Data Article

Database on the nonlinear optical properties of graphene based materials

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ABSTRACT

The knowledge of optical nonlinearity is pre-requisite for the utility of the nonlinear optical (NLO) materials for optoelectronic device fabrication. Z-scan experimental technique based on the principles of spatial beam distortion, has been successfully employed for years to precisely investigate the NLO parameters. In the field of optical nonlinearity, graphene has proven itself as a strong candidate material owing to the possibility of strong light-matter interactions. A detailed comparison of the NLO properties of graphene and its derivatives (G/GDs) is crucial to identify and accelerate their utility for future flexible optoelectronic device applications. Herein, we share the experimental records of the optical nonlinearity in G/GDs, obtained from the well established Z-scan technique from the available literature, reported in the period from 2009 to 2019 and were extracted from the provided raw data [1]. The data sheet includes material composition, characteristics of the excitation laser source (operating wavelength, laser energy/power/intensity) and the NLO parameters (nonlinear absorption (NLA), nonlinear refraction (NLR), saturation intensity, optical limiting threshold). For practical use, they are tabulated in the present paper and will enable users to search the material data and filter down the set of desired materials using given parameters for their possible optoelectronic device applications. The data is related to the research article entitled “Unraveling absorptive and refractive optical nonlinearities in...”

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CVD grown graphene layers transferred onto a foreign quartz substrate” (Agrawal et al., 2019) [2].
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1. Data

The database presented in this article describes a detailed comparison of the NLO properties of G/GDs, obtained experimentally from the Z-scan techniques, from the available literature reported in the period from 2009 to 2019. Fig. 1 (obtained from the raw data provided for the year-wise bifurcated research publications [1]) shows a histogram to graphically display the number of experimental research articles published from 2009 onwards, which clearly suggests the increasing interest of the scientific community to examine the optical nonlinearities in G/GDs. Fig. 2 depicts a schematic diagram for the Z-scan experimental setup, employed to investigate the optical nonlinearity. Fig. 3 illustrates a tree-like classification for the graphene based materials database, where the database is primarily classified in five families, including metal decorated-G/GDs, 2D transition metal dichalcogenides (TMDs) and post-transition metal trichalcogenides (TMTs)-G/GDs, semiconductor-graphene based materials, G/GDs dispersed in various solutions and single(SL)/few(FL)/multilayer(ML) graphene material based films. Each family has several members which are characterized by a set of attributes including: composition, laser parameters (operating excitation wavelength, laser energy/power/intensity) and experimentally derived NLO parameters (NLA, NLR, saturation intensity (Is), optical limiting threshold (Fth)). Table 1 listed the NLO parameters of various graphene based materials and
these entries makes up a material record which is highly valuable for the researchers interested in the optical nonlinearity in G/GDs from the experimental point of view.

2. Experimental design, materials, and methods

For all the literature presented in this article, the data was acquired from the well established Z-scan technique, pioneered by Sheik Bahae et al. [3–5], and has also been extensively described elsewhere [6,7]. Briefly, the NLO is the optics of light where NLA and NLR becomes intensity dependent. For this, a high power/intense laser light source is irradiated on the NLO material and the transmitted signal from the material was recorded as a function of intensity, varied by translating the sample through the focal plane of a tight focusing lens along its propagation (z) axis (Fig. 2). Z-scan experiment can be formed in two geometries: (i) open aperture (OA) geometry for extracting NLA, where all the transmitted light

![Fig. 1. Histogram showing the number of research articles published from 2009 onwards in the field of experimental determination of NLO parameters of graphene based materials.](image1)

![Fig. 2. Schematic of the Z-scan experimental setup.](image2)
was collected and focused onto the detector using another lens, and (ii) closed aperture (CA) geometry where only the on-axis beam is allowed to be collected at the detector for the determination of NLR.

It is noteworthy to mention here that graphene has attracted much attention after Andre Geim and Kostya Novoselov were awarded the 2010 Nobel Prize in Physics “for groundbreaking experiments regarding the 2D material graphene”. After that, this material and their derivatives decorated with other materials viz; decorated with metals, TMDs, TMTs, semiconductors has been extensively investigated for various properties (Fig. 3). This material has also gained tremendous interest in the field of flexible optoelectronic device applications because of the possibility of strong light-matter interactions and flexible nature.

Although, there are a number of theoretical as well as experimental reports published in the field of optical nonlinearities in G/GDs. Herein, only the experimentally derived optical nonlinearity employing Z-scan technique has been listed (Table 1). Usually, OA experimental curve/result exhibits either a sharp peak or valley at the focal plane of the tight focussing lens as a consequence of saturable absorption (SA) or reverse saturation absorption (RSA), respectively. However, in graphene based materials, a combination of SA and RSA has also been observed where the transmittance from the material is found to increase at both the ±z-direction with respect to the focal plane, followed by a dip at the focus [2]. On the other hand, under CA geometry, the far-field on-axis normalized transmittance as a function of traversed distance exhibits a peak followed by a valley or vice versa. The prefocal peak (valley) and postfocal valley (peak) in the experimentally obtained curve indicates the negative (positive) sign of the NLR coefficient. These parameters were obtained from the best possible theoretical fitting to the experimental Z-scan profile depending upon the property of the grown material. The theoretical fitting of the experimental Z-scan profile is based on various phenomenon including; multi-photon absorption (n-PA, where integer n > 1), SA, RSA, NLO scattering, thermal lensing or a combination of these effects. Further details regarding the functions used for the fitting of the experimental data curves are given elsewhere [2–7]. This work reflects the state-of-the-art of the novel graphene material and the NLO properties are not equally renowned for every derivative due to the lack of literature data. In view of this, listing of these entries (Table 1) makes up a material record which precisely represents the material property and will enable users to search the material data and filter down the set of desired materials using given parameters. The database was used by Agrawal et al. [2].
Table 1
Database for the NLO parameters (NLA/NLR/Is/Fth) investigated under various laser parameters (wavelength/laser power/energy/intensity) derived from Z-scan experimental studies for metal decorated-G/GDs, 2D-TMDs, post-TMTs-G/GDs, semiconductor-graphene based materials, G/GDs dispersed in various solutions and single/few/multilayer graphene material based films and many others. Parenthesis (column 2) indicates the reference number of published articles that are given in Ref. [1].

| Material | Ref. [1] | Laser parameters | NLO parameters |
|----------|---------|------------------|----------------|
| Graphene and its derivatives decorated with various metals | | | |
| Au FG | (21) | 514 nm | NLA = 128 cm/mW; NLR = − 0.292 cm²/MW |
| Pt NP/rGO | (25) | 532 nm; 1 Hz; 4 ns; 50 µJ | NLA = 1.38 cm/GW |
| Ni NP/rGO | (25) | 532 nm; 1 Hz; 4 ns; 50 µJ | NLA = 1.29 cm/GW |
| Pt–Ni NP/rGO | (25) | 532 nm; 1 Hz; 4 ns; 50 µJ | NLA = 1.64 cm/GW |
| Pt–Ni cluster/rGO | (25) | 532 nm; 1 Hz; 4 ns; 50 µJ | NLA = 1.98 cm/GW |
| GO-Ag | (30) | 532 nm; 10 ns; 0.20 GW/cm² | NLA = 45.4 cm/GW |
| GO-Ag | (30) | 532 nm; 10 ns; 0.16 GW/cm² | NLA = 39.7 cm/GW |
| GO-Ag | (30) | 532 nm; 10 ns; 0.10 GW/cm² | NLA = 32.4 cm/GW |
| GO-Ag | (30) | 532 nm; 10 ns; 0.08 GW/cm² | NLA = 30.0 cm/GW |
| NF-rGO/Ag-NPs(1 M) | (31) | 532 nm; 5 ns | NLA = 13.9 m/GW |
| NF-rGO/Ag-NPs(1 M) | (31) | 800 nm; 100 fs | NLA = 5.8 × 10⁻¹⁵ m/W |
| Au-NPs(16.55 nm)/GO | (39) | 532 nm; 180 mW | NLA = − 1.85 cm²/GW |
| Au-NPs(13.41 nm)/GO | (39) | 532 nm; 180 mW | NLA = − 2.7 cm²/GW |
| Au-NPs(9.52 nm)/GO | (39) | 532 nm; 180 mW | NLA = − 4.1 cm²/GW |
| Au-NPs(5.18 nm)/GO | (39) | 532 nm; 180 mW | NLA = − 5.8 cm²/GW |
| Pt/f-HEG | (49) | 532 nm; 5 ns; 0.5 Hz | Fh = 13.7 J/cm² |
| Pd/f-HEG | (49) | 532 nm; 5 ns; 0.5 Hz | Fh = 8.8 J/cm² |
| Pt/f-HEG | (49) | 800 nm; 100 fs; 0.5 Hz | Fh = 1.8 J/cm² |
| Pd/f-HEG | (49) | 800 nm; 100 fs; 0.5 Hz | Fh = 1.5 J/cm² |
| Ag NPs/G composite | (58) | 532 nm; 40 ps; 10 Hz | NLA = 912 cm²/GW; Is = 3.7 GW/cm² |
| Ag NPs/G composite | (58) | 1064 nm; 40 ps; 10 Hz | NLA = 600 cm²/GW |
| Ag NPs/rGO | (12) | – | Is = 18.5 MW/cm²; NLR = − 1.1 × 10⁻¹² m²/W |

2D TMDs/graphene derivatives, post-TMTs-G/GDs

| Material | Ref. [1] | Laser parameters | NLO parameters |
|----------|---------|------------------|----------------|
| MoSe2/G (Rt = 6h) | (7) | 532 nm; 30 ps; 10 Hz; 6.6 GW/cm² | NLA = − 6.46 × 10⁻¹² m/W; NLR = 1.54 × 10⁻¹¹ esu |
| MoSe2/G (Rt = 12h) | (7) | 532 nm; 30 ps; 10 Hz; 6.6 GW/cm² | NLA = − 6.12 × 10⁻¹² m/W; NLR = 1.35 × 10⁻¹¹ esu |
| MoSe2/G (Rt = 18h) | (7) | 532 nm; 30 ps; 10 Hz; 6.6 GW/cm² | NLA = − 3.90 × 10⁻¹² m/W; NLR = 1.18 × 10⁻¹¹ esu |
| MoSe2/G (Rt = 24h) | (7) | 532 nm; 30 ps; 10 Hz; 6.6 GW/cm² | NLA = − 2.30 × 10⁻¹² m/W; NLR = 1.14 × 10⁻¹¹ esu |
| MoS2/G | (27) | 800 nm; 1 Hz | NLA = − 1217.8 cm/GW |
| MoS2/G | (38) | 400 nm; 100 fs | Is = 1.427 GW/cm² |
| MoS2/G | (38) | 800 nm; 100 fs | Is = 2.02 GW/cm² |
| MoS2/G | (38) | 1562.6 nm; 565 fs | Is = 2.44 mW/cm² |
| G/MoS2/PMMA | (51) | 532 nm; 6 ns; 1 Hz; 66 µJ | NLA = 2110 cm³/GW |
| Bi2S3/rGO (15mg) | (8) | 532 nm; 30 ps; 10 Hz; 4.5 GW/cm² | NLA = 2.29 × 10⁻¹¹ m/W; NLR = 1.65 × 10⁻¹¹ esu |
| Bi2S3/rGO (30mg) | (8) | 532 nm; 30 ps; 10 Hz; 4.5 GW/cm² | NLA = 2.48 × 10⁻¹¹ m/W; NLR = 4.03 × 10⁻¹¹ esu |
| Bi2S3/rGO (45mg) | (8) | 532 nm; 30 ps; 10 Hz; 4.5 GW/cm² | NLA = 2.28 × 10⁻¹¹ m/W; NLR = 3.48 × 10⁻¹¹ esu |
| Bi2S3/rGO (60 mg) | (8) | 532 nm; 30 ps; 10 Hz; 4.5 GW/cm² | NLA = 1.77 × 10⁻¹¹ m/W; NLR = 1.81 × 10⁻¹¹ esu |

(continued on next page)
| Material | Ref. | Laser parameters | NLO parameters |
|----------|------|------------------|----------------|
| CdSe-rGO | (4)  | 532 nm; 30 ps; 10 Hz | NLA = 224.42 cm/GW; NLR = 48.90 × 10⁻¹¹ esu |
| rGO-PbS QDs | (36) | 532 nm; 4 ns; 10 Hz; 25 μJ | NLA = 7.9 × 10⁻¹⁰ m/W |
| G/CdS/PMMA | (50) | 532 nm; 6 ns; 1 Hz | NLA = 797 cm/GW |
| GNS–CdS QDs in DMF | (67) | 532 nm; 8 ns; 1 Hz; 250 μJ | NLA = 1.37 × 10⁻¹⁰ cm²/W; Fₚ₀ ~ 0.88 J/cm² |
| TiO₂/rGO (0.25 g) | (35) | 532 nm; 4 ns | NLA = 6.0 × 10⁻¹⁰ m/W |
| GO/Pt | (62) | 532 nm; 5 ns; 10 Hz | NLA = 26 cm/GW; NLR = 2.83 × 10⁻¹³ cm²/W |
| TiO₂/rGO (0.25 g) | (35) | 532 nm; 4 ns | NLA = 1.1 cm/GW; Is = 0.6 GW/cm² |
| S-rGO(10 mg)-ZnO | (46) | 532 nm; 5 ns; 10 Hz | NLA = 15 cm/GW; Is = 1.8 GW/cm² |
| H-rGO (10 mg) ZnO | (46) | 532 nm; 5 ns; 10 Hz | NLA = 15 cm/GW; Is = 1.8 GW/cm² |
| GO–Fe₃O₄ | (68) | 532 nm; 5 ns | RSA: enhanced by Fe₃O₄ |
| ZnFe₂O₄-rGO (40 wt%) | (24) | 532 nm; 5 ns; 10 Hz; 100 μJ | NLA = 1.26 × 10⁻¹⁰ m/W; NLR = 1.29 × 10⁻³⁸ esu |
| MgO-GO (T = 60 °C) | (22) | 532 nm; 10 ns; 200 Hz | NLA = 9.7 × 10⁻⁸ cm²/W; NLR = 1.95 × 10⁻¹² cm²/W |
| G/GDs dispersed in various solutions | | | |
| GO in DMF | (69) | 532 nm; 5 ns | NLA = 5.6 × 10⁻⁸ cm²/W; Is = 1.2 × 10⁸ W/cm² |
| G in DMA | (70) | 532 nm; 6 ns; 10 Hz | Fₚ₀ = 2 J/cm² |
| G in NMP | (70) | 532 nm; 6 ns; 10 Hz | Fₚ₀ = 2.5 J/cm² |
| G in GBL | (70) | 532 nm; 6 ns; 10 Hz | Fₚ₀ = 3 J/cm² |
| G in THF | (70) | 1064 nm; 6 ns; 10 Hz | Fₚ₀ = 4.2 J/cm² |
| G in NMP | (70) | 1064 nm; 6 ns; 10 Hz | Fₚ₀ = 7.8 J/cm² |
| G GO-NPs in water (57) | 810 nm; 150 fs; 80 MHz | NLA (2PA) ~ 0.045 cm/GW (740 nm) to ~ 0.023 cm/GW (820–850 nm) |
| Material                  | Laser Parameters | NLA | NLR |
|--------------------------|------------------|-----|-----|
| GO NPs in water          | (57)             |     |
| GO in DMF                | (53)             | 1260 nm; 130 fs; 1 kHz | 8.4 × 10^{-5} cm^3 GW^{-2} (1200 nm) to 0.6 × 10^{-5} cm^3 GW^{-2} (1260–1320 nm) |
| GO in DMF                | (53)             | 532 nm; 4 ns | 20.71 cm/GW |
| GO in DMF                | (54)             | 1064 nm; 4 ns | 12.53 cm/GW |
| G in DMF                 | (47)             | 800 nm; 120 fs; 1 kHz; 82.1 GW/cm^2 | 2.5 × 10^{-11} cm/W; NLR = −5.3 × 10^{-16} cm^2/W |
| G in DMF                 | (47)             | 532 nm; 6 ns; 2 Hz; 57–166 nJ | 2.89 ± 0.15 cm/GW |
| G in NMP                 | (47)             | 532 nm; 6 ns; 2 Hz; 57–166 nJ | 2.6 ± 0.13 cm/GW |
| G in SC                  | (47)             | 532 nm; 6 ns; 2 Hz; 57–166 nJ | 2.05 ± 0.10 cm/GW |
| GO sheets in water       | (44)             | 852 nm; 4 ns | 130.10 cm/GW |
| GO sheets in water       | (44)             | 1064 nm; 4 ns | 20.01 cm/GW |
| GO in DMF                | (43)             | 532 nm; 4 ns; 10 Hz; 0.43 J/cm^2 | 50 cm/GW |
| SLGO in water            | (28)             | 532 nm; 4 ns | 108.4 cm/GW |
| FLGO in DMF              | (28)             | 532 nm; 4 ns | 220 cm/GW |
| GO in water              | (28)             | 532 nm; 35 ps | 2.98 cm/GW |
| GO/Water (% V) 0.82      | (16)             | 532 nm | −7.060 cm^2/GW |
| GO/Water (% V) 1.63      | (16)             | 532 nm | −7.876 cm^2/GW |
| GO/Water (% V) 2.43      | (16)             | 532 nm | −8.679 cm^2/GW |
| GO/Water (% V) 3.22      | (16)             | 532 nm | −9.381 cm^2/GW |
| GO/Water (% V) 4.00      | (16)             | 532 nm | −9.971 cm^2/GW |
| G NSs in water (hydrazine hydrate=5ml) | (13) | 532 nm; 30 ps; 1 Hz | 1.11 cm/GW |
| G NSs in water (15 ml)   | (13)             | 532 nm; 30 ps; 1 Hz | 3.67 cm/GW |
| G NSs in water (25 ml)   | (13)             | 532 nm; 30 ps; 1 Hz | 4.32 cm/GW |
| GF in DMF                | (28)             | 532 nm; 4 ns | 12.7 cm/GW; NLR = 14.7 × 10^{-18} m^2/W |
| f-GF in water            | (28)             | 532 nm; 4 ns | −34.2 × 10^{-18} m^2/W |
| f-GF in water            | (28)             | 532 nm; 35 ps | 0.8 cm/GW; NLR = −1.2 × 10^{-18} m^2/W |
| GF in DMF                | (28)             | 532 nm; 35 ps | 0.016 × 10^{-18} m^2/W |
| GF in NMP                | (53)             | 532 nm; 4 ns | 20.71 cm/GW |
| GF in DMF                | (53)             | 1064 nm; 4 ns | 12.53 cm/GW |
| F—GO/water              | (59)             | 532 nm; 5 ns | 1.40 nm/W |
| HF—GO/NMP               | (59)             | 532 nm; 5 ns | 0.7 nm/W |
| GO—ZnPc in DMSO          | (43)             | 532 nm; 4 ns; 10 Hz; 0.43 J/cm^2 | 300 cm/GW |
| r-GO—ZnPc in DMSO        | (43)             | 532 nm; 4 ns; 0.43 J/cm^2 | 1500 cm/GW |
| G/Cu porphyrin in DMF   | (61)             | 532 nm; 6 ns; 10 Hz | 3570 cm/GW |
| GO—PcZn in DMF          | (63)             | 532 nm; 6 ns; 10 Hz | 51.16 cm/GW |
| GO—PcZn in DMF          | (63)             | 1064 nm; 6 ns; 10 Hz | 31.04 cm/GW |
| FGO2 (3–5 layers)/DMF   | (64)             | 800 nm; 120 fs; 1 kHz; 303 GW/cm^2 | 1 × 10^{-11} cm/W |
| Graphene, graphene oxide, reduced graphene oxide films/layers | | | |
| G/quartz                | (6)              | 690–1050 nm; 80 MHz; 100 fs | 9.07 × 10^{-9} to 1.76 × 10^{-8} cm^2/W |
| MLG/quartz              | (5)              | 633 nm; 20 mW | 15.4 × 10^{-3} m/W; NLR = −14.5 m^2/GW |
| Annealed MLG/quartz (250°C) | (5)            | 633 nm; 20 mW | 4.2 × 10^{-3} m/W; NLR = −1.4 m^2/GW |
| rGO/PMMA                | (17)             | 532 nm; 2 Hz; 300 μJ | 129.01 cm/GW |
| PFTP-rGO/PMMA           | (17)             | 532 nm; 2 Hz; 300 μJ | 215.77 cm/GW |
| Annealed PFTP-rGO/PMMA  | (17)             | 532 nm; 2 Hz; 300 μJ | 296.79 cm/GW |
| rGO/PMMA                | (17)             | 1064 nm; 2 Hz; 300 μJ | 148.42 cm/GW |

(continued on next page)
| Material                                   | Ref. | Laser parameters                  | NLO parameters                             |
|--------------------------------------------|------|-----------------------------------|--------------------------------------------|
| PFTP-rGO/PMMA film                         | (17) | 1064 nm; 2 Hz; 300 µJ             | NLA = 300.13 cm/GW                          |
| Annealed PFTP-rGO/PMMA film                | (17) | 1064 nm; 2 Hz; 300 µJ             | NLA = 309.89 cm/GW                          |
| MLG (5–7 layers)                           | (32) | 1150 nm; 100 fs; 1 kHz; 22GW/cm²  | NLA = 30.8 × 10⁶ cm/W; NLR = −0.55         |
| MLG (5–7 layers)                           | (32) | 1550 nm; 100 fs; 1 kHz; 22GW/cm²  | NLA = 0.9 × 10⁶ cm/W; NLR = −0.8           |
| MLG (5–7 layers)                           | (32) | 1900 nm; 100 fs; 1 kHz; 22GW/cm²  | NLA = 1.5 × 10⁶ cm/W; NLR = −1.4           |
| MLG (5–7 layers)                           | (32) | 2400 nm; 100 fs; 1 kHz; 22GW/cm²  | NLA = 1.9 × 10⁶ cm/W; NLR = −2.5           |
| electrochemically derived GO film          | (33) | 800 nm; 10 kHz; 85 fs; 80mJ/cm²   | NLA = −2 cm/GW; NLR = 3.63 cm²/GW           |
| electrochemically derived GO film          | (33) | 800 nm; 10 kHz; 85 fs; 100mJ/cm²   | NLA = +3 cm/GW; NLR = 2.82 cm²/GW           |
| electrochemically derived GO film          | (33) | 800 nm; 10 kHz; 85 fs; 200 mJ/cm²  | NLA = +5 cm/GW; NLR = 1.91 cm²/GW           |
| electrochemically derived GO film          | (33) | 800 nm; 10 kHz; 85 fs; 400 mJ/cm²  | NLA = +7 cm/GW; NLR = 0.57 cm²/GW           |
| GO films/glass                             | (60) | 400nm; 100 fs; 1 kHz              | NLA = 41 000 cm/GW                           |
| GO films/glass                             | (60) | 800 nm; 100 fs; 1 kHz              | NLA(2PA) = −31 cm/GW; NLA(3PA) = −0.47 cm³/GW⁻² |
| G layers/quartz                            | (55) | 1550 nm; 3.8 ps; 10 MHz            | NLR = 10⁻⁷ cm³/W                             |
| GO thin film                               | (48) | 800 nm; 100 fs; 70 GW/cm²          | NLA = 0.47 × 10⁻¹⁸ cm³/GW²                   |
| G/quartz                                   | (45) | 733 nm; 100 fs; 80 MHz; 94 GW/cm²  | NLA = 6 cm/MW; NLR = 1.4 cm²/GW             |
| GO films                                   | (26) | 1500 nm; 67 fs; 20 MHz             | NLA = 10⁵ cm/GW; NLR = 0.45 cm²/GW          |
| SGO                                        | (64) | 800 nm; 120 fs; 1 kHz; 303 GW/cm² | NLA = 4 × 10⁻¹¹ cm/W                         |
| GO1 (3–4 layers)                           | (64) | 800 nm; 120 fs; 1 kHz; 303 GW/cm² | NLA = 3 × 10⁻¹¹ cm/W                         |
| G/PMMA                                     | (50) | 532 nm; 6 ns; 1 Hz                | NLA = 242 cm/GW                              |
| Others                                     |      |                                   |                                             |
| GO                                         | (1)  | 532nm; 30 mW                      | NLA = 20.69 × 10⁻⁵ cm/W; NLR = 9.68 cm³/GW |
| GO                                         | (1)  | 532nm; 40 mW                      | NLA = 138 cm/MW; NLR = 10.64 cm³/GW         |
| GO                                         | (1)  | 532nm; 50 mW                      | NLA = 43.6 cm/MW; NLR = 12.54 cm³/GW        |
| rGO                                        | (2)  | 532 nm                           | NLA = −0.01 × 10⁻⁵ cm/W; NLR = −8.83 × 10⁻⁵ cm³/W |
| rGO (25%)-PANI                             | (2)  | 532 nm                           | NLA = −0.03 × 10⁻⁵ cm/W; NLR = −11.28 × 10⁻⁵ cm³/W |
| rGO (50%)-PANI                             | (2)  | 532 nm                           | NLA = −0.09 × 10⁻⁵ cm/W; NLR = −13.43 × 10⁻⁵ cm³/W |
| rGO (75%)-PANI                             | (2)  | 532 nm                           | NLA = −0.04 × 10⁻⁵ cm/W; NLR = −12.06 × 10⁻⁵ cm³/W |
| GO                                         | (3)  | 532 nm; 150 mW                    | NLR = 1.2 cm³/GW                             |
| GO–SiO2 (0.5:1)                            | (3)  | 532 nm; 150 mW                    | NLR = 0.6 cm³/GW                             |
| GO–SiO2 (1:1)                              | (3)  | 532 nm; 150 mW                    | NLR = 0.6 cm³/GW                             |
| GO–SiO2 (2:1)                              | (3)  | 532 nm; 150 mW                    | NLR = 0.6 cm³/GW                             |
| GO                                         | (4)  | 532 nm; 30 ps; 10 Hz              | NLR = 0.75 cm/GW; NLR = 0.21 × 10⁻¹¹ esu     |
| rGO                                        | (8)  | 532 nm; 30 ps; 10 Hz; 4.5 GW/cm²   | NLA = −1.23 × 10⁻¹¹ mW; NLR = 0.71 × 10⁻¹¹ esu |
| GO                                         | (9)  | 527 nm; 1 kHz; 150 ns; 28MW/cm²    | NLA = 15.14 cm/GW                            |
| f-GO/sol                                   | (9)  | 527 nm; 1 kHz; 150 ns; 28MW/cm²    | NLA = 53.10 cm/GW                            |
| GO                                         | (9)  | 527 nm; 1 kHz; 150 ns; 56MW/cm²    | NLA = 21.65 cm/GW                            |
| f-GO/sol                                   | (9)  | 527 nm; 1 kHz; 150 ns; 56MW/cm²    | NLA = 345.92 cm/GW                           |
| GO                                         | (9)  | 527 nm; 1 kHz; 150 ns; 113 MW/cm²  | NLA = 14.06 cm/GW                            |
| f-GO/sol                                   | (9)  | 527 nm; 1 kHz; 150 ns; 113 MW/cm²  | NLA = 378.43 cm/GW                           |
| ZnNcC4-GO                                  | (10) | 532nm; 4ns; 10 Hz; 0.56 J/cm²      | NLA = 220 cm/GW                              |
ZnNcC4-NGO (10) 532 nm; 4ns; 10 Hz; 0.56 J/cm²; NLA = 450 cm/GW
ZnPcC4-NGO (10) 532 nm; 4ns; 10 Hz; 0.56 J/cm²; NLA = 360 cm/GW
GO (11) 650 nm; 120 mW; NLA = 0.0808 cm/W; NLR = −2.36 × 10⁻⁷ cm²/W
rGO (10) 650 nm; 120 mW; NLA = 0.0025 cm/W; NLR = −1.33 cm²/MW
rGO (12) Femtosecond laser
GO (14) 1030 nm; 340 fs; 100 Hz; 18.7 GW/cm²; NLA(3PA) = −78.6 × 10⁻³ cm³/GW
G-ZnO (15) 1030 nm; 340 fs; 100 Hz; 28.1 GW/cm²; NLA(2PA) = −8.54 × 10⁻³ cm³/GW⁻²
G-ZnO (15) 1030 nm; 340 fs; 100 Hz; 46.8 GW/cm²; NLA(5PA) = 0.078 × 10⁻³ cm²/GW⁻⁴
h-BN Ns-GO (0.1mg/ml) (18) 532 nm; 8 ns; 0.13 GW/cm²; NLA = 13.4 cm/GW
h-BN Ns-GO (0.1mg/ml) (18) 532 nm; 8 ns; 0.16 GW/cm²; NLA = 17 cm/GW
h-BN Ns-GO (0.1mg/ml) (18) 532 nm; 8 ns; 0.20 GW/cm²; NLA = 14.3 cm/GW; NLR = 2.58 × 10⁻¹³ cm²/W
GO (19) 532 nm; 6 ns; 10 Hz; 150 μJ; NLA = 1.07 cm/GW
ZnP-GO (19) 532 nm; 6 ns; 10 Hz; 150 μJ; NLA = 2.80 cm/GW
PF-GO (19) 532 nm; 6 ns; 10 Hz; 150 μJ; NLA = 4.99 cm/GW
ZnP-rGO (19) 532 nm; 6 ns; 10 Hz; 150 μJ; NLA = 6.58 cm/GW
PF-rGO (19) 532 nm; 6 ns; 10 Hz; 150 μJ; NLA = 7.07 cm/GW
GO (19) 1064 nm; 6 ns; 10 Hz; 1000 μJ; NLA = 0.16 cm/GW
ZnP-GO (19) 1064 nm; 6 ns; 10 Hz; 1000 μJ; NLA = 0.23 cm/GW
PF-GO (19) 1064 nm; 6 ns; 10 Hz; 1000 μJ; NLA = 0.38 cm/GW
ZnP-rGO (19) 1064 nm; 6 ns; 10 Hz; 1000 μJ; NLA = 1.96 cm/GW
PF-rGO (19) 1064 nm; 6 ns; 10 Hz; 1000 μJ; NLA = 5.0 cm/GW
GO-X(=6, 8, 10, 12) (20) 1064 nm; 4 ns; NLA = 45 cm/GW (GO-6) to 9.8 cm/GW (GO-12)
Y(80, 100, 120, 140, 160)-rGO-X(6) (20) 1064 nm; 4 ns; NLA = 58 cm/GW (80-rGO-6) to 560 cm/GW (160-rGO-6)
Y(100)-rGO-X(6) (20) 1064 nm; 4 ns; NLR = +1.87 × 10⁻¹⁷ m⁴/W
Y(120)-rGO-X(6) (20) 1064 nm; 4 ns; NLR = +7.32 × 10⁻¹⁷ m³/W
Y(140)-rGO-X(6) (20) 1064 nm; 4 ns; NLR = +6.23 × 10⁻¹⁷ m³/W
Y(160)-rGO-X(6) (20) 1064 nm; 4 ns; NLR = +7.36 × 10⁻¹⁷ m³/W
Y(180)-rGO-X(6) (20) 1064 nm; 4 ns; NLA = 490 cm/GW; NLR = +8.40 × 10⁻¹⁷ m³/W
NFG (21) 514 nm; 6 ns; 50 μJ; NLA = 1.22 cm/GW
FG (21) 514 nm; 6 ns; 50 μJ; NLA = 1.22 cm/GW
r-GO (50) 532 nm; 50 mW; NLA = −961.6 cm/GW
GO (35) 532 nm; 1 Hz; 4 ns; 50 μJ; NLA = 9.61 cm/GW
G (62) 800 nm; 1 Hz; 6.1 × 10⁻³ cm/W; NLR = −4.0 × 10⁻⁸ cm³/W
GO (23) 532 nm; 50 mW; NLA = 1.58 × 10⁻² cm/W; NLR = −1.52 cm³/MW
NFG (21) 514 nm; 6 ns; 50 μJ; NLA = 8.75 × 10⁻² cm/W; NLR = −0.53 cm³/MW
FG (21) 514 nm; 6 ns; 50 μJ; NLA = −2.62 × 10⁻⁴ cm/W
r-GO (50) 532 nm; 50 mW; NLA = −961.6 cm/GW
GO (35) 532 nm; 1 Hz; 4 ns; 50 μJ; NLA = 1.22 cm/GW
G (62) 800 nm; 1 Hz; 6.1 × 10⁻³ cm/W; NLR = −4.0 × 10⁻⁸ cm³/W
GO (23) 532 nm; 50 mW; NLA = 1.58 × 10⁻² cm/W; NLR = −1.52 cm³/MW
NFG (21) 514 nm; 6 ns; 50 μJ; NLA = 8.75 × 10⁻² cm/W; NLR = −0.53 cm³/MW
FG (21) 514 nm; 6 ns; 50 μJ; NLA = −2.62 × 10⁻⁴ cm/W
r-GO (50) 532 nm; 50 mW; NLA = −961.6 cm/GW
GO (35) 532 nm; 1 Hz; 4 ns; 50 μJ; NLA = 1.22 cm/GW
G (62) 800 nm; 1 Hz; 6.1 × 10⁻³ cm/W; NLR = −4.0 × 10⁻⁸ cm³/W
ZnFe2O-(15%) rGO (29) 532 nm; 50 mW; NLA = 6.3 × 10⁻³ cm/W; NLR = −4.5 × 10⁻⁸ cm³/W
ZnFe2O-(25%) rGO (29) 532 nm; 50 mW; NLA = 6.3 × 10⁻³ cm/W; NLR = −4.5 × 10⁻⁸ cm³/W

(continued on next page)
| Material | Ref. [1] | Laser parameters | NLO parameters |
|----------|----------|------------------|----------------|
| ZnFe2O- (40%) rGO | (29) | 532 nm; 50 mW | NLA = 6.1 × 10⁻³ cm/W; NLR = 4.5 × 10⁻⁸ cm²/W |
| GO | (29) | 800 nm; 800 MHz; 150 fs | NLA = 12.0 × 10⁻¹² m/W; NLR = 14.7 × 10⁻¹⁸ m²/W |
| ZnFe2O- (15%) rGO | (29) | 800 nm; 800 MHz; 150 fs | NLA = 4.0 × 10⁻¹² m/W; NLR = 4.2 × 10⁻¹⁸ m²/W |
| ZnFe2O- (25%) rGO | (29) | 800 nm; 800 MHz; 150 fs | NLA = 3.1 × 10⁻¹² m/W; NLR = 2.8 × 10⁻¹⁸ m²/W |
| ZnFe2O- (40%) rGO | (29) | 800 nm; 800 MHz; 150 fs | NLA = 2.6 × 10⁻¹² m/W; NLR = 1.5 × 10⁻¹⁸ m²/W |
| GO | (30) | 532 nm; 10 ns; 0.20 GW/cm² | NLA = 17 cm/GW |
| GO | (30) | 532 nm; 10 ns; 0.16 GW/cm² | NLA = 13.5 cm/GW |
| GO | (30) | 532 nm; 10 ns; 0.10 GW/cm² | NLA = 12 cm/GW |
| GO | (30) | 532 nm; 10 ns; 0.08 GW/cm² | NLA = 10.8 cm/GW |
| NF-rGO | (31) | 532 nm; 5 ns | NLA = 2.8 × 10⁻¹⁰ m/W |
| NF-rGO | (31) | 800 nm; 100 fs | NLA = 2.5 × 10⁻¹⁵ m/W |
| GO | (34) | 532 nm; 4 ns; 10 Hz | NLA = 80 cm/GW |
| ZnPcC4 – GO | (34) | 532 nm; 4 ns; 10 Hz | NLA = 200 cm/GW |
| NGO | (34) | 532 nm; 4 ns; 10 Hz | NLA = 120 cm/GW |
| ZnPcC4 – NGO | (34) | 532 nm; 4 ns; 10 Hz | NLA = 370 cm/GW |
| rGO | (35) | 532 nm; 4 ns | NLA = 3.0 × 10⁻¹⁰ m/W |
| GO | (36) | 532 nm; 4 ns; 10 Hz; 25 µJ | NLA = 1.0 × 10⁻¹⁰ m/W |
| GO–Cz | (37) | 532 nm | NLA = 58.56 cm/GW |
| GO–Cz | (37) | 1064 nm | NLA = 23.08 cm/GW |
| G1.1/PMMMA | (40) | 532 nm; 6 ns; 1 Hz | NLA = 275 cm/GW |
| rGO | (41) | 800 nm; 100 fs; 32 µJ/cm | NLA = 40000 cm/GW |
| rGO | (41) | 800 nm; 100 fs; >50 µJ/cm | NLR = 10⁻⁹ cm²/W |
| f-HEG | (42) | 800 nm; 100 fs | Fₚ = 2.7 J/cm² |
| CuO/f-HEG | (42) | 532 nm; 5 ns | NLA = 10⁻¹⁰ m/W; Fₚ = 4.35 J/cm² |
| CuO/f-HEG | (42) | 800 nm; 100 fs | NLA = 10⁻¹⁴ m/W; Fₚ = 1.43 J/cm² |
| GO | (46) | 532 nm; 3 ns; 10 Hz | NLA = 5.4 cm/GW; Is = 1.7 GW/cm² |
| f-HEG | (49) | 532 nm; 5 ns; 0.5 Hz | NLA = 10⁻¹¹ to 10⁻¹⁰ m/W |
| f-HEG | (49) | 532 nm; 5 ns; 0.5 Hz | NLA = 10⁻¹⁵ m/W; Fₚ = 2.7 J/cm² |
| GO–NH₂–Pani hybrid | (52) | 532 nm; 5 ns; 10 Hz; 35 µJ | NLA = 8.5 cm/GW; Is = 0.8 GW/cm² |
| GO | (54) | 800 nm; 120 fs; 1 kHz; 82.1 GW/cm² | NLA = 1.6 × 10⁻¹¹ cm/W; NLR = 0.1 × 10⁻¹⁵ cm²/W |
| fG | (58) | 1064 nm; 40 ps; 10 Hz | NLA = 280 ± 18 cm/GW; Is = 8 ± 0.2 GW/cm² |
| G | (61) | 532 nm; 6 ns; 10 Hz | NLA = 132 cm/GW |
| G-Zn porphyrin | (61) | 532 nm; 6 ns; 10 Hz | NLA = 4720 cm/GW |
| GO | (62) | 532 nm; 5 ns; 10 Hz | NLA = 7.8 cm/GW; NLR = 9.74 × 10⁻¹⁴ cm²/W |
| GO | (65) | 532 nm | NLA = 1.5 ± 0.1 cm/GW |
| GONSs | (66) | 532 nm; 250 µJ/pulse | NLA = 0.29 × 10⁻¹³ cm/W; Fₚ > 3 J/cm² |
| GNSs | (66) | 532 nm; 250 µJ/pulse | NLA = 2.65 × 10⁻¹⁰ cm/W; Fₚ = 0.3 J/cm² |
| GONRs | (66) | 532 nm; 250 µJ/pulse | NLA = 1.65 × 10⁻¹⁰ cm/W; Fₚ = 0.7 J/cm² |
| GNRs | (66) | 532 nm; 250 µJ/pulse | NLA = 0.12 × 10⁻¹⁰ cm/W |
| GONSs | (66) | 1064 nm; 250 µJ/pulse | NLA = 0.12 × 10⁻¹³ cm/W |
| Material          | Laser Parameters | NLA (cm/W) | Fth (J/cm²) |
|-------------------|------------------|------------|-------------|
| GNSs (66)         | 1064 nm; 250µJ/pulse | \(1.16 \times 10^{-13}\) | 6.3 |  
| GONRs (66)        | 1064 nm; 250µJ/pulse | \(1.40 \times 10^{-13}\) | 4.0 |  
| GNRs (66)         | 1064 nm; 250µJ/pulse | \(1.6 \times 10^{-13}\) | 3.4 |  
| Hydrothermally r-GO (71) | 1560 nm; 100 MHz; CW | Transmittance ~57%; \(P_{out}/P_{in} = 0.49\) |  
| Hydrothermally r-GO (71) | 1560 nm; 100 MHz; 5 ns | Transmittance ~12%; \(P_{out}/P_{in} = 0.11\) |  

**Abbreviations:**

G: Graphene, GO: Graphene-oxide, rGO: reduced GO, NF-rGO: non-covalent functionalized r-GO, NPs: Nanoparticles, NSs: Nanosheets, NRs: Nanorods, HEG: hydrogen exfoliated G, f-HEG: functionalized HEG, PMMA: poly(methylmethacrylate), QDs: Quantum dots, DMF: N,N-dimethylformamide, S-rGO-ZnO: ZnO decorated GO deoxygenated in alkaline medium, H-rGO-ZnO: hydrothermally reduced GO decorated with ZnO, NMP: N-methyl-2-pyrrolidone, DMA: N,N-dimethylacetamide, GBL: g-butyro lactone, ACN: acetonitrile, THF: tetrahydrofuran, SC: sodium cholate, DMSO: Dimethyl sulfoxide, GF: G-fluoride, f-GF: non-covalent functionalized GF, F-GO: fluorinated GO, HF-GO: highly fluorinated GO, ZnPc: triethyleneglycol-substituted Zn(II) phthalocyanine, PcZn: zinc phthalocyanine, PFTP: poly[(9,9-dihexyl-9Hfluorene)-alt-(1,1,2,2-tetrapheny lethene)], PANI: polyaniline, f-GO/sol: functionalized GO in an organosiloxane matrix, ZnNcC4-GO: tetracarboxylic zinc naphthalocyanine-GO, ZnNcC4-NGO: tetracarboxylic zinc naphthalocyanine-amino GO, PcZn: Zinc phthalocyanine.
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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.105049.

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