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Scalable Microfabrication of Graphene Polymeric Strain Gauge

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Summary:

This paper presents the fabrication and characterization of a strain gauge based on chemical vapor deposition (CVD)-grown graphene integrated to an epoxy-based, photo-patternable and flexible SU-8 cantilever for sensing applications. The fabrication process involved a standard semiconductor microfabrication process to create serpentine-shaped graphene and gold/graphene sensing layers on a polymeric SU-8 layer. The performance of the strain gauge was evaluated by subjecting it to controlled bending, demonstrating a gauge factor (GF) of 2.73 and fast response time (0.55 s) affirming the viability of the fabricated strain gauge for practical sensing applications.

Keywords: Pressure sensor, Microfabrication, Strain gauge, Graphene, SU8

Introduction

Sensing technologies and specifically strain sensors are growing fast as their demand is increasing in industries including electronics, healthcare, manufacturing, transportation, defense, as well as scientific exploration.[1, 2] One of the most cost-effective and easy data analysis models for strain sensors is piezoresistivity which is working based on converting mechanical loading into resistance change. Designing high-performance piezoresistive sensors involves considering various parameters which among them, sensitivity, evaluated by the gauge factor (GF), remains a fundamental metric, which relates the ratio of relative change in electrical resistance, R, to the applied strain, ε. While conventional materials like metals offer limited gauge factors, graphene, one of the key 2D carbon-based nanomaterials with its remarkable mechanical and electrical properties, emerges as a promising candidate for strain sensors.[3] However there are challenges in obtaining high-quality, uniform graphene and repeatably integrating it into scalable device architectures.

In this study, we report the development of CVD-graphene based strain gauges on SU-8, an epoxy-based negative photoresist (PR), as a flexible substrate using standard microfabrication processes. The results obtained from the

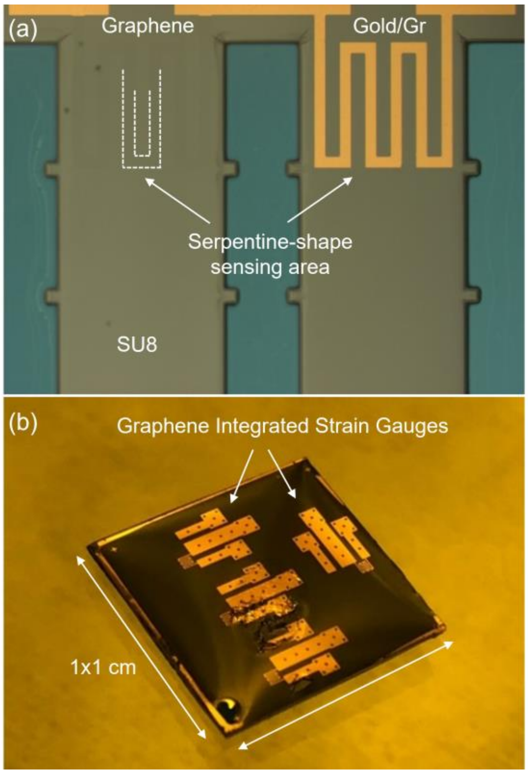

Fig. 1. (a) Graphene and gold/graphene integrated strain gauge on flexible SU-8 photopolymer. (b) Successfully fabricated four sensors from a 1×1 cm Nickel coated sample.

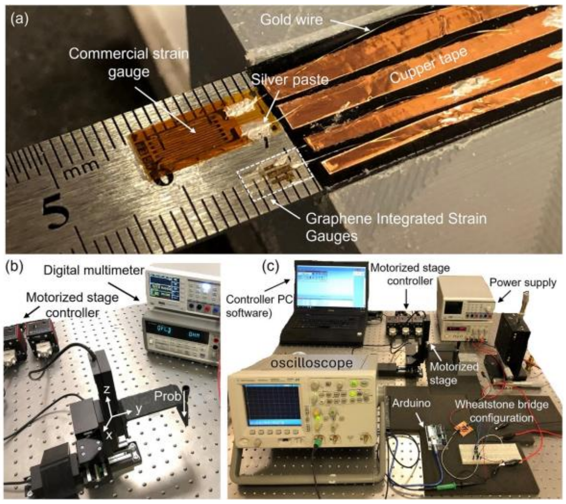

Fig. 2. (a) Mounted sensors on a metal bar. (b) Motorized stage and measurement devices. (c) Measurement setup and Wheatstone bridge configuration.

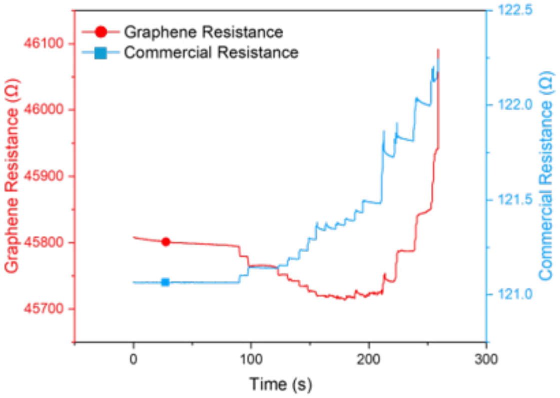

Figure 3. (a) Sensors' resistance behavior vs. time by applying force and bending the metal bar. (b) Relative resistance changes vs. applied strain for both commercial and graphene sensors

mechanical and electrical characterization of the device show a sensitivity (*GF*=2.73) comparable to that of a conventional metal-based commercial strain gauge.

Materials and Methods

A 1×1cm sample of nickel-coated silicon substrate onto which few-layer graphene (FLG) was grown was coated with a 300nm-thick layer of gold (Au) by e-beam evaporation that acts as both protective layer and conductive interconnects and pads. Then by using UV-lithography and wet etching the gold layer was patterned to the desired serpentine-shape and the graphene layer around it was etched by O_2 plasma. Moreover, the gold was selectively removed from one of the arms. Next, a 100µm thick SU-8 layer was spin-coated on the sample and patterned by UV-lithography to achieve a polymeric cantilever. Finally, the sample was immersed into buffered oxide etchant (BOE) for 3 h in order to release the structure. Figure 1 shows images of successfully fabricated sensors and their sensitive areas. Measurement of the variation in resistance of the sensors due to applied stress was achieved by mounting the sensor on a metal bar next to a 120Ω metal-foil commercial strain gauge (GF=2.14) as a reference (Fig. 2a). By applying loading from the free end of the metal bar and bending it, using a x-y-z motorized stage, a uniform stress is applied to the sensors (Fig. 2b). To calculate the applied stress, first, the strain measured in commercial strain gauge via resistance change, using a Wheatstone bridge configuration, and then the strain value was multiplied by the elastic modulus of Polyimide (2.5 GPa) (Fig. 2c). Furthermore, the derived stress value was divided by Young's modulus of SU-8 (3.6 GPa) to measure the strain experienced by the graphene sensor.

Results and Discussion

The strain gauges' behavior was assessed by controlled bending of the metal bar (Fig. 3). Using calculated strain and relative resistance change values, a higher sensitivity for fabricated strain gauges was observed compared to the commercial one. Graphene and gold-based strain gauges demonstrated approximately 30% higher sensitivity (GF) (GF=2.73) than the commercial strain gauge. Moreover, graphene shows a negative GF in low strains, and it changes to positive GF after a specific deflection, while the gold-based and commercial strain gauges both show linier response and direct relationship with tension.

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