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Research Article

Graphene Aerogel Based Nanogenerators for Health Monitoring

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Abstract

Artificial intelligence (AI) and machine learning (ML) lead a new era in remote health monitoring and preventive care, while making ZnO based strain sensor and nanogenerators a very attractive data collection tool. Here, we demonstrate flexible piezotronics strain sensor/nanogenerator, based on chemically modified graphene aerogels to monitor human hand/finger motions as well as gait asymmetries. The I-V characteristic of the sensor shows high sensitivity towards detection of human motion with a good gauge factor of as high as 95 has been demonstrated.

Keywords: Nanogenerator, Wearable electronics, Strain sensor, Piezotronics, Piezoelectric, Sensors, ZnO nanoparticles, Aerogels, Graphene, Health monitoring.

Sağlık İzleme için Grafen Aerojel Bazlı Nanojeneratörler

Öz

Yapay zeka (AI) ve makine öğrenimi (ML), uzaktan sağlık izleme ve önleyici bakımda yeni bir döneme öncülük ederken, ZnO tabanlı gerinim sensörünü ve nanojeneratörleri çok çekici bir veri toplama aracı haline getiriyor. Burada, insan eli / parmak hareketlerini ve yürüyüş asimetrilerini izlemek için kimyasal olarak modifiye edilmiş grafen aerojellere dayanan esnek piezotronik gerinim sensörü / nanojeneratör gösteriyoruz. Sensörün I-V özelliği, insan hareketinin algılanmasına karşı yüksek hassasiyet ,95 kadar, gösterge faktörü bulunmuştur.

Anahtar Kelimeler: Nanojeneratör, Giyilebilir elektronik, Gerinim sensörü, Piezotronik, Piezoelektrik, Sensörler, ZnO nanopartikülleri, Aerojeller, Grafen, Sağlık izleme.

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1. Introduction

With the rise of Artificial Intelligence (AI) and Machine Learning (ML) techniques, flexible piezotronics strain sensors and nanogenerators are a very attractive tool for data collection, especially with remote health monitoring and preventive care. Their high sensitivity and fast response times makes them an ideal candidate for effective data collection for these important applications, especially, since their nanostructured architectures have become very intriguing to researchers due to the potential benefit of flexibility, energy harvesting capability, and easy deployment [1-4]. Various nano-architectures have been designed and fabricated from many different piezoelectric materials [1-5]. Among these piezoelectric materials, a large number of applications use ZnO nanomaterials, due to its unique advantages, such as biocompatibility, low cost, easy synthesis, and optical properties [5-10]. Especially ZnO, which received great attention after Wang's group ZnO nanowire based nanogenerator formation [5], that demonstrated excellent strain induced response properties. Thus, ZnO nanowires (ZnO-NWs) have become a center of attention in building high sensitive strain sensors. However, ZnO-NWs requires compatible host materials that are electronically coupled with ZnO and allow flexible adaptive movements [6-7]. Because, without the proper host material, ZnO-NWs can be very brittle and not suitable for flexible applications, especially under stress, ZnO layer is more prone to cracking and failure [6-11]. Thus, ZnO-NWs is constantly embedded in various different materials to build flexible strain sensors, including different carbon fiber, carbon paper, polymer composite materials, etc [6-10].

In this paper, we present the fabrication and application of a flexible piezotronics strain sensor/nanogenerator, architecture based on chemically modified graphene aerogel (GA). The strain sensor fabricated with chemically induced ZnO nanoparticles on graphene aerogel substrate, and strain sensing, both static and dynamic loading, are demonstrated. The I-V behavior of the device showed high sensitivity with a gauge factor (GF) of as high as 95.

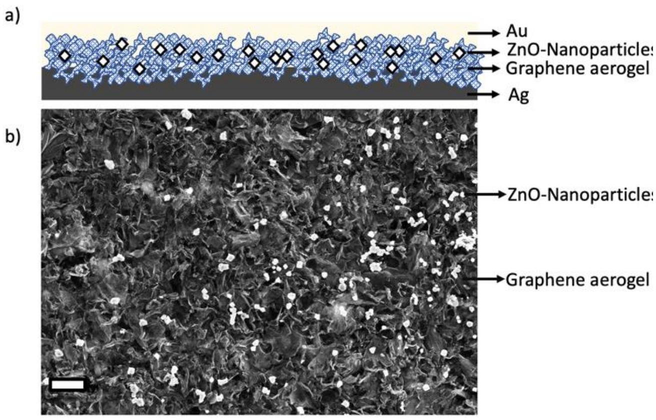

Figure 1 a) The schematic diagram ZnO-Nps/GA strain sensor. (b) The SEM image of the ZnO-Nps/GA.

2. Results and Discussion

The schematic of the strain sensor device and SEM image is shown in Fig. 1. Graphene aerogels are synthesized by the gelation of a graphene oxide (GO) suspension. GO was suspended (2 wt%) in deionized (DI) water and sonicated at ~ 40kHz. Then, in a glass vial, 5ml of the GO suspension was mixed with 500 µL of concentrated NH4OH (30%). This solution was then transferred to a glass slide attached to rubber rectangular molds and cured in an oven at 80°C for 72h. The resulting gels were removed from the molds and subject to chemical exchange with acetone and DI water, followed up by super critical CO2 drying and pyrolyzed, carbonized, at ~1000°C under a N2 atmosphere for 3h [12-14]. Resulted GA materials were then mixed with a ZnO nanoparticle (ZnO-Nps) solution (<100 nm) which is a very important step to produce high quality ZnO-Nps/GA interfaces [12]. Finally, the whole device architecture was developed with contacts, Au and Ag, top and bottom contact, respectively, for GA, and encapsulated with polydimethylsiloxane (PDMS) elastomer, which is very important to stabilized GA interconnected flakes.

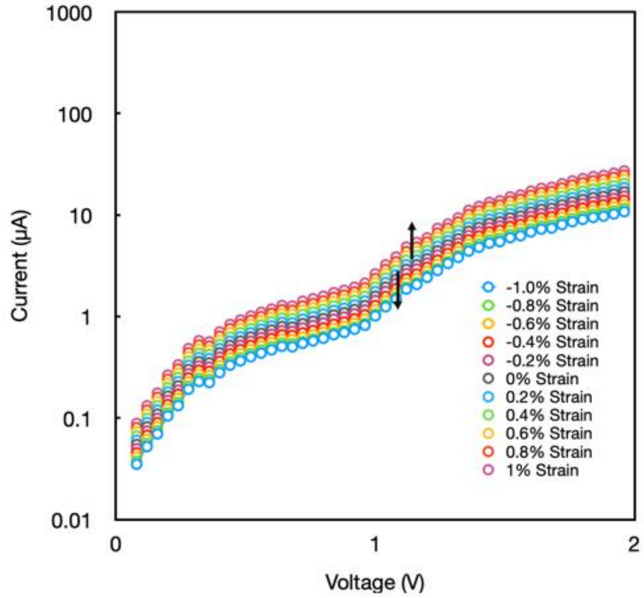

Figure 2 I-V characteristic of the strain sensor at different strain.

The characterization of the I-V behavior of the strain sensor was investigated under static loading, shown in Fig. 2. At different strains, Schottky barrier height (SBH) and current values in rectifying curves alters, shift upward and downward with compressive and tensile strain, respectively. The stability of the device was tested with many repeated full cycles of compressing and stretching, at a frequency of 2 Hz under a fixed bias of 1V (Fig. 3). It can be clearly seen that the current reaches approximately the same values in each cycle, which indicate a stable behavior and desirable electron transport behavior, due to good Schottky junction formations [6,7,16-17]. To determine the performance of the strain sensor, gauge factor is calculated 95 by

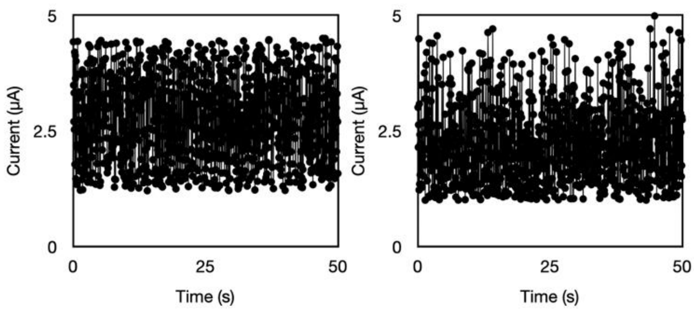

Figure 1 Current response of the strain sensor (a) compressed, (b) stretched at a frequency of 2 Hz under fixed bias 1 V.

the equation GF = (ΔR/R)/Δε, where R is the initial resistance, ΔR is the changed resistance, and Δε is the strain change (Fig. 5c). The best of our knowledge, this calculated value is much higher than values reported for ZnO/carbon based strain sensors [6,7].

We also tested the transient decay of electrons at a fixed strain (Fig. 4), strain sensors stretched for 100s and then released for 10s repeatedly. It can be clearly seen that strain sensor quickly recover to initial conditions once the stretch registered. The decay during the hold is due to ZnO-Nps charge trapping behavior which is widely reported in the literature. This experiments also clearly shows that graphene aerogel is a good host material to accommodate ZnO-Nps, which commonly have cracking and adhesion problem during dynamic loading [18,19]. GA enables continuous active contact to ZnO at any loading condition due to its flexibility and high porous structure.

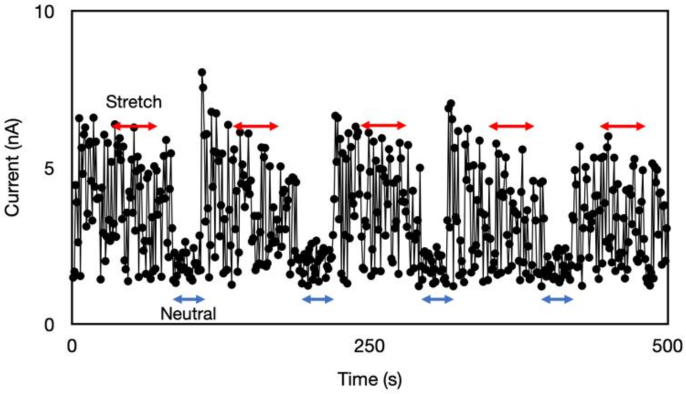

Figure 2 Dynamic response of the strain sensor at a frequency time dependent piezo electric effect repeated cycle.

3. Conclusions and Recommendations

In summary, we demonstrated a technique to produce a cost effective flexible piezotronics strain sensor based on nanoparticle enhanced graphene aerogel substrates. Graphene aerogels provide an excellent receiving substrate to ZnO nanoparticles, that piezoelectric effect can be maintained under any strain condition. I-V characteristic of the device demonstrates consistent SBH modulation and high sensitivity under static and dynamic loading. Moreover, it exhibits a very good gauge factor, flexibility, and stability so that important physiological changes can be detected, such as respiratory rate, movements of gait, and pulse detection. This device can be used with various healthcare applications such as remote health monitoring, preventive medicine, and diagnosis.

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The health monitoring features of these sensors were also studied. To study the respiratory rate and pattern, the sensor was placed on the chest of the subject. It can be clearly seen from Fig. 5b that the sensor accurately responded to each deep inhaling event, every 10s. To study the movements of gait, the sensor was placed on the left foot of the subject and it recorded each step (Fig. 5b). Moreover, a wrist pulse of 73 beats per minute (bpm) was successfully measured (Fig. 5c).

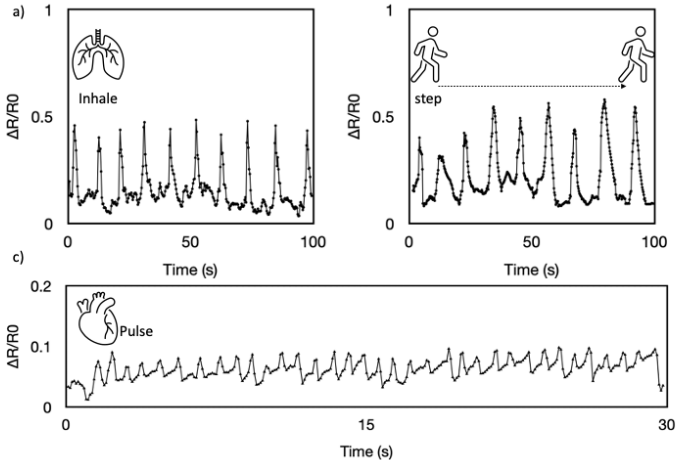

Figure 3 Physiological change detection (a) of breathing events. (b) gait movement c) pulse measureme

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