Transistors go flat out: Two-dimensional materials for beyond-silicon electronics

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Silicon Valley gets its name from the element found at the heart of all microelectronics - silicon. For decades, pure silicon single crystals have been the basis for computer chips. But as chips become smaller and faster, doubling the number of transistors on integrated circuits every two years in accordance with Moore's law, silicon is nearing its practical limits. Scientists are exploring radical new materials and approaches to take over where silicon leaves off. Two-dimensional materials like graphene and molybdenite (MoS_2) are already included in the International Technology Roadmap for Semiconductors (ITRS).

The scope of this lecture will be MoS_2, a two-dimensional material that proved its potential to replace silicon in near future. By proper substrate and dielectric engineering, carrier mobility, current on/off ratio and subtreshold swing in field-effect transistors can be improved enough to become at least close to state-of-the-art semiconductor technology. In fact, any potential replacement of silicon in CMOS-like digital logic devices is desired to have a current on/off ratio I_{on}/I_{off} between 10^4 and 10^7 and a band gap exceeding 400 meV. For the first time high current on/off ratio ~10^8, subtreshold swing as low as 74 mV/dec and moderately high electron mobility ~50 cm^2/Vs are demonstrated in any two-dimensional semiconducting material [1].

Subsequently, based on this platform, operations of the first logic gates, integrated circuits [2] and small-signal analog amplifiers were demonstrated, which paved the way for two-dimensional semiconducting materials based flexible electronics, and resulted in MoS_2 being included in the semiconductor industry ITRS roadmap.

Additionally, for the first time, a metal-insulator transition in one two-dimensional semiconducting material has been observed [3]. This transition point is in a very good agreement with theory and shows that monolayer MoS_2 could be an interesting new material system for investigating low-dimensional correlated electron behavior.

[1] B. Radisavljevic, *et al.*, "Single-layer MoS_2 transistors," *Nature Nanotechnology,* 2011.

[2] B. Radisavljevic, *et al.*, "Integrated Circuits and Logic Operations Based on Single-Layer MoS_2," *ACS Nano,* 2011.

[3] B. Radisavljevic and A. Kis, "Mobility engineering and a metal–insulator transition in monolayer MoS_2," *Nature Materials,* 2013.