Atomically thin 2D materials for nanoelectronics

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As nanoelectronic devices and integrated circuits become smaller and denser, performance degradation and excess heat dissipation on the chip become big issues. Atomically thin, inherently 2D semiconductors such as transition metal dichalcogenides (MX_2, M=Mo, W, X=S, Se, Te) offer excellent thickness scaling capabilities to improve electrostatic control. In addition, at the limit of a single layer, MX_2 become direct gap semiconductors with excellent response in the near IR and visible part of the solar spectrum making it suitable for light emitting devices and energy harvesting. Besides, these materials have high mechanical strength and because they are atomically thin they are bendable and stretchable so they can be used for transparent flexible displays and a number of low power versatile applications. It is quite impressive that advanced devices and integrated circuits have already been realized showing that they can impact nanoelectronics [1]. However, most of the device work worldwide has been performed on small (micron size) flakes exfoliated from bulk. For real world applications, large area synthesis of these materials is required. In this work, we demonstrate that high quality epitaxial single and few-layer $MoSe_2$ can be obtained by MBE on large area AlN(0001)/Si(111) substrates. The electronic band structure imaged by *in-situ* ARPES indicates a direct gap material verified by intense room temperature photoluminescence signals and well defined Raman shifts. The layer is uniform over the entire wafer and has an excellent stability upon exposure to air for several days, allowing transistor processing. In future novel device implementations, 2D semiconductors need to be combined with other 2D layered materials (e.g. dielectrics like BN, AlN) which could be preferably bonded by weak van der Waals forces. A short review will be given with an emphasis on our recent results [2] showing high quality epitaxial growth on Ag(111) substrates of hexagonal graphite-like few layer AlN, which can be considered as a precursor of the more stable AlN bulk wurtzite phase. Moreover, we will show that $MoSe_2$ semiconductor can be combined with other selenides such as Bi_2Se_3 to form multilayer structures with novel properties. Bi_2Se_3 belongs to new class of 2D layered materials known as topological insulators (TI). TIs present non-trivial insulator properties since they possess an excitation gap in the bulk co-existing with surface metallic states in the form of spin-polarized (helical) Dirac cones. Our newest data [3] will be presented showing the thinnest Bi_2Se_3 (3 quintuple layers) ever reported with gapless surface metallic states which is epitaxially grown on AlN(0001) by MBE. This means that Bi_2Se_3 can be scaled down to very small thickness which allows integration in the gate of Si MOSFETs to exploit the quantum capacitance of the surface 2D metallic states in novel steep slope switches aimed for low power/high performance applications.

This work is supported by the ERC Advanced Grant SMARTGATE-291260 and the Greek Program of EXCELLENCE (ΑΡΙΣΤΕΙΑ)-TOP ELECTRONICS -745

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