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Understanding and Exploiting the Electronic Interface in Stacked 2D Atomic Layered Materials

by Madan Dubey, Raju Nambarau, Pani Varanasi, and
Marc Ulrich

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Understanding and Exploiting the Electronic Interface in Stacked 2D Atomic Layered Materials

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14. ABSTRACT

An executive summary is provided on current FY2014 progress for the ARL Strategic Director's Initiative titled: "Understanding and Exploiting the Electronic Interface in Stacked 2D Atomic Layered Materials." The capabilities and achievements in the areas of material growth, material characterization, device fabrication, device testing, and theoretical modeling are described. The work presented is based on molecularly-thin MoS_2 and graphene.

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DSI, 2D Materials, Stacked Atomic Layers, 2D Layers, Annual Report

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1. Materials Growth

During the second year of the Director's Strategic Initiative (DSI), our team was able to make significant progress in the growth of MoS_2. We investigated the effect of the growth conditions on the structural, optical, and electrical properties of individual MoS_2 triangles, shown as well-fabricated and tested 2D-MoS_2 field effect transistor (FET). An example is shown in Fig. 1.

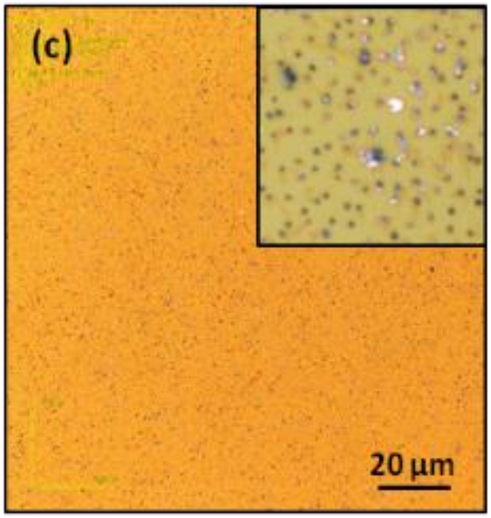

Fig. 1 **Optical microscope images of individual MoS_2 triangles grown**

2. Materials Characterization

Raman spectroscopy and photoluminescence (PL) measurements were used to characterize the in-house grown MoS_2 films. Raman intensity maps for the A_{1g} peak and the PL intensity of an 80 × 80 µm area for a standard MoS_2 growth can be seen in Fig. 2, as well as an optical image of the area mapped. Significant growth parameters identified from the Raman/PL characterization include sulfur precursor quality, growth temperature, and substrate.

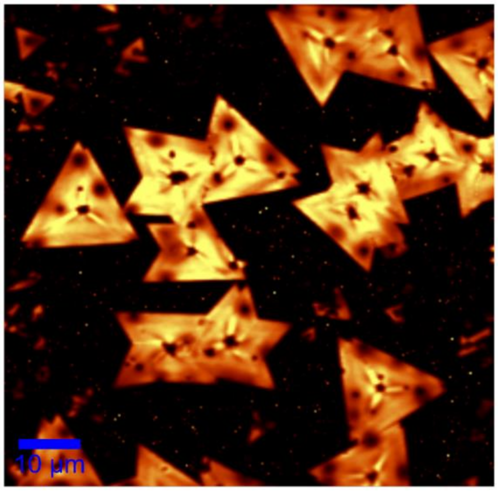

Fig. 2 Photoluminescence intensity map from in-house grown MoS_2 on SiO_2/Si using standard growth conditions

ARL's Raman mapping capability was used extensively in a collaboration with MIT and University Arizona. The consequence of applying a perpendicular electric field in the vicinity of the ABA(semiconducting)/ABC(metallic) intralayer interface in trilayer graphene on hBN was investigated. This interface consists of a strain soliton for which a portion is noted by the black oval in Fig. 3 (inset). This work demonstrated that by applying an electric field, this boundary (i.e., the soliton) could be moved. As a result, it is now possible for the first time to change the crystal structure and, hence, the phase of graphene in a controlled fashion.

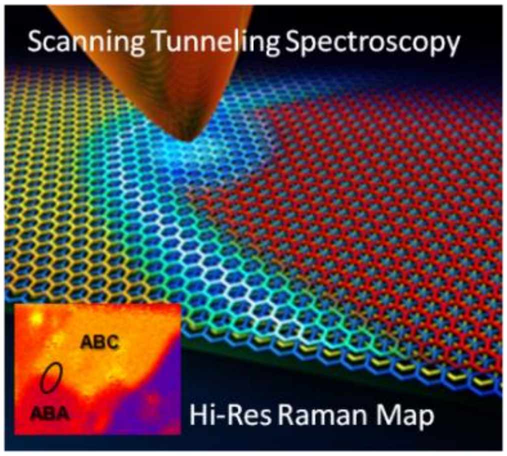

Fig. 3 An artistic interpretation of strain soliton movement in the trilayer graphene via the application of a perpendicular electric field by the STM tip is shown, along with the inset of the corresponding high-resolution Raman map of the trilayer graphene region described

3. Device Fabrication and Testing

The electrical transport properties of 2D materials grown at the US Army Research Laboratory (ARL) and its academic partners were measured. We studied MoS_2 FETs low frequency noise (LFN) analysis, which indicated signatures of both trapped charge scattering and correlated mobility scattering, shown Fig. 4. MoS_2-based flexible logic circuits using enhancement-mode and depletion-mode N-type FETs were fabricated to create functional inverters, negative-AND (NAND) gates, negative-OR (NOR) gates, and latches with a fabricated inverter, shown in Fig. 5.

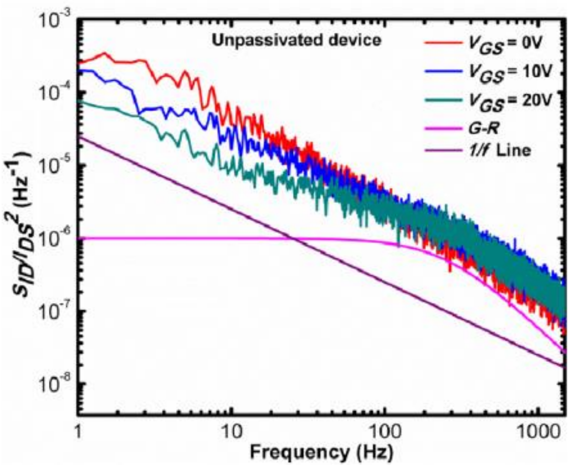

Fig. 4 Normalized noise power spectral density of drain current noise for unpassivated MoS_2 back-gated FET at 170 K

Fig. 5 Optical micrograph of a 2D MoS_2 inverter on flexible substrates with graphene contacts is shown

4. Theoretical Modeling

During the processing of the MoS_2 samples for device fabrication, a few grains were found to fold onto themselves. PL measurements were carried out on these samples, revealing that the PL for the folded bilayer MoS_2 (Fig. 6) was not quenched like the grown bilayer segment. Instead, it was found to blue-shift by 90 meV. Theoretical modeling was conducted to determine the nature of the blue shift, leading to the conclusion that it was due to exciton screening. This effect may enable improved electro-optic devices using folded MoS_2.

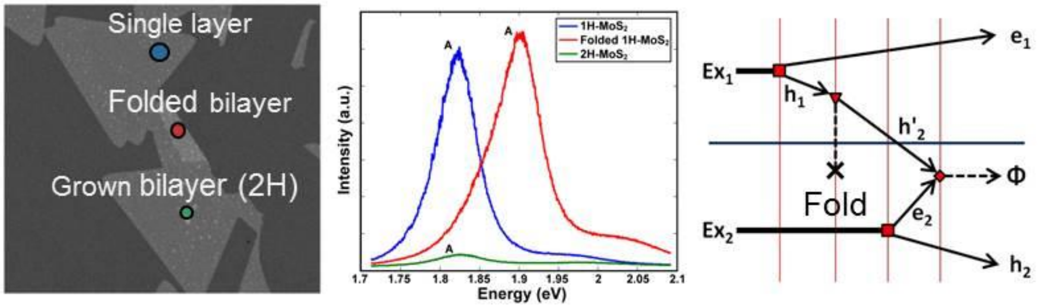

Fig. 6 Left: SEM image of single layer, folded bilayer, and grown bilayer MoS_2. Middle: PL spectra showing the blue shift observed for folded bilayer MoS_2. Right: Goldstone diagram for exciton screening.

5. Transitions

ARL/ARO awarded 3 small business technology transfer programs (also known as STTRs) for the transition of large area MoS_2 growth and FET for RF applications.

1. Kyma Technologies “Low Power Monolayer MoS2 FET for RF Applications”

Contract Number: W911NF-14-P-0028

2. N5 Sensors, Inc. “Two-Dimensional MoS_2 Transistors for Low-Power RF Applications”,

Contract Number: W911NF-14-P-0013

3. Applied Novel Devices, Inc. “Low Power monolayer MoS2 Transistors for RF Applications” Contract number: W911NF-14-P-030

6. Publications: Refereed Journals

1. Dong Liang et al. Theoretical study on strain induced variations in electronic properties of 2*H*-MoS_2 bi-layer sheets. Appl. Phys. Lett. 2014;104:053107. http://dx.doi.org/10.1063/1.4863827
2. Sharma Deepak et al. Electrical transport and low-frequency noise in chemical vapor deposited single-layer MoS_2 devices. Nanotechnology. 2014 Apr 18;25(15):155702
3. Amani Matin et al. Growth-substrate induced performance degradation in chemically synthesized monolayer MoS_2 field effect transistors. Appl. Phys. Lett. 2014;104:203506.
4. Fang Wenjing et al. Asymmetric Growth of Bilayer Graphene on Copper Enclosures Using Low-Pressure Chemical Vapor Deposition. ACS Nano. 2014;8(6):6491–6499. DOI: 10.1021/nn5015177
5. Yu Lili et al. Graphene/MoS2 Hybrid Technology for Large-Scale Two-Dimensional Electronics. Nano Lett. 2014;14(6):3055–3063. DOI: 10.1021/nl404795z
6. Das Saptarshi et al. High gain, low noise, fully complementary logic inverter based on bi-layer WSe2 field effect transistors. Appl. Phys. Lett. 2014;105:083511.

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