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DESIGN AND PERFORMANCE ANALYSIS OF A FLEXIBLE LIG THIN-FILM HEATER

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ABSTRACT

Gas sensors play vital roles in environmental, agricultural, and industrial monitoring, yet metal-oxide sensors require high operating temperatures. Conventional ceramic or metallic heaters consume high power and lack flexibility, limiting portable applications. Here, flexible thin-film heaters were fabricated using laser-induced graphene (LIG) on polyimide substrates. Two patterns with varied laser powers and scanning speeds were tested, and electrical and thermal performances evaluated. Higher laser power and lower scanning speed improved conductivity and heating efficiency. The optimized heater reached 411 °C at 20 V with uniform, stable, and flexible performance, showing strong potential for next-generation gas sensors.

Keywords: Flexibility, LIG, Thin-Film Heater, Polyimide

INTRODUCTION

Metal-oxide gas sensors provide high sensitivity and fast response but require elevated operating temperatures. Conventional heaters are power-intensive and rigid, restricting their integration into portable devices. To overcome these issues, this study applies laser-induced graphene (LIG) technology to develop a flexible thin-film heater and assess its electrical, thermal, and mechanical performance for gas-sensing applications.

MATERIALS AND METHODS

Polyimide (PI) substrates with 125 μm thickness were patterned into two heater designs using 450 nm laser ablation under different powers and scanning speeds. Both Linear and Interlaced structures were fabricated to obtain varied conductive properties, and nano-silver paste was applied on the pads for reliable electrical contact as illustrated in Figure 1. Electrical resistance was measured with a multimeter under flat and bent conditions to evaluate conductivity and flexibility. Heating performance was characterized using an infrared thermal imager and a DC power supply, and the corresponding average temperature (T_{avg}) and saturation temperature (T_{sat}) were recorded as shown in Figure 2. Surface morphology and elemental composition were analyzed by SEM and EDS to confirm the porous graphene structure.

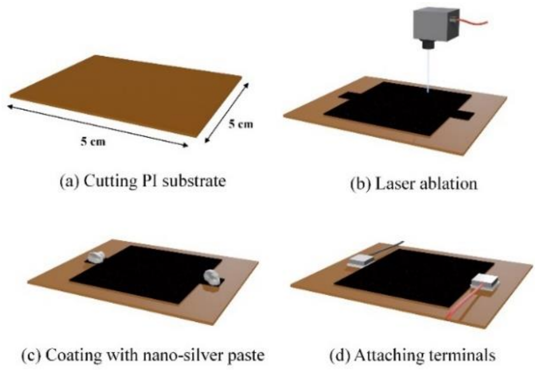

Figure 1. Fabrication of LIG heater.

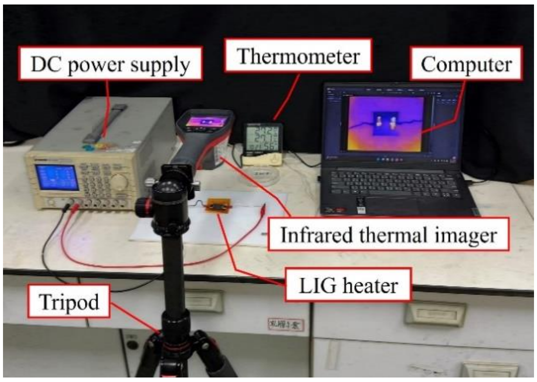

Figure 2. Measurement for heating.

RESULTS & DISCUSSION

SEM revealed that the Interlaced structure exhibited a denser pore distribution than the Linear structure, and Figure 3 further shows that higher laser power increased the LIG thickness. EDS confirmed that the samples were mainly composed of carbon and nitrogen with stable contents, indicating that nitrogen is generated during laser-induced graphene formation. With increasing laser power, sheet resistance decreased significantly. I–V measurements demonstrated linear behavior consistent with Ohm's law, and Pattern A was able to withstand higher voltages. As shown in Figure 4, Sample #11 achieved the highest average temperature of 411 °C, with markedly better thermal uniformity and stability than Pattern B; in addition, response time shortened as voltage increased. Bending tests indicated that resistance increased with curvature but still maintained stable Ohmic characteristics, demonstrating good reliability and flexibility.

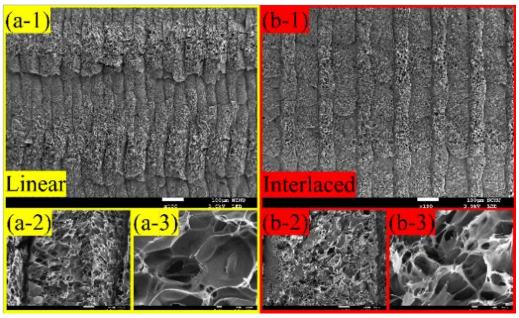

Figure 3. Surface SEM images.

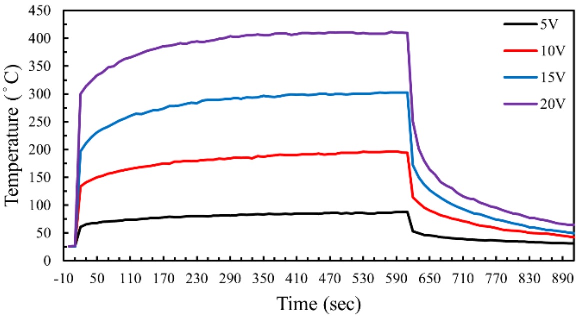

Figure 4. Temperature measurement.

CONCLUSIONS

A flexible LIG thin-film heater was fabricated with low resistance, high uniformity, fast response, and good flexibility, addressing the limits of traditional heaters. It shows strong potential for integration into rapid-response gas sensors.

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