A Hands-on University Course in Emerging and Low-Dimensional Materials

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Abstract: The IRDS road map for 2021 introduces both 2D-based devices as beyond-CMOS, and 2D- materials as channel materials for 2028. To support and accomplish this goal, many efforts are currently underway at the research and development level at both universities and industry. This is evidenced by the fact that the leading semiconductor manufacturing companies have been adopting and publishing results of devices fabricated with 2D materials. In addition, relevant research out of the USA, Asia and Europe now focuses on statistical results and reliability of relevant devices based on 2D materials. As a final ingredient for this effort to be successful and sustainable, universities need to prepare the workforce, not only at the research level, but also at the development level and the high volume manufacturing level.

In order to meet these needs, at Rochester Institute of Technology, we developed an undergraduate/graduate special topics university course titled: “Emerging and Low-Dimensional Materials.” This course was successfully run for the first time in the Spring semester of 2022, with the objective to introduce both undergraduate and graduate students of diverse academic backgrounds to the fundamental physics of emerging nanomaterials, including graphene, transition metal dichalcogenide monolayers, and more for applications in nanoelectronics and optoelectronics. Three faculty members who are actively involved in 2D materials research prepared the course materials from recent published literature and personal knowledge, while also incorporating aspects of their recent research activities.

The course includes in-depth lectures and laboratory modules on the synthesis, material characterization, processing and electrical characterization of two-dimensional (2D) materials and devices. Topics include a discussion of how low-dimensional materials fit in the IRDS roadmap; opportunities and challenges of integrating 2D materials in next generation computation (e.g., in-memory computing, neuromorphic computing); synthesis and epitaxial growth of monolayer materials; characterization using electron microscopy, scan probe microscopy, and optical spectroscopy; transferring methods of monolayer materials and 2D heterostructures; fabrication of 2D-based devices; and in depth discussion of emerging applications, including 2D optoelectronics, twistronics, straintronics, iontronics, and nonvolatile and resistive RAM.

The laboratory exercises provide students a hands-on experience on the fabrication of back-gated graphene-based field effect transistors including a double PMMA-mediated wet transfer and a PVA-lamination dry transfer, graphene etch, metal deposition and liftoff, and electrical characterization. Dry and wet transfers of 2x2-inch graphene films were characterized and compared through optical microscopy, SEM, AFM and Raman spectroscopy. The graphene layer was then defined via standard lithography with MiR701 photoresist, an i-line stepper, and resist development and hard bake though a wafer track. The fabricated back-gated graphene transistors were then tested in a semiconductor parameter analyzer. The I_D-V_G results showed Dirac points of 10-20 V, and measured hole and electron mobilities of 796.13 cm^2/Vs and 393.28 cm^2/Vs respectively. The participating students were involved in all these steps and benefiting from critical and lively discussions of the activities and results. This approach encourages curiosity, promotes creativity, and creates connections within other subjects and experiences as it prepares students for a successful career in micro/nano-electronics and/or 2D materials.