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A Study on Nanomaterials Incorporated Smart Materials for Flexible and Wearable Sensors

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Abstract

The latest advancements in electronic sensor technology are pushing the need for materials that are not only lightweight but also mechanically flexible, stretchable, and budget-friendly. That's where polymer-based composites come into play. By reinforcing them with hybrid nanomaterials, these composites deliver outstanding electrical properties while being light, flexible, and stretchable. As a result, flexible composites made from polymers and nanomaterials are gaining traction as the next generation of smart materials. They're being extensively researched for a variety of applications, including wearable electronic devices, supercapacitors, flexible displays, touch screens, health monitoring systems, motion detection, facial recognition, and human-machine interfaces, among others. In this study, we showcase the fabrication and testing of flexible composites and sandwich structures that incorporate nanomaterials with poly (dimethyl siloxane) (PDMS) for use in wearable sensors. We explored two different methods to create these PDMS-based flexible materials. The first method involved mixing various weight percentages of nanomaterials into the PDMS polymer matrix using a straightforward solution mixing process. The second method focused on creating a sandwich structure made of PDMS/nanomaterials coated parafilm/PDMS through a simple and cost-effective technique.

Keywords: Electronic Sensor**,** Pdms**,** Nanomaterials.

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Introduction

Sensors are essential components in nearly every tech sector we encounter today, from cars and smartphones to computers and smartwatches, as well as in healthcare, household items, manufacturing, and much more. In our tech-driven world, sensors play a crucial role in our daily lives, helping us monitor our health, detect human movement, track exercise and sports activities, and even keep an eye on the weather and environment. Over the past few decades, advancements in flexible materials like polymers, fabrics, and textiles have led to the creation of flexible sensors, and the demand for these wearable technologies is on the rise globally. Traditional electronic devices typically rely on thin-film materials such as silicon, metals, and metal oxides (like ITO, gold, and copper), along with organic materials. While these conventional sensors can deliver impressive electrical performance, they often struggle to provide accurate physiological readings because they can't maintain a strong connection with the human body (Kim et al., 2016).

Literature Review

In this literature review, we will focus specifically on resistive-type flexible, stretchable, and wearable strain sensors that relate to the work presented in this thesis. In this literature review, we dive into flexible sensors that utilize PDMS along with various nanomaterials, including silver nanoparticles (AgNPs) and carbon-based options like graphene, reduced graphene oxide (rGO), and carbon nanotubes (CNTs). some of the PDMS-based resistive flexible and wearable strain sensors that have been reported over the past few years, along with their performance characteristics (Zheng et al., 2021). The following section discusses some of the most recent and noteworthy studies. For instance, Y. Tang and colleagues introduced an ultrasensitive strain sensor made from rGO microtube/PDMS that is stretchable. This sensor demonstrated impressive sensitivity (GF = 630 at 21.3% applied strain) and durability, showing promise for detecting human movement even under significant strain (Ghosh et al., 2022).

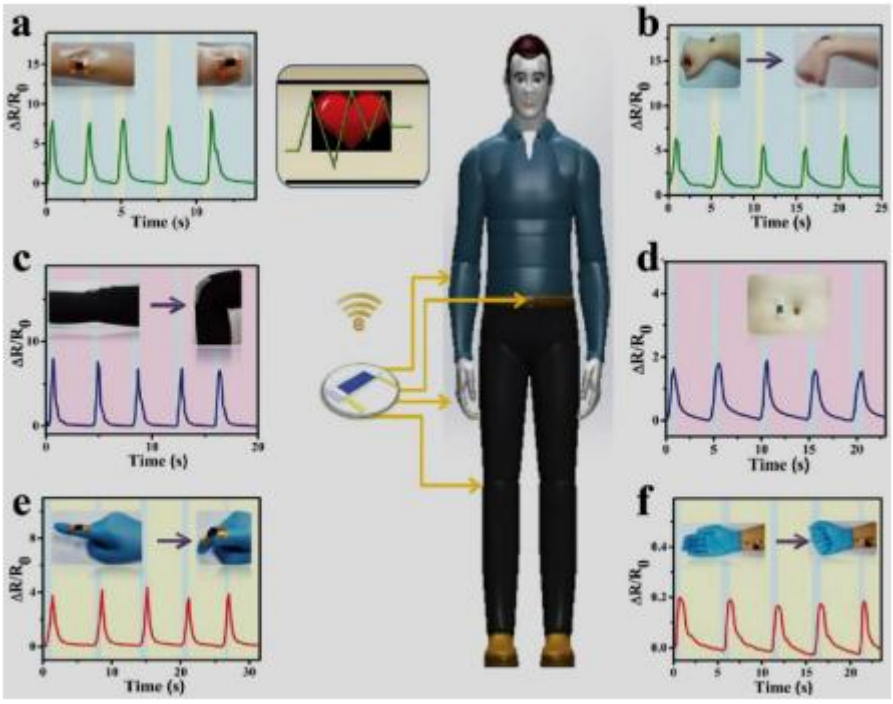

Fig. 1: Various Human Motion Detection by Using Sensor

Sensor Performance

The GE/PDMS composites demonstrated excellent conductivity, with a resistance of just 9.4Ω at 25 wt% GE loading. They tested this strain sensor for detecting subtle human motions, such as finger bending. G. Li and team introduced a straightforward method to create a uniform 3D conductive network by wrapping rGO nanosheets around an aligned TPU fibrous mat and encasing the sensing layer in PDMS (Libertino et al., 2018). The combination of the 3D conductive network made from rGO/TPU and the stretchable PDMS layer led to a broad reversible sensing range from 0% to 150%, high sensitivity of 593, solid stability, and a rapid response time of 160 milliseconds. This sensor was used to monitor movements in various body parts, as illustrated in Fig. 2.

The electrical, dielectric, and mechanical characteristics of polymer-nanomaterial composites hinge on how well the nano-filler materials are distributed within the polymer matrix

(Xie et al., 2023). Additionally, the interactions between the nano-fillers and the polymer chains, as well as the interactions among the fillers themselves, are crucial for achieving the desired electrical or dielectric properties. Nano-fillers like graphene and its derivatives often tend to clump together in the polymer matrix. Similarly, carbon nanotubes (CNTs) can get tangled up with one another. This clumping or restacking happens due to π-π interactions and van der Waals forces (Yao et al., 2020). To tackle this agglomeration, functionalizing graphene oxide (GO), reduced graphene oxide (rGO), and CNTs through various methods can be effective (Libertino et al., 2018).

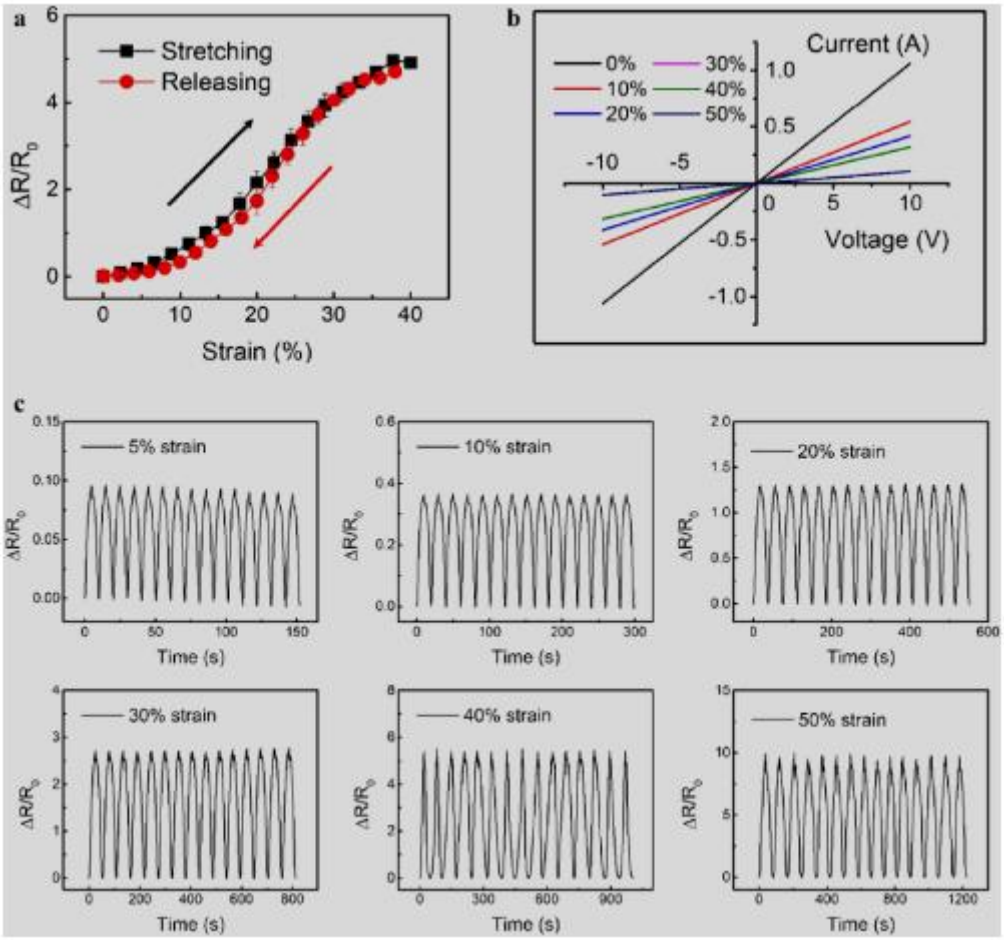

Fig. 2: Graphical Representation of Strain Sensing Performance

Challenges

Many existing methods for creating strain sensors rely on expensive equipment, and the production of flexible sensors often requires a significant amount of nanofiller materials. The flexible and stretchable polymer materials used in these wearable strain sensors must meet biocompatibility standards, ensuring they don't hinder blood circulation or cause skin irritation, inflammation, or bacterial infections (Yao et al., 2020).

Results

It turns out that the resistance changes almost linearly with the voltage applied. Additionally, the sensors' resistance goes up when they experience bending and twisting. The PDMS/Ag_SWCNT-Parafilm/PDMS sample shows minimal resistance change when bent, but it spikes significantly when twisted. Interestingly, the resistance remains fairly stable even as the voltage varies. The same trend is observed with the PDMS/Ag_rGO-Parafilm/PDMS sample, whsere resistance doesn't fluctuate much with the applied voltage either. Experimental results reveal that all samples exhibit a greater increase in resistance during twisting compared to bending. These findings suggest that the samples we created are quite effective for detecting both bending and twisting deformations, and we also conducted further tests by applying longitudinal strain to all of them (Yao et al., 2020

; Jayathilaka et al., 2019)

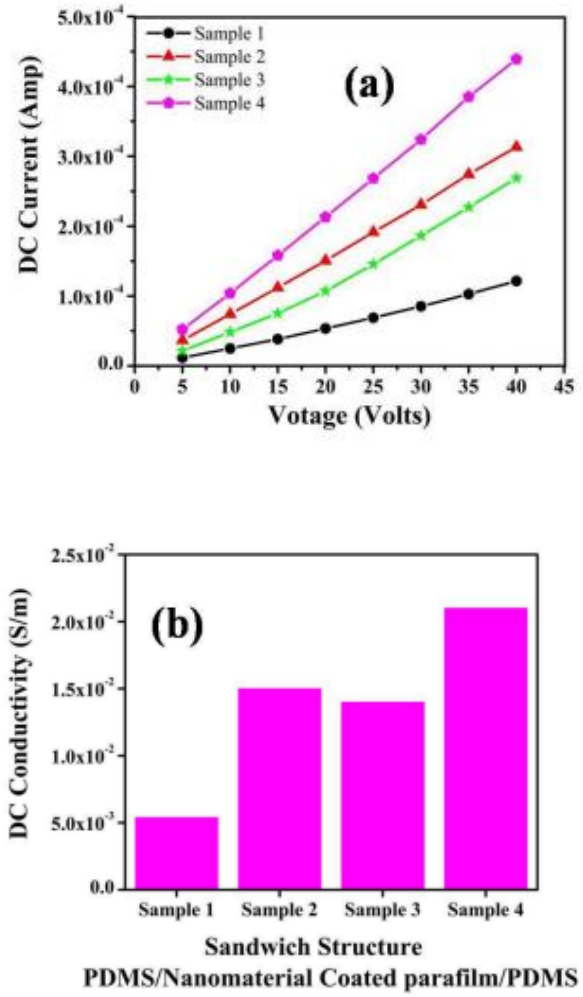

Fig. 3: I-V Characteristics Curve of the Sandwich Structure of Pdms

We carried out three different sets of tests to effectively monitor various movements of body parts in real-time, focusing on the finger, wrist joint, and elbow joint. We attached sensors to the joints of the finger, elbow, and wrist, ensuring they were positioned just below the midpoint of the samples. To test the sensors, we applied strain by bending the joints of the finger, wrist, and elbow at an angle of about 90 degrees, as illustrated in Fig. 4. As you can see in Fig. 4, the sensors are capable of detecting even the smallest movements, like the bending of a finger or wrist, where the change in resistance (ΔR/R0) is minimal due to the lower strain on the sensitive material (Jayathilaka et al., 2019). On the other hand, they can also pick up larger movements, such as those of the elbow, where the change in resistance is significantly greater because the muscles in the hand exert much more strain on the sensitive material.

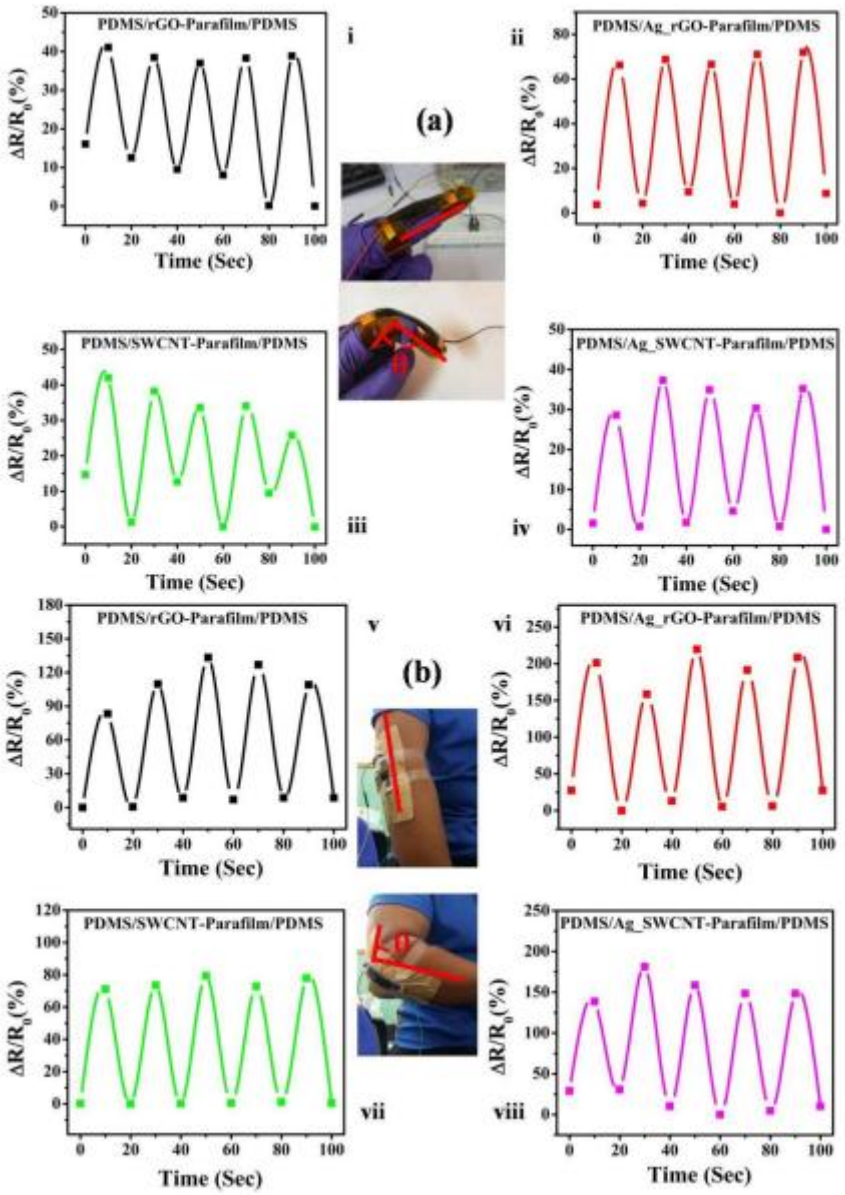

Fig. 4: Detection of Various Movements of the Human Body by the Fabricated Sensors

We measured how the resistance changes when the sensing material is slightly deformed as the joints bend. To get the best results, we set a 10-second interval in our data acquisition system between bending the joints and letting them relax. This way, we could capture the optimal change in resistance. We recorded the data points according to the cycle of motion for both bending and relaxing the joints.

Conclusion:

We created PDMS-based sandwich structured sensors by applying nanomaterials like rGO, Ag_rGO, SWCNT, and Ag_SWCNT onto parafilm films using a budget-friendly method that ensures no material is wasted. These sensors have demonstrated impressive responsiveness to applied strain, along with great sensitivity, flexibility, and stretchability. The resistive-type strain sensors excel at detecting various movements in real-time, such as the motion cycles of the index finger, elbow, and wrist joints, all while maintaining a quick response time. Notably, the strain sensors made from nanomaterials like Ag_rGO and Ag_SWCNT have shown superior performance in tracking human motion over extended periods. This means that PDMS/Nanomaterials coated parafilm/PDMS-based sandwich structured flexible strain sensors could be a game-changer for wearable devices aimed at recognizing human movement.

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