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Simulation and Analysis of Mems-Based Flexible Capacitive Pressure Sensors with COMSOL

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Abstract : The technological advancements in Micro-Electro-Mechanical Systems (MEMS) have significantly contributed to the development of new, flexible capacitive pressure sensors,which are pivotal in transforming wearable and medical device technologies. This study employs the sophisticated simulation tools available in COMSOL Multiphysics® to develop and analyze a MEMS-based sensor with a tri-layered design. This sensor comprises top and bottom electrodes made from gold (Au), noted for their excellent conductivity, a middle dielectric layer made from a composite of Silver Nanowires (AgNWs) embedded in Thermoplastic Polyurethane (TPU), and a flexible, durable substrate of Polydimethylsiloxane (PDMS). This research was directed towards understanding how changes in the physical characteristics of the AgNWs/TPU dielectric layer—specifically, its thickness and surface area—impact the sensor's operational efficacy. We assessed several key electrical properties: capacitance, electric potential, and membrane displacement under varied pressure conditions. These investigations are crucial for enhancing the sensor's sensitivity and ensuring its adaptability across diverse applications, including health monitoring systems and dynamic user interface technologies. To ensure the reliability of our simulations, we applied the Effective Medium Theory to calculate the dielectric constant of the AgNWs/TPU composite accurately. This approach is essential for predicting how the composite material will perform under different environmental and operational stresses, thus facilitating the optimization of the sensor design for enhanced performance and longevity. Moreover, we explored the potential benefits of innovative three-dimensional structures for the dielectric layer compared to traditional flat designs. Our hypothesis was that 3D configurations might improve the stress distribution and optimize the electrical field interactions within the sensor, thereby boosting its sensitivity and accuracy. Our simulation protocol includes comprehensive performance testing under simulated environmental conditions, such as temperature fluctuations and mechanical pressures, which mirror the actual operational conditions. These tests are crucial for assessing the sensor's robustness and its ability to function reliably over extended periods, ensuring high reliability and accuracy in complex real-world environments. In our current research, although a full dynamic simulation analysis of the three-dimensional structures has not yet been conducted, preliminary explorations through three-dimensional modeling have indicated the potential for mechanical and electrical performance improvements over traditional planar designs. These initial observations emphasize the potential advantages and importance of incorporating advanced three-dimensional modeling techniques in the development of Micro-Electro-Mechanical Systems (MEMS)sensors, offering new directions for the design and functional optimization of future sensors. Overall, this study not only highlights the powerful capabilities of COMSOL Multiphysics® for modeling sophisticated electronic devices but also underscores the potential of innovative MEMS technology in advancing the development of more effective, reliable, and adaptable sensor solutions for a broad spectrum of technological applications.

Keywords : MEMS, flexible sensors, COMSOL Multiphysics, AgNWs/TPU, PDMS, 3D modeling, sensor durability
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