High repetition rate, compact micro-pulse all-solid-state laser

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A high repetition rate, compact micro-pulse all-solid-state laser is designed. The diffusion bonded crystal of YAG, Nd:YAG, and Cr^{4+}:YAG is taken as a monolithic cavity. The optimized initial transmission, output coupling, and pumping size of Cr^{4+}:YAG are calculated. The experimental results show that the laser satisfies the requirement of a spaceborne laser range finder.

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Micro-pulse laser has been used in laser altimeter and lidar due to its merits of compact and light weight[1,2]. Recently, the spaceborne laser range finder is paid attention to the applications in the spacecraft guidance, rendezvous, and docking or safe landing[3]. Compact, rugged, and narrow pulse width laser source is attractive. In this letter, a passively Q-switched, near-infrared (NIR) solid-state laser is designed and developed for a spaceborne laser range finder.

The under-developing spaceborne laser range finder is intended to measure the distance between two spacecrafts. The laser head and receiver in this finder will be hold on a gimbal mount. For the laser head, pulse energy larger than 50 μJ, pulse repetition frequency (PRF) around 5 kHz, and pulse width rise time less than 2 ns are required. Stable average power, low jitter, and good beam quality are also desirable. In addition, the fiber coupled, diode pumped, and Cr^{4+}:YAG Q-switched Nd:YAG laser is chosen to simplify the design of thermal management and to construct a light laser head under the rigorous limitations of weight, size, and environment in space application. The lighter the laser head is, the more compact the system will be. It is also an advantage of this kind of laser with the absence of actively controlling elements.

Among the saturable absorbers in NIR spectrum, the crystal Cr^{4+}:YAG has larger absorption cross-section and lower saturable intensity at the wavelength of 1060 nm, therefore there has the top-priority to be used as a Q-switcher at this wavelength. Compared with Nd:YVO$_4$, Nd:YAG is more appropriate to be used as the gain material because its longer fluorescent lifetime can make it powerful to acquire larger single-pulse energy and avoid double-pulse phenomenon at around 5 kHz. Moreover, the higher conductivity of Nd:YAG is beneficial for conductive cooling in space environment.

The compact monolithic micro-pulse laser has a cavity length of 12 mm, and the pump source is a fiber-coupled diode with the power of 6 W. The focus size in the laser medium is the same as the fiber diameter. The roundtrip dissipative loss is assumed to be negligible, and the beam area is assumed to be equal to the area of the TEM$_{00}$ mode. According to Degnan and Zayhowski's theory on the optimization of passively Q-switched lasers[4,5], the optimum parameters of the laser are analyzed. The initial transmission of optimum absorber of 0.57 and the reflectivity of output mirror of 0.37 are obtained. Other parameters such as cross sections of Cr^{4+}:YAG and Nd:YAG are the same as those in Ref. [5]. With these designed parameters, a maximum pulse energy of 96 μJ and a pulse width of about 1.6 ns are achieved.

Since the diffusion bonded crystal was reported by Andrauskas *et al.* in 1991[6], it has been widely used in microchip lasers[7,8]. Similar configuration is shown in Fig. 1. The laser cavity is a monolithic crystal diffused with two end caps of undoped YAG and one Cr^{4+}:YAG inside, it is useful to reduce the thermal stress at the coatings which are directly coated onto the Nd-doped YAG crystals. The crystal is end-pumped by a fiber-coupled 808-nm diode laser with a core diameter of 0.2 mm, a numerical aperture of 0.22, and a maximum output power of 10 W. A pair of aspherical lens is used to reimage the pump beam into the laser crystal, with a 15-mm focal length. The coupling efficiency is about 90%. The input face of the crystal is coated for high transmission (HT) at 808 nm and high reflectivity (HR) at 1064 nm. The output coupler has a reflectivity of 50% at 1064 nm. The gain medium is a 1.0 at.-% Nd:YAG crystal with a diameter of 5 mm and a length of 3 mm. The absorber is a 3-mm-long Cr^{4+}:YAG with initial transmission of $T_0 = 50\%$. Each individual segment of the crystal is 3 mm in length. The reflectivity of output mirror and the transmission absorber of Cr^{4+}:YAG are different from the calculation values. It is due to the underestimation of roundtrip dissipation in design.

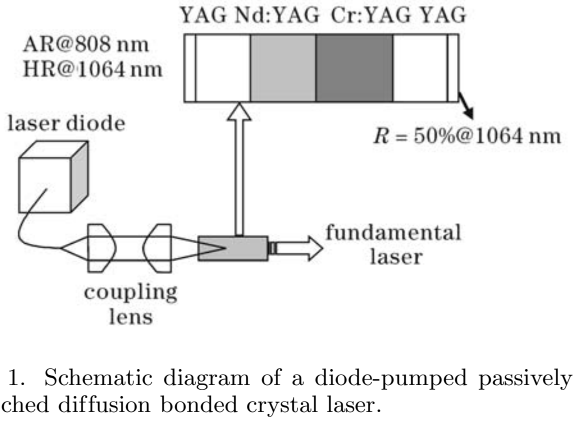

Fig. 1. Schematic diagram of a diode-pumped passively Q-switched diffusion bonded crystal laser.

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This kind of configuration is of benefit to temperature controlling. The diode laser is held in a seal box close to the driver and temperature controller. The large waste heat from diode laser is isolated to laser head. The whole diffusion bonded crystal is wrapped with indium foil and mounted in a conductivity-cooled copper heat sinker of laser head. It will give uniform heat gradient in doped area. And the laser head is also conductively cooled by a colder heat sinker connected with radiation cooler by heat pipe. It is very significant for application in space environment.

With the simple plano-plano resonator as shown in Fig. 1, it is easy to obtain the efficient passive Q-switching oscillation with high pulse energy output. At first, groups of coupling lenses are tested to get an optimized pump beam size. When the focusing lens with effective focal length (EFL) of 15 mm are used, the output power and PRF versus pump power are shown in Fig. 2. The corresponding optical-to-optical conversion efficiency is about 27%. With the increase of pump power, the PRF is increased to 8.33 kHz from 1.67 kHz. The pulse energy is larger than 80 μJ, and the peak power is about 50 kW. From Fig. 2, it can be seen that the output power is saturated with pump power larger than 6.5 W. Though the laser with the repetition rate of 4 kHz is enough for the developed spaceborne laser range finder, the saturation of output power indicates that the thermal effect of the crystal in the plano-plano cavity cannot be ignored under high pump power. Higher output power could be achieved with the reduction of crystal diameter and optimization of pump beam size.

In order to get smaller size of pumping laser, the collimating lens with EFL of 11 mm, and the focusing lens with EFL of 6.16 mm are used. The output energy is larger than 100 μJ at 6.8 W. The PRF of 2.78 kHz with the stability of 2% is measured by Tektronix TDS3052B as shown in Fig. 3. In our specified system, the smaller pump size makes the pump rate higher, and hence increases the output pulse energy. Furthermore, the experimental results show that the stability of PRF increases with the decrease of pump size.

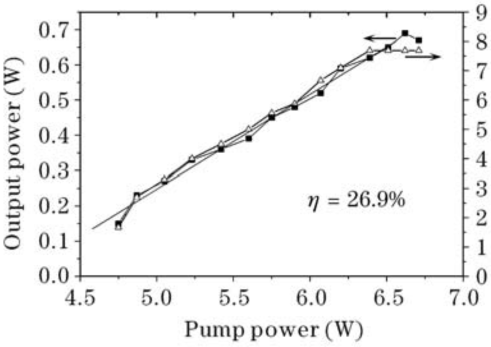

Fig. 2. Output power and PRF versus pump power.

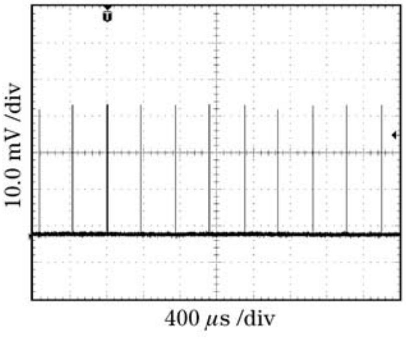

Fig. 3. Output pulse train with the stability of 2%.

The temporal pulse at pump power of 5.7 W is shown in Fig. 4, and the width is about 1.6 ns. The pulse width is always about 1.6 ns when the pump power is larger than threshold of 4.75 W. It is found that the measured results of pulse width agree well with the calculated values. While the sub-pulse cannot be eliminated, the initial transmission of the absorber or the reflectivity of the output coupling must be optimized furthermore. When the reflectivity of the output coupler is decreased from 50% to 30%, the sub-pulse phenomenon is obvious, and the single pulse energy is correspondingly larger than 100 μJ.

When the laser is operated with output energy of 80 μJ, the beam quality factor is measured by Spricon beam analyzer. M_x^2 and M_y^2 are 1.66 and 1.54 as shown in Fig. 5, and the beam diameter is 2.5 mm. It can be seen that the laser has good beam quality even in a simple plano-plano cavity.

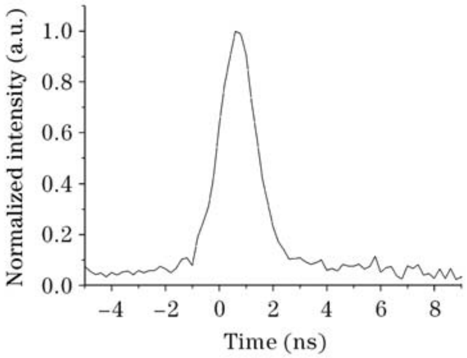

Fig. 4. Output pulse width of the laser.

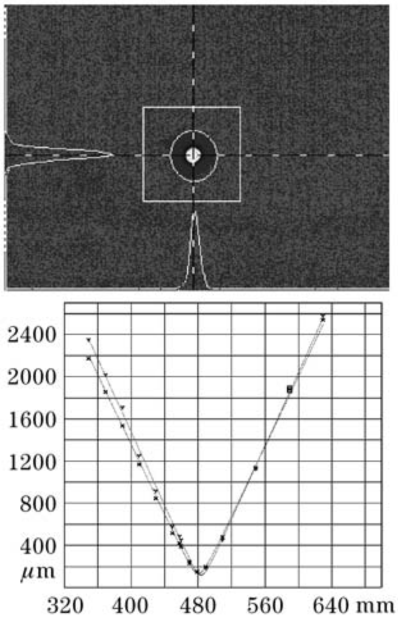

Fig. 5. Beam quality of laser at output energy of 80 μJ.

In this paper, the design and demonstration of high repetition rate, compact micro-pulse all-solid-state laser are fulfilled. This laser utilizes a diffusion bonded monolithic crystal consisting of YAG, Nd:YAG, and Cr^{4+}:YAG. Compact size is achieved with the configuration of fiber-coupled diode laser end-pumping and conductive cooling of crystal. The results are suitable for the spaceborne laser range finder. The space environmental simulation test will be done in near future.

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