Mustansiriyah Journal of Pure and Applied Sciences, Print ISSN: 2957-9910. Online ISSN: 2957-9929, Vol. 4, No. 2, 2026, Pages 1-7
DOI: 10.47831/mjpas.v4i2.384

MJPAS

MUSTANSIRIYAH JOURNAL OF PURE AND APPLIED SCIENCES

Journal homepage: https://mjpas.uomustansiriyah.edu.iq/index.php/mjpas

RESEARCH ARTICLE - PHYSICS

Laser induced graphene based heaters from polyimide film

Sinan E. Rajab [1], Mariam M. Abud [2*], Mohanad M. Azzawi [3]

[1] Department of Physics, College of Education, Mustansiriyah university, Baghdad, Iraq

[2] Department of Physics, College of Education, Mustansiriyah university, Baghdad, Iraq

[3] Ministry of Higher Education and Scientific Research, Baghdad, Iraq.

[*] Corresponding author E-mail: marmoh_1968@uomustansiriyah.edu.iq

Article Info.

Article history:

Received
12 February 2025

Accepted
30 April 2025

Publishing
30 June 2026

Abstract

A new and promising technique called laser-induced graphene (LIG) uses a CO_2 laser to create graphene on a flexible polyimide substrate in a single step without the need for additional steps. The structure and surface properties of the graphene were analyzed using Raman spectroscopy and scanning electron microscopy. This study also investigates the electrothermal properties of the fabricated heaters by varying the applied voltage concerning temperature, current, and power to assess their performance. The area of the three manufactured heaters was modified to evaluate its impact on performance, along with a new design that accommodates the bending of the heater, allowing it to function as a flexible device. The results indicated that the resistance of the heater decreased as the area increased, leading to an enhanced thermoelectric response and improved performance. Furthermore, the heater's compact size and lightweight nature highlight its significance for the development of flexible electronics.

The official journal published by the College of Education at Mustansiriyah University

Keywords: Heater; Graphene; Polyimide (PI); LIG; Electro thermal properties.

1. Introduction

In recent years, graphene a sheet of sp^2-bonded carbon atoms packed closely together in a honeycomb crystal lattice and only one atom thick has drawn a lot of interest as a potential next-generation electronic material [1]. High current density, ballistic transport, chemical inertness, high thermal conductivity, optical transmittance, and super-hydrophobicity at the nanoscale are only a few of its remarkable qualities [2].

Many electronic devices can be made from graphene, which is very light and thin, so it has become an alternative material to expensive silicon [3, 4]. One classification for intrinsic graphene is zero-gap semiconductor or semi-metal. Due to its distinct electrical characteristics, it has an incredibly low absorption rate of only 2.3% of white light and a shockingly high opacity for a single atomic layer [5].

At normal temperature, electrical characterization has revealed exceptionally high electron mobility, with values surpassing 15,000 $cm^2/V \cdot s$ [3].The graphene sheet has a resistance of about 10^{-6} ohm-cm, which is less than that of silver, the material with the lowest known resistivity at room temperature [6]. Compared to conventional thermal techniques, laser technology provides more accuracy in thermal induction since it is non-contact, non-toxic, and extremely controlled. Applications for this technology are numerous and include manufacturing, medical care, material processing, and military equipment [7, 8].

Using a mid-infrared (MIR) CO_2 laser system, Tour et al. [9] showed in 2014 how to transform a commercial polyimide (PI) sheet into three-dimensional porous laser-induced graphene (LIG) in ambient settings. Great porosity (340 m^2/g), good electrical conductivity (25 S/cm), and great thermal stability (up to 900 °C) are only a few of LIG's exceptional qualities [9]. The photothermal effect that arises from the interaction between the laser and the material is the foundational working concept of LIG technology. Numerous applications, such as energy storage [10], gas sensors [11], micro-supercapacitors [12], antibacterial therapies [13], and water treatment [14], hold tremendous potential thanks to its novel one-step laser scribing technique [9].

This research aims to present electronic devices, which is flexible, easily-fabricated, lightweight and low-cost graphene-based using an easy method called laser-induced graphene (LIG) technology with CO_2 laser in one step without complicated operations by laser interaction with flexible polyimide (PI) substrate at different design sizes.

2. Materials and methods

Polyamide films, commonly known as Kapton Tape, were utilized. Polyamides are available in various shapes and thicknesses, and they are thermally stable and highly flexible, making them ideal for the manufacture of flexible electronics [9].

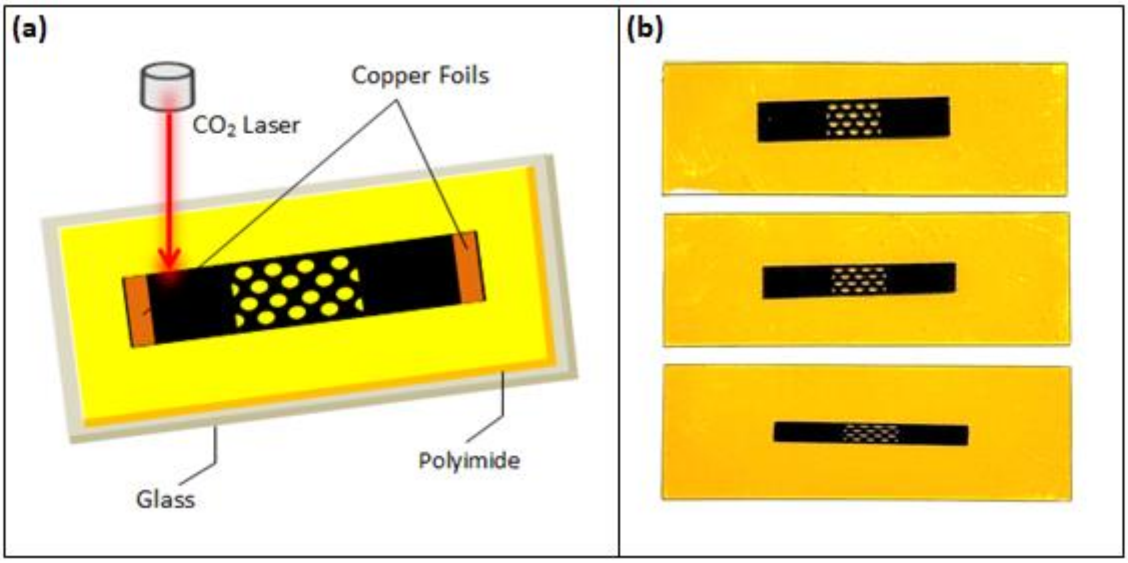

Fig. 1: (a) Schematic diagram showing how the LIG-heater is made from polyimide film. (b) Three heaters are ready.

The preparation process involves adhering the polyamide tape to a glass substrate. A CO_2 laser (Model: 3020 CNC CO_2 laser, wavelength 10.6 µm, power 50W) is then used to turn the polyamide into graphene through photo-thermal decomposition (see Fig.1.a). The laser is set to 3W power, and the scan speed is 400 mm/s. This process transforms the surface layer of the polyimide into high-quality graphene with excellent conductivity, free from defects or cracks, as illustrated in Figure 1b. Copper foil electrodes are directly attached to both ends of the heater to evaluate the performance of the manufactured heaters. The thermoelectric properties of three heaters with different shapes and widths (8 mm, 6 mm, and 4 mm), each with a constant length of 3 cm, were examined at laboratory temperature (29 ± 1 °C).

3. Results and discussion

3.1. LIG structural characteristics

Confocal Raman microscopy (Model: Sentera, Bruker, Germany) and scanning electron microscopy (SEM) (Model: TESCAN VEGA3, Czech Republic) were used to examine the microstructure of the LIG heaters. SEM pictures of laser-induced graphene at various magnifications are shown in Figure 2, which shows a carbonized and porous structure that is about 40 µm thick above the remaining polyimide (PI). The porous multilayer graphene flakes that make up the LIG are visible in the high-magnification SEM pictures.

The LIG exhibits a laminar, porous structure reminiscent of a sponge, which is particularly evident in Figure 2(b). Some laminar sheets of the LIG tend to curl, and the material's pores are easily observable, with the surface displaying a relatively homogeneous pore distribution [15,16].

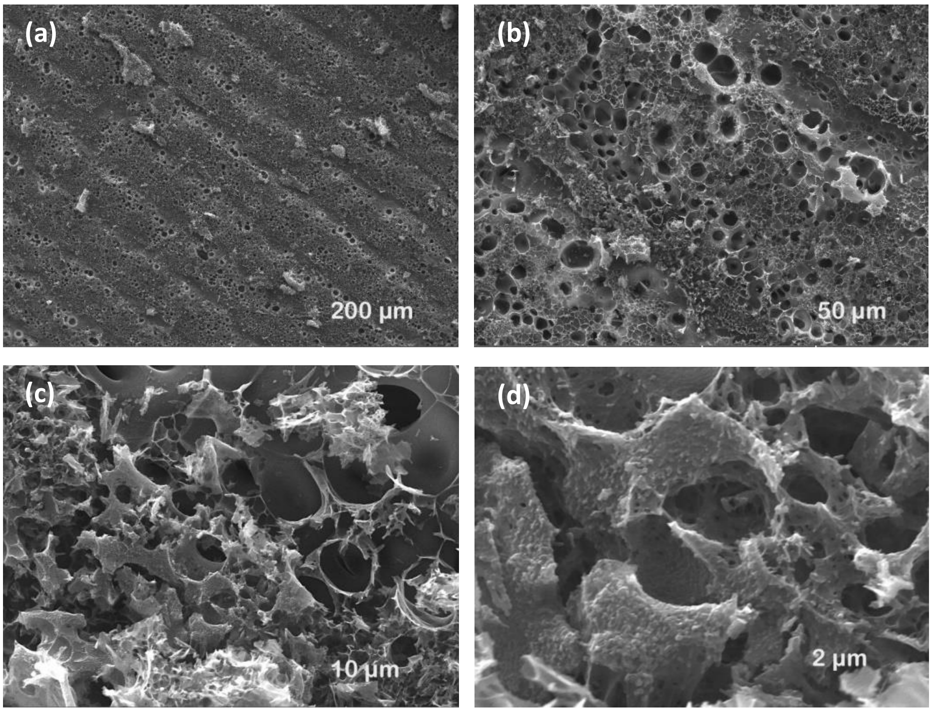

Fig. 2: SEM images at various magnifications of LIG: (a) 200μm, (b) 50μm, (c) 10μm, and (d) 2μm.

The graphene's Raman spectrum was examined using a laser source with a 532 nm excitation wavelength (λ excitation) at room temperature (25 °C) and 1% power (10 seconds integration time). A Raman spectrometer with a 50 cm focal length was used to analyze the laser beams scattered from the graphene. Raman spectroscopy is an invaluable method for the non-invasive characterization of such samples, providing extensive structural information about the treated surface and enabling the quantification of defects and disorders caused by the ablation process [17].

Following laser treatment, the PI surface's Raman spectra are shown in Fig. 3. Three prominent peaks D, G, and 2D that differ slightly in width, intensity, and location describe the crystalline structure of laser-induced graphene. The material's identity as graphene is confirmed by the 2D peak at 2683 cm^{-1}; the G peak at 1580 cm^{-1} shows the number of LIG layers, and the D peak at 1344 cm^{-1} describes the flaws or edges of LIG. The created graphene's disorder, crystallinity, and flaws are shown by the ratio of the D to G peaks [18-20].

In line with earlier studies, a 2D peak appears in the representative Raman spectra following CO_2 laser irradiation, indicating the development of a few-layer graphene on the PI surface [21]. A disordered in-plane structure is indicated by a high I(D)/I(G) ratio of 1.17, but a graphene structure made up of several graphene sheets is suggested by an I(2D)/I(G) ratio of 0.66. Usually, these band intensity ratios are examined. F. Vitalij et al. [22] came to a similar conclusion.

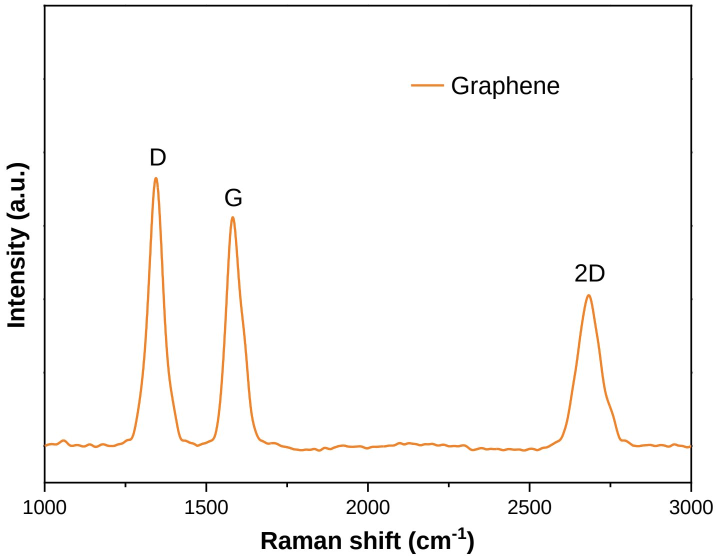

Fig. 3: Raman spectra of (LIG) layer.

3.2. Electrothermal properties of LIG heaters

The prepared heater was connected between the two terminals of a power supply (IKococater SPPS-C Series), where a voltage between 1 and 30 V was used. Figure 4 shows the relationship between temperature and input voltage for three heaters of different areas, and the temperature increases quadratically with voltage, which is consistent with the literature [23,24]. The recorded temperatures of the heaters were 124, 154, and 190 ^{o}C for the areas A_1, A_2, and A_3, respectively, so the heater with the larger area has the lowest resistance which leads to a higher thermal response that is, the equation states that the heater resistance is inversely proportional to the area. ($R=\rho L/A$). The electrothermal response followed Joule's law for the heaters prepared by the LIG technique [25].

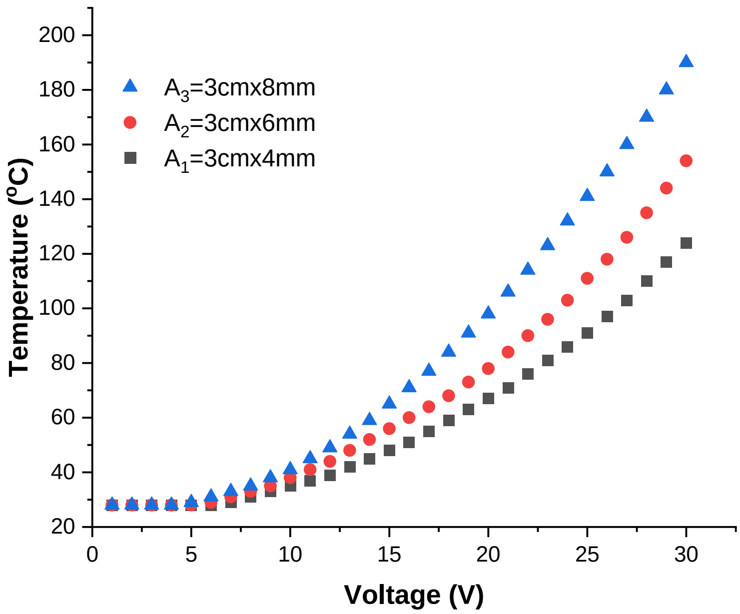

Fig.4: Temperature versus applied voltage of LIG heaters prepared at different areas.

I-V characteristics are important electrical properties, thus, a relationship between voltage and current for the three heaters that were prepared was drawn. As seen in Figure 5, the results demonstrated a linear connection between I and V with satisfactory ohmic behavior in every example [26]. Ohm's law states that when the voltage is progressively raised, the current likewise rises. ($I=V/R$), this agree with Liu et al. [27]. It is noted that heater A_3 has the highest current value due to the decrease in resistance, which leads to better electrical performance.

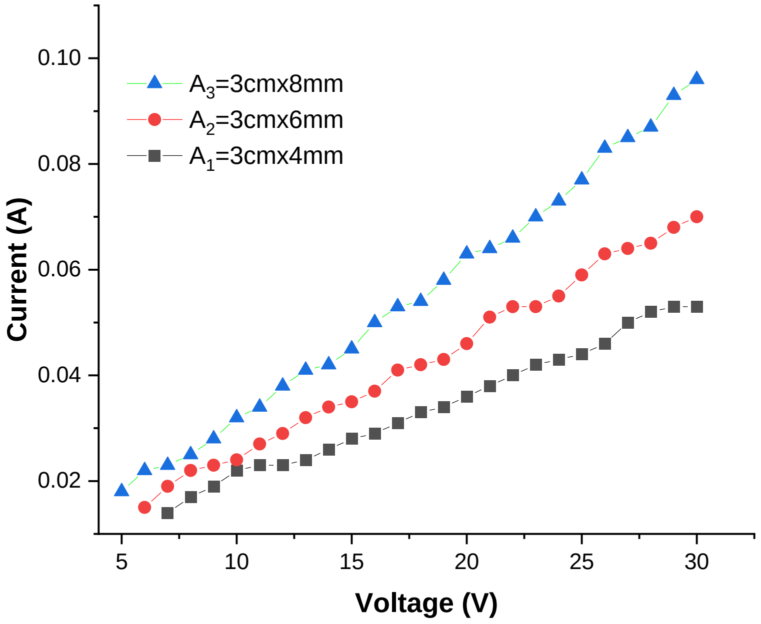

Fig.5: I-V characteristics of fabricated LIG heaters.

Power-voltage curves are important in interpreting the performance of heaters. The power was calculated from the product of current and voltage according to the equation $(P = VxI)$ resulting from the previous data. Figure 6 shows that the power increases with the square of the voltage [28-30]. Since the current increases with the voltage, the heater power increases accordingly. Therefore, it is noted that the A3 heater has the highest power compared to others.

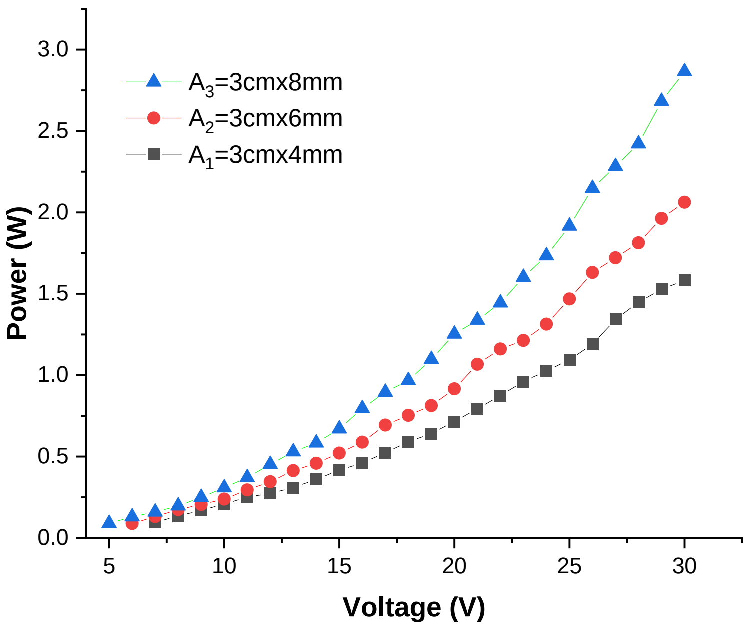

Fig.6: Relationship between electrical power and input voltage of prepared LIG heaters.

The low power across low input voltage and high temperature of the prepared graphene-based heaters make it a promising material for the fabrication of thermoelectric devices and is therefore a subject of interest for much future research in this field**.** From the above, we can say that we can control the temperature of the heater by changing the active area of graphene, thus it can be used in many applications and according to the required temperature.

Conclusion

Laser-induced graphene (LIG) was formed by photothermal decomposition on a commercial flexible polyimide substrate using a CO_2 laser. LIG was shown to have high thermal conductivity and withstand high temperatures without any surface effects on the graphene; it can be used as a resistive heater. The findings demonstrate that when the heater area grows, the thermoelectric response rises due to the resistance decreasing. The obtained temperatures were 124, 154, and 190 for heaters A_1, A_2, and A_3, respectively. The heater with the largest area showed the best performance among all heaters because it has both the highest temperature and the lowest resistance. Electrothermal response compared to the rest of the manufactured heaters, thus it is suitable for applications that require a relatively large area, such as heating surfaces, de-icing systems, and others.

Acknowledgement

We extend our heartfelt gratitude to Mr. Hussein from the Ministry of Science and Technology for his exceptional support and invaluable assistance.

Reference

[1] J. H. Chen, C. Jang, S. Xiao, M. Ishigami, and M. S. Fuhrer, "Intrinsic and extrinsic performance limits of graphene devices on SiO2," Nature Nanotech, vol. 3, no. 4, pp. 206-209, 2008.
[2] A. K. Geim and P. Kim, "Carbon wonderland, Scientific American, vol. 298, no. 4, pp. 90-97, 2008.
[3] A. S. Abdulhameed, H. A. Hadi, and R. A. Ismail. "Structural and optical properties of black silicon prepared by wet chemical etching," Mustansiriyah Journal of Pure and Applied Sciences, vol. 3, no. 1, pp. 123-134, 2025.
[4] N. D. Hayif, I. H. Hashim, and H. A. Hadi, "Non-thermal atmospheric jet plasma effects on the morphological, electrical and optical properties of nanocrystalline silicon, " Mustansiriyah Journal of Pure and Applied Sciences, vol. 2, no. 4, pp. 93-103, 2024.
[5] A. B. Kuzmenko, E. V. Heumen, F. Carbone, and D. V. D Marel, "Universal optical conductance of graphite,", Phys. Rev. Lett., vol. 100, no. 11, pp. 117401, 2008.
[6] A. K. Geim, and K. S. Novoselov,"The rise of graphene, " Nature Mater., **vol. 6**, no. 3, pp. 183-191, 2007.
[7] N. J. Hogan, A. S. Urban, C. A.- Orozco, A. Pimpinelli, P. Nordlander, and N. J. Halas, "Nanoparticles heat through light localization," Nano Lett, vol. 14, no. 8, pp. 4640–4645, 2014.
[8] T. Stensitzki, Y. Yang, V. Kozich, A. A. Ahmed, F. Kössl, O. Kühn, and K. Heyne, "Acceleration of a ground-state reaction by selective femtosecond-infrared-laser-pulse excitation," Nat Chem, vol. 10, no. 2, pp. 126–131, 2018.
[9] J. Lin, Z. Peng, Y. Liu, F. R.-Zepeda, R. Ye, E. L. G. Samuel, M. J. Yacaman, B. I. Yakobson, and J. M. Tour, "Laser-induced porous graphene films from commercial polymers," Nature communications, vol. 5, no. 1, pp. 5714, 2014.
[10] Jo, Seung Geun, Rahul Ramkumar, and Jung Woo Lee, "Recent Advances in Laser-Induced Graphene-Based Materials for Energy Storage and Conversion," ChemSusChem, vol. 17, no. 5, pp. e202301146, 2024.
[11] S.-F. Tseng, P.-S. Chen, S.-H. Hsu, W.-T. Hsiao, W.-J. Peng, "Investigation of fiber laser-induced porous graphene electrodes in controlled atmospheres for ZnO nanorod-based NO2 gas sensors," Applied Surface Science, vol. 620, pp.156847, 2023.
[12] J. Coelho, R. F. Correia, S. Silvestre, T. Pinheiro, A. C. Marques, M. R. P. Correia, J. V. Pinto, E. Fortunato, and R. Martins, "based laser-induced graphene for sustainable and flexible microsupercapacitor applications," Microchimica Acta, vol. 190, no. 1, pp. 40, 2023.
[13] S. Beikzadeh, A. Akbarinejad, J. Taylor, S. Swift, D. Simonov, J. Ross, J. Perera, P. A. Kilmartin, and J. T.-Sejdic, "Charged laser-induced graphene electrodes exhibit strong capacitance-based antibacterial and antiviral properties," Applied Materials Today, vol. 31, pp. 101753, 2023.
[14] M., Utkarsh, N. Dixit, and S. P. Singh, "Effect of laser parameters on laser-induced graphene filter fabrication and its performance for desalination and water purification," ACS Applied Materials & Interfaces, vol. 15, no. 6, pp. 7899-7910, 2023.
[15] A. Kaidarova, M. T. Vijjapu, K. Telegenov, A. Przybysz, K. N. Salama, and J. Kosel, "Enhanced graphene sensors via multi-lasing fabrication," IEEE Sens. J., vol. 21, no. 17, pp. 18562–18570, 2021.
[16] J. P. A. Gonzalez, R. G. Aguilar, and J. O. López, "Synthesis and Characterization of Laser Induced Graphene (LIG) and laser Reduced Graphene Oxide (lrGO) by using a pulsed CO2 laser," MRS Adv., vol. 4, no. 61–62, pp. 3327–3335, 2019.

[17] J.-B. Wu, M.-L. Lin, X. Cong, H.-N. Liu, and P.-H. Tan, “Raman spectroscopy of graphene-based materials and its applications in related devices,” Chem. Soc. Rev., vol. 47, no. 5, pp. 1822–1873, 2018.
[18] F. Mori, M. Kubouchi, and Y. Arao, “Effect of graphite structures on the productivity and quality of few-layer graphene in liquid-phase exfoliation,” Journal of materials science, vol. 53, pp.12807-12815, 2018.
[19] H. Y. Zheng, T. T. Tan, and W. Zhou, “Studies of KrF laser-induced long periodic structures on polyimide,” Opt. Lasers Eng., vol. 47, no. 1, pp. 180–185, 2009.
[20] S.-Y. Jeong, Y.-W. Ma, J.-U. Lee, G.-J. Je, and B. Shin, “Flexible and highly sensitive strain sensor based on laser-induced graphene pattern fabricated by 355 nm pulsed laser,” Sensors, vol. 19, no. 22, p. 4867, 2019.
[21] Y. Zhu, H. Cai, H. Ding, N. Pan, and X. Wang, “Fabrication of low-cost and highly sensitive graphene-based pressure sensors by direct laser scribing polydimethylsiloxane,” ACS Appl. Mater. Interfaces, vol. 11, no. 6, pp. 6195–6200, 2019.
[22] V. Fiodorov, R. Trusovas, Z. Mockus, K. Ratautas, and G. Račiukaitis, “Laser-Induced Graphene Formation on Polyimide Using UV to Mid-Infrared Laser Radiation,” Polymers (Basel)., vol. 15, no. 21, p. 4229, 2023.
[23] Y. Huang, L.Q. Tao, J. Yu, K. Zheng, G. Wang, and X. Chen, “Improved performance of flexible graphene heater based on repeated laser writing,” IEEE electron device letters, vol. 41, no.3, pp. 501-504, 2020.
[24] Y. Zhang, F. Yang, H. Liu, Y. Zhang. Z. Hu, and J. Liu, “Transparent heaters based on CVD grown few-layer graphene,” Journal of Materials Science: Materials in Electronics, vol. 33, no.7, pp. 3586-3594, 2022.
[25] I. Naseri, M. Ziaee, Z. N. Nilsson, D. R. Lusting, and M. Yourdkhani, “Electrothermal performance of heaters based on laser-induced graphene on aramid fabric,” ACS omega, vol. 7, no. 4, pp. 3746-3757, 2022.
[26] J. U. Lee, C. W. Lee, S. C. Cho, and B. S. Shin, “Laser-induced graphene heater pad for de-icing,” Nanomaterials, vol. 11, no.11, pp. 3093, 2021.
[27] Y. Liu, Z, Liu, W. S. Lew, and Q. Wang, “Temperature dependence of the electrical transport properties in few-layer graphene interconnects,” Nanoscale research letters, vol. 8, pp. 1-7, 2013.
[28] X.F Zhang, D. Li, K. Liu, J. Tong, and X. S. Yi, “Flexible graphene-coated carbon fiber veil/polydimethylsiloxane mats as electrothermal materials with rapid responsiveness,” International Journal of Lightweight Materials and Manufacture, vol. 2, no. 3, pp. 241-249, 2019.
[29] Y. Kim, T. Kim, J. Lee, Y. S. Choi, J. Moon, S. Y. Park, Tae. H. Lee, H. K. Park, S. A. Lee, M. S. Kwon, H. G. Byun, J. H. Lee, M. G. Lee, B. H. Hong, and H. W. Jang, “Tailored Graphene Micropatterns by Wafer-Scale Direct Transfer for Flexible Chemical Sensor Platform,” Advanced Materials, vol. 33, no. 2, pp. 2004827, 2021.
[30] D. Xia , H. Li and P. Huang, “Understanding the Joule-heating behaviours of electrically-heatable carbon-nanotube aerogels,” Nanoscale Advances, vol. 3, no. 3, pp. 647-652, 2021.