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Composite Materials COMMENTARY

Fiber integrated circuits prepared by thin-film rolling

Ruijie Xie[1,*]

[1]Institute of Flexible Electronics (IFE, Future Technologies), Xiang'an Campus, Xiamen University, Xiang'an South Road, Xiamen 361102, China

*Correspondence: iferjxie@xmu.edu.cn

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Fiber-based electronics feature a microscale size in two dimensions, enabling minimally invasive independent access to tissues or narrow cavities for acquiring deep physiological signals from the human body. They can also be woven into wearable forms such as clothing, facilitating information exchange between humans and their environment. As such, they are regarded as one of the key platforms for the next-generation human–machine interface. Current fabrication methods for fiber devices primarily include fiber spinning, (micro)fluidics, functionalization, and coating of commercial fibers, and thermal drawing. However, most of these strategies are limited to the surface processing of fibers.[1] Although single-function components such as fiber-based sensors, energy devices, and displays have been successfully developed, the level of system integration remains significantly constrained owing to their soft, cylindrical geometry and limited surface area. Notably, the integration of signal processing units on fibers has yet to be achieved, representing a critical bottleneck in the advancement of this field.

The thin-film rolling strategy, which involves patterning circuits on ultrathin films and then rolling them into fiber form, fully leverages the interior space of fibers while maintaining compatibility with conventional planar fabrication techniques. This approach represents a critical pathway toward significantly enhancing the functional integration level of fiber-based devices. For instance, Yang Liu et al. fabricated a 1024-channel "Neuroscroll" probe by rolling a thin-film electrode with U-shaped conductive traces, enabling neural signal acquisition across brain-scale regions in non-human primates and humans.[2] Meanwhile, Ruijie Xie et al. integrated a 60-channel EMG electrode and a capacitive strain sensor into a single fiber with a diameter of 175 μm via rolling of a patterned stretchable film, allowing stable long-term monitoring of muscle strain and electromyographic signals in implanted rats.[3] Muhammad Khatib et al. developed high-resolution recording and stimulation electrodes on fibers—termed Spiral-NeuroString—using the same rolling strategy.[4] These advances underscore the strong capability of thin-film rolling in creating multifunctional fiber sensors. Nevertheless, most existing devices remain focused on electrophysiological signal monitoring and have not yet incorporated on-fiber signal processing units, indicating a key direction for future development.

Recently, employing a similar strategy, Zhen Wang et al. fabricated compo-

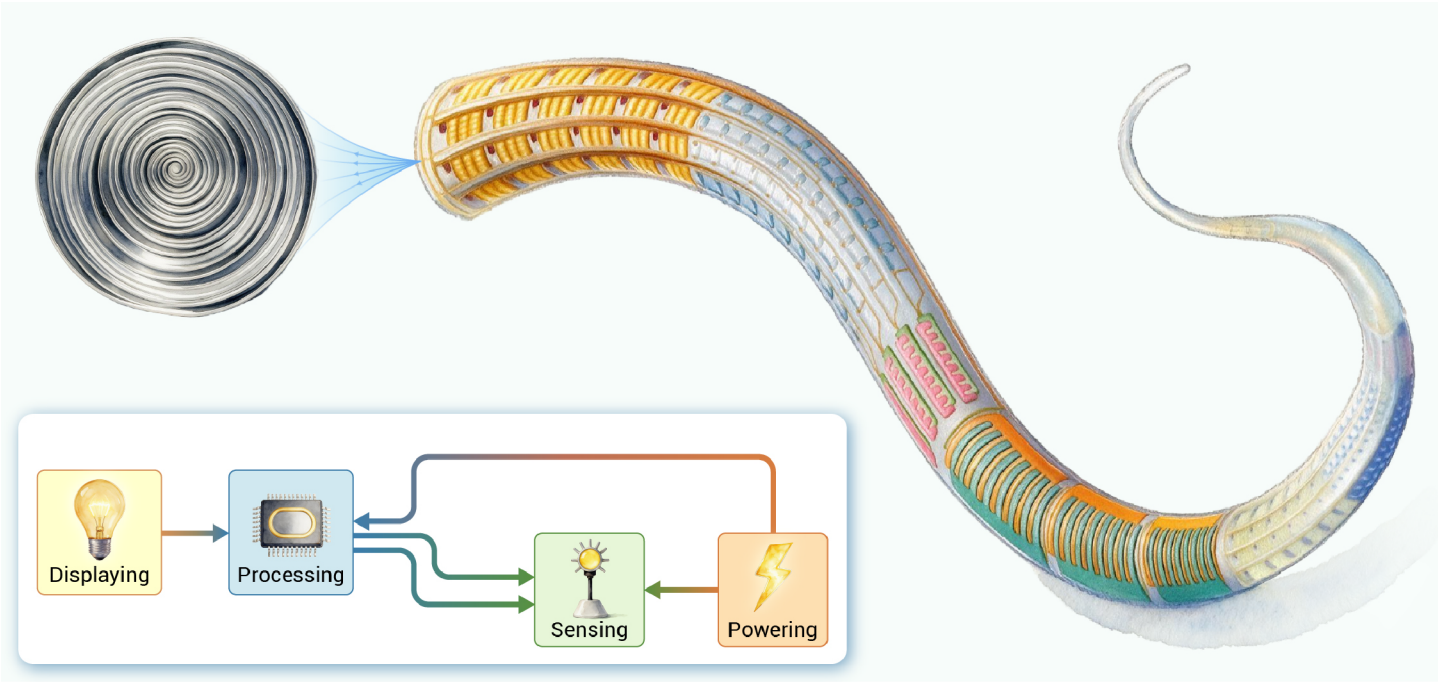


Figure 1. Fibre integrated circuits prepared by thin-film rolling.

nents such as transistors, resistors, and capacitors on thin films via photolithography, which were then rolled into fiber chips capable of information processing.[5] The integration density reaches 100,000 transistors per centimetre, which effectively satisfies the requirements for interactive fibre systems. The Fibre integrated circuits (FICs) can not only process digital and analogue signals similar to typical commercial arithmetic chips but also achieve high-recognition-accuracy neural computing similar to that of the state-of-the-art in-memory image processors. It could continuously operate for 12 h with a maximum temperature less than 34.5°C. The FICs are stable under harsh service conditions that bulky and planar counterparts have difficulty withstanding. The electrical properties of the FIC, including the on–off ratio and threshold voltage of transistors, remained stable (with < 5% variation) during complex deformations such as bending (1-mm radius), twisting (180° cm^{-1}) and stretching (30% strain). When the FICs was washed for 50 cycles, the threshold voltage and on-off ratio show negligible changes. After 10 days of 10% stretching and 1,000 cycles of 40°C thermal cycling, the FICs exhibited consistent resistance and current output, with variations of less than 6% and no circuit delamination observed.

Efficient information processors are the key components for building intelligent fibre systems. Previously, fibre systems mainly relied on external bulky chips for signal processing and control, an integration model that often resulted in challenges such as complex electrical interconnections, compro-

mised wearing comfort, and reduced safety for implantation. Fibre-integrated circuits have enabled a novel integration strategy for fibre systems by incorporating closed-loop functions into a single thin fiber. As an example, a 300-μm-diameter fibre system with different functional modules arranged in segments inside, such as sensing, display, power supply, energy storage, and signal processing functionalities, was developed. The cooperative processing units process the raw signals from the sensing inputs and then control the display outputs after logical judgement. The independent operation of FICs without external control units was successfully realized, enabling users to regulate the light emission of OLED modules by simply touching the integrated sensing point in the system. Furthermore, the fibre systems demonstrated skin-like softness, with a bending stiffness of 10^{-3} μN m^2, ensuring their seamless compatibility with the biological tissues. This characteristic makes the system highly suitable for both implantable and wearable applications. For brain-machine interfaces, integrating high-density electrode arrays with in situ signal-processing circuits as preprocessing units allows the system to achieve a signal-to-noise ratio of up to 7.5 dB for neural sensing outputs. Furthermore, FICs enable the fabrication of fully flexible, woven textiles capable of high-resolution displays and precise haptic feedback. This capability supports natural interaction in applications such as virtual reality, while maintaining durability and low power consumption.

Undoubtedly, the fabrication of fiber-based integrated chips (FICs) addresses the long-standing critical bottleneck in fiber electronics—the lack of on-fiber information processing capability. By integrating sensing, power, storage, and computation into a single fiber strand, this advancement eliminates the dependence on external rigid chips, thereby overcoming key constraints in interconnect complexity, flexibility, and implant compatibility. Consequently, it will significantly accelerate the development and deployment of flexible and intelligent fiber-based devices. Enabled by FICs, fiber systems now exhibit full mechanical flexibility comparable to conventional polymer yarns, while functioning as efficient and autonomous platforms. This transforms how electronic systems interact with the human body and environment, moving from attached external devices to truly woven, wearable, and even implantable forms. Such systems can seamlessly integrate into textiles, biological tissues, and daily objects without compromising comfort or functionality. It is foreseeable that we will soon be able to wear or even implant high - performance electronic computers on our bodies, turning science fiction into reality.

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DECLARATION OF INTERESTS

The author declares no competing interests.