Ti:sapphire laser directly pumped by 478- and 520-nm laser diodes

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Titanium-doped Al₂O₃ (Ti:sapphire) laser can be directly pumped by recently developed green and blue indium gallium nitride (InGaN) laser diodes (LDs), and mode-locking operations of the laser with these pump sources have already been reported from several groups. Rohrbacher et al. achieved an average output power of 460 mW using two 2.9-W LDs at 450 nm, and a pulse width of 82 fs was obtained by semiconductor saturable absorber mirror (SESAM) mode-locking [1]. However, the 450-nm pumping has been reported to induce an absorption loss in Ti:sapphire crystals, called pump-induced loss, by Roth et al. According to their qualitative experiment, the pump-induced loss was not observed when pump wavelength was longer than 456 nm [2]. A pumping at green wavelength was more efficient than the 450-nm pumping due to not only the lack of the pump-induced loss but also the higher Stokes and absorption efficiencies. However, the available output power from a single green LD (~520 nm) is lower than that at 450-nm. Sawai et al. demonstrated the first green-diode-pumped Ti:sapphire laser [3], and recently, Gürel et al. reported a successful power scaling resulting 650-mW output power in continuous-wave (CW) operation, and an average output power of 450 mW with a pulse width of 39 fs by Kerr-lens mode-locking, using two overdriven 520-nm LDs [4]. Toward further power scaling, we investigated the characteristics of Ti:sapphire laser pumped by different wavelength.

As pump sources, we used 450-, 478-, and 520-nm LDs, whose output power was 3.5, 1.0 and 1.0 W respectively. In the experiment, three Ti:sapphire crystals of different nominal figure of merit (FOM) produced by different manufactures. In our qualitative experiment, we conducted the sequence presented in [2]. The pump-induced loss was confirmed in the 450-nm pumping by the gradual deterioration of output power, while that was not observed in the 478-nm pumping, for all Ti:sapphire crystals. These results agreed with the report of the previous study [2]. To investigate quantitatively the influence of pump wavelength to the Ti:sapphire laser, we examined an intracavity loss of a CW Ti:sapphire laser by Findlay-Clay and Caird analyses. As the result, it was found that the longer the pump wavelength the smaller the intracavity loss, even longer than 478 nm in which gradual deterioration of output power was not observed for all crystals. However, the estimated loss with the 478-nm pumping was much smaller than that with the 450-nm pumping. Hoffstädt tentatively attributed the mechanism to the charge transfer between Ti³⁺ and Ti⁴⁺ [5], but a further investigation is required for deeper understanding. We conclude here that the 520-nm pumping was advantageous but the 478-nm LD was good candidate for power scaling regardless the crystal’s FOM.

Since the green LD’s power was limited to 1 W, we used two 520- and 478-nm LDs for a power-scaling of Ti:sapphire laser. At an incident pump power of 3.0 W, 2.4 W was absorbed by 2.5-mm long Ti:sapphire crystal. A maximum output power of 656 mW was achieved in CW operation (Fig. 1 left). The optical-to-optical conversion efficiency with respect to the incident power was 22%. The slope efficiency with respect to absorbed power was 34 and 40% for 478- and 520-nm pumping, respectively. The result indicated that the use of 478-nm LD was an efficient approach. In SESAM mode-locking operation, an average output power of 315 mW and a pulse width of 126 fs were obtained (Fig. 1 right).

**Fig. 1** Output characteristics in continuous-wave operation (left) and interferometric autocorrelation trace of SESAM mode-locked Ti:sapphire laser (right).

**Example References**


