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Seamless on-skin and self-powered hybrid ZnO-based thin films: progress and perspective

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A B S T R A C T

The free-form thin film electronics invented to laminate onto the skin imperceptibly provide human skin with flexible electrical components for health and information technologies. As of now, the 3-D deformable thin film of hybrid ZnO-based nanostructures system proves to have the capability to interact with the human body. The expansion of the usage, specifically in electronic skin (e-skin) thin film ranging from wearable to e-textile, is tremendously progressing, besides the limitation to both the biocompatible power sources, high-resolution display and conformability with aesthetics design still exist. The recent trend for free-form display that can stretch and embed in textiles with crumple-ability for use in the realistic tactile sensation while maximising throughput and minimising cost is poised to change the way the interaction with e-skin devices is handled. The review also analyses the current state of the 3-D free-form displays based on hybrid ZnO thin film and scrutinises the technological challenges not only focusing on hybrid ZnO thin film but also other nanomaterials as well to accomplish the next generation of on-skin thin-film electronics.

1. Introduction

To date, much effort has been devoted in this hyper-connected society to investigating the next-generation electronic skin (e-skin) pyroelectric and piezoelectric nanogenerators thin film [1–3]. The nano-based thin film displays have become an indispensable part of human life, which evolved to have better form factors and functionality. These include flexible architectures, ease-of-use, lightweight, uniform high responsivity, high stability, versatile control of multiple stimuli responses, energy storage, self-luminous and sensitivity/selectivity. These also relate to the emulating tactile sensing and processing as humans do in bio-realistic nerves-based thin film, which is essential in advanced bio-inspired sensory systems to process diversified multimodal/multi-task recognition sensory inputs. By mimicking the properties of human skin that demand integration of an 'ideal' low-power consumption system over large area electronic on non-conventional flexible substrates, they are capable of not only detecting and distinguishing simultaneous tacting inputs but also recognising the operational parameters (*e.g.*, contact force, sliding speed/strike, *etc.*). Both tactile sensing and stretchable/deformable parameters are vital because tactile features allow the skin to interact with the surrounding environment, whereas skin elasticity/stretchability enables free movement [4–6]. In this regard, most of the reported structured e-skin devices comprised of sensing nanomaterials on flexible substrates (*e.g.,* polymer, paper, fabrics, *etc.*) as their flexibility and performance firmly rely on the interconnection between the absorption nanolayer and substrate. It is worth noting that the flexible substrate, especially plastic-based architecture widens the emulation and memorising capabilities that permit the human response to adapt to their artificial bio-inspired sensory system via touch in addition to vision and hearing.

Considering these issues, the realisation of generating an on-demand voltage-controlled soft material system that modulates manifold crucial skin functions is a must. These feelable displays require well-aligned highly crystalline semiconductor nanostructures that have uniform responses over large areas, safe, convenient, and primarily related to the on-skin and under-skin implantable displays [7–9]. These ultimate wearable displays need the utmost free-form deformation results from the dynamic movement of the skin layer, large reversible biaxial (*x-y* axes) stretchability and unconventional ultralight thinness of thin film apart from low power consumption and temperature independence. These configuration capabilities indicate interactive operation and

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