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Engineering

Special Topic: Flexible Electronics and Micro/Nanomanufacturing

Flexible electronics and micro/nanomanufacturing

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Flexible electronics is an emerging technology, which breaks through the constraints of traditional rigid electronics, enabling electronic devices to adapt to various complex application scenarios. Meanwhile, a variety of functions including sensing, actuation and energy harvesting, promote flexible electronics to be widely used in healthcare, robotics, Internet of Things, and so on. Micro/nanomanufacturing is the key technology to realize flexible electronics. Through micro/nanomanufacturing, various micro/nano-scale electronic components such as transistors and sensors can be precisely fabricated on flexible substrates, endowing flexible electronics with excellent performance. On the other hand, the development of flexible electronics also provides new challenges for micro/nanomanufacturing, due to the new flexible materials and device morphology. Currently, flexible electronics and micro/nanomanufacturing have attracted great attention from researchers around the world. Scientists explore new materials and techniques to further expand the applications of flexible electronics. On this basis, we have organized a special topic on "Flexible Electronics and Micro/Nanomanufacturing" in *National Science Open* (NSO) to discuss the development of flexible electronics. The topic focuses on key issues in the design and manufacturing of flexible electronics. We have invited nine scientists from different fields to present their latest research findings and prospective analyses of flexible electronics systematically.

Nano-imprint is a promising micro/nanomanufacturing technology for flexible electronics, which has the advantages of high spatial resolution, low cost, and large-area processing. Xin *et al*. combine a simple magnetic-field-orientation and nano-imprinting process to fabricate a micropillar arrayed sensor [1]. The output of the sensor demonstrates an improvement of 115.5% due to the strain confinement effect, enabling a high sensitivity and rapid response capability to human motion.

Electrohydrodynamic printing also enables the efficient manufacturing of flexible electronics. Wang *et al*. fabricate embedded Ag/Cu metal-mesh flexible transparent electrodes (FTE) with a sheet resistance of 0.08 Ω/sq and 83.4% optical transmittance through self-confined electrohydrodynamic printing and selective electroplating of Cu [2]. The FTEs demonstrate good resistance stability under repetitive bending and stretching and exhibit excellent performance in flexible transparent heaters and electromagnetic shielding films.

Healthcare is a major application scenario of flexible electronics. Wang *et al*. report a body temperature-triggered, phase change dry electrode for long-term comfort electroencephalography (ECG) monitoring [3]. The phase transition at body temperature ensures superior signal quality and stability in long-term EEG monitoring. Tang *et al*. introduce a paradigm-shifting method for accurate and continuous blood pressure monitoring by using a flexible ultrasonic array [4]. The approach eliminates the need for frequent calibration and enhances accuracy, which holds promise for revolutionizing continuous blood pressure monitoring, contributing to early detection and intervention in hypertensive individuals.

In addition to sensing, flexible electronics can also be used as actuators in soft robotics. Liquid crystal elastomer (LCE) is an important soft actuating material capable of generating large and reversible actuation strain, which can be widely exploited for next-generation soft robots. Liu *et al*. summarize several possible approaches to enhance the actuation performance of LCEs, including reducing physical sizes, introducing active heating-cooling mechanisms, utilizing mechanical instability, and developing dielectric LCEs [5]. They also discuss the future research opportunities and challenges for the rapid actuation of LCEs.

The flexible sensor is one of the key components of flexible electronics, playing a fundamental role in flexible electronics. Flexible flow sensors are widely used for monitoring airflow, blood flow, breath, and water flow for applications in underwater robotics, human-machine interfaces, and bioelectronics. Li *et al*. systematically summarized the recent advances in flexible flow sensors and applications [6], ranging from the primary working mechanisms of these sensors, various applications and future trends.

A portable power supply, especially as a form of micro-energy system on-chip, is critical for the stable work of microelectronics of flexible electronics, especially for the sensors, actuators, modulators and display. Xu *et al*. summarized the state-of-the-art fundamentals and applications of micro energy systems on chip (MESOC). The microscale energy harvesting devices, advanced energy storage devices, high-efficiency management modules and system integration are comprehensibly discussed [7]. Considering energy harvesters based on semiconductors, such as solar cells, are typically susceptible to environmental multi-physics fields such as illumination, temperature, and humidity, affecting the energy conversion capabilities, the environmental multi-physics coupled tribovoltaic effect for energy harvesting emerged as a new rising star for powering flexible electronics. Feng *et al*. systematically summarized the recent progress of tribovoltaic nanogenerators (TVNGs), focusing on the electric outputs when capturing and converting a wide range of mechanical energies, including wind, rain, waves and illumination [8].

Manipulation of cells and bio-particles via acoustofuidics is an emerging branch of the flexible electronics community, playing a critical role in practical applications in clinical and research arenas. The acoustofluidic manipulation involves elevated frequencies, programmable control, and seamless integration with an auxiliary microfluidics system. Wang *et al*. summarized the recent progress in acoustofluidics manipulation towards cells and particles [9], especially focusing on the development of acoustic streaming manipulation, integration of acoustic manipulation with droplet microfluidics, and the coupling between acoustic radiation force and acoustic streaming for achieving improved precision, resolution, and flexibility in microfluidic particle control and sample screening.

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