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Passive Q-Switching in a Flash-Lamp Pumped Nd∶YAG Laser with Ion-Implanted GaAs Wafer

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Abstract: A passive Q-switched flash-lamp-pumped Nd∶YAG laser with the ion-implanted semi-insulating GaAs wafer is reported. The wafer is implanted with 400keV As^+ ions in the concentration of $10^{16}cm^{-2}$. Using GaAs wafer as an absorber and an output coupler, 62ns pulse duration of single pulse is obtained.

Key words: ion-implanted GaAs; passive Q-switching; flash-lamp-pumped
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1 Introduction

Q-switching all-solid-state lasers employing solid-state saturable absorber are desirable for many applications such as micromachinning, ranging, remote sensing, and microsurgery. Compared with the active Q-switching, passive Q-switching techniques can significantly simplify the operation, improve the efficiency, reliability, and compactness, and reduce the cost of laser sources[1]. So far, a variety of solid-state saturable absorption materials have been investigated, such as LiF∶F_2, tetravalent chromium-doped crystals, semiconductor saturable absorber mirrors (SESAMs), particularly those with the GaAs quantum-well structures[2~6]. SESAM is attractive as a saturable absorber because its coefficient of absorption, time of recovery, and saturation energy flunence can be designed and controlled. But SESAM is expansive, and is mainly used for passive modelocking. GaAs substrate is at low cost for passive Q-switching. However, its absorption depth is limited and its recovery time is hard to be controlled. Li *et al.*[2] obtained 80ns pulse duration from passive Q-switched flash-lamp-pumped Nd∶YAG laser using GaAs substrate as a saturable absorber and an output coupler. In this paper, we report 62ns pulse generation from passive Q-switched flash-lamp-pumped Nd∶YAG laser with ion-implanted GaAs as an absorber, our experiment with ion implanted semi-insulating GaAs, and as well as an output coupler we obtained. When we increase the pump power, the pulse duration of main pulse decreases while the intensity of the other minor pulses increases.

2 Theory

The photon energy at 1.06μm wavelength is far below the GaAs band gap of 1.42eV, the absorption at this wavelength is believed due to the EL2 defect, which forms a deep donor level $EL2^0$/$EL2^+$ located 0.82eV below the conduction band within the band gap (shown in Fig. 1).

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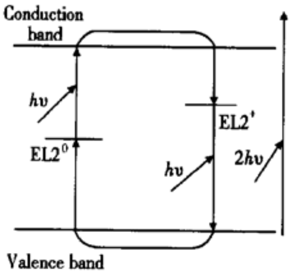

Fig. 1 EL2 defect energy level diagram

EL2 is a defect energy level that normally exists in GaAs wafer. Under the laser illumination, transitions from $EL2^0$ to the conduction band absorb optical energy and produce free electrons in conduction band and positively charge donors $EL2^+$ while valence to $EL2^+$ transitions produces free holes in valence band and neutral donors $EL2^0$. The absorption for this process is saturable with the increase in laser irradiance in GaAs. This absorption is taken as the single-photon absorption (SPA). There is a general understanding that GaAs can be used as passive *Q* switch as a result of this saturable absorption. However, apart from SPA, there are also two-photon absorption (TPA) and free-carrier absorption (FCA) at a higher laser irradiance. TPA generates free electrons in conduction band and free holes in valence band whereas FCA promotes electrons into the higher conduction band and holes into the deeper valence band. TPA has effect on the formation of Q-switched pulse as well[2]. However, FCA only generates nonsaturable loss. To avoid such loss, we chose semi-insulated GaAs substrate in our experiments. The concentration of semi-insulate GaAs was about $10^5 cm^{-3}$. Therefore, its FCA was near zero. GaAs bulk materials grown by LEC (liquid encapsulated Czochralski) method have EL2 concentration three to five times as much as by VGF (vertical gradient freezing) method. Thus we often choose GaAs materials made by LEC method. Generally, the concentration of EL2 in semi-insulate GaAs made by LEC method is limited in between $1.0 \times 10^{16} cm^{-3}$ and $2.0 \times 10^{16} cm^{-3}$ because most of applications for GaAs wafer in microelectronics require least EL2 defect in GaAs wafers. We can change it by controling the grow condition. In this study, we increase the concentration of EL2 by As^+ ion implantation. By this method, we can process the GaAs wafer freely by the implantation dose, energy, and GaAs area to obtain the recovery time and saturation depth as designed.

3 Preparation of ion-implanted GaAs

We implanted 500μm thick semi-insulating GaAs wafer with 400keV As^+ ions with a dose of $10^{16} cm^{-2}$. We simulated the profile of vacancy concentration generated after the implantation by program trim 95 as Fig. 2. The vacancy concentration is related to the concentration of EL2 generated after the ion implantation. The added EL2 defects after the ion implantation distributed near the surface of the GaAs wafer. The thickness of the implantation layer was about 400nm.

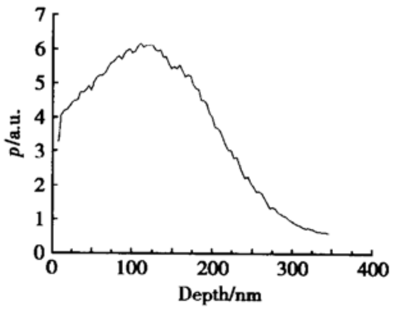

Fig. 2 Profile of vacancy concentration generated after implantation

The absorption spectrum is shown in Fig. 3. The vertical axis represents the difference between non-ion-implanted GaAs and ion-implanted GaAs, which can be taken as the absorption that generated after the implantation. We think that it is related to the added EL2 concentration after the ion implantation. EL2 concentration increases very much after the ion implantation, which will be advantageous for *Q*-switching at 1.06μm in solid-state lasers with GaAs absorber. We can see that the range of high absorption is from 900nm to 1100nm, which indicates that we can use ion-implanted GaAs for the absorber in Q-switching of solid state lasers at the wavelength near 946nm.

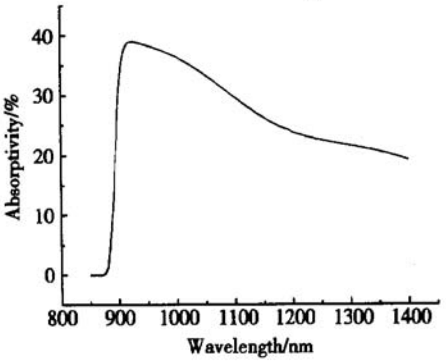

Fig. 3 Added absorption against wavelength in GaAs after ion implantation

4 Passive Q-switched flash-lamp-pumped Nd∶YAG laser with ion-implanted GaAs

Figure 4 shows a schematic diagram of the experimental set-up. The reflectivity of mirror at 1064nm is 100%, the transmission of GaAs at 1064nm is about 15%. The Nd∶YAG laser is pumped by pulse pumping source of Xe lamp at the frequency of 1Hz. The focusing lens is aimed to enhance the intensity of light on the GaAs material. When we tuned the voltage of flash lamp a little up to the threshold voltage (700V), We can see the pulse shape of flash-lamp-pumped Nd∶YAG that is shown in Fig. 5 and pulse shape of passive Q-switching flash-lamp-pumped Nd∶YAG as shown in Fig. 6. The pulse duration before Q-switching is about 200μs while the pulse after the passive Q-switching with ion-implanted GaAs is 62ns. When we increase the voltage of flash lamp from 700V to 830V, the pulse duration increases from 62ns to 300ns.

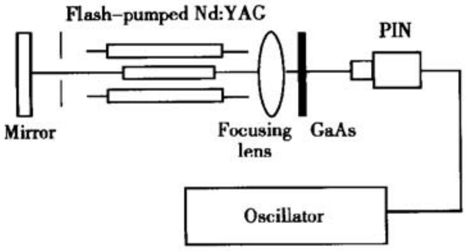

Fig. 4 Passive Q-switched flash-lamp-pumped Nd∶YAG laser with ion-implanted GaAs

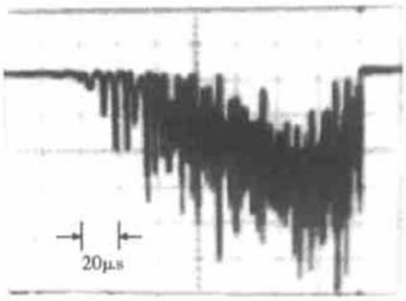

Fig. 5 Pulse shape of flash-lamp-pumped Nd∶YAG laser

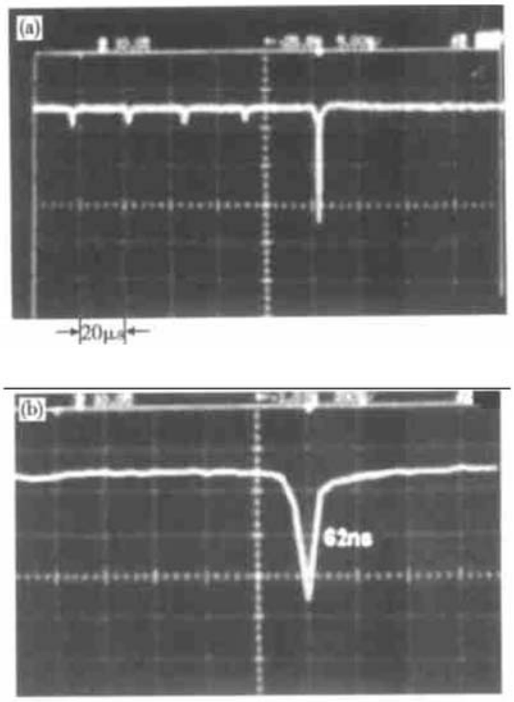

Fig. 6 Pulse profile of Q-switched flash-lamp-pumped Nd∶YAG laser with ion-implanted GaAs

In our experiment, we succeeded to transform the 200μs pulse into 62ns pulse by the Q-switching with ion-implanted GaAs. There are several other minor peaks near the main peak. But the intensity of minor peaks is very weak and we can neglect them. We believe we can obtain better results after the improvement of the ion-implanted GaAs so that we can realize ns-level ultrashort optical pulses in flash-lamp-pumped Nd∶YAG laser without using dye or other active Q-switching.

5 Summary

We implanted As$^+$ ions into semi-insulate GaAs wafer with an energy of 400keV at a dose of 10^{16}cm^{-2}. Using this GaAs wafer as an absorber and an output coupler, we obtained 62ns pulses from a passively Q-switched flash-lamp-pumped Nd∶YAG laser. Better results can be obtained with optimized ion-implanted GaAs after annealing at compatible temperature and time.

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用离子注入GaAs晶片实现闪光灯泵浦Nd∶YAG激光器中的被动调Q

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摘要: 对半绝缘GaAs晶片进行As$^+$注入, 注入能量为400keV, 剂量为10^{16}cm^{-2}. 用这种注入条件下的GaAs晶片作为吸收体和输出镜, 在被动调Q闪光灯泵浦的Nd∶YAG激光器上获得了62ns的单脉冲宽度. 这是迄今为止国内最好的报道结果.

关键词: 离子注入GaAs; 被动调Q; 闪光灯泵浦
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