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A highly efficient graphene oxide absorber for $Q$-switched Nd:GdVO$_4$ lasers

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Abstract

We demonstrated that graphene oxide material could be used as a highly efficient saturable absorber for the $Q$-switched Nd:GdVO$_4$ laser. A novel and low-cost graphene oxide (GO) absorber was fabricated by a vertical evaporation technique and high viscosity of polyvinyl alcohol (PVA) aqueous solution. A piece of GO/PVA absorber, a piece of round quartz, and an output coupler mirror were combined to be a sandwich structure passive component. Using such a structure, 104 ns pulses and 1.22 W average output power were obtained with the maximum pulse energy at 2 $\mu$J and a slope efficiency of 17%.

(Some figures may appear in colour only in the online journal)

1. Introduction

$Q$-switched lasers are of great importance to the optoelectronics industry because of their applications to remote sensing, range finding, telecommunications, and so on. In recent years, passively $Q$-switched lasers with semiconductor material such as GaAs $[1, 2]$ and semiconductor saturable absorber mirrors (SESAMs) as $Q$-switching elements have been reported $[3, 4]$. However, $Q$-switched lasers with GaAs absorber tend to be unstable and SESAMs require complex fabrication and packaging. A single-walled carbon nanotube absorber has been used for a passively $Q$-switched solid-state laser $[5]$. In recent years, another kind of carbon based material—graphene—has frequently been used for passively mode locked lasers $[6–8]$. Graphene absorbers are also used for $Q$-switched or mode locked fiber lasers $[9–11, 6]$ or solid-state lasers $[12, 13]$. Graphene is a potential absorber to take the place of the GaAs, SESAMs or other crystal absorbers for $Q$-switched or mode locked lasers. However, it is difficult to grow graphene film with high quality, which makes graphene absorbers expensive. Furthermore, graphene cannot be dissolved in water so that the efficiency for film fabrication by graphene aqueous solution is decreased. Graphene oxide has traditionally served as a precursor for graphene because of its very low cost and simple fabrication method $[14]$. Graphene oxide nanosheets can be readily dispersed in water for the carboxyl and hydroxyl group in its structure, which lead to higher deposition efficiency in the vertical evaporation method $[15]$. The graphene absorber can be applied in a broad wavelength range because of its unselective absorption. The graphene oxide has similar ultrafast characteristics as that of graphene $[16, 17]$. The vertical evaporation method is a good method to form flat and orderly film $[18, 19]$. In this paper, we demonstrate a kind of novel graphene oxide absorber fabricated by graphene oxide material and the vertical evaporation method. A piece of GO/PVA absorber, a piece of round quartz and an output coupler mirror were combined to be a sandwich structure. By using this structure, stable and high power $Q$-switching pulses were obtained.

2. Preparation and characterization of the GO absorber

The graphene oxide (GO) sheets used in this experiment were fabricated by ultrasonic agitation after chemical oxidation of graphite. The number of atomic layers of the sheet is one to three and the diameter of the sheet is 0.1–5 $\mu$m. First, several milligrams of GO sheets were poured into 10 ml 0.1% SDS (sodium dodecyl sulfate) aqueous solution. Here SDS was
used as a surfactant. In order to obtain GO aqueous dispersion with high absorption, the diluted GO aqueous solution was ultrasonically agitated for 10 h. After the ultrasonic process, the dispersed solution of GO was centrifuged to induce sedimentation of large GO clusters. The upper portion of the centrifuged solution was decanted to a bottle and diluted for use. Some PVA powder was poured into the solution and dissolved at 90 °C with ultrasonic agitation for 3 h. Then, the GO/PVA dispersion was poured into a polystyrene cell as shown in figure 1. Finally we put these cells in an oven for evaporation. The temperature of the oven was kept at 40 or 45 °C. It took about one or two days for complete evaporation. When the evaporation was finished, the wall and the bottom of the cell were coated with a thin plastic film. The PVA aqueous solution has strong viscosity to the polystyrene cell so that it adheres to the wall of the cell. When the cell was dry, the PVA film lost the viscosity to the cell, so we could easily strip the PVA film cell off the polystyrene cell with a pair of tweezers. The GO sheets were carried by PVA to the surface of the wall and the bottom of the polystyrene cell during the evaporation process. The GO/PVA film on the wall of the cell had higher quality than that on the bottom so that we can use the former as an absorber for Q-switching. The procedure to fabricate the GO absorber is very simple. It is estimated that the cost of a GO absorber cell was less than ten US dollar. In practice, we cut off the GO absorber cell into many pieces for use in Q-switching. In this way, the cost of the absorber is further reduced. The absorber can be directly used for the Q-switched or the mode locked fiber laser. However, the absorber cannot be directly used for solid-state laser Q-switching or mode locking because it is not freestanding. To use it in the solid-state lasers, we designed a sandwich structure. We adopted two pieces of quartz (or glass) at the sides to press the GO absorber in the middle. One of the quartz (or glass) could be replaced with a piece of output coupler. We could adjust the transmission of the side mirrors so that the combined absorber had flexibility in the cavity. An UV–visible–NIR spectrophotometer was employed to measure the linear optical transmission of the PVA cell and GO/PVA absorber cell, as shown in figure 2 (the PVA cell is fabricated by PVA solution, not the GO/PVA composite dispersion). Figure 3 shows the Raman spectrum from the GO absorber. The absorber was excited by a 488 nm Ar ion laser. The spectrum reveals the two characteristic peaks 1D and 1G of GO (the 1D peak at 1375 cm$^{-1}$ and the 1G peak at 1600 cm$^{-1}$). The 1D peak is from the structural imperfections created by the attachment of hydroxyl and epoxide groups on the carbon basal plane. The 1G peak corresponds to the first-order scattering of the E$_{2g}$ mode.
3. Results and discussion

The schematic setup of our laser with a linear cavity is shown in figure 4. A fiber-coupled diode-array laser with center wavelength of 808 nm was used as the pump source. The laser crystal is a $3 \times 3 \times 8 \text{ mm}^3$ a-cut Nd:GdVO$_4$ crystal (with 0.5 at.\% Nd$^{3+}$ concentration). One side of the laser crystal is high reflection (HR) coated at 1064 nm and anti-reflection (AR) coated at 808 nm as an end mirror of the resonator; while the other side with a $2^\circ$ wedge is AR coated at 1064 nm. We chose an output coupler mirror with reflectivity of 85% at 1064 nm to generate the mode locked laser.

Figure 5(a) shows the Q-switched pulse train under the incident pump power of 6 W. The relationship between the average output power and incident pump power is plotted in figure 5(b). It can be seen that the average output power increases linearly with the incident pump power. Under the incident pump power of 10 W, an average output power and the pulse energy are 1.22 W and 2 $\mu$J respectively. When the incident pump power is higher than 10 W, the output power will decrease slowly and the absorber will be damaged. The corresponding slope efficiency was 17%. The repetition rate depending on the incident pump power was recorded by a digital oscilloscope and is indicated in figure 5(c). The repetition rate increases from 25 to 600 kHz when the incident pump power increases from 3.2 to 10 W. At a pump power of 10 W, the minimum pulse width of 104 ns was obtained, which is shown in figure 5(d). The sandwich structure has many flexible design freedoms. We could coat anti-reflection or high reflection films on the side mirrors so that we get different combinations of absorbers, which is similar to some type of SESAMs (high finesse, low finesse, AR coating, and so on). The damage threshold of the GO absorber and the output average power of the Q-switched laser could be improved by these adjustments.

4. Conclusions

In this paper, we demonstrated the highly efficient performance of a novel graphene oxide absorber for a Q-switched Nd:GdVO$_4$ laser with 1.22 W for the average output power and 2 $\mu$J for the pulse energy. The core of the absorber is a GO absorber, which could be prepared at low cost using a novel but simple fabrication method. The combined GO absorber, a viable alternative to the conventional SESAMs, could be combined in different ways and adapted to different types of cavities, and could be operated at pump power levels.

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References