Researchers build a silicon-graphene-germanium transistor for future THz operation

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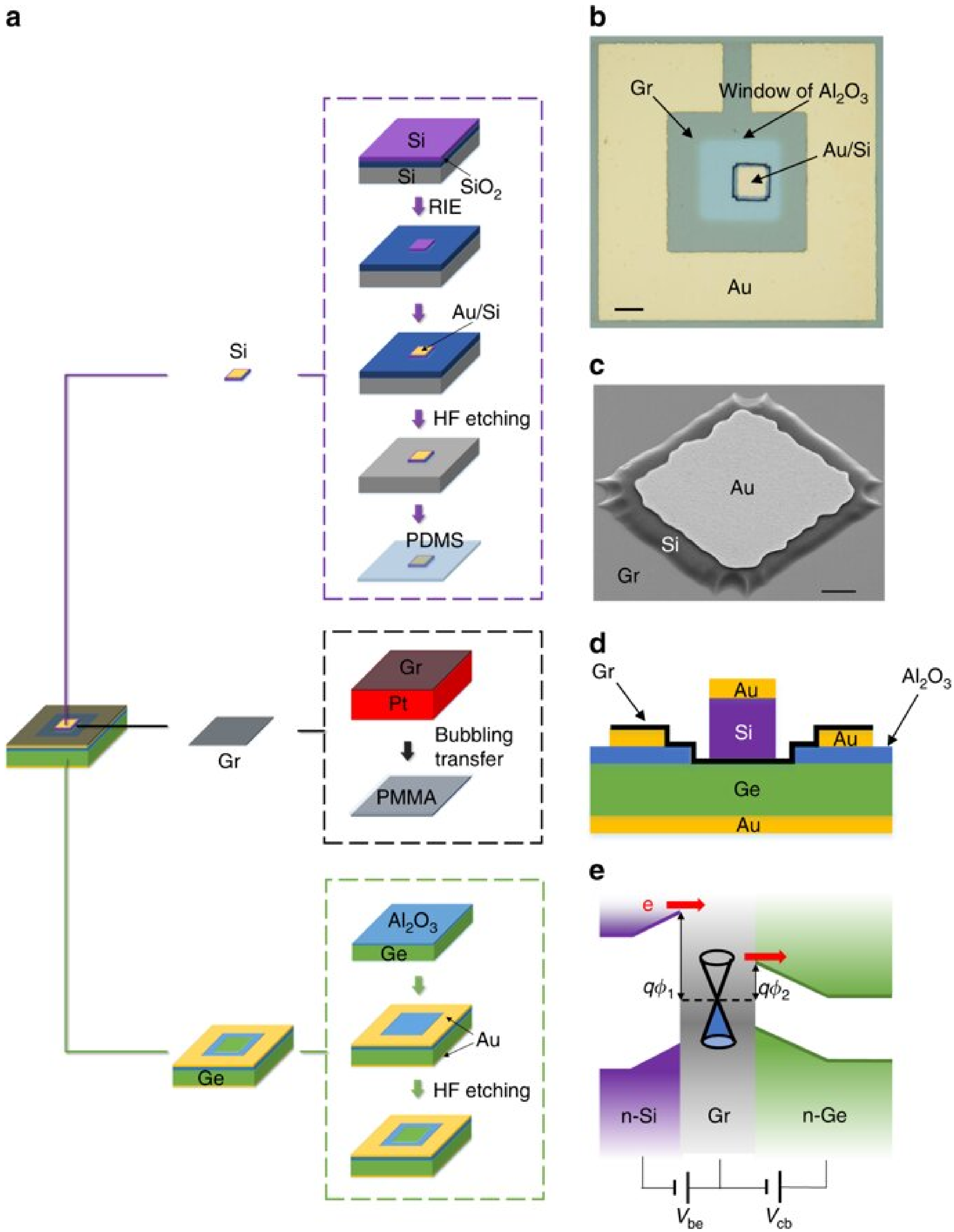

Device design and fabrication. a A Si–Gr–Ge transistor is built by directly stacking a Si membrane, single-layer graphene and a Ge substrate. b Optical image of a Si–Gr–Ge transistor (scale bar: 20 μm). c SEM image of a Si membrane on graphene (scale bar: 4 μm). d Illustration of the cross-section of the transistor. e Illustration of the basic operating principle of the transistor. Credit: *Nature Communications*

In 1947, the first transistor, a bipolar junction transistor (BJT), was invented in the Bell Laboratory and has since led to the age of information technology. In recent decades, there has been a persistent demand for higher frequency operation for a BJT, leading to the inventions of new devices such as heterojunction bipolar transistors (HBT) and hot electron transistors (HET). The HBTs have enabled terahertz operations, but their cut-off frequency is ultimately limited by the base transit time; for the HETs, the demand of a thin base without pinholes and with a low base resistance usually causes difficulties in material selection and fabrication.

Recently, researchers have proposed graphene as a base material for transistors. Because of the atomic thickness, the graphene base is almost transparent to electron transport, leading to a negligible base transit time. At the same time, the remarkably high carrier mobility of graphene will benefit the base resistance compared with a thin bulk material. Graphene-based transistors (GBTs) generally use a tunnel emitter that emits an electron through an insulator. However, the emitter potential barrier height seriously limits the cut-off frequency. Theoretical study has indicated that a Schottky emitter may solve this potential barrier limitation.

A team of researchers at the Institute of Metal Research, Chinese Academy of Sciences, has built the first graphene-based transistor with a Schottky emitter, which is a silicon-graphene-germanium transistor.

Using a semiconductor membrane and graphene transfer, the team stacked three materials including an n-type top single-crystal Si membrane, a middle single-layer graphene (Gr) and an n-type bottom Ge substrate.

Compared with the previous tunnel emitters, the on-current of the Si-Gr Schottky emitter shows the maximum on-current and the smallest capacitance, leading to a delay time more than 1,000 times shorter. Thus, the alpha cut-off frequency of the transistor is expected to increase from about 1 MHz by using the previous tunnel emitters to above 1 GHz by using the current Schottky emitter. THz operation is expected using a compact model of an ideal device. The electrical behavior and physical activity of the working transistor are discussed in detail in the published paper in *Nature Communications*.

With further engineering, the vertical semiconductor-graphene-semiconductor transistor is promising for high-speed applications in future 3-D monolithic integration because of the advantages of atomic thickness, high carrier mobility, and the high feasibility of a Schottky emitter.

More information: Chi Liu et al. A vertical silicon-graphene-germanium transistor, *Nature Communications* (2019). DOI: 10.1038/s41467-019-12814-1

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