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GO-neutral red nanocomposite reduction by nanosecond, picosecond and femtosecond lasers

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Abstract

Graphene has attracted significant interest from researchers due to its unique physical properties. One of graphene production methods is based on graphene oxide (GO) reduction which can be implemented by laser irradiation. Our previous research has shown that the best quality laser-induced graphene (LIG) coating is obtained using a GO-neutral red (GO-NR) nanocomposite precursor.
In this work, we performed GO reduction experiments using nanosecond, picosecond and femtosecond IR lasers irradiation. Irradiated GO-NR films were investigated by Raman spectroscopy. It was shown that the best quality LIG was formed by nanosecond laser irradiation using 26 J/cm^2 irradiation dose. When this dose was applied, the Intensity ratio of Raman spectral lines I(2D)/I(G), showing GO reduction quality was 0.9.

Keywords: graphene; graphene oxide reduction; Raman

1. Introduction

The focused laser beam has become an essential tool for modifying thin layers and creating micro and nanostructures in 2D crystals (Trusovas et al. 2013, 2018, 2019; Jagminas et al. 2016). Laser microfabrication allows creating both a small and broad area modifications of GO. This method allows manipulating the physical and chemical properties of the produced graphene. Such reduction is based on the laser-induced

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local temperature increase, which results in structural changes in the GO - interruption of the chemical bonds between the oxygen-containing functional groups and the graphene flakes.

An essential factor in researching of carbon-based materials is the ability to identify and characterise carbon allotropes. The appropriate tool for characterisation must be non-harmful to the tested sample, possess high resolution and provide structural and electronic information. Raman spectroscopy has all these qualities. It helps to characterise the structure and the degree of disorder in the carbon materials. Spectral characteristics of graphite-type materials are observed in the 1000-3000 cm^{-1} region. Raman spectral characteristics of graphene and its derivatives consist of three major peaks - D (1333 cm^{-1}), G (1578 cm^{-1}) and 2D (also known as G ') (2682 cm^{-1}).

2. Experiment

GO samples were synthesised using Standard Hummers - Offeman and modified synthesis protocols. The thickness of the GO-NR coating on the polycarbonate substrate was 400 nm.

The GO reduction to graphene experiment was performed using three different lasers: picosecond (Atlantic, 10 ps, 100 kHz, Ekspla), nanosecond (Baltic HP, 10 ns, 100 kHz, Ekspla) and femtosecond (Pharos, 190 fs, 100 kHz, Light Conversion).

Raman spectroscopy measurements were performed to evaluate the structure and quality of the resulting derivatives (Fig. 1). These measurements were performed using a Raman spectrometer/microscope (Renishaw, UK) with a thermoelectric cooled (-70° C) CCD detector. Spectrum was excited using He-Ne laser, 632.8 nm wavelength. 1200 grooves/ mm diffraction grating was used. The Raman spectrum was obtained using a 50×/0.75 NA objective. Integration time was 100 s.

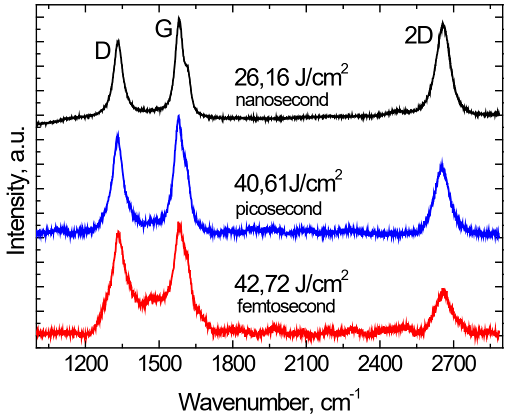

Fig. 1. Raman spectra of GO-NR reduced with different lasers at best reduction levels and used irradiation doses.

The results showed that when the GO-NR sample is treated with a nanosecond laser, the best quality graphene layers are obtained - the value of the I2D/IG ratio is 0.90 when this ratio is only 0.58 for the picosecond laser and 0.43 for the femtosecond. The optimal irradiation dose for the nanosecond laser was 26.16 J/cm^2, picosecond 40.62 J/cm^2, and femtosecond 42.72 J/cm^2. The presence of defects - the value of the ID/IG ratio was also the lowest in the case of the nanosecond laser - 0.80, and in the picosecond and femtosecond treatment - 0.81 and 0.93 respectively. We observe that with shorter pulse duration, the resulting graphene derivative becomes less close to the ideal one-layer graphene, and the density of defects also increases. The defects may be induced by the fact that when the pulse duration is short, the samples are subjected to nonlinear absorption effects. The nonlinear effects of laser radiation interaction with the GO film interrupt the integrity of the crystal lattice structure of graphene sheets. While treating the GO sample with nanosecond pulses, the material is being linearly heated until the temperature required for GO reduction is reached.

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