Size-Dependent Percolation and Junction-Dominated Charge Transport in Graphene-Polyurethane Piezoresistive Sensors

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Abstract

Piezoresistive polymer nanocomposites are foundational to the evolution of soft robotics, wearable diagnostics, and structural health monitoring. While graphene is a premier conductive filler for these applications due to its exceptional intrinsic conductivity and mechanical robustness, the fundamental structure-property relationships governing its performance in stretchable matrices remain poorly understood[1]. Current research typically focuses on filler loading and matrix chemistry, often overlooking the decisive influence of nanosheet geometry-specifically lateral size and thickness on network formation and strain sensitivity.

In this work, we systematically isolate the effect of graphene morphology by incorporating size-selected nanosheets, produced via liquid-phase exfoliation, into a polyurethane elastomer. By spanning a wide range of controlled dimensions, we investigate the transition from static electrical percolation to dynamic electromechanical response under large-scale deformation. Our analysis reveals that classical geometric models are insufficient to describe the transport behavior in these soft systems. Instead, we identify a complex interplay between nanosheet electronic structure, polymer-mediated junctions, and three-dimensional network topology. These results challenge conventional design assumptions and provide a new physical framework for the predictive optimization of graphene-based flexible sensors.

References

[1] Garcia, J. R., O'Suilleabhain, D., Kaur, H., & Coleman, J. N. (2021). A Simple Model Relating Gauge Factor to Filler Loading in Nanocomposite Strain Sensors. *ACS Applied Nano Materials*, *4*(3), 2876-2886. https://doi.org/10.1021/acsanm.1c00040