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FABRICATION OF LASER-INDUCED GRAPHENE HEATER INTEGRATED INTO FLEXIBLE PRINTED CIRCUIT BOARDS

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Abstract

Flexible Printed Circuit Board (FPCB) are widely used in portable devices, wearable systems, and biomedical sensing applications because their flexibility, thinness, and high integration. With the development of the Internet of Things and smart agriculture, sensors are evolving toward lightweight and multifunctional designs, including applications in temperature and humidity monitoring, pressure sensing, physiological signal acquisition, and gas detection. Most gas sensors require high-temperature operation to enhance sensitivity and response rate; thus, the heater becomes a key component of the system. Among them, thin-film gas sensors have attracted increasing attention for their simple structure, low cost, and potential for miniaturization. This study presents the design of a laser-induced graphene (LIG) thin-film heater that can be directly integrated into an FPCB. The effects of different fabrication parameters on its electrical and thermal performance were investigated. During fabrication, laser powers ranging from 1 to 2 W were applied, and aluminum heat sinks combined with deionized water were used to regulate thermal conduction. Substrates including Polyimide (PI) and FPCB-PI were evaluated in terms of surface roughness, sheet resistance, bending degree, and heating performance. Experimental results show that FPCB-PI exhibits a more stable surface morphology, which reduces uneven laser carbonization and achieves good conductivity and uniform temperature distribution at 1.25 W. Although higher laser powers improve conductivity, they can also lead to substrate burning without proper heat dissipation. The fabrication of laser-induced graphene heaters integrated into flexible printed circuit boards offers programmable processing, flexible integration, and stable heating capability, making it suitable for the future development of low-power gas sensing modules.

Keywords: Flexible Printed Circuit Board, Laser-Induced Graphene, Thin-Film Heater, Surface Roughness, Heat Dissipation

INTRODUCTION

Flexible printed circuit board (FPCB) are lightweight, bendable, and highly integrable, enabling applications in displays, wearables, and sensors. Gas sensors often require elevated temperatures for higher sensitivity, making integrated heaters essential. Laser-induced graphene (LIG) offers high conductivity and direct patterning on PI, providing a promising solution for flexible heating devices.

MATERIALS AND METHODS

LIG heaters were fabricated on FPCB consisting of a 50 μm PI layer, an 11.7 μm copper electrode, and a 25 μm PI cover, using laser powers of 1 to 2 W at 25 mm/s. The heater size was 19.5 × 15.5 mm with a 0.05 mm pitch, and the substrate was mounted on an aluminum heat sink with deionized water cooling to reduce thermal stress and minimize substrate bending. Surface roughness, sheet resistance, and heating performance were evaluated using a profilometer, multimeter, DC power supply, and infrared thermal imager.

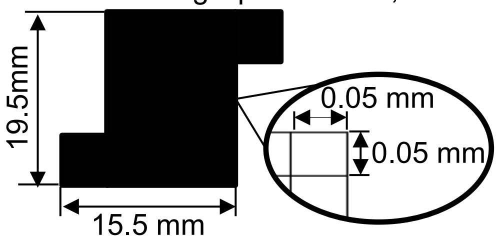

Fig 1. Design of the LIG heater.

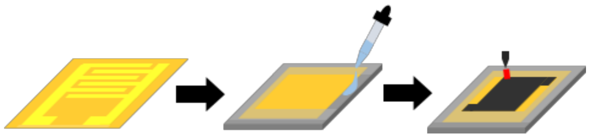

Fig 2.LIG heater cooling process

RESULTS & DISCUSSION

FPCB-PI showed microstructures, speculated to disperse thermal stress and enhance laser tolerance. Sheet resistance decreased with power, with 1.25 W giving lower and more uniform values, while PI burned above 1.5 W but FPCB-PI stayed stable. Heating tests confirmed 1.25 W enabled steady heating at 20 V, unlike higher powers that caused instability.

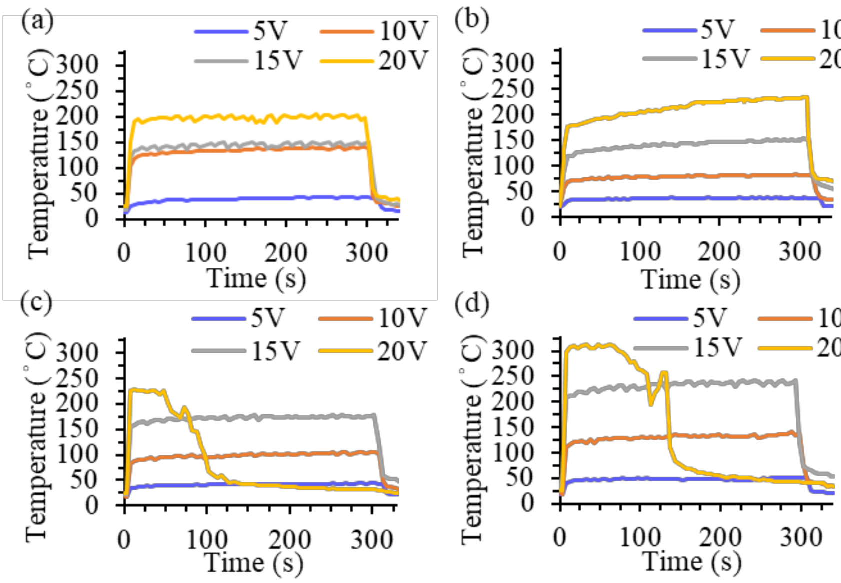

Fig 3. (a~d) Heating of FPCB LIG heaters at 1, 1.25, 1.5, and 2 W.

CONCLUSIONS

LIG heaters were successfully integrated on FPCB, showing stable electrical and thermal performance. FPCB-PI demonstrated better thermal durability than PI and reduced bending with cooling design. The 1.25 W process balanced resistance and heating efficiency, offering a low-cost, flexible solution for future gas sensing applications.

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