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NEWS AND VIEWS

Flexible sensors based on hybrid materials

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With the rapid development of mobile Internet and intelligent devices, flexible electronic technology has attracted wide attention driven by the huge demand of the market. As one type of flexible electronic devices, flexible sensors have attracted great interest because of their promising prospects in artificial intelligence, medical health, and environmental protection. In recent years, flexible sensors with high sensitivity, selectivity, good deformability, reliable stability, and portability are urgently needed to meet the developments of artificial skin, human-computer interaction, point of care diagnostics and wearable electronic devices.

The selection of materials is critical for the fabrication of sensors. Excellent material properties contribute to flexible sensors with high sensitivity, wide detection, or superior durability. In fact, various high-quality materials, including metals, inorganic semiconductors and conjugated organic semiconductors, are some the most widely used and important ones. Compared with single-component materials limited by their inherent properties, researchers find that the hybrid composite of organic and inorganic materials combination can enhance the final performance of sensors, which brings synergetic advantages from the set of individual physicochemical properties combining the excellent flexibility of organic polymers with the structural support and good conductivity of inorganic semiconductors. What's more, the function of the materials can be "cut" and "assembled" to meet the demands of people by adjusting the proportion of the organic phase and the inorganic phase components in hybrid materials.

In recent years, various flexible sensors based on hybrid materials have been fabricated to detect different signal stimuli such as pressure, deformation, humidity, light, heat, gas, current. For example, Shen's research group reported a strain sensor based on the nanostructures of poly (vinylidene fluoride–trifluoroethylene) (PVDF-TrFE) fibers/ZnO nanowires composites[1]. The as-fabricated device can also function properly when transferred to the fingers to detect muscle movements such as finger bending or straightening. Polydimethylsiloxane/Ag-nanowires composite dielectrics can be used to fabricate a flexible, transparent and ultra-sensitive capacitive pressure sensor[2]. Capacitive sensors generally exhibit better linearity, less hysteresis and better repeatability than resistive sensors, but resistive sensors are generally more sensitive[3]. Temperature sensors obtained via combining the pyroelectric polymer and $BrTiO_3$ nanomaterial have been demonstrated as an accurate device with standard deviation of 0.006–0.012 Kelvin[4]. TiO_2-nanoparticles/polypyrrole and TiO_2-nanoparticles/polypyrrole/poly-[3-(methacrylamino) propy] trimethyl ammonium chloride composite thin films formed by the in-situ photopolymerization can be utilized to fabricate flexible resistive-type humidity sensors, where different centration of water vapor in air leads to a change of the material conductance[5]. For optical sensing, organic–inorganic poly(3-hexylthiophene)/CdSe-nanowire heterojunction photodetectors have exhibited good photoelectric performance and potential application prospect as image sensors[6]. In addition, the performance of sensing elements is largely determined by the structural design of a sensor. For example, flexible pressure sensors based on a Ti_3C_2/natural-microcapsule-biocomposite film mimicking the skin structure have excellent flexibility, mechanical deformability, and the ability to detect weak physiological signals[7]. Recently, gas sensors composed of ultrathin single-walled carbon nanotubes and chitosan with reference to the three-dimensional biomimetic templating of a structurally hierarchical butterfly wing enable the highly selective detection of diabetes-related volatile organic compounds[8]. With the further development of interdisciplinary research, more flexible hybrid materials with good electrical properties will be developed. Emerging organic-inorganic hybrid perovskite materials, such as $CH_3NH_3PbI_3$ ($MAPbI_3$) and $MAPbBr_3$, have exhibited highly attractive photoelectric characteristics. These materials are promising candidates for high-performance flexible image detectors[9]. Electroluminescent sensors composed of hybrid materials also have greatly competitive advantages in electronic skin applications through visualizing accurate stimulus distribution[10], the reliability of the pressure map by sensors can be proved (Fig. 1).

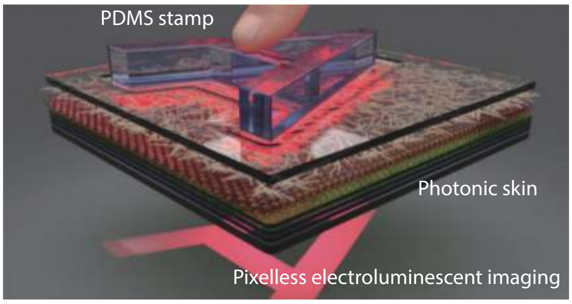

Fig. 1. (Color online) Schematic illustration of the photonic skin. Reproduced with permission[10] . Copyright 2020, Nature Publishing Group.

At present, organic/inorganic hybrid sensors remain in the research & development stage. The physicochemical mech-

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anism of hybrid materials needs to be further studied through optimizing hybrid materials or designing hybrid structures. Moreover, most sensor systems still require external power sources, which limits the use of sensors in fields such as flexible wearable electronics and medical health. Self-powered materials based on piezoelectric, frictional or thermoelectric effects can be envisioned. We believe that the unique advantages provided by hybrid materials, coupled with innovations in sensor device architectures, can greatly accelerate the development of flexible sensors in the next few years.

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