Dirac electrons into a heavily doped layer of Dirac holes, as witnessed by the Hall-effect sign reversal. The samples studied were prepared at Linköping University, Sweden. Two sets of graphene samples were grown under the same conditions; one set was left as-grown while the other set of samples was intercalated with hydrogen. The growth process was optimized to obtain 1-2 layers of graphene at relatively low temperature of 1400ºC under vacuum level of 5×10^{-6} mbar for 1 hour. Ultra high purity hydrogen was used for intercalation of graphene layers at 700 ºC for 1 hour under hydrogen background pressure of 500 mbar and samples were cooled down without exposing to air.



Longitudinal (red) and Hall (blue) magneto-resistances measured on as-grown sample



Longitudinal (red) and Hall (blue) magneto-resistances measured on hydrogenated sample

The negative sign of the Hall voltage of as-grown sample indicates the presence of electrons in the layer. The Hall plateaux are close to those predicted for a *single layer* of Dirac fermions. The concentration determined from low-field Hall effect is $N_H = 1.9 \times 10^{12}$ cm^{-2}. The positive sign of the Hall voltage of sample with intercalated hydrogen and the phase of observed Shubnikov de Haas (SdH) oscillations are typical for a *single layer* of Dirac holes. The high Hall concentration of carriers, $N_H = 1.5 \times 10^{13}$ cm^{-2}, agrees well with SdH concentration, $N_{SdH} = 1.3 \times 10^{13}$ cm^{-2}, determined from the period of SdH oscillations.

GRAPHENE ON C-FACE SiC

L.I. Johansson (1), J. Hassan (1), C. Xia (1), A.A. Zakharov (2), S. Watcharinyanon (1), E. Janzén (1), R. Yakimova (1) and C. Virojanadara (1)*

(1) Department of Physics, Chemistry and Biology, Linkoping University, SE-58183 Linkoping, Sweden

(2) MAX-lab, Lund University, SE 22100 Lund, Sweden

* E-mail: chavi@ifm.liu.se

Graphene grown on Si- or C- face SiC by thermal sublimation of Si atoms is considered a most promising route to obtain homogeneous large area graphene sheets on a semi-insulating substrate. There is a general consensus concerning the experimental findings for graphene on Si-face SiC. However, this is not the case for graphene grown on the C-face SiC surface. Whereas Si-face graphene exhibits sharp spots in LEED and the Bernal stacking, multilayer graphene on the C-face has been reported to stack in such a way that adjacent graphene layers are rotated with respect to each other. This rotational disorder was suggested to explain why multilayer graphene show single layer electronic properties, i.e. a single π-band [1-3]. We recently prepared graphene in a furnace at higher temperatures [4], 1800-2000°C, than commonly utilized earlier for C-face SiC. We found formation of µm sized crystallographic domains, which exhibited sharp (1x1) spots in µ-LEED and six Dirac cones in the Brillouin zone in recorded photoelectron angular distribution patterns. Adjacent domains showed different azimuthal orientations so macro-LEED patterns mimicked earlier published ring-like LEED patterns. Our findings clearly showed that within a domain adjacent layers are not rotationally disordered. Therefore we prepared graphene samples on C-face SiC at 1400-1600°C, i.e. at temperatures utilized by other groups, and investigated them using LEEM, XPEEM, XPS and ARPES. Also these showed the presence of µm sized crystallographic domains of few layers well ordered graphene. Effects of Na exposures on the electron band structure of C-face graphene were also studied using ARPES. These results will be presented and discussed in view of earlier findings.

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Magneto-optical studies and applications of monolayer and multilayer epitaxial graphene

I. Crassee (1), N.Ubrig (1), J. Levallois (1), D. van derMarel (1), M. Orlita (2), M. Potemski (2), A.L. Walter (3), E. Rotenberg (3) M. Ostler (4), F. Fromm (4) T. Seyller (4),
A.B.Kuzmenko (1)*
(1) University of Geneva, Switzerland
(2) Grenoble High Magnetic Field Laboratory, France
(3) Advanced Light Source, Berkeley, USA
(4) University of Erlangen-Nuremberg, Germany
* E-mail: A.B.Kuzmenko@unige.ch

Magneto-optical spectroscopy is a powerful technique in graphene research, by the virtue of probing buried atomic layers and interfaces, inaccessible by photoemission and tunneling spectroscopy, an extremely broad spectral range and a selective excitation of electrons and holes. We studied extensively various types of mono- and multilayer epitaxial graphene grown on different faces of SiC using the magneto-optical THz and infrared absorption and Faraday rotation.

In highly doped monolayer graphene grown on Si face we observe a strong Drude peak, which transforms into a field-linear classical cyclotron resonance at finite magnetic fields. Interestingly, this gives rise to a giant Faraday rotation [1] with an unparalleled value of the effective Verdet constant, making graphene promising for magneto-optical applications. In this type of graphene we also found an unexpectedly strong terahertz plasmonic absorption [2] due to the terrace steps in SiC. When a field is applied, the plasmon peak splits in two modes, which is a hallmark of the magnetoplasmon physics found earlier in 2D electron gases in semiconductors. The presence of terrace steps blueshifts the useful spectral range with a large Faraday rotation, which may provide new ways of controlling magneto-optical effects graphene.

In quasineutral twisted multilayer graphene on the C-face of silicon carbide, we observe transitions between Landau levels with a typical square-root like dependence on the magnetic field, in agreement with previous studies [3]. However, the effective number of graphene layers giving rise to these transitions, as estimated from the optical intensity, is several times smaller than the actual number of layers [4], and moreover depends on the field. This implies that not all quasineutral graphene planes contribute equally to the optical response and that they cannot be simply regarded as a collection of independent monolayers. The presence of different Fermi velocity even in the same sample is found [1,4], which we attribute to random twist angles.

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Biosensors with metal oxides/reduced graphene oxide nanocomposites

N. Donato, D. Aloisio, E. Patti, M. Latino, S. G. Leonardi, G. Neri*
Dept. of Electronic Engineering, Chemistry and Industrial Engineering, University of Messina, Italy
* ndonato@unime.it

Carbon nanomaterials exhibit substantial advantages for electrochemical sensing by providing shorter effective lengths for both electronic and ionic transport and a higher electrode/electrolyte contact area. Graphene, as a two dimensional (2D) nanomaterial, has high theoretical specific surface area which might be favorable for electrochemical biosensing applications [1]. Graphene-based heterostructures have been also recently used to modify the electrode surface for enhancing electrochemical response due to their electro-catalytic properties [2].
Many methods have been developed to produce such hybrid heterostructures by depositing metal oxide and/or metal nanoparticles on the surface of graphene. Here, we focused our attention on Pt-MOx/reduced graphene oxide (RGO) composites which have been synthesized by a simple and fast non-aqueous sol-gel procedure assisted by microwave. The prepared samples were characterized by X-ray diffraction (XRD), scanning and transmission electron microscopy (TEM), photoelectron spectroscopy (XPS) and infrared spectroscopy (FT-IR). Electrochemical characteristics of Pt-MOx//RGO-modified screen printed flexible electrodes were investigated. Amperometric sensors based on these composite electrodes to detect hydrogen peroxide (H2O2) and dissolved oxygen has been developed. The strategy of integrating metal, metal oxide, and reduced graphene oxide will provide new insight into the design of non-enzymatic flexible electrodes for a wide range of applications in biosensing, bioelectronics, and lab-on-a-chip devices.

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ETC-LPT vision on the large scale production of Graphene on SiC

Marco Mauceri

ORAL CONTRIBUTIONS - ABSTRACTS

Friday 7 Dec, morning

Large-scale dielectric function mapping and magneto-IR ellipsometry of epitaxial graphene

V. Darakchieva (1) , A. Boosalis (2), P. Khüne (2), T. Hofmann (2) M. Schubert (2), T. Iakimov (1), N. Ben Sedrine (1), V. Stanishev(1) and R. Yakimova (1)*

(1) Department of Physics, Chemistry and Biology, IFM, Linköping University, Linköping, SE-581 83 Sweden

(2) Department of Electrical Engineering, University of Nebraska-Lincoln, NE 68588-0511, USA

* E-mail: vanya@ifm.liu.se

Understanding the physical origin of the substantially different transport properties of epitaxial and free-standing graphene remains one of the major issues in the field and prevents further technological advances. The key point is to identify and control the substrate effects on graphene uniformity, thickness and carrier mobility. In this work we exemplify two different types of spectroscopic ellipsometry techniques to shed light on the properties of epitaxial graphene. We explore the properties of epitaxial graphene (EG) grown by high temperature sublimation on Si and C faces of home-grown 3C-SiC(111) bulk and the C-face of 6H SiC (0001) in relation to the substrate surface status, defects and polarity, and growth conditions.

First, we will discuss the large dielectric function and thickness mapping of EG on 3C-SiC. Spectroscopic ellipsometry from 0.73 eV to 5.3 eV with a 30μm beam spot is uded to probe the uniformity of the EG thickness and properties on a cm-scale. Our results reveal that homogeneous large scale 1 to 2 monolayer (ML) graphene can be grown on polished 3C-SiC substrates. The polished surface further enabled elimination of the puckers and reduction of strain in the EG. Few areas where the carbon bunched up and formed islands of multilayer graphene are also observed. In these areas the free carriers have lower scattering time, i.e. lower mobility, while the large area of 1 to 2 ML graphene show high mobilities and good graphene-like band energy. We also find correlation between the number of graphene MLs and the buffer layer coverage and surface roughness, which may be associated with substrate defects such as stacking faults. The electronic and transport properties of EG grown on Si and C-face of 3C SiC will be discussed in a comparative manner and conclusions on the polarity effects will be drawn.

Second, we will present initial results from magneto-ellipsometry in the mid-IR spectral range that allow Landau Level spectroscopy and we will discuss results on EG grown on 6H-SiC.

Controlling Growth of Large Area Graphene on SiC

D.K. Gaskill
U.S. Naval Research Laboratory, Washington, DC 20375 USA
gaskill@nrl.navy.mil

The SiC sublimation approach is one of only two methods for forming uniform layers of graphene on large area substrates amenable to Si processing technology. After a brief historical perspective, we describe and give examples of the current state-of-the-art in SiC wafer technology focusing on properties critical to large area graphene films. The sublimation conditions with regard to the polarity of the SiC surface are generally described. For the case of EG formation on the C-face, island nucleation at threading screw dislocation sites dominates under typical processing conditions and this gives rise to a stochastic growth process which is consistent with experimental data from many laboratories. For the case of the Si-face, EG formation depends upon surface preparation and is also a function of surface misorientation; a step retraction and carbon diffusion process dominates graphene formation. Control of step formation on the Si-face is thus significant for achieving uniform EG thickness on terraces as well as to minimize additional growth at the step edge and this will be demonstrated using atomic force microscopy and scanning electron microscopy images in combination with Raman spectroscopy maps and x-ray photoelectron spectroscopy analysis. The impact of processing factors such as temperature control, laminar gas flow and substrate rotation on large area EG uniformity are described using examples grown in a commercial SiC epitaxy reactor. Contactless Lehighton resistivity maps of 75 mm wafers will be used to illustrate the current state-of-the-art, which is about ±3%. Lastly, example applications for RF devices, functionalized sensors, and mode-locked lasers based on graphene saturable absorption will be given.

Theory and process simulation in epitaxial graphene on SiC

I. Deretzis, A. La Magna#*
Istituto per la Microelettronica e Microsistemi (CNR-IMM), VIII strada 5, 95121 Catania, Italy
* ioannis.deretzis@imm.cnr.it, # antonino.lamagna@imm.cnr.it

This talk will theoretically focus on the interface properties and the formation dynamics of epitaxial graphene on a SiC substrate. In the first part of the talk we will try to answer a simple question: Is there always a buffer layer at the graphene/SiC interface? *Ab initio* results will be presented for epitaxial graphene on the $(6\sqrt{3}\times6\sqrt{3})R30°$-reconstructed SiC(0001) surface (Si face) [1], the (3×3)-reconstructed SiC(000-1) surface (C face) and the nonpolar SiC(11-20)/SiC(1-100) surfaces. Moreover, the structural and electronic alterations in the presence of H-, Li- and Ge-intercalated atoms at the graphene/SiC interface will be discussed [1,2]. In the second part of the talk we will focus on the formation kinetics of quasi-freestanding graphene starting from the buffer-layer/SiC(0001) system exposed to an H-rich gaseous ambient, with the aid of a first-principles calibrated Kinetic Monte Carlo (KMC) model [3]. We will show how a nucleation phenomenon induces the transformation of the buffer layer into graphene. We will discuss: (a) the kinetic stages (adsorption on the graphene buffer layer, diffusion at the interface, stabilization of one-atom-thick islands) leading to the formation of the intercalated layer, (b) the stability of the intercalated structure against the process parameters, and (c) the concentration of hydrogen defects that remain at the end of the intercalating process.

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Micro-Raman and micro- transmission studies of Graphene on 6H- SiC

Antoine Tiberj (1,2), Jean-Roch Huntzinger (1,2), Nicolas Camara[#] (3), Philippe Godignon (3), Jean Camassel (1,2)*
(1) University Montpellier 2, Laboratoire Charles Coulomb UMR 5221, Montpellier, France
(2) CNRS, Laboratoire Charles Coulomb UMR 5221, F-34095, Montpellier, France
(3) IMB-CNM-CSIC, Campus UAB Bellaterra, Barcelona 08193, Spain
[*] E-mail: Antoine.Tiberj@univ-montp2.fr

A detailed comparison of true epitaxial graphene monolayers grown on both faces of 6H SiC substrates (Si and C faces) is made by combining micro-Raman spectroscopy with transmission measurements. We have already shown that such combination allows to discriminate without any ambiguity between a graphene monolayer and a twisted or folded graphene bilayer (AA') grown on the C face of 6H SiC [1]. In this presentation, we will focus on the Raman spectra and the transmission measurements performed on graphene monolayers grown on the Si face of 6H SiC. The graphene growth was tuned to get a mixed surface at the early stage of graphitization with i) bare SiC, ii) buffer layer and iii) in some localized areas small monolayers flakes on top of the buffer layer. These unique samples enabled to measure properly the Raman spectrum of the buffer layer (carbon layer with a large number of sp3 bonds) and its optical extinction at 514.5 nm. The Raman spectrum of this buffer layer remains visible after the growth of one monolayer on top but the Raman intensity is strongly reduced (typically divided by a factor of 3). This cannot be attributed to the absorption coefficient of graphene which is relatively low (few percents). Finally, several Raman mapping reveal the uniformity of the graphene monolayers in terms of thickness and crystalline quality, but also that they are subjected to a non uniform compressive strain.

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[#]present address: University of Tours, CNRS, Laboratoire GREMAN UMR 7347, 16, rue Pierre et Marie Curie, 37071 Tours Cedex 2, France

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Lithium electronic interlayer states after intercalation on SiC buffer layer

F. Bisti (1) , G. Profeta (1,2), H. Vita (3), F. Perrozzi (1), M. Donarelli (1), P. Moras (4), T. Seyller (5), K. Horn (3), L. Ottaviano (1,2)*

1) Dipartimento di Scienze Fisiche e Chimiche, Università dell'Aquila, Via Vetoio 10, 67100, L'Aquila, Italy
2) CNR-SPIN L'Aquila, Via Vetoio 10, 67100 L'Aquila, Italy
3) Fritz-Haber Institut der Max-Planck Gesellschaft, 14195 Berlin, Germany
4) Istituto di Struttura della Materia, Consiglio Nazionale delle Ricerche, Trieste, 34149, Italy
5) Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Erwin-Rommel-Strasse 1, 91058 Erlangen, Germany

* E-mail: federico.bisti@aquila.infn.it

Lithium deposition on graphene was recently proposed as a possible viable way to make graphene superconducting [1]. If graphene interlayer state is shifted at the Fermi level a strong enhancement of the electron-phonon coupling was predicted. The theoretical prediction is based on the simple model of isolated graphene layer with Li on top forming a $\sqrt{3}x\sqrt{3}$ reconstruction (the LiC6 system).[1]

A real system that can approximate this condition is the graphene layer obtained from the buffer layer of the 6H-SiC(0001) $(6\sqrt{3}x6\sqrt{3})R30°$ reconstructed surface by Li intercalation. Previous experimental studies have demonstrated buffer layer decoupling using Li intercalation.[2,3] Furthermore, two theoretical models have been proposed for the interpretations of this effect that differs in the Li adsorption [4,5].

In this work we have investigated the electronic structure of this system. The LEED patterns and the core level photoemission spectra obtained are in agreement with the previous studies.[2] The ARPES data revealed the presence of new low energy states near the Fermi level, never investigated before. Theoretical calculations, using the two proposed structural models [4,5], allow to assign these new features to Li states. These states originate from the reconstruction of the SiC surface states after Li absorption.

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