Gradient-Modulus PDMS-CNT Composite Materials for Robotic Tactile Perception

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Three-dimensional (3D) microstructures have attracted considerable attention due to their significant advantages in softness and compressibility, showing potential applications in biomedical monitoring, human-machine interaction interfaces and robotic tactile sensing. For flexible pressure tactile sensors, the mechanical properties of the structured dielectric layer play a crucial role in determining the performance of the sensor. Sensitivity and detection limit are important characteristics of pressure sensors which determines the ability to detect subtle pressures and usually depend on the deformation of the dielectric material under pressure: the greater the deformation, the higher the sensitivity, but the lower the detection limit. Increasing voids in the dielectric layer and enhancing its compressibility through microstructural engineering is an effective strategy for achieving high sensitivity in sensors. The presence of micropores makes the structure more compressible, significantly improving sensitivity compared to solid dielectric materials. However, this high sensitivity is limited to low pressure conditions due to Young's modulus constraints. Constructing gradient porous materials in layers is an effective way to address such issues, but the design and preparation of complex pores requires the further development of advanced or complex fabrication processes. This paper proposes a simple strategy for adjusting the mechanical properties of porous materials based on Polydimethylsiloxane (PDMS), using freeze-drying technology to prepare a carbon nanotube (CNT) conductive scaffold and introducing PDMS as a filling material. Negative pressure filling technique for localized filling of PDMS into the pores of the stent surface. The resulting PDMS-CNT composite material exhibits anisotropic electrical conductivity, manifesting different force-resistance characteristics under normal and tangential forces. The Young's modulus of the composite material displays a gradient distribution, with higher values around the periphery and lower values at the center, ensuring that the dielectric material can withstand higher pressure load and enables the pressure sensor to cover a wider pressure sensing range (0-150 kPa) while maintaining high sensitivity.