

# All solid-state, injection-seeded Ti:sapphire ring laser

Ting Yu (余 婷)<sup>1,2</sup>, Weibiao Chen (陈卫标)<sup>1</sup>, Jun Zhou (周 军)<sup>1</sup>,  
Jinzi Bi (毕进子)<sup>1</sup>, and Junwen Cui (崔俊文)<sup>1</sup>

<sup>1</sup>Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800

<sup>2</sup>Graduate School of the Chinese Academy of Sciences, Beijing 100039

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In this letter, we present an all solid-state, injection-seeded Ti:sapphire laser. The laser is pumped by a laser diode pumped frequency-doubled Nd:YAG laser, and injection-seeded by an external cavity laser diode with the wavelength between 770 and 780 nm. The single longitudinal mode and the doubling efficiency of the laser are obtained after injection seeding. The experimental setup and relative results are reported. It is a good candidate laser source for mobile differential absorption lidar (DIAL) system.

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The differential absorption lidar (DIAL) technique is proved to be a powerful tool to monitor air pollutant gases such as NO<sub>x</sub>, SO<sub>2</sub>, O<sub>3</sub><sup>[1]</sup>, especially, mobile DIAL system is important to study atmosphere pollution's transportation. The development of good solid-state, tunable, narrowband, high pulse energy, and high reliability lasers are attractive for mobile DIAL system. Several DIAL systems have been demonstrated with solid-state flash-lamp-pumped Ti:sapphire lasers<sup>[2,3]</sup>. Ti:sapphire laser demonstrated a good performance in DIAL system. Due to shorter lifetime of upper state, flash-lamp-pumped Ti:sapphire has lower efficiency and is difficult to realize narrowband output. A common approach is pumped by a frequency-doubled Nd:YAG laser to improve conversion efficiency of Ti:sapphire. However, the electro-optical (E-O) efficiency of the flash-lamp-pumped Nd:YAG is still limited. The whole wall-plug efficiency can be improved if Ti:sapphire laser is pumped by a diode laser pumped frequency-doubled Nd:YAG.

Injection seeding has been employed to reach narrowband output<sup>[4]</sup>. Though the self-injection seeding technique has simple configuration<sup>[5]</sup>, it has a shortcoming of lower pulse energy compared with the external injection seeding. In addition, a higher temporal jitter in the output pulses for self-injection seeding technology is generally not suitable for our application<sup>[6]</sup>. A single frequency seed laser is used to induce stimulated emission on a particular longitudinal mode of the main oscillator. The output pulse energy is only limited by the pump energy and the damage threshold of Ti:sapphire.

In this letter, a detailed description of an all solid-state, injection-seeded ring Ti:sapphire laser for mobile DIAL is given. The scheme of the all solid-state, injection-seeded Ti:sapphire ring laser is illustrated in Fig. 1. The pump laser is a laser diode pumped, E-O Q-switched, and frequency-doubled Nd:YAG. In order to get good beam pattern, Nd:YAG rod is side-pumped within a diffuse cavity. The output energy of 532 nm is 60 mJ with a near-Gaussian spatial profile and a pulse width of 7 ns. Three planar mirrors constitute a ring cavity, and Ti:sapphire crystal is inserted between pump-input mirror and output coupling mirror. The ring cavity is configured as a compact, 45°-45°-90° triangle with os-

cillation occurring on the p polarization. The cavity length is 40 cm. The output coupler has a reflectivity of 70% between 750 – 850 nm. The other two mirrors have high reflection (HR) in the same wavelength range. Ti:sapphire crystal is cut with a Brewster angle. The absorption coefficient is 1.0 cm<sup>-1</sup> at 514 nm, and the size is  $\phi 10 \times 20$  mm, so the absorption efficiency for pumped laser is about 90%.

Seed laser is an external cavity laser diode (Toptica Corp.) with a power of 15 mW. It can be tuned between 767 – 777 nm. The diode is isolated from the ring laser with two Faraday isolators (OFR, IO-5BB-800) with a reverse attenuation of 35 dB to each other between 748 to 851 nm. So much an isolation is needed because of the sensitivity of the laser diode to any feedback from the ring laser. A half-wave plate reorients the polarization of the seed beam for injection into the ring cavity. The seed beam is injected into the ring cavity through the output coupler.

The length of the ring cavity is actively stabilized to match a particular longitudinal mode of the ring cavity to the frequency of the seed beam. The stabilization works on the basis of optimizing the coupling of the seed beam into the ring cavity. A portion of laser beam from HR mirror is detected and digitized by a computer. A piezoelectric transducer (PZT) controlled HR mirror is tuned to maximize the output of photodiode, and stabilized on an optimal position by software control.

When the transmission of the output mirror is 30%, the output energy is shown in Fig. 2. The Ti:sapphire

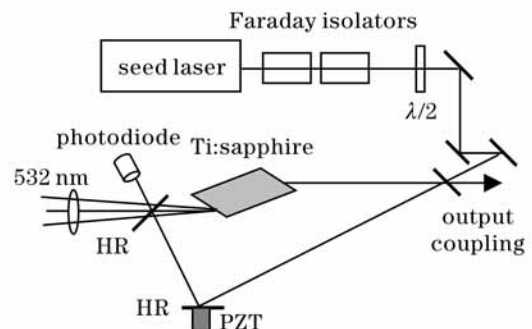


Fig. 1. The setup of injection-seeded, Ti:sapphire ring laser.

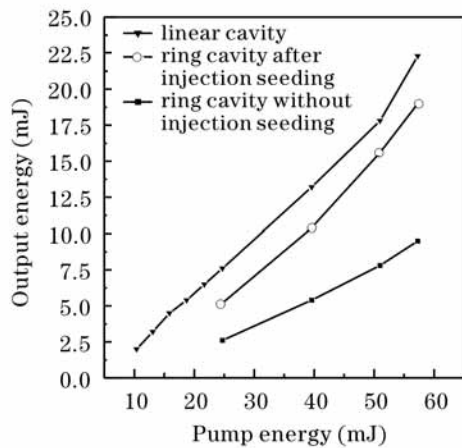


Fig. 2. Output energy versus the pump energy for different cavities.

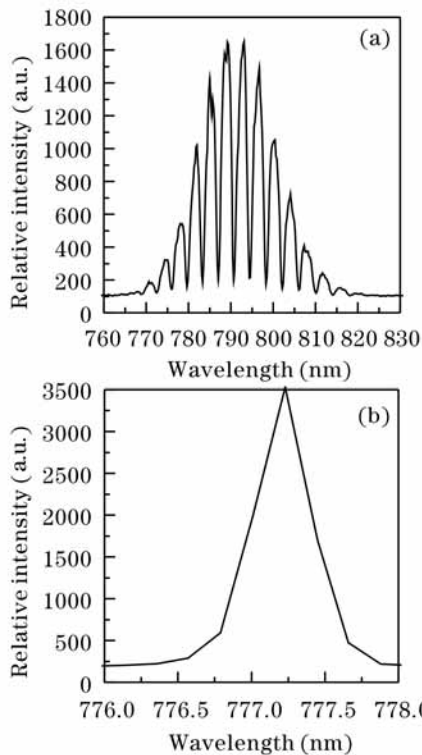


Fig. 3. Output spectra of Ti:sapphire laser before (a) and after (b) injection seeding.

is operated at 777.2 nm, which is about 13 nm from the peak of Ti:sapphire laser<sup>[7]</sup>. The transfer efficiency is 34%, and the slope efficiency is up to 44%. It also showed that the ring cavity is run unidirectional after injection seeding. This is due to the suppression of the clockwise lasing direction. Therefore, the output energy is roughly twice that of unseeded case. For comparison, the output energy of the stationary wave cavity with the same

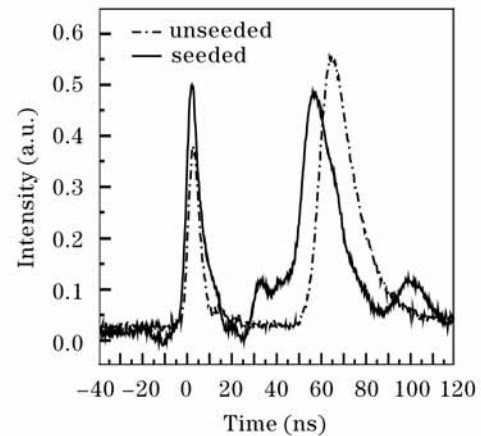


Fig. 4. Output pulses of Ti:sapphire laser.

output coupling is also presented in Fig. 2. The result showed the efficiency of a ring cavity with injection seeding is comparable to a stationary wave cavity.

The output spectra before and after injection seeding are shown in Fig. 3. The spectrum of laser after seeding is limited by the resolution of 0.25 nm (Ocean Optics HR2000). It can be seen that the oscillation of other wavelength is suppressed even in the peak of 790 nm.

The temporal behavior of the all solid-state, injection-seeded ring Ti:sapphire laser was also checked. The output pulses before and after seeding are shown in Fig. 4. It can be seen that the buildup time of the laser pulse is reduced after injection seeding.

This letter describes an all solid-state, injection seeded Ti:sapphire ring laser which produces high conversion efficiency, single-frequency pulses. It can be used in a DIAL system which requires the high energy and narrow bandwidth. In our DIAL system, the on-line and off-line wavelengths of pollutant gas can be obtained by the mixing of residual 1064-nm laser and output of Ti:sapphire. Therefore, the whole efficiency of laser system will be improved, which is important for a mobile DIAL system.

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