Abstract

Electronics is at a crossroads. The materials and technologies that have enabled the information revolution of the last 60 years are quickly reaching their ultimate physical limit. Fortunately, a new generation of atom-thick materials has recently been discovered. This talk will review these new materials, all of them less than one nanometer thick, and the novel devices and applications enabled by their amazing properties.

Graphene was the first one of these materials to be discovered. A two-dimensional structure of carbon atoms with sp² bonding, graphene has demonstrated the highest electron and hole mobility at room temperature in any semiconductor material. Its transport properties make it ideal for all kind of non-linear analog electronics, it shows extremely high frequency performance, and its one-atom-thickness enables transparent and highly flexible electronics.

MoS₂ and other transition metal dichalcogenides (TMD) materials are another example of two-dimensional materials with unique properties. Made of only three-atoms thick, they can complement graphene to build flexible digital and mixed-signal circuits, overcoming its lack of bandgap while still sharing many of graphene’s excellent mechanical and thermal properties. We will describe some of our recent results on the development of 2D nanoelectronics on MoS₂ and TMD materials. First, large-area single-layer MoS₂ material is grown by chemical vapor deposition (CVD) that makes the wafer-scale fabrication of MoS₂ devices and circuits possible for the first time. Second, the top-gated transistors, fabricated for the first time on single-layer MoS₂ grown by CVD, show multiple state-of-the-art characteristics, such as high mobility, ultra-high on/off current ratio, record current density and current saturation. Finally, the first fully integrated digital and analog circuits based on MoS₂ are constructed to demonstrate its capability for both logic and mixed-signal applications. Key circuit building blocks for digital and analog electronics such as inverter, NAND gate, memory and ring oscillator circuits are demonstrated.

References


Figures

a) b)

Figure 1. a) Graphene transistors and chemical sensors transferred to a transparent, flexible substrate. b) Optical micrograph of a MoS₂ integrated circuit, a 5-stage ring oscillator.
But recent developments in materials-engineering and nanotechnology have introduced new pathways for electronics. While traditional silicon electronics will remain the main focus, alternative trends are emerging. These include graphene, which may have started this 2D revolution in electronics, but silicene, phosphorene and stanene, atom-thick allotropes of silicon, phosphorus and tin, respectively, have a similar honeycomb structure with different properties, resulting in different applications. All four have the potential to change electronics as we know it, allowing for miniaturization, higher performance and cost reduction. Several companies around the globe, including Samsung and Apple, are developing applications based on graphene. Organic electronics. All our electronics have measures in place to guard against excess heat. This is because excess heat can lead to malfunctions and even cause lithium battery explosions. However, those heat-protecting measures take up quite some space making our electronics larger. Now, Stanford researchers have devised of a new heat protector that consists of just a few layers of atomically thin materials. Related: physicists discover graphene can behave as both an insulator and a superconductor. Same insulation as a sheet of glass 100 times thicker. The novel invention can provide the same insulation as a sheet of glass 100 times thicker. The tools of factory production, from electronics assembly to 3-D printing, are now available to individuals, in batches as small as a single unit. Anybody with an idea and a little expertise can set assembly lines in China into motion with nothing more than some keystrokes on their laptop. A few days later, a prototype will be at their door, and once it all checks out, they can push a few more buttons and be in full production, making hundreds, thousands, or more. Then haul your golden goose to Maker Faire and become the poster child for the DIY industrial revolution. As Kearns is getting close to firing up his facility, Ford abruptly backs out of the deal. With no revenue in sight, the factory shuts down before producing a single wiper.