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Full Length Article

Picosecond laser micropatterning of graphene films for rapid heating chips

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ABSTRACT

This research aims to pattern multilayer graphene films for rapid heating chips with a multichannel electrode structure and to investigate the interaction between picosecond pulsed green lasers and graphene films coated on glass substrates. The optimal laser direct writing conditions consisted of the laser fluence of 4.72 J/cm^2, the pulse repetition frequency of 300 kHz, the scanning speed of a galvano scanner of 1500 mm/s, the overlapping rate of laser spots of 66%, and parallel lines of the laser processing path with the line-scan spacing of 1 μm in one-cycle process to fabricate the graphene-based heating chips with multichannel electrode structures. The surface morphology, cross-sectional profile, current-voltage (*I-V*) curve, material characterization, and electric heating behavior on graphene/glass substrates were detected by a confocal laser scanning microscope, a Hall effect probing measurement system, a Raman spectroscopy, and a temperature recorder, respectively. The experimental results showed that the laser ablating depths increased from 9 μm to 14.2 μm when the overlapping rates of laser spots increased from 11% to 94%, respectively. Moreover, the electric heating results revealed that the temperature of graphene-based heating chips increased with increasing the applied DC voltage. The heating rate of 6 °C/s for laser-patterned graphene films was larger than that of 1.5 °C/s for unpatterned graphene films. In addition, the maximum heating temperature of laser-patterned graphene films with multichannel electrode structures was approximately 93.4 °C when the applied DC voltage was 25 V.

1. Introduction

Due to the graphere material with high optical transparency, thermal conductivity, mechanical strength, specific surface area, and electron mobility, lots of studies directed toward to industrial applications of graphene electrodes replacing indium tin oxide (ITO) for touch screens, smart windows, liquid-crystal displays (LCDs), light-emitting diodes (LEDs), organic light-emitting diodes (OLEDs), solar cells, flexible stretchable electronic devices, sensing devices, and so on [1–6]. Meanwhile, laser direct writing (LDW) is widely used for patterning grapheren electrode layers due to its fabrication properties of low-cost, high-speed, programmable manufacture, maskless, and one-step noncontact process compared with the photolithography, electrochemical reaction, and focused ion beam writing. In recent years, many literatures reported the LDW technique with different facilities and methods for patterning graphene electrode structures. Wakaya et al. [7] used a KrF excimer laser with a wavelength of 248 nm, pulse width of 20 ns, and pulse repetition frequency of 30 Hz to pattern graphene films coated on a silicon substrate. The feeding rate of specimen stage was 0.6 mm/s, and the laser beam was shaped to a stripe with an area of 0.4 × 60 mm^2. The maskless patterning of graphene films in the air was performed by laser irradiation with 10 MW/cm^2 that no graphene existed on the laser-patterned trenchs. Mortazavi et al. [8] reported selective patterning of chemical vapor deposition (CVD) single layer graphene coated on SiO_2/Si substrate using a KrF laser with a wavelength of 248 nm and pulse width of 10 ns. Laser patterning was performed with various laser fluencies ranging from 11 to 20 mJ/cm^2 at pulse repetition frequencies of 10, 20, 30, 40, and 50 Hz, and scanning speeds of 50 and 100 μm/s. Moreover, a Raman spectroscopy was used to investigate the effects of laser irradiations on the graphene film. Tseng et al. [9] presented an ultraviolet (UV) laser structuring technology for removing multilayer graphene with parallel electrode array on glass substrates for rapid inspections of moisturizing efficacy. The graphene-based impedance sensing chip was achieved in the one-cycle laser structuring process involved the parallel lines of the laser processing path with the line-scan spacing of 1 μm, laser fluence of 3.4 J/cm^2, scanning speed of 600 mm/s, and laser pulse repetition frequency of 100 kHz. The inspection results revealed that the electrochemical impedance spectroscopy (EIS) combined

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with graphene sensing chips had high sensitivity and saving time than weight loss of solutions detected by a precision electronic balance. Zhang et al. [10] adopted an ultrafast laser with a central wavelength of 800 nm and a pulse duration of 100 fs to pattern graphene coated on a glass substrate. The ablation threshold of graphene was determined to be 0.16–0.21 J/cm^2. Narrower channels of about 25 μm on graphene were formed by a laser fluence of 0.48 J/cm^2 and a scanning speed of 5 mm/s in ambient air. Lee et al. [11] utilized a pulsed nanosecond Nd:YVO_4 (λ = 1064 nm) laser processing system to ablate single-layer graphene films (SLGFs) on glass and poly(ethylene terephthalate) (PET) substrates. The experimental results showed that the ablated line widths of SLGFs decreased with increasing the scanning speeds and pulse energies. After the laser patterning, graphene films were completely removed verifying by a Raman spectroscopy.

In this work, we present the laser direct patterning of multilayer graphene films (MGFs) coated on glass substrates for heating chips with multichannel electrode structures via the focused picosecond laser patterning. Various scanning speeds of a galvano scanner were used to calculate the overlapping of laser spots and to investigate the laser ablation depths of MGFs. The surface morphology, cross-sectional profile, current-voltage (*I-V*) curve, material characterization, and electric heating behavior after laser patterning graphene films were detected by a confocal laser scanning microscope, a Hall effect probing measurement system, a Raman spectroscopy, and a temperature recorder, respectively.

2. Experimental details

2.1. Picosecond pulsed laser processing apparatus

A picosecond pulsed laser with a maximum average output power of 5 W was used to pattern MGFs coated on the soda-lime glass substrate. Fig. 1 shows a schematic diagram of the picosecond pulsed green laser processing apparatus for patterning the multichannel electrode structure on the MGF surface. The laser beam with a central wavelength of 532 nm, pulse repetition frequencies ranging from 100 kHz to 1 MHz, and a pulse width of 7 ± 2 ps was delivered by four total reflective mirrors, an XY-axes galvano scanner, and a f-θ focusing lens. The focal length of f-θ lens, the 1/e^2 laser beam diameter at the exit port, and the focused spot size were approximately 105 mm, 1.4 ± 0.02 mm, and 15 μm, respectively. Moreover, the transverse mode was TEM_{00} (M^2 < 1.3). The scanning speed of galvanometers could be adjusted ranging from 5 mm/s to 6000 mm/s. A PZT linear stage was used to adjust the focus ranges in a Z-axis direction. The completed specifications of the picosecond pulsed green laser patterning apparatus were presented in Table 1. The average laser powers, the pulse repetition frequencies, and the scanning speeds of galvanometers on the MGF surface were adjusted by commercial software, which allows an automatic control operation during the laser patterning process.

2.2. Fabrication procedures of graphene-based heating chips

Fig. 2 shows fabrication procedures of graphene-based heating chips. Graphene/glass substrates were prepared by using spin coating graphene inks on soda-lime glass substrates with a thickness of 1.1 mm, shown in Fig. 2(a). The spin coating procedure included two steps in order to coat uniform graphene inks on the glass surface. First step is to set the spin coating at a speed of 3000 rpm for 20 s, and second step is to set the spin coating at a speed of 4500 rpm for 40 s. Then, a dry graphene film with a thickness of about 13 μm was achieved by a hot plate at 130 °C for 90 min. After the graphene/glass sample was performed, the laser direct patterning technique was used to pattern the multichannel electrode structure on the graphene surface by the picosecond laser

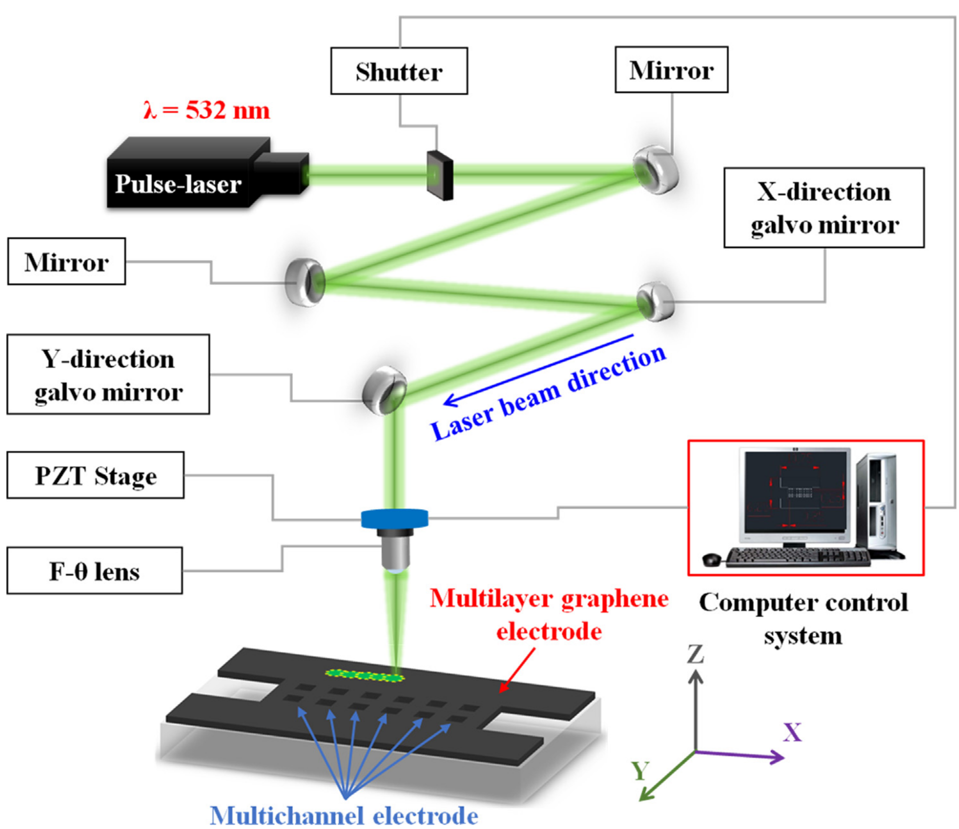

Fig. 1. The schematic diagram of the picosecond pulsed green laser patterning apparatus.