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A Review of Laser Parameters Affecting Laser-Induced Graphene (LIG) Formation

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Abstract

This review investigates the influence of laser parameters on the fabrication of laser-induced graphene (LIG). Laser power, wavelength, pulse duration, scanning speed, and repetition rate are examined for their impact on LIG quality, yield, and characteristics. The optimization of these parameters is crucial for achieving high-quality LIG. Recommended ranges for the parameters include: laser power (0.5-5 W), wavelength (355-1064 nm), pulse duration (100 fs-10 ns), scanning speed (5-100 mm/s), and repetition rate (1-500 Hz). However, optimal values may vary depending on the specific substrate, laser system, and desired properties of LIG. Understanding and adjusting these parameters effectively are vital for successful LIG synthesis.

Keywords: *Laser-induced graphene, Laser parameters, and LIG quality*

1. Introduction

Laser-Induced Graphene (LIG) is a promising approach for producing high-quality graphene using low-cost and scalable methods. The technique involves exposing various carbon-based materials, such as polyimide or Kapton, to laser irradiation, which results in the formation of graphene on the material's surface. The laser irradiation induces a chemical reaction, converting the carbon-based material into graphene.

Several research studies have investigated the use of LIG for various applications such as water purification, energy storage, and gas sensors. For instance, a study by Chen et al. [1] demonstrated that LIG-based supercapacitors exhibit high specific capacitance and excellent cycling stability. Similarly, Li et al. [2] showed that LIG can be used as an efficient and cost-effective electrode material for capacitive deionization, a water purification technique.

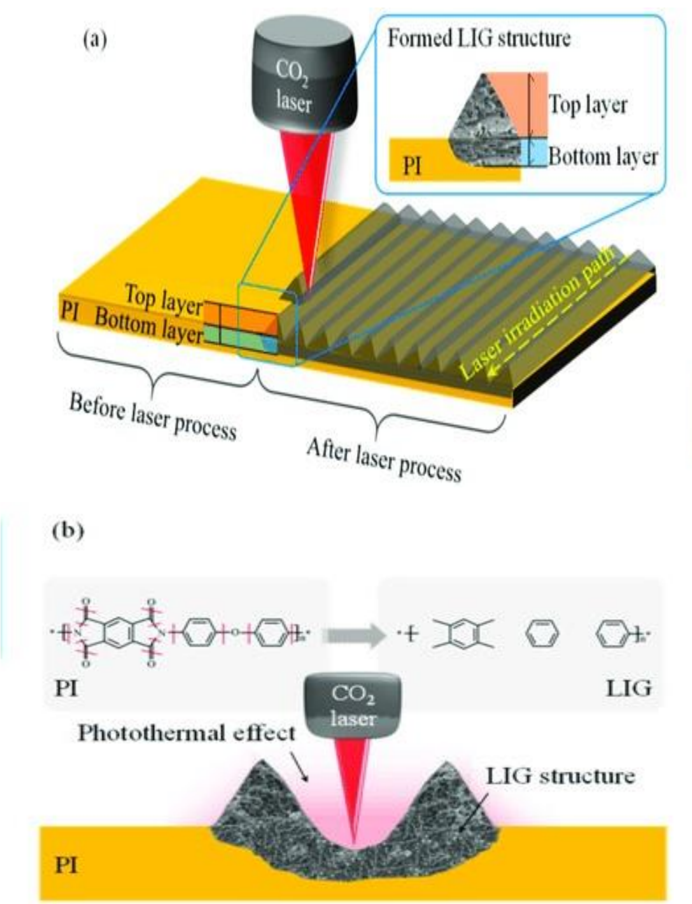
LIG has several advantages over traditional graphene synthesis methods such as chemical vapor deposition (CVD). LIG can be produced in a single step, does not require expensive equipment, and can be easily patterned using simple techniques such as mask-assisted laser ablation [3]. Additionally, LIG can be produced on various carbon-based materials, including wood, paper, and fabric, which makes it highly versatile [2].

Overall, LIG represents a promising approach for producing high-quality graphene using low-cost and scalable methods. The research studies mentioned above provide insights into the potential applications of LIG and highlight its advantages over traditional graphene synthesis methods.

1.1 Operating Principle of LIG

Laser-induced graphene (LIG) is a type of graphene material synthesized from commercial polymers, such as polyimide, by using laser irradiation. The basic operating principle of LIG is the conversion of the polymer into graphene through a photothermal process induced by laser irradiation.

When a polymer is exposed to laser irradiation, the energy from the laser is absorbed by the polymer surface, resulting in localized heating and the formation of temperature gradients. The high temperature triggers a carbonization process, which transforms the polymer into a graphene-like structure. This transformation occurs due to the breaking of C-C bonds in the polymer and the release of hydrogen and nitrogen atoms, leading to the formation of sp2-bonded carbon networks that constitute the graphene structure. The size and quality of the resulting graphene flakes depend on various factors, such as laser power, wavelength, pulse duration, scanning speed, and repetition rate.



Schematic of (a) LIG fabrication by laser irradiation and (b) reaction principle of laser irradiation process.

2 Laser Parameters in LIG Fabrication

The present review summarizes the results of several research studies that investigated the effects of different laser parameters on LIG formation, including laser power, wavelength, pulse duration, scanning speed, and repetition rate. The studies highlighted the importance of finding an optimal balance between laser power and scanning speed to achieve high-quality LIG with a high yield. Moreover, the studies demonstrated that shorter wavelengths and pulse durations can result in higher quality LIG with fewer defects.

2.1 Laser Power: Laser power is a critical parameter that affects LIG formation. The laser power determines the amount of energy transferred to the carbon-based material, which affects the size and quality of the resulting graphene flakes. Higher laser power leads to larger graphene flakes but also increases the risk of thermal damage to the substrate, leading to lower quality LIG. Therefore, it is essential to find an optimal laser power to achieve high-quality LIG with a high yield. Several research studies have investigated the effects of laser power on LIG formation. For instance, a study by Kiani et al. [5] observed that higher laser power could result in larger graphene flakes but also increased the risk of thermal damage to the substrate, leading to lower quality LIG. Similarly, a study by Li et al. [6] demonstrated that an optimal laser power can produce high-quality LIG with a high yield.

2.2 Wavelength: The wavelength of the laser beam is another critical parameter that affects LIG formation. The photon energy of the laser beam is proportional to its wavelength, which affects the strength of the interaction between the laser beam and the carbon-based material. Shorter wavelengths provide higher photon energy, resulting in stronger interaction with the substrate and faster graphene growth. A shorter wavelength can also produce higher quality LIG with fewer defects. Several research studies have investigated the effects of laser wavelength on LIG formation. For instance, a study by Guo et al. [7] demonstrated that shorter wavelengths can result in higher quality LIG with fewer defects. Similarly, a study by Akhavan et al. [8] found that shorter wavelengths can lead to more efficient conversion of carbon-based materials into graphene.

2.3 Pulse Duration: The pulse duration of the laser beam affects the temporal energy distribution of the laser, which influences LIG formation. Shorter pulse durations result in more localized heating, leading to less thermal damage to the substrate and fewer defects in the graphene. Moreover, shorter pulse durations can result in more efficient conversion of the carbon-based material into graphene. Several research studies have investigated the effects of laser pulse duration on LIG formation. For instance, a study by Lee et al.[9] observed that shorter pulse durations could produce higher quality LIG with fewer defects. Similarly, a study by Zhang et al. [10] demonstrated that shorter pulse durations can lead to more efficient conversion of carbon-based materials into graphene

2.4 Scanning Speed: Scanning speed refers to the speed at which the laser beam moves across the carbon-based material. Slower scanning speeds allow for better energy transfer and graphene growth, resulting in larger graphene flakes. However, slower scanning speeds can also lead to lower overall yield. Therefore, an optimal scanning speed should be chosen based on the desired size and quality of the LIG. Several research studies have investigated the effects of scanning speed on LIG formation. For instance, a study by Zhao et al. [11]) observed that slower scanning speeds led to larger graphene flakes but also lower overall yield. Similarly, a study by Liu et al. (12) found that an optimal scanning speed could produce high-quality LIG with a high yield.

2.5 Repetition Rate: The repetition rate of the laser beam refers to the number of pulses delivered per second. A higher repetition rate can result in smaller graphene flakes and lower overall yield. However, lower repetition rates can result in larger graphene flakes with higher quality. Therefore, an optimal repetition rate should be chosen based on the desired size and quality of the LIG.
Several research studies have investigated the effects of repetition rate on LIG formation. For instance, a study by Yang et al.(13) found that lower repetition rates could produce higher quality LIG with fewer defects.

3.0 Results and discussion from the review

The optimum values for each laser parameter for LIG synthesis depend on various factors such as the type of substrate, laser system, and desired size and quality of LIG. Therefore, finding an optimal balance between these parameters is essential to achieving high-quality LIG with a high yield.

3.1 Laser Power: The laser power is a crucial parameter that affects LIG formation. The optimum laser power typically ranges from 0.5 W to 5 W, depending on the wavelength, pulse duration, scanning speed, and repetition rate. Higher laser power can result in larger graphene flakes, but it also increases the risk of thermal damage to the substrate, leading to lower quality LIG.

3.2 Wavelength: The wavelength of the laser beam is another critical parameter that affects LIG formation. The optimum wavelength typically ranges from 355 nm to 1064 nm, depending on the substrate and laser system. Shorter wavelengths can result in higher quality LIG with fewer defects.

3.3 Pulse Duration: The pulse duration of the laser beam affects the temporal energy distribution of the laser, which influences LIG formation. The optimum pulse duration typically ranges from 100 fs to 10 ns, depending on the substrate and laser system. Shorter pulse durations can produce higher quality LIG with fewer defects and more efficient conversion of carbon-based materials into graphene.

3.4 Scanning Speed: Scanning speed refers to the speed at which the laser beam moves across the carbon-based material. The optimum scanning speed typically ranges from 5 mm/s to 100 mm/s, depending on the substrate and laser system. Slower scanning speeds can lead to larger graphene flakes, but they can also result in lower overall yield.

3.5 Repetition Rate: The repetition rate of the laser beam refers to the number of pulses delivered per second. The optimum repetition rate typically ranges from 1 Hz to 500 Hz, depending on the substrate and laser system. Lower repetition rates can result in larger graphene flakes with higher quality, but they can also lead to lower overall yield.

It is important to note that these values are not universal for all cases, and the optimal values for each parameter depend on various factors specific to each case. Therefore, it is essential to determine the optimum values through experimentation and optimization techniques, such as design of experiments (DOE) or machine learning algorithms. Understanding the effect of laser parameters on LIG formation is crucial to optimizing the synthesis of high-quality graphene materials using low-cost and scalable methods.

4.0 Conclusion

In conclusion, this review emphasizes the importance of optimizing laser parameters for laser-induced graphene (LIG) formation. By finding the right balance among laser power, wavelength, pulse duration, scanning speed, and repetition rate, researchers can achieve high-quality LIG with a desirable yield. Future research should focus on investigating the interaction between laser parameters and specific substrate materials to further enhance LIG synthesis. Additionally, exploring the scalability and cost-effectiveness of LIG fabrication methods and utilizing advanced optimization techniques would contribute to the practical application of LIG in various fields.

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