Graphene based strain sensor with LCP substrate

M Nie, H S Yang and Y H Xia

Key Laboratory of MEMS of Ministry of Education, Southeast University, Nanjing, China
E-mail: mnie1980@163.com

Abstract. A flexible strain sensor constructed by an efficient, low-cost fabrication strategy is presented in this paper. It is assembled by adhering grid-like graphene on LCP substrate. Kinds of measurement setup have been designed to verify that the proposed flexible sensor device is suitable to be used in health monitoring system. From the experiment results, it can be proved that the sensor exhibits the following features: ultra-light, relatively good sensitivity, high reversibility, superior physical robustness, easy fabrication. With the great performance of this flexible strain sensor, it is considered to play an important role in body monitoring, structural health monitoring system, fatigue detection and healthcare systems in the near future.

1. Introduction
Flexible strain sensors are important for various future applications, such as wearable sensors[1-2], touch-on flexible displays[3,4], soft robotics[5,6] and structural health monitoring system[7]. The research concentrates on the characterization of structures, fatigue studies of materials and so on to monitoring damage detection, which can be realized by measuring deformations of the objects with strain sensor embedded inside. Moreover, it has given significant advantages to instead the traditional methods in monitoring human physiological signals to evaluate human health even at the current age of highly developed medical technology. Sensors based on various nano materials such as nanoparticles[8], nanotubes[9], nanowires[10], thin films[11–13] and their assemblages have been attracting interest recently due to their strain sensing characteristics. The strain sensors based on new materials (such as ZnO nanowires, carbon nanotubes etc.) have exhibited distinct advantages and performances, for instance, fast response, excellent strain gauging performances, good conductivity, high-transparency, superior physical robustness, and easy fabrication[10]. For graphene-based sensors, the electrical conductance[14] and the principal vibrational frequencies of graphene strongly depend on its crystal structure which can be controlled by applying strain, such characteristics make graphene film can be utilized in strain sensor to obtain high sensitivity[15].

In addition, to date, the substrate material of the flexible electronic device is popular chosen Polydimethylsiloxane (PDMS), because PDMS has excellent material properties such as high elasticity, biocompatibility, and it is easy to be integrated with two dimension materials. However, the problem is the fabrication process of PDMS is complicated. Especially to fabricate micro patterns inside PDMS, such as cube, line or pyramid to increase the sensitivity of the sensor which always need the patterned Si moulds, the Si moulds are always complicated and expensive. Despite the excellent pressure sensing performance, it still has a lot of difficulties to monitoring human motion signals by the sensors because of the complicated structures, fabrication process, sophisticated equipments.

In this work, a flexible strain sensor with LCP as its substrate was designed, in the meanwhile, the two dimension material graphene has been chosen as the sensitive film of the structure. The proposed device is easily to realize and is readily to measure various strain levels of human motion signals.
Because LCP has its own particular properties such as good dimensional stability, flexibility and biocompatibility, which can offer the proposed sensor has good stability and ultrahigh reversibility. At the same time, the advantages of low-cost and simplicity in device fabrication can be ensured, and the versatility of detecting various signal changes of non-plane objects can be realized as well.

2. Fabrication

The fabrication process is described in the schematic shown in figure 1. For the sensor fabrication, we used LCP(R-F700T, Panasonic Corp provided) shown in figure 1(a), a 125μm thick LCP film with copper cladding on one side, which had the thickness of 18μm. Figure 1(b) shows a 5μm thick photoresist was patterned on the copper cladding. The exposed copper cladding area was etched away by an aqueous solution of FeCl₃(0.5mol/L) and HCl(0.5mol/L), the remained copper was used as electrodes of the strain sensor as shown in Fig.1(c). Subsequently, transparent adhesive tape (3M Corp provided) was patterned on the exposed LCP and copper electrodes as shown in figure 1(d). Then graphene oxide (GO, Nanjing XFNANO Materials Tech Co.,Ltd provided) was deposited into exposed LCP, transparent adhesive tape and copper electrodes by simple spin-coating and drying as shown in figure 1(e). The spin-coating was repeated for 45 times and the solution of GO is 4mg/ml. Finally, the transparent adhesive tape was lift off and then the GO was heated in the high-temperature furnace for 2h under 200℃, nitrogen was used as protective gas in the whole heating process. Figure 1(g) is the side view of the sensor structure and figure 1(h) is the top view of the sensor structure. Figure 2(a) presents a photo image of the strain sensor of about 3cm×3cm, the width of each graphene strip is 0.2cm. As seen in the photo, the mechanical property of LCP substrate was strong enough to prepare a large-scale sheet fabric. The strain sensor can be easily tailored to pieces with appropriate size for sensing applications. Figure 2(b) shows the magnified optical microscope image of the strain sensor. The average resistance of the graphene mesh film was about 45±25 KΩ.

*Figure 1. Overview of the fabrication process flow for the proposed strain sensor.*
3. Experiment and Discussions

As shown in figure 3(a) and 3(b), graphene mesh forms an electrical network with a variable resistor assembled to each current pathway. Partial cracks perpendicular to pathways will lead to an increase of the resistance while the across cracks will result in breaking off the pathways. Figure 3(b) shows a schematic model of the current pathway within the graphene mesh. It was shown that cracks were uniformly distributed in the stretched graphene mesh. As the tensile stresses were applied on the strain sensor, high density cracks generated in the graphene mesh, which causing the current pathways decreased and the resistance increased. Finally, the sensitivity of the strain sensor was improved greatly. On the contrary, when the compressive stress was applied on the sensor, the overlaps of graphene with some micro cracks are created, which lead to decrease the resistance of the strain sensor[7]. And because of the higher Young’s moulds of LCP than which of PDMS, strain sensors based on LCP substrate have greater stability and repeatability than that on PDMS substrate.

The resistance changed significantly with the hand motion from stretch to clench, as shown in figure 4, when the strain sensor was coherent on the back of a hand. As shown in figure 4(b), peaks represent hand motion with fast response, the relative change of the resistance were around 20% for each peak. In addition, the stability and the reversibility of the strain sensor were very good during 200 seconds.

Respiratory is one of the important parameters to be detected in hospitals as a vital sign. The strain sensor can take this sign easily under both stationary state and exercise state. The signals of the breathing rate under stationary state and excise state are shown in figure 5(a) and (b), respectively. The peaks and valleys were assigned to the chest stretch and shrink, respectively, and each cycle represented a breath. Figure 5 demonstrates that the signal had a higher frequency and a larger amplitude after exercise than that of stationary state. The breath numbers in stationary state and after exercise state were 50 and 70, respectively, in 400 seconds. The relative change of resistance of the
respiratory in still state and after exercise state was 2% and 4%, respectively. Moreover, it can been seen clearly from figure 5(b) that as the testing time went on, the frequency decreased after exercise, the respiratory went towards the stationary state.

![Figure 4](image1.png)

**Figure 4.** Relative changes of resistances in hand motion from stretch to clench

The strain sensor also can be used to distinguish out the different signals of the muscle motions when a tester spoke different words or phrases. The results in figure 6 illustrates that the strain sensor exhibited high sensitivity and distinctive patterns when the speaker spoke different words such as “Hi”, ”Hello” and ”SEU (Southeast University)”, respectively. The red frame 2 was an amplified view of red frame 1. It can be seen that wave form of single curve was apparently different. All the tests and data were obtained by a healthy adult.

![Figure 5](image2.png)

**Figure 5.** Relative changes of resistances of the respiratory in (a) stationary state and (b) exercise state.

![Figure 6](image3.png)

**Figure 6.** Relative changes of resistances in the muscle motions in speech.
In all the experiments, the double faced adhesive tape (3M Corp provided) was used to stick the strain sensor to the skin or flexible surface. The electrical properties were recorded by a digital sourcemeter (Keithley4200-SCS), and the Source-Drain voltage with 1V DC bias.

4. Conclusion
We have developed a graphene-on-LCP flexible strain sensor to monitoring human physiological signals and microstrain (0.16%) structural variation, and the low-cost feasible fabrication scheme has been designed. The experiment results demonstrated the sensor has a high sensitivity and stability over a wide testing time range. According to the above advantages and facilitative measurement platforms, the proposed flexible sensor can be used in a quite widely applications from the wearable electronic skins to structural health monitoring in bridges, buildings, and other critical infrastructures under severe natural disasters.

5. References
[1] Mannsfeld S C B, Tee B C K, Stoltenberg R M and Bao Z N 2010 Nat. Mater. 9 859
[2] Kaltenbrunner M, Sekitani T, Reeder J and Someya T 2013 Nature 499 458
[3] Lipomi D J, Vosgueritchian M, Tee B C K, Hellstrom S L, Lee J A, Fox C H and Bao Z N 2011 Nat. Nanotechnol. 6 788
[4] Fan F R, Lin L, Zhu G, Wu W Z, Zhang R and Wang Z L 2012 Nano Lett. 12 3109
[5] Someya T, Sekitani T, Iba S, Kato Y, Kawaguchi H and Sakurai T 2004 Proc. Natl Acad. Sci. USA101 9966
[6] Cheng M Y, Huang X H, Ma C W and Yang Y J 2009 J. Micromech. Microeng.19 115001
[7] Liao X Q, Liao Q L, Yan X Q, Liang Q J, Si H N, Li M H, Wu H L, Cao S Y and Zhang Y 2015 Adv. Func. Mat. 25 2395
[8] Herrmann J, Muller K H, Reda T, Baxter G R and Raguse B 2007 Appl. Phys. Lett. 91 183105
[9] Obitayo W and Liu T 2012 J. Sensors 652438
[10] Ferna´ ndez-Regu´ lez M Plaza J A, Lora-Tamayo E, and Paulo A S 2010 Microelectr.Engin.87 1270
[11] Loh K J, Kim J H, Lynch J P, Kam N W S and Kotov N A 2007 Smart Mater. Structures 16 429
[12] Song X H, Liu S, Gan Z Y, Lv Q, Cao H and Yan H 2009 Microelectronic Engin. 86 2330
[13] Kumar S B and Guo J 2012 Nano Lett. 12 1362
[14] Sakhaee-Pour A, Ahmadian M T and Vafai A 2008 Solid State Commun.147 336

Acknowledgments
This work was supported by National Natural Science Foundation of China (Grand No. 61474023) and National Key Technology Support Program of China (Grand No.2015BAF16B01).