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News & Views

Two meters graphene film for generators

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Physicists and especially applied physicists long for a convenient way for converting mechanical, solar energy, and thermal energy into electricity, which makes up our modern lives — from a small LED light to many integrated communication devices. Since the breakthrough work by Faraday in the beginning of the 19th century, the harvesting of electricity has been the hot topic in our modern society. However, electric powers are heavily relied on the motion of metal in the magnetic field, following by the work of Faraday. Nowadays, electricity is used in a more dispersive way as more and more wearable and portable devices are created. On the other hand, graphene has been the toy of condensed physicists for exploring the quantum Hall effect and the long-term dream of chemists for developing high efficient lithium batteries. Searching for a unique application of graphene is indispensable [1]. In the past few years, applied physicists have been working very hard to bring many attractive and unique applications of graphene in solid electronic or optoelectronic devices [2].

Written in recent two papers, Prof. Shisheng Lin's group [3,4] in Zhejiang University has brought us the unique application of graphene in the area of generators. Starting from home-built system, two meters graphene film has been produced with extraordinary flexibility and conductivity. Lin's group built up a quasi-industrial film casting system to fabricate large-area, free-standing graphene assembled film. Originating from graphene dispersion solution, the graphene film was casted on a polyethylene terephthalate (PET) belt and was dried by a large area hot plate (Fig. 1a). Because of the highly parallel structure realized by solvent evaporation, the graphene assembled film maintain a high mechanical strength leading to the achievement of $2.0\ \text{m} \times 0.2\ \text{m}$ free-standing graphene assembled film (Fig. 1b). Through scanning electron microscope (SEM) image, the highly parallel structure and thin thickness are clarified (Fig. 1c). Based on this high quality graphene assembled film, some unique applications in the field of generator are invented.

The first idea is dynamic Schottky generator as a sustainable energy source using graphene as the metal side. Lin's group [3] has developed a novel direct current generator based on moving or dynamic Schottky diode, which has been published in *Advanced Materials*. Especially, a flexible macroscale direct current generator through the moving van der Waals Schottky diode composed by graphene/metal film and Si or GaAs. As shown in Fig. 2a, the flexible graphene wristband is demonstrated for the first time, which can convert the mechanical energy of hand into electrical energy by simply move between the large area graphene film and the semiconductor film. The mechanism is based on the novel physical picture which highlights the built-in electric field bounding back diffusion electrons emitted by the breaking balance between drift current and diffusion current in static van der Waals Schottky diode (Fig. 2b). The graphene film fabricated by macroscale assembly of graphene flakes can be stably used for the moving Schottky diode generator, which does not show obvious degradation after 10,000 times of running (Fig. 2c). The direct current generator has the potential of converting mechanical and vibrational energy into electricity and enables many promising applications. This moving Schottky diode direct current generator can be used to light up a blue LED, as shown in Fig. 2d. This represents a fundamental breakthrough of usage of the graphene film as the moving Schottky diode generator. In static Schottky diode, the diffusion current balances with the drift current, which will be broken in the dynamic Schottky diode. This dynamic Schottky diode generator opens a new avenue for energy harvesting, which should definitely call for more following papers in this area.

The second idea is thermal generator with high power factor graphene film. Lin's group [4] developed a doped graphene thermoelectricity film with high power factor of 8.4 μW/(cm K^2), which was published in *Nano Energy* recently. In this research, they realized a large-area graphene film with high thermal electrical power factor based on the adjustable Fermi level and high electrical conductivity of graphene and demonstrated two thermal electrical application scenarios of large area graphene thermoelectricity film. Firstly, as shown in Fig. 3a, a graphene thermoelectricity film serial array was settled on a window shade to absorb the thermal energy from the sunlight. Because of the broad band light absorption of graphene, the graphene thermoelectricity film will efficiently absorb the sunlight and output current. Especially, when the sunlight was concentrated on the array, the temperature of the film would be highly increased leading to highly improvement of the output power. The second demonstration is the thermal electrical device in a smart phone (Fig. 3b). They put a graphene thermoelectricity film array in a running smart phone to harvest the heat energy generated by the central processing unit (CPU). The electrical energy generator by the graphene thermoelectricity film generator is shown in Fig. 3c. As the phone running, the heat flow along the graphene film will be converted into current. The most interesting point is that since the graphene film have a good IR

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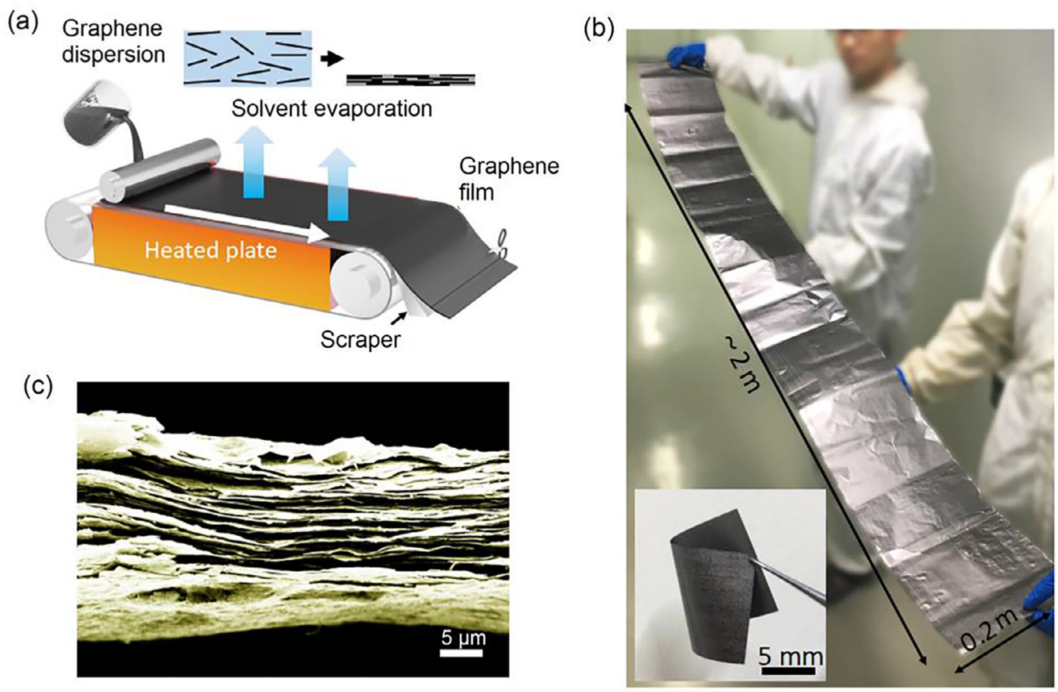

Fig. 1. (Color online) Basic properties and fabrication process of the graphene film. (a) The schematic of the fabrication process of the film. (b) The optical image of the achieved product of graphene film with the size about 2 m × 0.2 m. Inset: demonstration of the high flexibility of the film. (c) The cross-section SEM images of the free-standing graphene film with a highly parallel structure.

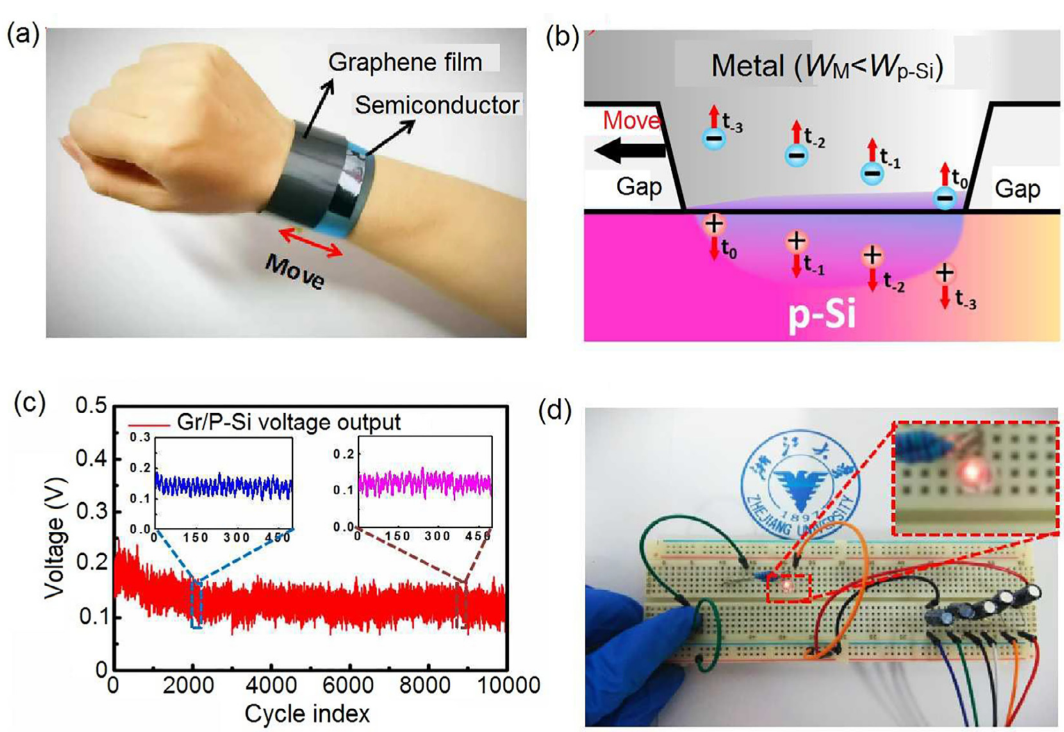

Fig. 2. (Color online) The novel application of the graphene film as moving Schottky diode generator. (a) The optical image of the first time demonstrated flexible graphene film wristband. (b) The schematic diagram of the moving Schottky diode generator. (c) The direct and continuous voltage output of the moving graphene film/Si generator for 10,000 cycles. (d) Picture taken from video to show the luminance of the blue light LED powered by moving Schottky diode generator.

absorbing ability and high thermal conductivity, the phone with graphene film generator will be cool down as the heat energy has been converted. The hottest temperature of CPU was reduced by 1.4 °C from 33.5 to 32.1 °C after inserting graphene film array (Fig. 3d). This demonstration indicated that graphene thermoelectricity film array can work as an effective thermoelectric generator and sensitive thermal sensor, showing its potential in the field of thermal management system.

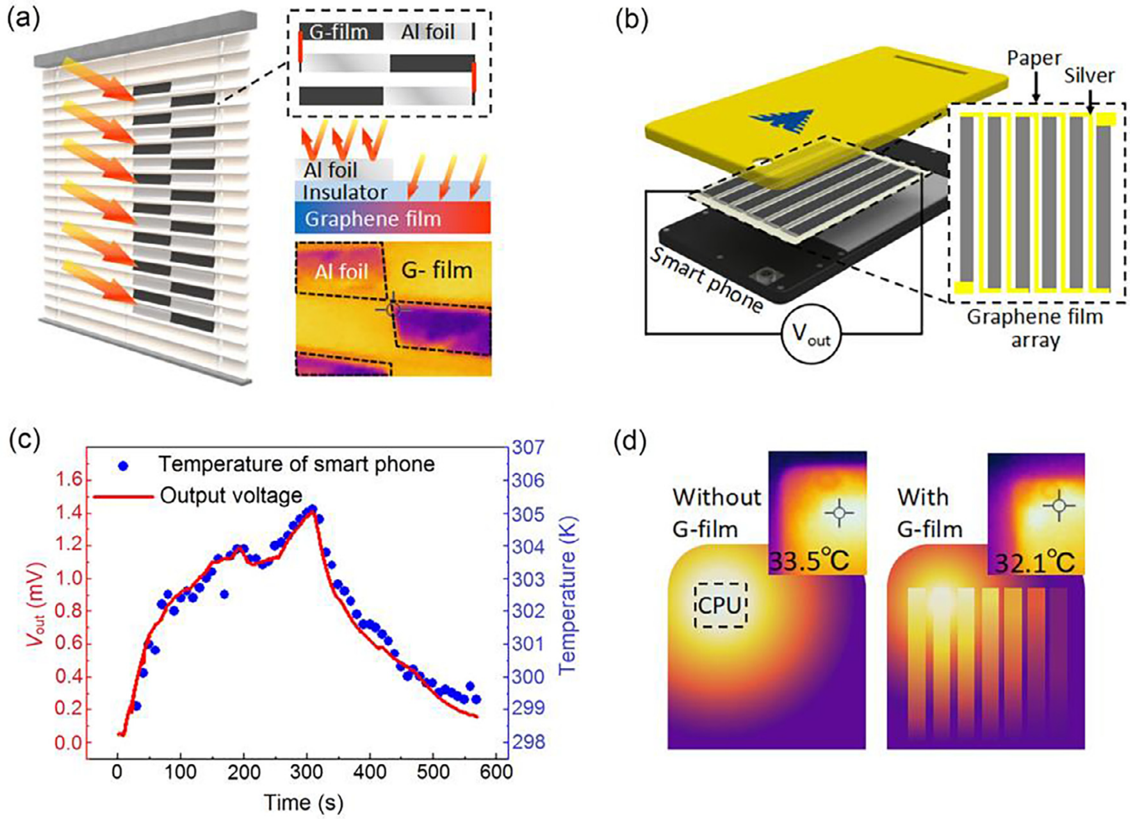

Fig. 3. Application scenarios and properties of the graphene film. (a) The sketch of our generator used on the window-shade. (b) Graphene film used on mobile phone cooling and radiative TE generation. (c) The voltage output measured with different temperatures of the mobile phone. (d) The schematic diagram of mobile phone cooling. Inset: Thermal image of the running mobile with and without graphene film.

Applied physicists have come up with using graphene film for dynamic Schottky generator and thermoelectric generator, which is counter-intuitive, however, attractive. This intriguing proposal is based on the novel fabrication method of large area graphene film assembled by microscale few layer graphene, which has an extremely high conductivity and high power of factor, which is the key for improving the output of the generators.

Conflict of interest

The authors declare that they have no conflict of interest.

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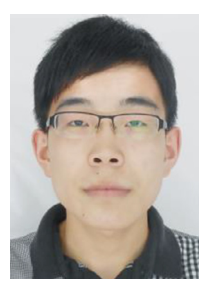

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