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Passively Q-switched Er,Yb:GdAl3(BO3)4 laser with SWCNT as a saturable absorber

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Erbium lasers emitting in the 1.5-1.6 μm spectral range are widely used in different industrial areas such as laser range-finding, optical location and LIBS (Laser Induced Breakdown Spectroscopy) systems because of eye-safety and weak absorption in the atmosphere. Passive Q-switching is probably one of the most efficient and easy-to-realize method to obtain short laser pulses at high repetition rate for abovementioned applications.

$Er,Yb:GdAl_3(BO_3)_4$ (Er,Yb:GdAB) crystal was shown recently to be efficient laser material for the 1.5-1.6 μm spectral range [1]. A passively Q-switched regime of operation of Er,Yb:GdAB laser was demonstrated with $Co^{2+}:MgAl_2O_4$ crystal as saturable absorber and pulse energies of 18.7 μJ at a repetition rates of 32 kHz with pulse duration of 12 ns were obtained [2].

Recently, single-wall carbon nanotube based saturable absorbers (SWCNT-SAs) have attracted much attention due to wide spectral range of operation from 1 to 2 μm, simple fabrication process, low cost, and fast recovery time. SWCNT-SAs have been successfully used in Q-switched bulk lasers emitting near 1 μm and 2 μm [3]. However, only few implementations of SWCNT-SAs in 1.5 μm Q-switched fiber lasers are known. In this report a diode-pumped passively Q-switched Er,Yb:GdAB laser emitting at 1550 nm with SWCNT as a saturable absorber is demonstrated.

The Q-switched laser experiments have been made using a plano- plano cavity, consisted of a flat input mirror (IM) antireflection coated (AR) for 950-1050 nm and high-reflection (HR) coated for 1500-1600 nm and output coupler (OC) with different transmissions of 6% and 9% at the laser wavelength. A 976 nm fiber-coupled laser diode emitting output power up to 12 W was used as a pump source. After passing simple lens system the pump beam was focused into 120 μm spot inside the crystal. The active element (AE) - 1.5-mm-thick c–cut Er,Yb:GdAB crystal absorbed about 90% of pump power was AR coated for both pump and lasing wavelengths, wrapped in indium foil for good thermal contact and mounted between two copper slabs with the hole in the center to permit passing of pump and laser beams. The temperature of active element was kept at 14°C by means of thermo-electrical cooling elements with water-cooled heatsink. The SWCNT-SA was inserted between the active element and OC. The minimal physical cavity length was about 9 mm, that was limited by the design of active element cooling system. The experimental setup is shown in Fig. 1.

The stable passively Q-switched regime of operation was obtained only for OCs with transmission of 6 and 9%, while damage of SWCNT-SA was observed for OCs with lower transmission.

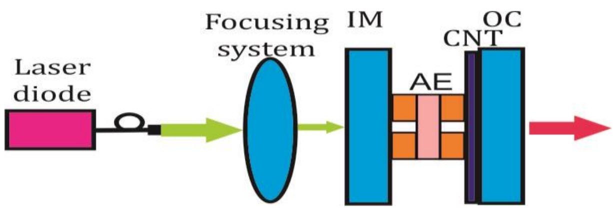
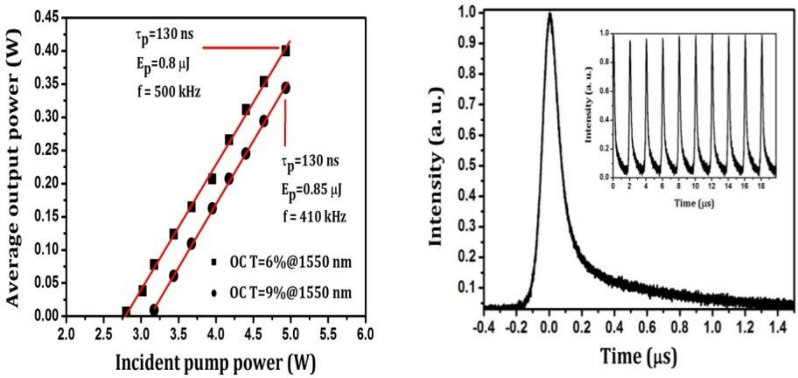


Fig. 1 - The setup for Q-switched laser experiments: plano-plano cavity

Laser pulses with energy of 0.8 μJ and pulse duration of 130 ns were obtained at a the highest repetition rate of 500 kHz at 1550 nm for the output coupler with transmission of 6% when incident pump power was 5 W (Fig.2). The input-output characteristics while using 9% OC were close to 6% OC. The spatial profile of the output beam was TEM00-mode with M2 < 1.2.



a) b)

Fig. 2 - a) Input-output characteristics of passively Q-switched Er,Yb:GdAB laser with SWCNT-SA in the plano-plano cavity; b) single pulse with the duration of 130 ns. The inset in (b) shows the output pulse train with the repetition rate of 500 kHz

Along with the experimental investigations a mathematical model of such laser was developed on the basis of the approaches described in details in [4]. The relevant energy levels of Er^{3+} and Yb^{3+} ions in Er,Yb:GdAB are given in Fig. 3. Taking into account the short lifetimes of $^4I_{11/2}$ (≈100 ns) all up-conversion processes were neglected. The recovery time of the SWCNT is much shorter than laser pulse duration, therefore an approximation of fast passive modulator was used.

In Table 1 experimental and calculated data are given for the incident pump power of 5 W.

Table 1. Experimental and calculated laser performance for the laser with plano-plano cavity

OC transmission (%)	Pulse energy, μJ		Pulse duration, ns		Repetition rate, kHz	
	exp.	calc.	exp.	calc.	exp.	calc.
6	0.8	0.8	130	116	500	507
9	0.85	0.79	130	135	410	388

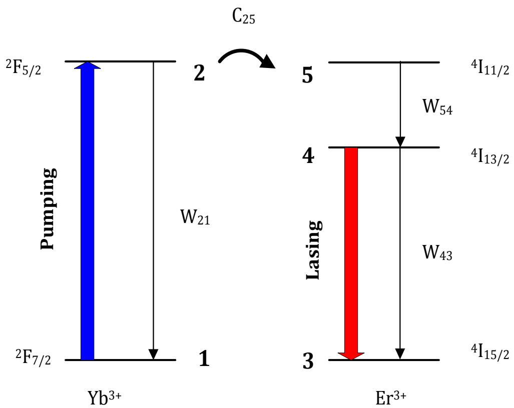


Fig. 3 - Diagram of energy levels of Yb^{3+} and Er^{3+} ions

In conclusion, passively Q-switched Er,Yb:GdAB laser was demonstrated by using SWCNT as a saturable absorber. The shortest Q-switched laser pulses with duration of 130 ns at a maximum repetition rate of 500 kHz were obtained in plano-plano cavity. Simulation of Er,Yb:GdAB laser parameters with rate equations gives reasonable agreement with experimental results.

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Military transportation robots

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Logistics have always been an important part of successful warfare. Military transportation robots can increase the efficiency of logistics as well as aid soldiers in movement. There are a lot of things to move both on the battlefield as well as in its vicinity. Indeed, weapons, ammunition and different supplies have to be moved to the point of action. At the end - causalities also have to be picked up from the battlefield. By putting humans to this work they are often exposed to a risk that could be avoided. We are not talking only about people that carry things around in a backpack - more about the drivers that have to drive into dangerous areas. Sure, that is what they do for living. Still, these hazards could be avoided and the transportation jobs made more effective. This is where military transportation robots come into the story. You can imagine how the robots could ease causality extraction from the battlefield. Also, different transportation jobs could be made