Applied Surface Science 428 (2018) 94–97

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Full length article

Micropatterning of CVD single layer graphene using KrF laser irradiation

Somayeh Mortazavi[a], Mahmoud Mollabashi[a,*], S. Ismat Shah[b,c]

[a] School of Physics, Iran University of Science and Technology, Tehran 16844, Iran
[b] Department of Physics & Astronomy, University of Delaware, Newark, DE 19716, USA
[c] Department of Materials Sciences and Engineering, University of Delaware, Newark, DE 19716, USA

ARTICLE INFO

Article history:
Received 4 June 2017
Received in revised form 29 July 2017
Accepted 11 September 2017
Available online 13 September 2017

Keywords:
CVD graphene
Laser patterning
Raman spectroscopy

ABSTRACT

Selective patterning of CVD single layer graphene on SiO_2/Si substrate has been performed using a KrF laser. Channels that their widths are affected by laser fluence were produced on graphene film surface in atmospheric environment. Dependence of ablation width of the channels on various laser parameters such as laser fluence and pulse repetition rate was investigated at different scanning speeds. Raman spectroscopy, optical and scanning electron microscopy were employed in order to evaluate the effect of laser irradiation on graphene film. Raman spectra confirm formation of uniform channels on graphene surface. Such patterned graphene films have significant importance in microelectronics and spintronics applications.

1. Introduction

Graphene is a two-dimensional hexagonal lattice of carbon atoms. Many devices are being now made using graphene plans, because the 2D structure of graphene makes it a promising candidate for electronic applications due to its high carrier mobility, chemical and physical properties as well as mechanical stability [1,2]. The most common approaches for production of graphene include mechanical exfoliation of HOPG, chemical vapor deposition (CVD) and reduction of graphene oxide (GO). In particular, CVD method has been a promising approach for growing large area graphene for mass production [3]. On the other hand, patterning of graphene film is also of significant importance for various applications of the material. So laser patterning of large area CVD graphene films can solve limitations that exists by other production and patterning techniques included non-large-area production, or need to patterning with mask and resist.

While most of the studies use femtosecond lasers irradiation on graphene films that contains producing micro and nano-disks [4], graphene folds on SiO_2/Si substrate [5] and producing graphene patterns on glass substrate [2,6,7], studies of graphene ablation have been also reported by focused irradiation of cw CO_2 and Nd:YAG lasers [8,9]. Furthermore, there are studies [10,11] on the effect of KrF laser irradiation on multilayer graphene produced by mechanical exfoliation method to study the change of the graphene layers thickness under laser irradiation. They [11] also raised supersonic elastic vibrations of the substrate surface as mechanisms involved in removal of graphene layers from substrate that occurs as a result of temperature rise and thermal expansion due to the absorbed light in Si layer. KrF excimer lasers were generally used in laser interactions of graphene-based materials because of more efficient optical coupling of the laser photon energy with those of chemical bonds of the materials and its advantages in producing features with improved resolution.

There is lots of ongoing research in field of spintronics which involves depositing high quality magnetic films on graphene [12], and one of best ways to do this is to use high energy UV PLD, like KrF laser. In this study, patterning of CVD grown graphene film on SiO_2/Si substrate was investigated using KrF laser irradiation under various laser parameters such as laser fluence and pulse repetition rate. Graphene single layer has been scanned to obtain desired patterns at different scanning speeds. Graphene patterns were characterized by optical and scanning electron microscopy, and Raman spectroscopy. Based on our knowledge, there is no study on patterning single layer graphene using KrF laser irradiation. Our final goal is to put graphene substrate in deposition chamber, which because of simplicity of our patterning system is easily achievable,

* Corresponding author.
E-mail address: mollabashi@iust.ac.ir (M. Mollabashi).

http://dx.doi.org/10.1016/j.apsusc.2017.09.083
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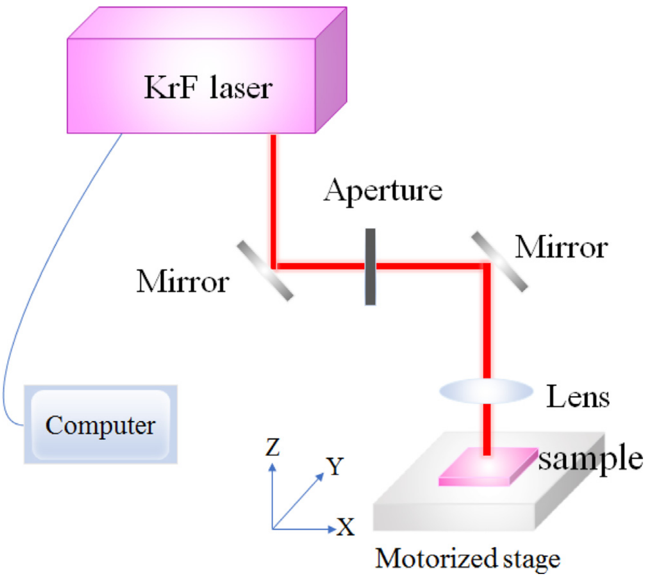

Fig. 1. Schematic of patterning process of single layer graphene on SiO_2/Si substrate using KrF laser.

and do patterning and deposition in one load, which we believe will help to make higher quality devices in spintronics applications.

2. Experimental

Single layer graphene sample (Graphenea) was grown on Cu foil by CVD method and then was transferred on SiO_2/Si substrate using wet transfer process. Grain size of graphene is up to 10 μm with a coverage of >95% and transparency of >97%. That contains some defects such as small holes, wrinkles, small islands of multi-layers graphene and some residues which are less than 5% of the surface. Si wafer of P type with orientation ⟨100⟩ was oxidized to form a 300 nm thick layer of SiO_2. The substrate size is 1 cm × 1 cm. Experimental setup of UV laser processing system has been shown in Fig. 1. A pulsed KrF laser (Lambda Physics) of 248 nm wavelength and 10 ns pulse duration was used for the patterning of graphene films. A 150 μm aperture was employed to image on sample using a projection beamline as approximately similarly reported by ref [13]. A 75 mm lens focuses a laser beam on sample. Average laser power were measured by a laser power meter (Coherent, Field-mate) and shows stability of laser output during laser irradiation process. Laser pulse duration and repetition rate were also measured to be 10 ns and 10 Hz, respectively, using a photodiode and an oscilloscope 100 MHz (Tektronix TDS 3014B). So pulse energy of each laser pulse and average laser fluence can be easily calculated and because of high stability of the laser power, assuming a constant energy for each pulse seems to be reasonable. Laser processing of graphene sample was carried out in air atmosphere and at room temperature. Graphene film has been translated perpendicular to the laser beam at different speeds.

Raman spectrometer (Thermo Scientific, DXR) with a 532 nm laser source was used to characterize graphene sample at room temperature. Raman spectra were obtained at range 500–3000 cm^{-1} with spectral resolution of 4 cm^{-1}. A 2 mW laser power was chosen to avoid graphene damage. 50 × objective lens results in a 0.7 μm spot size that represent laser power density ~5.2 × 10^5 W/cm^2 at the sample plane. A Nikon Eclipse microscope and a charge coupled device (CCD) was used to record optical micrograph of irradiated film. Image of scanning electron microscopy (SEM) were obtained with JSM-7400F microscope operated at 15 kV.

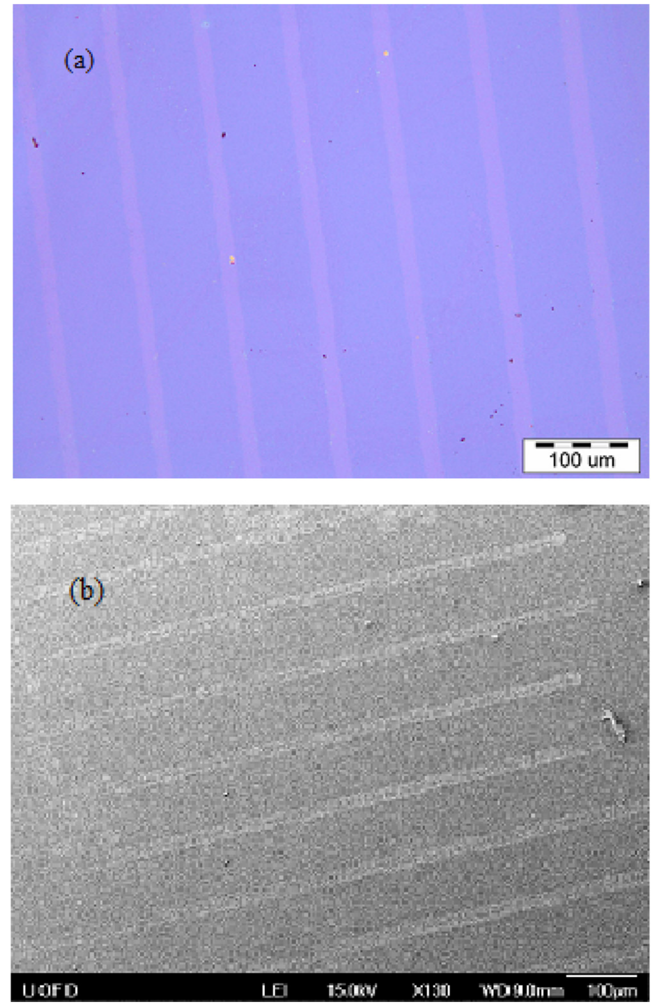

Fig. 2. Images of (a) optical microscopy and (b) SEM of produced channels on graphene surface with various fluencies of 11–20 mJ/cm^2 at the same repetition rate and scanning speed.

3. Results and discussion

To produce channels on graphene film, laser beam was focused on the graphene surface and graphene film was translated respect to the laser beam with about 1 mm in length. Laser patterning was performed with laser fluencies in the range of 11–20 mJ/cm^2 in five various laser pulse repetition rates ranging from 10 to 50 Hz. Fig. 2(a) shows optical image of patterned graphene film at various laser fluencies, whereas scanning speed and pulse repetition rate were fixed at 100 μm/s and 20 Hz, respectively. Different regions of graphene film are easily distinguishable by good optical contrast that exists between graphene and substrate. Bright and dark areas correspond to cut and uncut areas, respectively. As observed from the image of optical microscopy, channels of different widths were produced under various laser fluencies. An increase trend of channels width is clearly observable in the optical microscopy image from the left to the right. Fig. 2(b) is also a SEM image of the patterned graphene film. Channels of widths from 14 to 24 μm were produced in the range of employed laser fluencies. The similar experiments were also performed at scanning speed of 50 μm/s.

Fig. 3 indicates channels width as a function of laser fluence at pulse repetition rates of 10, 20, 30, 40 and 50 Hz, and scanning speeds of 50 and 100 μm/s. As shown in the figure at scanning speed 100 μm/s channels widths are increased with increasing laser fluence with an approximately same trend for all pulse repetition