WEARABLE GRAPHENE SENSORS ON ADHESIVE TAPES

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ABSTRACT

We report a simple, reliable, and cost-effective method of fabricating wearable graphene-based physical sensors on adhesive tapes for detecting mechanical signals, such as pressure, force, and strain. The device fabrication mainly involves two steps, including patterning graphene by repeated “sticking and peeling off” processes with scotch tapes, and then transferring the patterned graphene to another adhesive tape. Once a reusable mold is formed by soft lithography, no further film deposition, lithography or etching processes are required to obtain graphene-based wearable sensors. We demonstrate using the strain and pressure sensors made on polyimide tapes to track body motion, as well as monitor pressure applied to a flexible object.

INTRODUCTION

Wearable sensors have been widely used in real-time motion tracking, human and structural health monitoring, smart prosthetics, and humanized robotic systems. In particular, flexible mechanical sensors with high sensitivity and low cost, such as pressure and strain sensors, have attracted considerable attention. Mechanical flexibility is crucial in developing wearable sensors, which may allow for direct contact between the sensors and sensed surfaces of objects with irregular shapes. Recently many elastomer-based conductive composites have become popular sensor materials for wearable mechanical sensors. They are formed by introducing different conductive nanomaterials (e.g., carbon nanotubes, graphite, etc.) into flexible and stretchable elastomers (e.g., silicone, polyimide, polyethylene, etc.), exhibiting good flexibility and electrical conductivity. Also, due to high piezo resistivity and stretchability, the two-dimensional material, graphene, has become a promising candidate for sensitive material of pressure and strain sensors formed on various flexible and stretchable substrates [1, 2].

Here we report a simple, reliable, and cost-effective method of fabricating wearable graphene sensors on adhesive tapes for detecting pressure, force, and strain.

FABRICATION PROCESS

Fig. 1(a) depicts the fabrication process. First, SU-8 mold was obtained by conventional soft photolithography method, then the desired channels (with 0.21mm depth) was obtained on PDMS by pouring, thermally curing, and peeling it off from the SU-8 mold. Then, a graphene dispersion in ethanol and distilled water mixtures (volume ratio of 70:30 [3]) was sonicated for 400 min and drop cast onto a polydimethylsiloxane (PDMS) mold pretreated with oxygen plasma. After drying on a hotplate at 90 °C for 5 min, a graphene film was formed, covering the whole surface of the mold. Subsequently, scotch tapes were used to stick and peel off multiple times until all excess graphene was removed from the top surface of the PDMS mold, leaving behind the desired graphene filled in the channels of the mold. Then, another adhesive tape (here, 25 μ m thick polyimide film with adhesive on one side) was laid flat and adhered to the PDMS mold. Afterwards, the whole structure was annealed in an oven at 200 °C for two hours. The annealing treatment allows increasing electrical conductivity of the graphene patterns by about two orders of magnitude and strengthening the adhesion between polyimide and graphene. Lastly, the thin polyimide tape was peeled off from the mold and the conductive graphene patterns were transferred to the polyimide tape. Fig. 1(b)

shows transferring of graphene patterns from microfluidic channels onto a polyimide tape. Fig. 1(c) shows different patterns formed on the tapes. Fig. 2 shows scanning electron microscopy (SEM) images for the multilayer graphene patterns onto the polyimide tape.

Figure 1: (a) Schematic of fabrication processes to make graphene sensors on adhesive tapes. (b) Photos showing how to transfer graphene patterns onto a polyimide tape. Scale bars: 4 mm. (c) Fabricated graphene structures. Scale bars: 1 mm.

Figure 2: Scanning electron microscopy of the graphene patterns transferred onto a polyimide substrate.

RESULTS AND DISCUSSION

Fig. 3a shows the relative resistance change of the graphene sensor on the polyimide tape (Fig. 1b) as a function of applied tensile strain along the length of the graphene pattern. The response of sensor to tensile strain is almost linear. The strain sensor is adhered on the middle joint of index finger (Fig. 3c) to track different bending positions of the finger (Fig. 3b). As the finger bends, the resistance of the sensor increases. Once the finger goes back flat from bending position, the resistance follows to go back to its initial value, indicating that the sensor has high reversibility.

As another application of graphene pattern sensor, the sensor is attached to the surface of a balloon to track dynamic changes in tension on the balloon during inflation. (Fig. 4). The pressure of air source is kept at 3 pounds per square inch or PSI during the measurement, while the duration of flowing the air to the balloon changes. Fig. 4 shows that as the balloon is inflated, the resistance of the sensor increases. As the balloon stays at a given inflated state, the resistance becomes stable.

Table 1: Relative resistance changes of five pressure sensors (F1-F5) and five strains sensors (B1-B5) attached to fingers during catching a tennis ball

	Pressure (kPa)					$\Delta R/R$ (%)				
	F1	F2	F3	F4	F5	B1	B2	B3	B4	B5
Preparation	0	0	0	0	0	1.7	1.5	1.2	1.3	1.4
Adjustment	4.4	5	6.5	5.3	2.5	3.5	3.4	3.2	3.1	3.5
Catching	420	456	547	467	469	4.9	4.6	4.7	4.3	4.2

Figure3: (a) Relative resistance change as a function of tensile strain applied along the surface of polyimide tape. (b, c) Demonstration of tracking motion of the index finger.

Figure 4: Demonstration of tracking changes in tension on the balloon during inflation.

The graphene pattern formed on the tape can detect pressure applied to the surface of the pattern. Fig. 5a shows the relative resistance change of the graphene sensor as a function of external pressure applied normal to the surface of the graphene pattern. The mouse clicking pressure is monitored using the sensor attached on the left side of the mouse. When the mouse is clicked, the resistance of the sensor becomes lower and when the clicking pressure increases the relative resistance change becomes more. Fig. 5b tracks how the sensor responds to different clicking pressure and frequency.

Fig. 6 demonstrates using two sets of sensors (total 10) to track bending and pressure levels involved during catching a tennis ball bounced up from the hard floor. Each finger is equipped with a strain sensor at the top of the finger joint and a pressure sensor at the fingertip. Table 1 shows the obtained pressure and strain values at the three states: preparation, adjustment, and catching.

Figure 5: (a) Relative resistance change as a function of pressure applied normal to the surface of the tape. (b) Demonstration of tracking mouse clicking pressure and frequency.

Figure 6: (a, b) Positions of five strain sensors (F1-F5) and five pressure sensors (B1-B5). (c) Demonstration of tracking pressures and strains during catching a tennis ball. The pressure and strain signals are read out at three states: preparation (left), adjustment (middle), and catching (right).

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