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Novel Graphene Devices

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Abstract

Laser scribing technology, a low cost and time-efficient method of fabricating graphene is introduced in this paper. The patterning for electronic devices can be directly performed on flexible and solid substrates. Therefore, many novel devices such as strain sensors, earphone and artificial throat based on laser scribing graphene have been fabricated. Graphene strain sensors can be fabricated with both large sensitivity and strain range simultaneously. Graphene earphone, the thinnest sound source in the world, can play sounds ranging from 100 Hz to 100 kHz. Artificial throat can not only generate sound but also detect sound. It will assist for the disabled whose throat can generate vibrations with different intensity or frequency. These devices have great potential for wide applications in the future.

1. Introduction

Graphene is a kind of two-dimensional material with excellent properties such as ultra-high mobility, thermal conductivity, Young's modulus and transparency. Therefore, great deal of attention has been focused on it since its discovery in 2004 [1]. Many methods have been proposed to grow graphene. All of them have their advantages and disadvantages. Chemical vapor deposition (CVD) is a common method to grow high-quality and large-area graphene. Xu et al. has grown meter-sized single-crystal graphene on industrial Cu foil in 20 min [2]. However, the cost of CVD is too high and the time of multi-step process including annealing, growth, cooling is too long. What's more, the CVD graphene is vulnerable in the patterning and etching process. Other methods such as micromechanical exfoliation, thermal decomposition of silicon carbide are inefficient, neither. Laser-scribing reduction is a novel method to transfer the graphene oxide (GO) thin film into graphene.

In the report, we introduced our recent devices based on laser-scribing graphene (LSG). Growth and etching can be achieved at the same time by changing the power of laser without mask [3]. 10*10 cm^2 size LSG can be produced in 30 min or less. A large number of LSG based devices have been reported such as strain sensors [4], earphone [5] and artificial throat [6].

2. General Instructions

2.1 Graphene patterning by laser scribing

A GO dispersion with a 2 mg/mL concentration was first dropped on arbitrary including leaves, notes, polyimide (PI) films, even wings of butterfly. Then the as-prepared GO film was directly processed in air with the mask-free and programmable laser scribing technology. The laser power was varied from low to high resulting in three distinct regions: the growth region, the transition region and the etch region shown in the Fig .1. In the growth region, GO is converted to LSG with a higher thickness. In the transition region, both growth and etching of the LSG occurs simultaneously. The final thickness is almost the same as the initial GO thickness. In the etch region LSG layers are fully etched due to the gasification of both oxygen and carbon species caused by high laser power. It has promising applications for scalable manufacturing of graphene-based devices.

2.2 Graphene strain sensor

Conventional strain sensors rarely have both a high gauge factor and a large strain range simultaneously. We manufactured the sensors based on patterned LSG, which can meet demands in both subtle and large motion situations. In order to avoid irreparable damage to graphene during the stretching, the laser induced graphene is encapsulated in the elastic Ecoflex. The performance of the strain sensors can be easily tuned by adjusting the patterns of the graphene. The strain sensor with high density mesh has a larger sensitivity. While the strain sensor with no mesh has a larger strain range. Fig. 2 shows the no-mesh LPG strain sensors can be used for gesture detection and gesture control. The strain sensors have an excellent strain range of up to 100% and an ultrahigh GF of 457.

2.3 Graphene earphone

Wafer-scale graphene earphones have been realized using laser-scribing technology. Graphene with high thermal conductivity and low thermal capacity is an ideal material for electro-thermoacoustic (ETA) devices. The short-time laser pulses on a small area of GO, which may generate oxygen rapidly and result in expanding the layer to layer spacing. Therefore, there are air gaps between layers of graphene, which prevent thermal leakage to the substrate. Compared with commercial earphone, the LSG earphone exhibits a reasonably flat frequency response and a lower sound pressure fluctuation in a wider frequency range (100 Hz to 50 kHz), shown in Fig. 3. Humans can hear sound frequencies ranging from 20 Hz to 20 kHz. However, many animals can communicate in a larger frequency range over 20 kHz in the ultrasonic range. Our device realized the communication with the dog by 35 kHz sound waves, which opened up a new way of interspecies communication.

2.4 Graphene artificial throat

Apart from the GO thin film, PI film can be directly converted into graphene by laser scribing [7]. The high thermal conductivity and low heat capacity of LSG is ideal for thermoacoustic sound sources. Besides, the porous structure has a sensitive response towards weak vibrations, which is suitable for sound detection. When the device attached on the throat, it can detect both SP and throat vibration, which can be clearly differentiate the characteristics of different tones and volumes according to their unique waveforms, shown in Fig. 4. Useful waveforms can be summarized by pattern recognition and machine learning. The intelligent LSG artificial throat will significantly assist for disabled person.

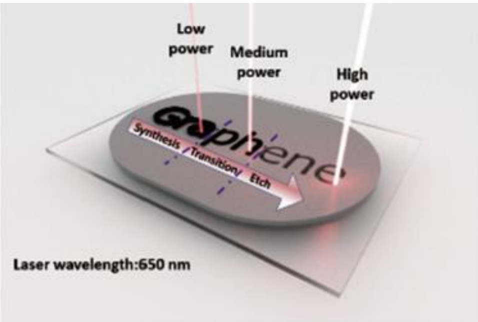

Fig. 1 A schematic diagram showing three laser beams irradiating a GO film under three different laser power levels.

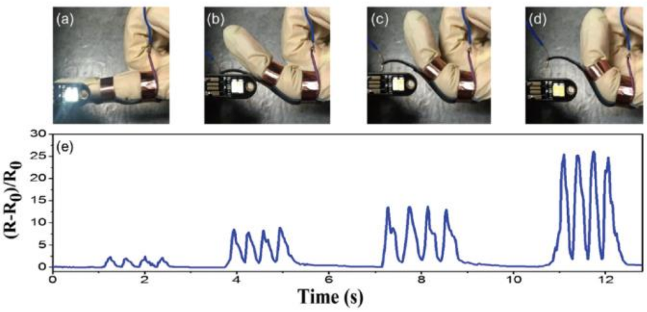

Fig. 2 The no-mesh LPG strain sensor that was used to control the brightness and detect the finger's bending degree. (a–d) The brightness of the LED becoming darker and darker with the increase of the finger's bending degree. (e) The relative resistance change at different finger bending degrees.

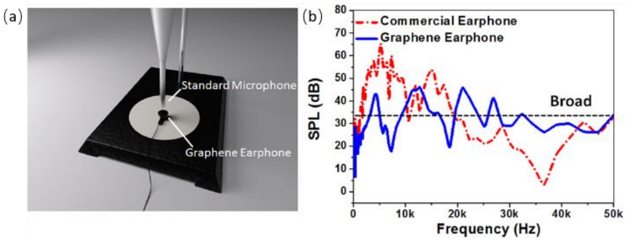

Fig. 3. Sound pressure and frequency characteristics of the graphene earphone. (a) Experimental setup for the graphene earphone. (b) Sound pressure level (SPL) curves of a graphene earphone compared with a commercial earphone. It is observed that the graphene earphone has a lower fluctuation than a commercial earphone due to its resonance-free oscillation.

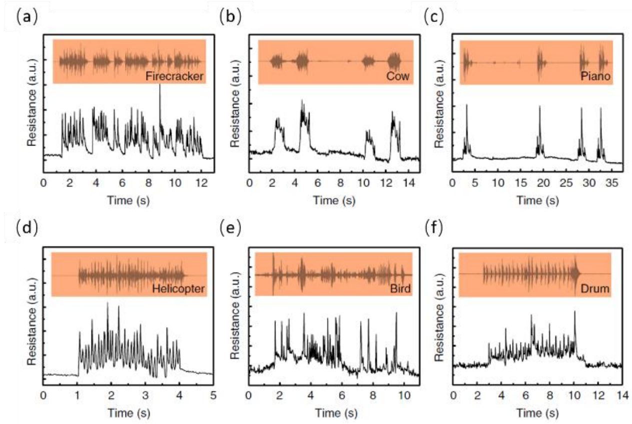

Fig. 4. Responses towards different audios from a loudspeaker. The LIG is placed 3 cm away from the loudspeaker. The orange insets above indicate the sound wave profiles of the original audios. Relative resistance changes show almost synchronous response to profiles of the original audios when the loudspeaker plays the audio of (a) firecrackers, (b) a cow, (c) a piano, (d) a helicopter, (e) a bird and (f) a drum.

3. Conclusions

In conclusion, laser scribing technology is a low cost and time-efficient method to produce graphene. The patterning for electronic devices can directly be performed on a large number of substrates based on this technology. Strain sensor, earphone and artificial throat based on LSG were realized, which have great potential for wearable devices in the future.

Acknowledgements

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