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Graphene-based Piezoresistive Pressure Sensing for Uniaxial and Biaxial Strains

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Abstract — The piezoresistive effect in graphene has been experimentally demonstrated for both uniaxial and biaxial strains. For uniaxial strain, rectangular membranes were measured while circular membranes provided biaxial strain. Gauge factors have also been extracted and compared to previous literature as well as simulations.

I. INTRODUCTION

Graphene's extraordinary mechanical and electronic properties have led to pressure sensors based on the piezoresistive effect [1, 2]. Graphene can be used as a pressure sensor by suspending a graphene membrane over a cavity – trapping the air inside. As the environmental pressure changes, this causes a pressure difference compared to the air trapped under the cavity. This strains the graphene, changing its electronic properties. Such sensors show enormous sensitivity, and are hundreds of times more sensitive per unit area than conventional silicon pressure sensors. This high sensitivity allows for aggressive scaling [1]. Measurements for both biaxially and uniaxially strained graphene sensors are compared to simulation. Typical gauge factors for graphene range from 2 to 6 [1, 2].

II. FABRICATION

Fig. 1a shows the process flow of the pressure sensors. Thermal silicon dioxide (SiO₂) is grown on a silicon wafer with a thickness of 1.5 μm (Fig. 1a-1). A 1.5 μm cavity is etched into the SiO₂ (Fig. 1a-2). Contacts are then imbedded into the SiO₂ with thicknesses of 170 nm of Ti and 500 nm of Au (Fig. 1a-3). Graphene is then transferred to the wafer using chemical vapor deposited (CVD) graphene grown on copper foil (Fig. 1a-4). The graphene is patterned using O₂ plasma (Fig. 1a-5). The chip is then packaged and wire bonded as shown in Fig. 1a-6). A commercial pressure sensor is measured simultaneously with the graphene device as a reference measurement. Fig. 2 shows a color enhanced SEM image of a wire bonded pressure sensor with a circular membrane.

III. RESULTS

Devices were measured in vacuum by pumping and venting the chamber with argon gas (suppressing parasitic gas sensing effects [1]). Fig. 1c shows an equivalent resistance model used to calculate the resistance of the graphene membrane for biaxial strain. Fig. 2a shows a resistance change from the graphene sensor versus time. Fig. 2b shows a COMSOL simulation of a circular graphene membrane at a pressure difference of 0.8 pressing against the membrane – thereby deflecting it. The model matches closely with AFM deflection measurements performed by Bunch et al. [3] and Koenig et al. [4]. Fig. 2c compares gauge factors of uniaxially strained 6 by 64 μm rectangular cavity devices with biaxially strained 24 μm circular cavity devices. Simulation as well as previous literature is also shown for comparison [5]. The average value of the extracted gauge factors is 3.

IV. CONCLUSION

Experimental data from the sensors were compared to simulated data. Experimental gauge factors range from 1 to 9, which - in combination with its ultimate thinness - makes graphene an extremely scalable piezoresistive NEMS material.

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Figure1: a) Process flow for fabrication of pressure sensors. b) Color enhanced SEM of a circular membrane sensor. Light green shows the cavity region, blue shows the graphene region, gold shows the contacts and light red shows the wire bonds. c) Color enhanced SEM illustrating the resistor network used for the extraction of gauge factors.

Figure 2: a) The resistance change over time of a graphene sensor. b) COMSOL model of the deflection of a circular cavity device. c) Gauge factor comparison of different experimental devices with theory.