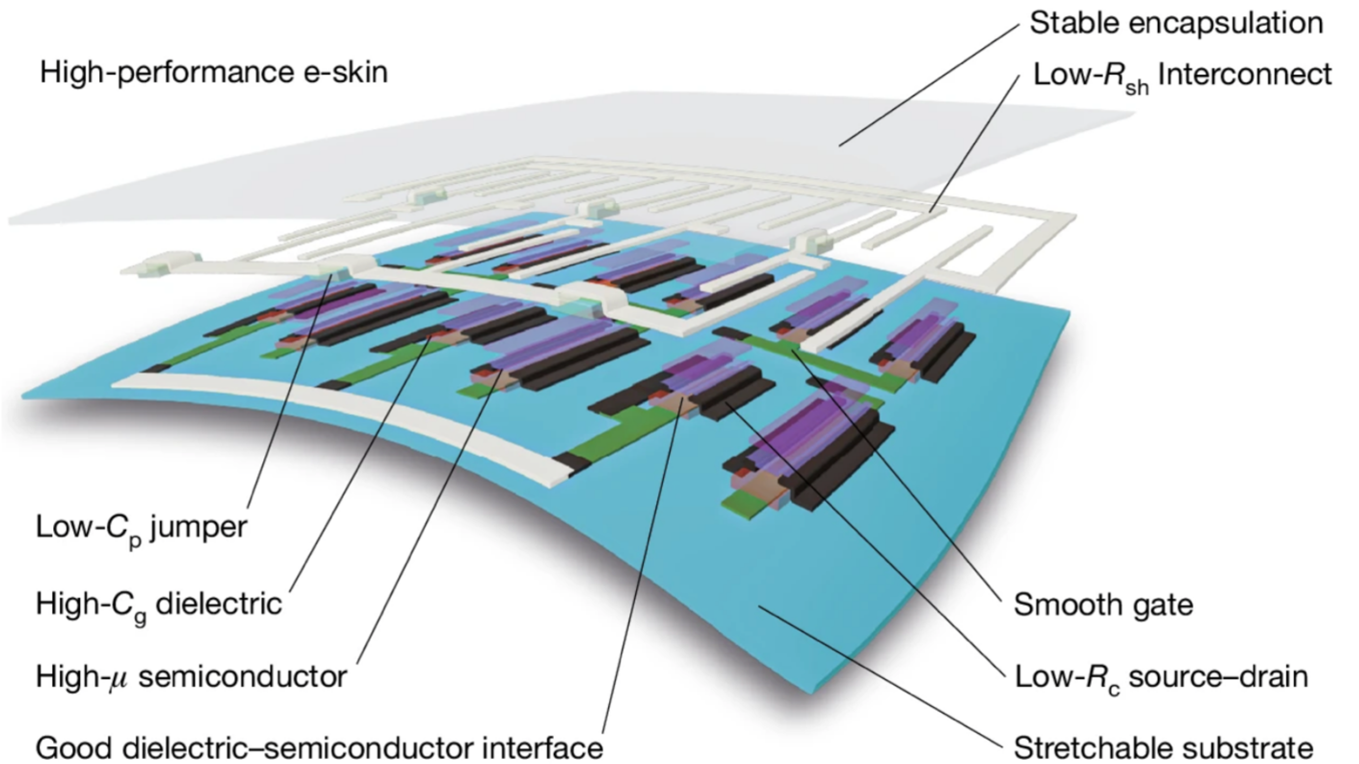
Docket #: S22-399

Materials, devices, and manufacturing methods for high-speed and large-scale intrinsically stretchable electronics

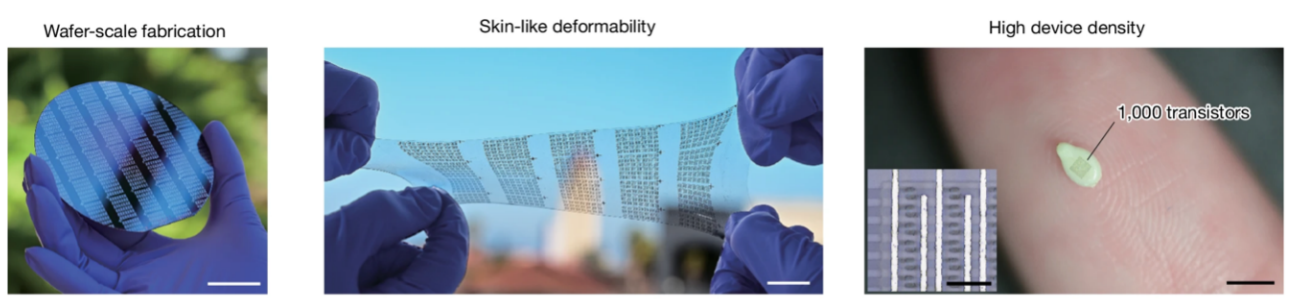
Researchers in the Bao Group demonstrated a first in class, stretchable, high performance, high transistor density device. Using semiconducting carbon nanotubes (CNTs) and soft elastic electronic materials developed in Bao's lab (see Figure 1), the group developed the fabrication process and circuit design to create their highest performing device to record. Unlike silicon, which is hard and brittle, the carbon nanotubes structure sandwiched between elastic materials continue to function while they stretch and deform. The as-fabricated transistors have a device yield of >99.3% for 20 ?m channel length (Lch), charge-carrier mobility of ~21.5 cm2 V-1 s-1 under 100% strain, and a record transistor density of 100,000 cm-2 including interconnects. The drive current is comparable to state-of-the-art flexible transistors, including CNT, oxide, organics and polycrystalline silicon (poly-Si). The 527-stage ring oscillator (RO) prototype achieved record-high operation with a stage switching speed of > 1 MHz.

The Bao Lab's large-scale integration (LSI) of stretchable electronics with skin-like mechanical properties is a significant advancement in the field of wearable technology and biomedical devices. These electronics maintain high electrical performance even under substantial mechanical deformation, making them ideal for continuous physiological monitoring, implantable devices, wearables, and other flexible electronics.



(Image courtesy the Bao Group)

Figure 1 High-performance, stretchable electronics 3D diagram, consisting of the stretchable substrate, gate electrode (bottom electrode), gate dielectric, S/D electrodes, semiconductor, channel encapsulation, jumper dielectric, top electrode (interconnect) and top encapsulation.



(Image courtesy the Bao Group)

Figure 2 Stretchable Electronics Photos (from left to right): High-speed circuit units fabricated on a 4-inch wafer, Electronics under large deformation, High-density transistor array attached to a single white sesame seed with 1,000 transistors in an area of 1?mm2 on a fingertip.

Stage of Development – Prototype
Future research includes encapsulation and interface engineering for improved device stability; power consumption reduction through intrinsically stretchable N-type, CMOS logic transistors; self-aligned source/drain fabrication process for enhanced performance and uniformity; and an on-skin Near Field Communication tag prototype for health monitoring.

Applications

- Human-machine interfaces and implantable devices, such as neural implants and gut probes
- Wearable electronics and high-fidelity physiological monitoring
- Sensorimotor function reconstruction for prosthetics
- Soft robotics / robotic sensors
- Flexible displays and other flexible electronics

Advantages

- **Soft**, will not scratch or damage tissues
- **Skin-like, stretchable, and durable**
  - **High deformability and mechanical robustness**
  - Maintains intimate tissue contact while accommodating movement and size changes
- First in class
  - First intrinsically **stretchable large-scale integrated circuit with > 1,000 transistors and > 500 logic gates**
- Smaller and faster
  - **Five times smaller** than earlier versions and a **record-high device density** of 100,000 transistors per square centimeter including interconnecting lines – more than twice a dense than previous records
  - A **high carrier mobility** of ~21.5 cm2V-1s-1 under 100% strain and a high transconductance (~0.8 ?S/?m) with ~ 1,000 times enhancement over all other stretchable transistors

    - A **record-high stage switching frequency** of > 1 MHz - one thousand times higher speeds than earlier versions
    - A **high drive current** that delivers approximately 2 ?A ?m?¹ at a supply voltage of 5V for a powerful and responsive electronic components that can function effectively under mechanical stress
    - Optimized circuit design with reduced parasitic capacitance and resistance

Publications

- Zhong, D., Wu, C., Jiang, Y., Yuan, Y., Kim, M. G., Nishio, Y., ... & Bao, Z. (2024). High-speed and large-scale intrinsically stretchable integrated circuits. *Nature, 627*(8003), 313-320.
- Smaller, more powerful stretchable electronics for wearables and implantables

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