

Pre-pumped passively Q-switched Nd:YAG/Cr:YAG microchip laser

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A pre-pumped passively Q-switched Nd:YAG/Cr:YAG microchip laser is demonstrated with a peak power of 7.5 kW at pulse repetition rate of several kilohertz. The full-width at half-maximum (FWHM) is 734 ps, and the pulse energy is 5.5 μJ with a fundamental spatial mode. In this system, the pre-pumped microchip laser of Nd:YAG/Cr:YAG wafer which is bonded through the thermal-bonding technique has achieved a time jitter value of 12 μs and a Q-switched amplitude instability of 1.26% (1 δ) through the pre-pumped modulation technique.

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Passively Q-switched microchip lasers have some unique advantages over traditional solid-state laser systems, such as robustness, small volume and weight, simple mechanical structure, excellent beam quality, all-solid-state sources of coherent, sub-nanosecond, and multi-kilowatt pulses at high repetition rate. In 1994, pumping with a 1.2-W diode laser, Zayhowski *et al.* firstly reported the passively Q-switched Nd:YAG/Cr:YAG microchip lasers that produce pulse as short as 337 ps with peak power in excess of 28 kW at pulse repetition rate of 6 kHz^[1]. Later, pumped with a 15-W diode laser, passively Q-switched Nd:YAG/Cr:YAG/YAG microchip lasers that produce pulse as short as 400 ps with pulse energy of 320 μJ at pulse repetition rate of 400 Hz were reported in 2000^[2].

In China, pumping with absorbed pump power of 440 mW, Dong *et al.* reported a passively Q-switched monolithic Cr,Nd:YAG microchip laser that produces a peak power of 370 W with pulse width of 7 ns at repetition rate of 35.5 kHz in 2003^[3]. Using the pre-pumping technique to improve the stability of monolithic Cr,Nd:YAG microchip lasers, the pulse energy of 1.1 μJ , the peak power instability of 1.8%, and time jitter of 5 μs were reported in 2003^[4].

In this paper, we demonstrate a pre-pumped passively Q-switched Nd:YAG/Cr:YAG microchip laser which combines the thermal-bonding and pre-pumping techniques together. With the thermal-bonding technique, simpler and robust mechanical structure can be achieved. With the pre-pumping technique, higher pulse peak stability and higher frequency stability can be realized. With the combined system, the time jitter value of 12 μs at pulse repetition rate of 1 kHz, the pulse peak instability of 1.26% (1 δ), and the pulse energy of 5.5 μJ with pulse width full-width at half-maximum (FWHM) of 734 ps have been achieved. In addition, our passively Q-switched Nd:YAG/Cr:YAG microchip is packed in a box of volume of 854 mm³ ($\phi 8 \times 17 \text{ mm}^3$), including the end of fiber-coupled laser diode (LD) pump source. This stabilized high peak power and high repetition rate miniature laser is quite potential for many application areas.

In our experiment, the Nd:YAG/Cr:YAG microchip

laser only consists of a fiber-coupled LD pump source and a Nd:YAG/Cr:YAG crystal wafer, as shown in Fig. 1. The output fiber core diameter of the LD (Hi-Tech Optoelectronics Co., Ltd.) is 100 μm with a numerical aperture (NA) of 0.12 and its maximum output power from fiber is 1.3 W. The Nd:YAG/Cr:YAG crystal wafer is made by the thermal-bonding technique in our lab. The thickness of Nd:YAG crystal is 0.6 mm with a doping content of 1.8 at.-%, and the thickness of Cr:YAG crystal is 0.37 mm with an absorption coefficient of 5.2 cm^{-1} at 1064 nm. The Nd:YAG/Cr:YAG crystal wafer is polished to a planar-planar geometry as a laser resonator. The planar surface on the side of Nd:YAG crystal is coated for high transmission at 808 nm and high reflection at 1064 nm (HT@808 $\geq 95\%$, HR@1064 $\geq 99.8\%$). The planar surface on the side of Cr:YAG is coated for part reflection of 91.3% at 1064 nm (PR@1064=91.3%) as the output coupler and high reflection at 808 nm (HR@808 $\geq 99.2\%$). The volume of the Nd:YAG/Cr:YAG wafer is $\phi 6 \times 0.97 \text{ mm}^3$, and the overall cavity length is 0.97 mm. The misalignment of the axes of the two mirrors is measured to be less than 10 $''$. The pumping driver is SDL 820 power source. In order to stabilize the LD output power, the working temperature fluctuation of the LD is controlled within 0.1 $^{\circ}\text{C}$. A Molectron EPM 2000 laser energy/power meter, an Agilent 1.2-GHz oscilloscope, and a Focus 12-GHz high speed photo detector are used to measure the laser

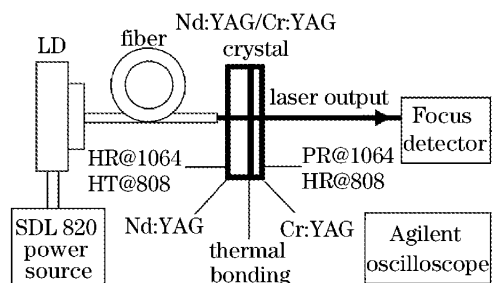


Fig. 1. Experimental setup of LD pumped passively Q-switched microchip laser.

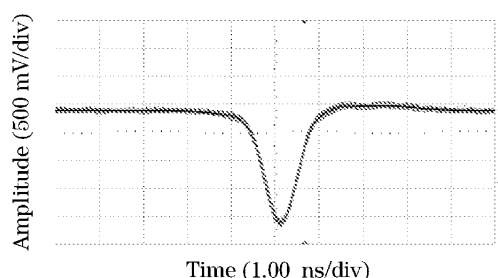


Fig. 2. Instability of pulse amplitude pumped with the pre-pumping modulation.

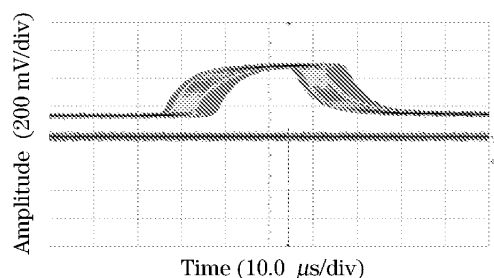


Fig. 3. Pulse time jitter pumped with the pre-pumping modulation (electric modulation current triggered by the Q -pulse of laser).

output energy and pulse trace.

When applying pre-pumping modulation in this laser, the pulse energy of $5.5 \mu\text{J}$ which is measured through the ratio of average power at the pulse repetition rate of 1 kHz and the pulse width of 734 ps (FWHM) with the peak power of 7.5 kW have been realized. Furthermore, the instability of pulse peak power is decreased to 1.26% (1σ) shown in Fig. 2, in contrast with the instability of pulse peak power of 2.1% (1σ) when pumped with the pulse pumping. The time jitter of frequency instability is reduced to 12 μs shown in Fig. 3, comparing with the time jitter of over 33 μs when pumped with the pumping at pulse repetition rate of 1 kHz.

A fundamental spatial mode is measured by Spiricon LBA-500PC spatial mode analyzer, as shown in Fig. 4. The values of M^2 are 1.14 along X -axis and 1.06 along Y -axis. The beam quality of the microchip laser is insensitive to the power operation point of the laser.

Pre-pumping modulation controls the laser output by means of the superposition of DC pumping current and the pulse pumping current^[5-7]. Compared with the general modulation models of continuous wave (CW) and pulse pumping, pre-pumping modulation can get higher laser peak power stability and higher frequency stability. Although a repetition rate of over 4 kHz has been demonstrated in this microchip laser by CW pumping, the instability of its frequency, especially the superimposed effect in frequency, confines its application. Similarly, large values of peak power instability and time jitter in pulse pumped laser also do harm to its application. To the pre-pumping modulation, because of the DC pumping current, a steadier laser pulse with less of peak power instability and time jitter can be obtained. In the mean time, because of the pulse pumping current, the frequency instability caused by the superimposed effect can also be eliminated.

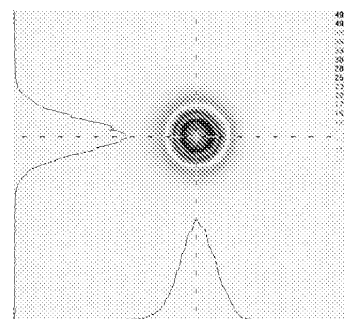


Fig. 4. A fundamental spatial mode.

Many advantages can be derived from the thermal-bonding technique. First of all, according to our experimental results, there is almost no reflection between Nd:YAG and Cr:YAG wafers adopting the thermal-bonding technique, which will largely reduce the cavity loss caused by the reflection in the discrete Nd:YAG/Cr:YAG cavity. Secondly, laser pulse with shorter pulse width and higher peak power can be achieved by a shorter cavity length. Thirdly, contrasting to monolithic Cr,Nd:YAG microchip laser, this Nd:YAG/Cr:YAG microchip laser that adopts thermal-bonding technique can freely choose the thicknesses of Nd:YAG and Cr:YAG crystals and can easily realize lower initial transmission of Cr:YAG crystal in microchip laser. Therefore, a much narrower pulse width of sub-nanosecond can be realized in Nd:YAG/Cr:YAG microchip lasers compared with that of several nanosecond in monolithic Cr,Nd:YAG microchip lasers. Finally, a compact constructure with flexible laser design can also be formed from it.

In summary, a pre-pumped passively Q -switched Nd:YAG/Cr:YAG microchip laser with pulse width of 734 ps, pulse energy of $5.5 \mu\text{J}$, peak power of 7.5 kW, and jitter value of 12 μs has been demonstrated. For its high peak power and high stability benefited from the pre-pumping modulation and thermal-bonding technique, it is promising for the application of passively Q -switched microchip laser, such as ranging finder, laser radar, three-dimensional imaging, and communication and medical equipments.

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