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Green Laser-Induced-Graphene (LIG) Electronics by Direct Laser Writing on Wooden Materials

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Wood is one of the most attractive material because it is abundant, eco-friendly, recyclable, and bio-degradable. However, while carbon neutrality policy is implemented, green material is re-spotlighted. Moreover, for using wood more effectively, people try to invent technologies of treating woods for overcoming the limitation of material. Here, we formed LIG (Laser-Induced-Graphene) electrodes on wooden material using ultrashort pulse laser. Ultrashort pulse laser is suitable for LIG formation because it can reduce the unwanted thermal ablation or thermal defects. Therefore, Wood surface is directly converted into LIG after irradiating by high repetition rate fs (femtosecond) laser without additional fire-retardant treatments in ambient air. Complex design of LIG electrodes can be easily patterned by fsLDW (Laser Direct Writing) technology. High quality three-dimensional porous with high electrical conductivity of LIG (~ 6 Ω/□) is generated on wooden materials. Furthermore, LIG electrodes can be applied for smart green home applications, or smart wooden furniture.

1. Introduction

30 % of earth is covered by forests, and most of forests are composed of woods [1]. Because it is natural and abundant material, people used woods since the prehistoric age. Wood are being used for dishes, containers, papers, furniture, constructions, and fuels [2]. While global warming is emerging, carbon neutrality policy is spread all around the world, green technologies are spotlighted. Wood is one of the most suitable materials for implementing green technology because wood is biocompatible, sustainable, recyclable, renewable, and biodegradable material [3].

However, since wood itself varies greatly depending on moisture contents which means wood can be easily deformed. Also, it is a material from nature that can be decayed due to insects and weathering. These disadvantages mean that the material and strength are not uniform. For a while, various materials were developed and used to avoid the problems, but at the same time, many technologies were developed to overcome the shortcomings of wood. Compressing wood for making stronger [4], transparent wood for adapting more diverse applications [5], increasing the density of wood through chemical treatment for making to preserve longer have been suggested through various studies. Furthermore, in order to utilize the wood itself in more diverse ways, a method of giving conductivity on non-conductive wood can be considered. In fact, the James Tour group at Rice university suggested the generation of LIG (Laser-Induced-Graphene) by irradiating a CO_2 laser on wood in 2017 [6]. In the case of 3D porous LIG, it has the advantages of large surface area, high thermal stability, high electrical conductivity, and high productivity with free design. However, due to the disadvantage that the wood is ablated when irradiating the laser in ambient air, there is an inconvenience such as forming the LIG in a vacuum condition or adding fire-retardant treatment. This requires a significant loss in terms of production cost and production time.

In order to overcome this problem, our research team presented a method for generating high-quality LIG on wood in ambient air using ultrashort fsLDW (femtosecond Laser Direct Writing) technology in 2019 [3]. It refers that higher-quality LIG can be produced at a higher speed at a lower cost than in previous studies. In this paper, by further optimizing this technology, Yb-doped 250 fs fiber is used and fulfilled to obtain ~ 6 Ω/□ of sheet resistance which is the highest electrical conductivity of LIG electrodes on wood. It is also confirmed that high-quality graphene can be produced on wood using SEM, Raman spectroscopy, XRD, and XPS analyses. The LIG-based heater, LIG temperature sensor, and the LIG boiler were implemented on wood for various applications. These technologies have the potential to be applied to eco-friendly smart green homes. Furthermore, the fsLDW technology was applied to recycled wood such as particleboard and MDF (Medium Densified Fiberboard), and it is also confirmed that high-quality LIG can be obtained. Through this, the applicability of eco-friendly smart furniture applications is also confirmed.

2. Results and Discussion

2.1 Characterization of LIG on Wooden Materials

In this research, 1040 nm wavelength with 200 kHz repetition rate, 250 fs pulse duration of yttrium-doped fiber laser is used. The laser beam is scanned by Galvano scanner for multiplex design of LIG patterning. By using this fsLDW system as seen in figure 1 (A), LIG is generated on the wood surface. Hardwood has higher lignin contents which assist LIG formation more effectively, because of its dense structure with abundant aromatic carbon ring. Mulbau wood and MDF are selected for LIG formation. With 0.9 W of laser power with 25 mm/s conditions, 6 Ω/□ of LIG's sheet resistance is obtained as seen in figure 1 (B). MDF-LIG's best sheet resistance is 5.8 Ω/□ with 1.5 W, 40 mm/s conditions as seen in figure 1 (C). These electrical conductivities are the highest value among the previous research of LIG electrodes on wooden materials. As seen in Figure 1 (D), SEM images show that a flat and clean wood surface is converted into three-dimensional porous graphene while fs laser beam is irradiated. Furthermore, it is confirmed that high quality LIG is successfully generated by using Raman spectroscopy, XPS, TGA, and XRD analysis.

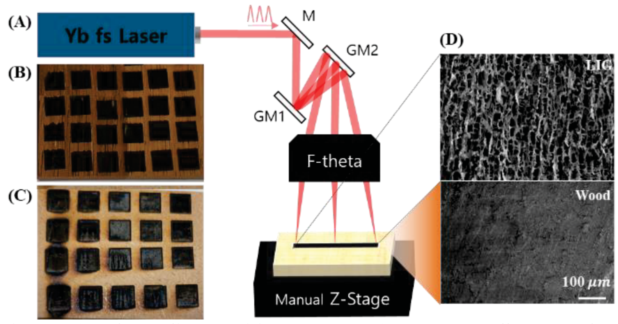
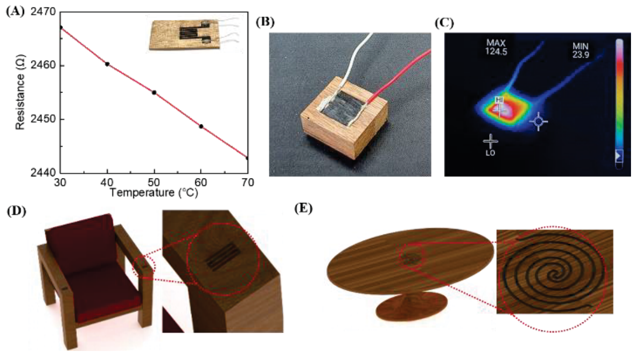


Fig. 1 (A) fs laser direct writing system (B) LIG on Mulbau wood (C) LIG on MDF (Medium Density Fiberboard) (D) SEM image of wood and LIG

2.2 Application of LIG Electrodes on Wooden Materials

LIG based temperature sensor is tested as seen in Figure 2 (A). Using the resistance change according to the temperature difference, the LIG temperature sensor is tested from 30 to 70 ℃. This temperature sensor's response time and recovery time are almost the same as conventional platinum temperature sensor which has a high reaction rate. It means LIG temperature sensor's performance is sufficient for green home applications. Figures 2 (B) and (C) show LIG heater on wood. This heater works on the principle of joule heating. With 5 V, 0.36 A condition, the temperature goes up to 125 ℃ without burning or damage. However, over 80 ℃, moisture inside the wood begins vaporization, so the wood can be distorted or partially deformed which can affect the LIG electrodes' resistance. Therefore, a heater for underfloor heating of a green home can be the suitable application.

Furthermore, we plan to use high quality with high electrical conductivity of LIG electrodes on recycled wood that we obtained for smart furniture applications because most of the furniture is made of recycled wood such as MDF or particleboard. Because LIG electrodes proved that it is sensitive, we plan to adapt to the pulse sensor application on chair armrests as seen in figure 2 (D). Furthermore, by using our experiences of LIG heater fabrication on woods, LIG stove warmer on a recycled wood-based dining table will



be fabricated as seen in figure 2 (E).

Fig. 2 (A) Wood based LIG temperature sensor test (B) Wood based LIG heater (C) IR image of LIG heater (D) Further application illustration of LIG based pulse sensor on chair armrests (E) Further application illustration of LIG based stove warmer on dining table

3. Conclusions

Ultrashort pulse LDW based LIG is generated on the hardwood in ambient air without additional treatments. Three dimensional porous structure, low sheet resistance (~6 Ω/□), and high-quality LIG electrodes are successfully formed on hardwood. For green home applications, LIG electrodes, temperature sensors, and heaters are fabricated and tested. These technologies can be rapidly adapted to green building constructions for saving time and money. Furthermore, high-quality LIG electrodes are formed on MDF which is mainly used as furniture material. These LIG electrodes can be fabricated as pulse sensors and stove warmer for green smart furniture.

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