

All-solid-state narrow-linewidth 455-nm blue laser based on Ti:sapphire crystal

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A compact, all-solid-state, narrow-linewidth, pulsed 455-nm blue laser based on Ti:sapphire crystal is developed. Pumped by a 10-Hz, frequency-doubled all-solid-state Nd:YAG laser and injection-seeded by an external cavity laser diode, the narrow-linewidth 910-nm laser with pulse width of 20 ns is obtained from a Ti:sapphire laser. 3.43-mJ blue laser can be obtained from the laser system by frequency-doubling with BBO crystal. This research is very useful to determine the roadmap of developing the practical, high power blue laser. This kind of laser will have potential application for underwater communication.

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Blue-green laser as “seawater transparent window” is paid attention to in the applications of ocean lidar and underwater laser communication. The laser with blue-green wavelength is also used in differential absorption lidar for atmospheric pollution monitoring. In the case of underwater laser communication, the wavelength of laser source is hoped to match the line of atomic filter with a wide filed-of-view and a narrow bandwidth for optimum receiving. Passive cesium atomic filter has a high transmission at 455 nm and a simple configuration so that it is a best candidate filter in the underwater laser communication. Research of an all-solid-state, high-efficiency, narrow-linewidth, narrow-pulse-width, and highly reliable 455-nm laser source is attractive and of great importance.

Ti:sapphire lasers are ideal for generating blue laser because of their broad spectral tuning range (670 – 1070 nm), high output energy and high efficiency^[1–4]. In our group, a mixing method to output 455-nm laser with 1064- and 795-nm lasers has been demonstrated^[5]. However, the configuration was complicated and not stable for long-time operation because a long delay of 1064 nm. In this letter, we try to get 455-nm blue laser from the frequency-doubled 910-nm Ti:sapphire laser. The motivation is to develop a stable, simple, and more practical laser at 455 nm.

Schematic of the system is shown in Fig. 1. The Ti:sapphire laser was pumped by an all-solid-state, frequency-doubled Nd:YAG laser with 10 ns pulse width and 10-Hz repetition rate. 110-mJ output of 532-nm laser using KTP frequency-doubling crystal was obtained to pump Ti:sapphire.

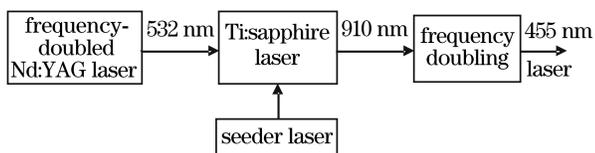


Fig. 1. Schematic of the 455-nm blue laser system.

The resonant cavities based on gain-guiding effect of Ti:sapphire crystal can generate high-quality, high-efficiency laser when pumped by 532-nm laser^[6–8]. Ti:sapphire laser using flat-flat resonant cavity can obtain the most efficient laser output^[6]. Linear and ring Ti:sapphire resonators were used in the experiment and the schematic diagrams are shown in Fig. 2. The linear resonator, as shown in Fig. 2(a), was a flat-flat cavity consisting of a high reflector (HR) and an output coupler (OC) with the output ratio of 10% at 910 nm. The ring resonator, as shown in Fig. 2(b), consisted of four flat mirrors, HR1, HR2, HR3, and OC. The OC had the output ratio of 6% at 910 nm. There was a birefringent filter (BF) in the cavity to limit the linewidth of the Ti:sapphire laser^[9]. A Ti:sapphire crystal rod with 10-mm diameter and 20-mm length, and cut at the Brewster angle (60.4°) was placed in a water-cooled copper mount. The pump laser was adjusted to the polarization direction

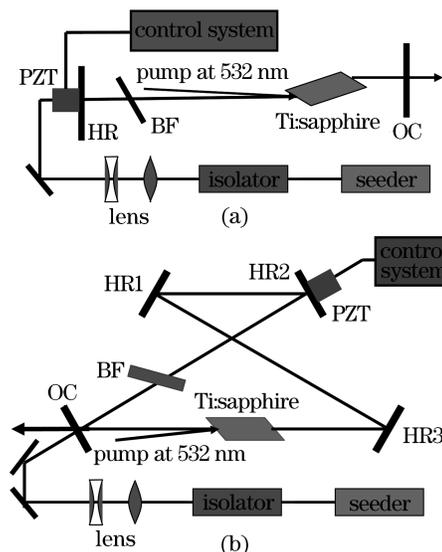


Fig. 2. Schematic diagrams of (a) linear and (b) ring Ti:sapphire resonators. PZT: piezoelectric transducer.

which can be efficiently absorbed by Ti:sapphire crystal with a half-wave plate and focused into the Ti:sapphire crystal with a 618-mm focusing lens.

Injection-seeding was employed to reach narrow-band output^[10–12]. The seeder laser was an external cavity laser diode (Toptical Corp., Taipei) with a power of 100 mW and a linewidth of 5 MHz. The diode was isolated from the Ti:sapphire laser with two Faraday isolators. A half-wave plate reoriented the polarization of the seed beam for injection into the Ti:sapphire resonator. The length of the Ti:sapphire cavity was actively stabilized to match a particular longitudinal mode of the cavities to the frequency of the seeder. A piezoelectric transducer (PZT) controlled HR mirror was tuned to maximize the output of photo-diode, and stabilized on an optimal position by software control.

The 910-nm output energies at various pump energies are shown in Fig. 3. When the pump energy was 110 mJ, the output energies of the linear resonator and ring resonator were 21.7 and 12.6 mJ, respectively, and the corresponding linewidths were 20 and 40 nm respectively when there was not any mode selector in the cavities. After injection-seeding, because there was a BF inserted in the cavities, the corresponding output energies were reduced to 11.73 and 6.80 mJ, respectively. Obviously, the efficiency of linear cavity was higher than that of the ring cavity because of the longer cavity length and higher loss in the latter one. The spectral profiles of linear resonator cavity Ti:sapphire laser before and after injection seeding are shown in Fig. 4. The linewidth of Ti:sapphire laser was greatly reduced and became similar to the seeder laser itself. The linear cavity was employed in the subsequent experiments. The temporal behaviors of the

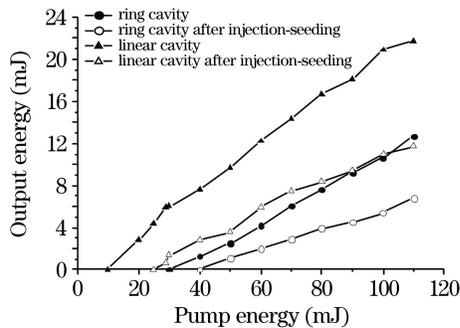


Fig. 3. Ti:sapphire laser output energies of linear resonator and ring resonator at various pump energies at 532 nm.

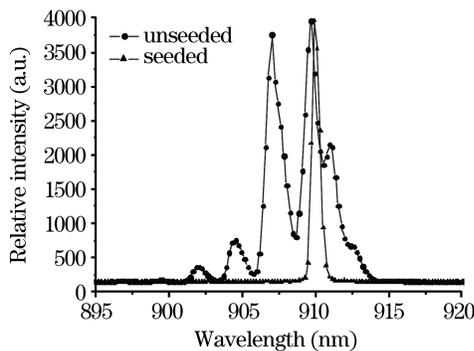


Fig. 4. Spectra of Ti:sapphire linear resonator before and after injection-seeding.

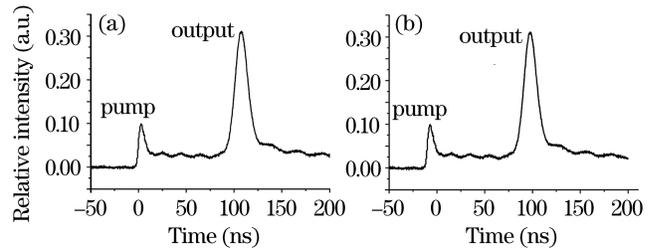


Fig. 5. Temporal profiles of the Ti:sapphire laser linear resonator (a) before and (b) after injection-seeding.

linear resonator Ti:sapphire laser before and after injection-seeding were also checked, as indicated in Fig. 5, and the output pulse width was about 20 ns.

A type I β -barium borate (BBO) nonlinear crystal ($6 \times 6 \times 6$ mm) was used to generate the second-order harmonics from the fundamental wave because of its high nonlinear coefficient and high optical-damage threshold. As to the broad spectral output of the Ti:sapphire laser before injection-seeding, the frequency doubling efficiency could only reach about 10.8% when the fundamental wave entered the BBO crystal directly using external cavity frequency doubling method without being focused. However, 3.43-mJ output of 455-nm laser can be generated from 11.73-mJ 910-nm fundamental wave after injection-seeding using the above frequency doubling method, corresponding to a conversion efficiency of about 29.2%. If there is a higher power intensity of the 910-nm laser or using intracavity frequency doubling when the pump energy is higher, the conversion efficiency may be higher^[1,2,13]. The spectral profile and the temporal behavior of the 455-nm blue laser are shown in Figs. 6 and 7.

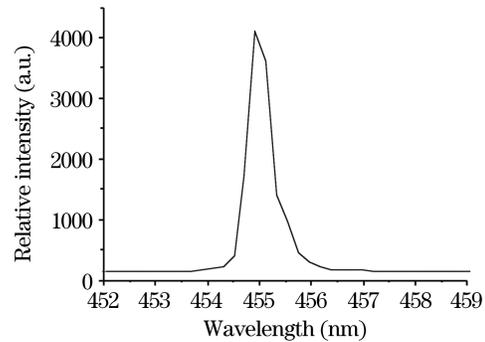


Fig. 6. Spectral profile of the 455-nm blue laser.

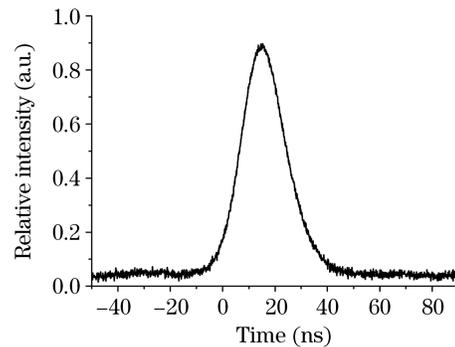


Fig. 7. Temporal profile of the 455-nm blue laser.

In conclusion, an all-solid-state, narrow-linewidth, narrow-pulse-width 455-nm blue laser based on Ti:sapphire crystal was developed. 3.43-mJ blue laser at 455-nm wavelength was obtained through frequency doubling technology. This laser system was compact in structure and stable in practical operation. It will be a good candidate laser source for underwater laser communication.

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