2D Materials Focus Topic

Room Hall B - Session 2D-ThP

2D Materials Poster Session

2D-ThP1 Activated Reduction Plasma Assisted Sulfurization in Layered WS₂ Synthesis, *Chien-Pao Lin, C.-N. Hsiao,* ITRC,NARL, Taiwan, Republic of China*; P.-S. Chen, C.-A. Jong,* No Matching Affiliation, Taiwan, Republic of China

CVD process is known as a promising method in large domain size and continuous 2D film synthesis. Sulfurization of Group VIB contained precursor (metal or metal oxide) for sulphide formation were widely studied. Sulfur is also reported as reduction agent of metal oxide at initial stage. In some cases, H_2 flew along with sulfur vapor during reduction time in MOCVD [1] and ALD [2] process. H_2 could be beneficial in the impurity removal and to enlarge the domain size effectively.

Plasma source in vacuum technology is useful especially in lowering the process temperature and for increasing the precursor decomposition efficiency in CVD or ALD process. R. Morrish et al., revealed that a and longer than 30 min at 500°C for sulfurization process using 10% H_2S plasma could reduce the activation energy between WO_3 and H_2S [3]. The presence of energetic radicals such as atomic S and H during sulfurization, the temperature and the exposure time are important.

In this study, we demonstrated the sulfurization process by two steps: (1) The energetic hydrogen (H*) generated by ICP plasma in WO_3 reduction at early stage, (2) Reaction between the activated hydrogen (H*) and sublimated sulfur vapor for WS_2 formation. The hydrogen concentration, plasma exposure time, the reaction temperature and duration time are evaluated for the sulfurization of WO_3.

WO_3 film was deposited on Si substrate covered by 90 nm thermal dry oxide. Samples were sulfurized in a 4 inch inductively coupled plasma (ICP) reactor with copper coil connected to a 13.56 MHz RF power supply. The reaction temperature varied from 700 to 900°C. Raman and PL spectrum were adopted for the film quality inspection. The surface roughness of formed WS_2 layers were examined by AFM. The best condition performed when the reaction temperature was 850°C with 5% H_2 plasma pre-treatment for 20min. Higher H% is harmful for film formation, which was similar to the report by K. N. Kang et al. that sulfurization can etch the damage of the film [4]. Raman and photoluminescence (PL) spectroscopy were taken with 532 nm excitation. The uniform Raman signals and PL spectrum within 4 cm² are shown and the center of the PL peak was at 629 nm (1.97 eV).

Reference:

[1] K. Kang et al, Nature, 520, 656 (2015).

[2] Y. Kim et al, Sci rep., 6, 18754 (2016)

[3] R. Morrish et al., Chem. Mater. 26, 3986–3992 (2014)

[4] K. N. Kang et al., Scientific Reports, 5, 13205 (2015)

2D-ThP2 Quantized States, Berry Phases, and Quantum-Hall Wedding-Cake structures in Graphene Quantum Dots, *Fereshte Ghahari Kermani, D. Walkup, C. Gutiérrez,* National Institute of Standards and Technology (NIST)/ University of Maryland, College Park*; C. Lewandowski,* Department of Physics, Massachusetts Institute of Technology*; J. Rodriguez-Nieva,* Massachusetts Institute of Technology*; K. Watanabe, T. Taniguchi,* National Institute for Materials Science, Japan*; L. Levitov,* Massachusetts Institute of Technology*; N.B. Zhitenev, J.A. Stroscio,* National Institute of Standards and Technology (NIST)

Recent progress in creating and probing graphene quantum dots (QDs) with fixed build-in

potentials has offered a new platform to investigate Klein tunneling related phenomena . In this talk, I describe scanning tunneling spectroscopy measurements of the energy spectrum of graphene QDs as a function of energy, spatial position, and magnetic field. In the absence of a magnetic field, confinement of graphene carriers in a *p-n* junction resonator gives rise to a series of quasi-bound single particle states which result from oblique Klein scattering at the *p-n* interface. Applying a weak magnetic field, we observe a giant and discontinuous change in the energy of time-reversed angular-momentum states, which manifests itself as the appearance of "new" resonances in the tunneling density of states. This behavior corresponds to the on/off switching of a π- Berry phase when a weak critical magnetic field is reached. With increased applied magnetic field, the QD states can be confined even further as they condense into highly degenerate Landau levels providing the first spatial visualization of the interplay between spatial and magnetic confinement. This is observed as formation of the seminal wedding-cake structures of concentric compressible and incompressible density rings in strong magnetic fields.

2D-ThP3 Growth Phenomena and Mechanism of MoS2 Formed by Conventional Chemical Vapor Deposition, *Cheol-Min Hyun, J.H. Choi, S.W. Lee, J.-H. Ahn,* Korea Maritime and Ocean University, Republic of Korea

In recent years, transition metal dichalcogenide (TMDC) compound, have heen studied as a platform for next generation semiconductor devices. One of the most representative two-dimensional TMDC materials, MoS2 is applied as a device as well as various synthesis methods are known, including chemical vapor deposition. However, in-depth research on the synthesis process and the mechanism of the variable has not been done yet. Therefore, in this study synthesis of single layer MoS2 by using conventional chemical vapor deposition, as MoO3 and sulfur powder, we observe and discuss the synthesized crystal shape on the substrate, according to the distance of sulfur and MoO3. The synthesized nano-crystals were characterized by optical microscopy (OM), x-ray diffraction (XRD), raman spectroscopy. Fig. 1. shows the OM-image and raman spectra of synthesized MoS2, MoO2 crystals on S1 and S2 substrate, respectively. MoS2 crystals are synthesized on the S1 substrate close to the sulfur source, MoO2 crystals are synthesized on the S2 substrate. From these results, we were able to studies the mechanism of MoS2 synthesis. In the synthesis of MoS2, using a MoO3 and sulfur powder, the synthesis mechanism was shown as a schematic of the various experiments and in-depth understanding.

Therefore, we have demonstrated that the importance of MoO2 formation as the intermediate phase in MoS2 synthesis using MoO3 and sulfur powder. And then, the MoS2 synthesis mechanism was easier to understand through the schematic illustration.

2D-ThP4 Graphene Micro Wires Defined by Photolithography and Plasma Etching for Field Effect Transistors, *F.C. Rufino, A.M. Pascon,* University of Campinas, Brazil*; D.G. Larrude,* Mackenzie Presbyterian University, Brazil*; W.C. Mariano, José Alexandre Diniz,* University of Campinas, Brazil

With the need of the development of smaller devices, the search for materials with physical and chemical properties favorable to these advances has become a priority. However, Moore's Law is no longer verified [1], reinforcing research into new technologies, with a strong focus on 2D materials. The graphene, a 2D material, composed of sp2 hybrid carbon atoms, emerges as a strong candidate in nanotechnology applications due to its outstanding electronic properties, high electrical conductivity, mobility, flexibility, mechanical strength and transparency [2], making it the ideal material to replace the silicon in the traditional FETs.

We report the fabrication of transistors based on graphene channel (GraFETs), applying the photolithography and oxygen plasma etching processes to define the graphene channel region, creating ten micro wires, which are parallel connected, at the same device, as FinFET transistors based on silicon nanowires. Usually, the graphene channel region is not formed by the wires in parallel, but by square or rectangular shapes. Devices, with wires in parallel, can get an increase in drain-source current and the transconductance response, which can improve the sensitivity of sensors based on GraFETs. Thus, in this work is presented the fabrication of GraFETs with: i) High quality CVD (Chemical vapour deposition) monolayer graphene, which was transferred on the GraFETs; ii) The channel, with total width of 3.6 μm, was formed by ten micro wires in parallel, with each width of about 0.36 μm, (obtained by lithography and O_2 plasma etching).

The Raman spectroscopy was used to investigate the integrity of graphene structure on GraFETs during the fabrication. The Scanning Electron Microscopy (SEM) was used to show the channel formation with ten graphene wires and to measure the dimensions of these wires. The drain-source current versus drain-source voltage, the drain-source current versus gate voltage, and the transconductance versus gate voltage, were extracted to evaluate the electrical characterization of our GraFETs. The graphene used in the manufacture of the transistor was obtained through CVD, where the graphene is grown on a copper substrate by surface catalysis of the CH_4 and H_2 gases [3]. The growth process is done in a CVD chamber with a vacuum of 10^{-3} torr and a temperature of 1000 ºC, the transference of CVD monolayer graphene on the device region using wet transfer method and PMMA as a supporting layer [4].

[1]H. N. Khan et al., Nat. Electronics , 14 (2018).

[2]K. S. Novolselov et al, Science **306**, 666 (2004).

[3]Xuesong Li, et al., Science **324**, 1312 (2009).

[4]L. Jiao et al., Am. Chem. Soc. , 12612 (2008).

2D-ThP6 In-Operando AFM/STM and Transport Measurements of a Graphene Hall Bar Device, *Johannes Schwenk,* National Institute of Standards and Technology (NIST)/ University of Maryland, College Park*; S. Kim,* National Institute of Standards and Technology (NIST) / Department of Physics and Astronomy, Seoul National University, Seoul, Korea*; F. Ghahari,* National Institute of Standards and Technology (NIST)/ University of Maryland, College Park*; J. Berwanger,* Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany*; W.G. Cullen, S.R. Blankenship,* National Institute of Standards and Technology (NIST)*; Y. Kuk,* Department of Physics and Astronomy, Seoul National University, Seoul, Korea*; F.J. Giessibl,* Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany*; N.B. Zhitenev, J.A. Stroscio,* National Institute of Standards and Technology (NIST)

We present initial studies of a backgated graphene Hall bar device using simultaneous measurements of atomic force microscopy (AFM), scanning tunneling microscopy (STM) and electronic transport. Laterally resolved spectroscopy with high energy resolution is used for the investigation of exotic ground states and edge channels within the two-dimensional graphene electron system, which enables us to explore links between the local microscopic behavior of the device and its mesoscopic transport properties.

A recently constructed microscope uses a self-sensing quartz sensor (qPlus) and operates in an ultra-high vacuum (UHV) environment inside a dilution refrigerator (DR) with a base temperature of 10 mK and magnetic fields up to 15 T [1]. Radio frequency (RF) filtering of all signal lines entering the UHV chamber and improved home built RF powder filters at the 10 mK stage were implemented to produce an improved energy resolution in tunneling spectroscopy. Low noise preamplifiers for the sensor deflection [2] and the STM current signal [3] were implemented at the 4 K stage within the DR. This allows for reduced Johnson noise of the amplifier feedback resistors and a relatively short distance (1.2 m) between amplifier and the STM/AFM module where the sensor is operating. In this poster we describe aspects of the instrumentation and initial measurements of the graphene Hall bar device.

[1] Song et al., Review of Scientific Instruments 81, 121101 (2010); doi: 10.1063/1.3520482

[2] Huber and Giessibl, Review of Scientific Instruments 88, 073702 (2017); doi: 10.1063/1.4993737

[3] adapted from le Sueur and Joyez, Review of Scientific Instruments 77, 123701 (2006); doi: 10.1063/1.2400024

Author Index

Bold page numbers indicate presenter

— A —
Ahn, J.-H.: 2D-ThP3, 1
— B —
Berwanger, J.: 2D-ThP6, 2
Blankenship, S.R.: 2D-ThP6, 2
— C —
Chen, P.-S.: 2D-ThP1, 1
Choi, J.H.: 2D-ThP3, 1
Cullen, W.G.: 2D-ThP6, 2
— D —
Diniz, J.A.: 2D-ThP4, **1**
— G —
Ghahari Kermani, F.: 2D-ThP2, **1**
Ghahari, F.: 2D-ThP6, 2
Giessibl, F.J.: 2D-ThP6, 2
Gutiérrez, C.: 2D-ThP2, 1

— H —
Hsiao, C.-N.: 2D-ThP1, 1
Hyun, C.M.: 2D-ThP3, **1**
— J —
Jong, C.-A.: 2D-ThP1, 1
— K —
Kim, S.: 2D-ThP6, 2
Kuk, Y.: 2D-ThP6, 2
— L —
Larrude, D.G.: 2D-ThP4, 1
Lee, S.W.: 2D-ThP3, 1
Levitov, L.: 2D-ThP2, 1
Lewandowski, C.: 2D-ThP2, 1
Lin, C.-P.: 2D-ThP1, **1**
— M —
Mariano, W.C.: 2D-ThP4, 1

— P —
Pascon, A.M.: 2D-ThP4, 1
— R —
Rodriguez-Nieva, J.: 2D-ThP2, 1
Rufino, F.C.: 2D-ThP4, 1
— S —
Schwenk, J.: 2D-ThP6, **2**
Stroscio, J.A.: 2D-ThP2, 1; 2D-ThP6, 2
— T —
Taniguchi, T.: 2D-ThP2, 1
— W —
Walkup, D.: 2D-ThP2, 1
Watanabe, K.: 2D-ThP2, 1
— Z —
Zhitenev, N.B.: 2D-ThP2, 1; 2D-ThP6, 2