Research Highlight

Silicene transistors: silicon-based nanoelectronics from a single atom layer

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Abstract: The discovery of graphene, a single-atom thin sheet of carbon, led to the worldwide race for the discovery of similar two-dimensional materials of other elements, especially of common semiconductor materials such as silicon and germanium. Although graphene may be electrically the most conductive material, it is not suitable for making a transistor because of the lack of an energy band gap. In contrast, silicene and germanene, single-atom layers of silicon and germanium, pose a small band gap that can be used for making nanoelectronic transistors. A recent work has demonstrated the proof of concept of this transistor, which is made of a single layer of silicon atoms.

Two-dimensional materials consisting of a single atom layer has been a hot research topic since the isolation of the first graphene by Andre Geim and Konstatin Novoselov in 2004 [1], for which they have received the Nobel Prize in Physics in 2010. Although graphene may be electrically the most conductive material, this material is not suitable for making a transistor because of the lack of an energy band gap. Due to their corrugated nature and the associated small band gap, much hope has been placed on silicene and germanene, single-atom layers of silicon (Si) and germanium (Ge). In 1994, Takeda and Shiraishi reported the first theoretical work on the possibility of two-dimensional Si and Ge using first-principles total-energy calculations [2]. This work pointed out that while carbon atom prefers to form a flat layer, Si and Ge prefer to form a corrugated surface. In 2007, Guzman-Verri and Voon reported the theoretical electronics properties of silicon-based counterparts of graphene and carbon nanotube, and coined the term “silicene” for the two-dimensional single-atom layer of silicon [3]. Silicence does not exist in nature and there is no bulk silicon material similar to graphite. Recently, Le Lay’s group has successfully synthesized silicene nanoribbons on crystalline silver Ag(110) [4]. The same group later reported in 2012 the synthesis of epitaxial silicene layers on a silver (111) substrate [5]. Although silicence layers can be synthesized, unlike graphene, they are extremely unstable in air making it difficult to process in subsequent steps to make useful devices such as transistors.

Recently, Tao *et al.* [7] reported a significant progress on making a stable silicene layer and demonstrated subsequently a silicene transistor. The technology allows for the transfer of the silicene layer to a more useful substrate such as silicon. The process starts with the epitaxial growth of silicene on a thin Ag(111) layer deposited on a mica substrate, Fig. 1(a). The silicene layer was then protected by a 5-nm thick layer of alumina (Al_2O_3), Fig. 1(b). The silicene layer sandwiched between and protected by the silver and alumina layers could be then detached from the mica substrate, Fig. 1(c). The alumina/silicence/silver film was than flipped upside down and transferred to a conventional oxidized silicon substrate, Fig. 1(d,e). The silicon acts as the gate electrode, while the silver layer was etched to form drain and source electrodes of the transistor, Fig. 1(f). To prevent the oxidization of the silicene layer, the authors developed a gentle potassium iodine-based etchant. Although the exposed silicene and the transistor have a lifetime of few minutes, the device has demonstrated the characteristics of a truly nanoelectronic transistor.

In the near future, protecting the exposed silicene with another layer of more stable material such as Teflon could extend the life of the transistor. Making multi-layer silicences and allowing the upper layer to be oxidized could also protect the silicene working as semiconductor for the transistor. This proof-of-concept device may open up a new research field and probably a new industry of nanoelectronics.

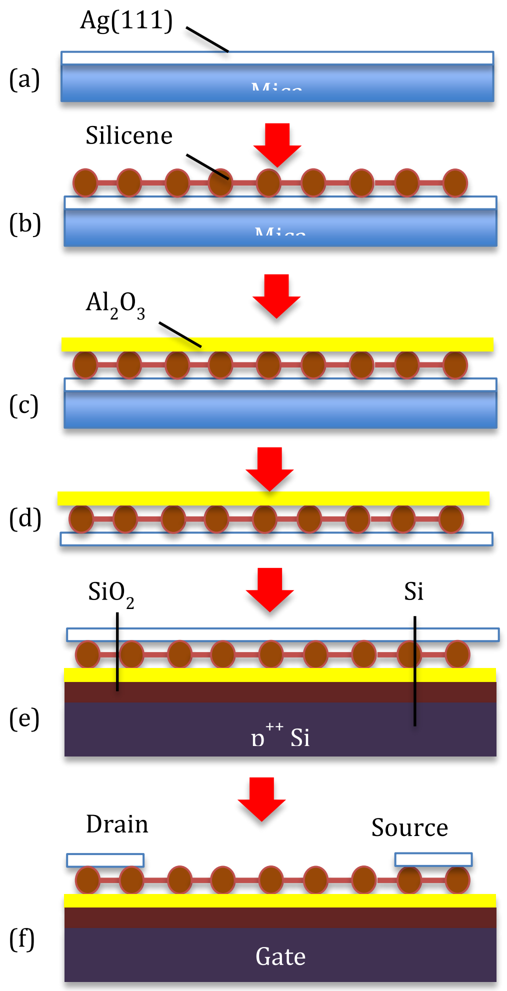

Figure 1. Fabrication steps of the silicene transistor

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