P7 Narrow-band Tunable Solid-state Lasers for Lidar Applications

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A wide tuning range of a high-power Ti^{3+}:sapphire laser with a narrow bandwidth is obtained by developing a tunable injection laser. The injection laser was an all-solid-state spectrally narrowed cw Cr^{3+}:$LiSrAlF_6$ (Cr^{3+}:LiSAF) laser with a grating in the auxiliary cavity. A tunable operation of the pulsed Ti^{3+}:sapphire laser (818-848 nm) with a narrow-band linewidth of 0.006 $cm^{-1}$and an amplified output energy of 38 mJ was obtained. Single-mode operation of the Cr^{3+}:LiSAF laser was also obtained by replacing the grating with a fiber grating. This configuration can allow a very simple and compact cavity construction.

1 Introduction

For the application of a Ti^{3+}:sapphire laser for remote sensing with laser radar technique, a narrow spectral emission is the main requirement. An efficient method to achieve narrow bandwidth operation is injection seeding[1)]. The applicability of this method can be extended further by using a widely tunable cw injection laser source to match with the broadly tunable Ti^{3+}:sapphire laser (≈650-1100 nm). If an all-solid-state narrow-band cw Cr^{3+}:LiSAF laser (≈750-1000 nm) is used as an injection laser, a wide tuning range is obtainable. Though as a tunable injection laser, a cw Ti^{3+}:sapphire laser can also used, the absorption band of the Cr^{3+}:LiSAF in the range from 600 to 700 nm matches with the emission band of the commercially available InGaAlP diode lasers which is not the case of the Ti^{3+}:sapphire laser. Thus as an injection laser Cr^{3+}:LiSAF laser has the advantage that it allows a compact construction of the tunable laser by means of laser-diode pumping[2)].

We report an application of a spectrally narrowed tunable cw Cr^{3+}:LiSAF laser as an injection laser for a tunable narrow-band operation of a Ti^{3+}:sapphire ring oscillator. Subsequently, the oscillator output is amplified to obtain a high-power narrow-band Ti^{3+}:sapphire laser output. Furthermore, the cavity design of the Cr^{3+}:LiSAF laser is also improved by replacing a grating with a fiber grating. Fiber grating has an advantage that it can be manufactured with the required reflectivity to provide an optimum feedback for single-mode operation.

2 Injection Seeding of Ti^{3+}:sapphire Lasers

Figure 1 shows an experimental setup. It consists of three parts, namely an injection laser, a Ti^{3+}:sapphire oscillator and a two-stage amplifier.

The injection laser was a cw Cr^{3+}:LiSAF laser pumped by a diffraction limited diode laser (679 nm, SDL-7350-A6). Spectral narrowing of the Cr^{3+}:LiSAF laser was achieved using the first order dispersive feedback from a diffraction grating (1200 grooves/mm) in an auxiliary cavity coupled externally to the main cavity. Spectrally narrowed output was obtained in the range of 818-850 nm with a maximum output

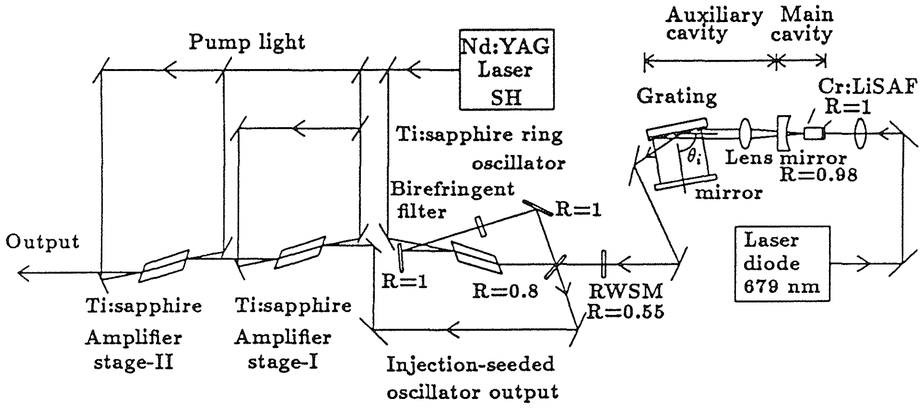


Fig. 1. Experimental setup.

power of 12 mW at 828 nm. The spectral width of the Cr^{3+}:LiSAF laser was measured using a stationary type Fabry-Perot interferometer (Burleigh RC-140) set for a free spectral range (FSR) of 0.25 cm^{-1}. The linewidth was measured as 0.04 cm^{-1}.

As shown in Fig. 1 the Ti^{3+}:sapphire oscillator was a three-mirror ring cavity with a flat output mirror (R=85% @ 830nm). A Q-switched, frequency-doubled, Nd:YAG laser (Spectra-Physics GCR-3) with a pulse duration of 6 ns was used for pumping the Ti^{3+}:sapphire crystal at a repetition rate of 10 Hz. A birefringent filter of thickness 0.5 mm was used for a coarse control of the Ti^{3+}:sapphire laser wavelength. The tuning range of the Ti^{3+}:sapphire laser was between 790 and 850 nm with a bandwidth of $\approx$ 20 nm. An output energy of $\approx$ 5 mJ at 830 nm was obtained for a pump energy of 65 mJ (pump fluence of $\approx$ 2 J/cm^2) with a threshold at 45 mJ.

Using the Cr^{3+}:LiSAF laser, injection seeding was performed at different wavelengths and a spectrally narrowed Ti^{3+}:sapphire laser output was obtained. Details of the spectra of the Ti^{3+}:sapphire laser at different injection power at a typical wavelength of 828 nm is shown in Fig. 2(a), (b) and (c). Increasing the injection power resulted in quenching of the broadband emission and spectrally pure output was obtained with the same output energy as without injection seeding. An injection power of 500 μW was sufficient for complete injection-seeding at 828 nm. Figure 3 shows the spectrally narrowed output of the Ti^{3+}:sapphire laser, when injection-seeded at different wavelengths between 818 nm and 848 nm.

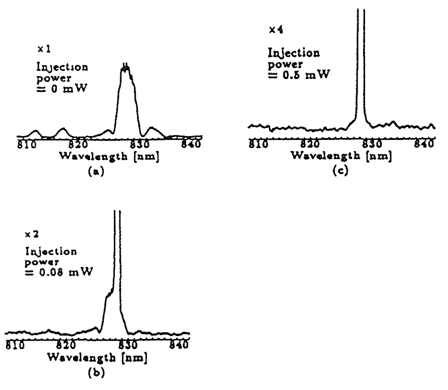


Fig. 2. Spectra of Ti^{3+}:sapphire laser
(a) without injection seeding,
(b) with injection power 0.08 mW,
(c) with injection power 0.5 mW.

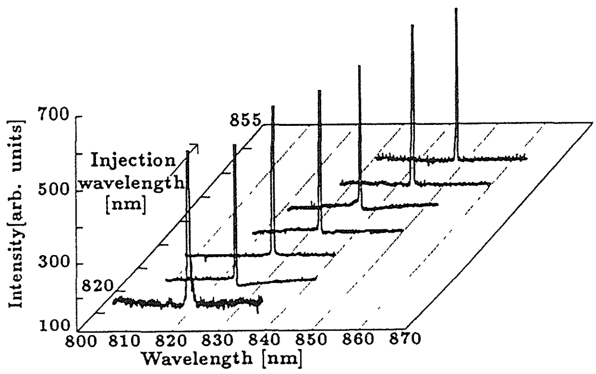
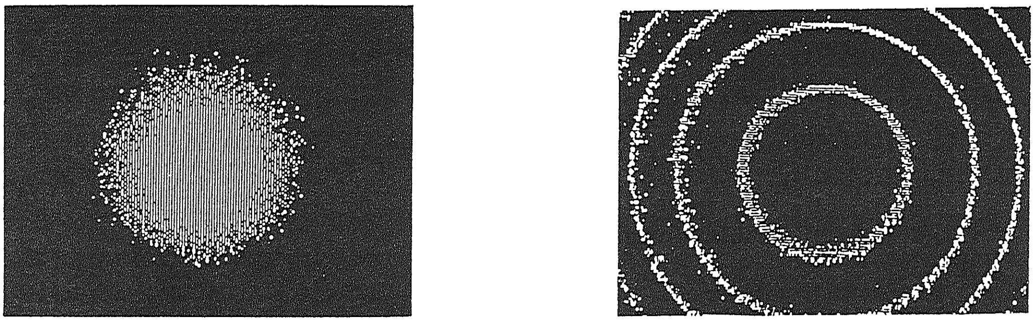


Fig. 3. Tuning of pulsed Ti^{3+}:sapphire laser injection seeded by Cr^{3+}:LiSAF laser. Tuning range 818-848 nm.



(a) (b)

Fig. 4. Fabry-Perot interference fringe pattern of Ti^{3+}:sapphire laser (a) without injection seeding, (b) with injection seeding. Free spectral range 0.1 cm^{-1}. Spectral width 0.006 cm^{-1}.

Figure 4 shows the fringe pattern (a) without injection seeding and (b) with injection seeding. The FSR of the Fabry-Perot interferometer was 0.10 $cm^{-1}$with the resolution of $\approx$ 0.002 cm^{-1}. Without injection seeding the Ti^{3+}:sapphire laser had a broadband output and no visible fringe pattern was obtained as shown in Fig. 4(a). Figure 4(b) shows that with injection seeding well defined fringes with a bandwidth as narrow as 0.006 cm^{-1}were obtained.

Subsequently, the single-mode output of the Ti^{3+}:sapphire oscillator was amplified by a two-stage Ti^{3+}:sapphire amplifier in order to obtain a high energy output. Each amplifier had a single-pass design pumped by the same Nd:YAG laser as shown in Fig. 1. The total pump energy for the two-stage amplifier was $\approx$ 270 mJ with a fluence of $\approx$ 2 J/cm^2. Figure 5 shows the Ti^{3+}:sapphire laser output as a function of wavelength without amplification (solid circles) and with the two-stage amplification (solid squares). The amplified output was also single-mode with a linewidth matching the injection-seeded oscillator linewidth.

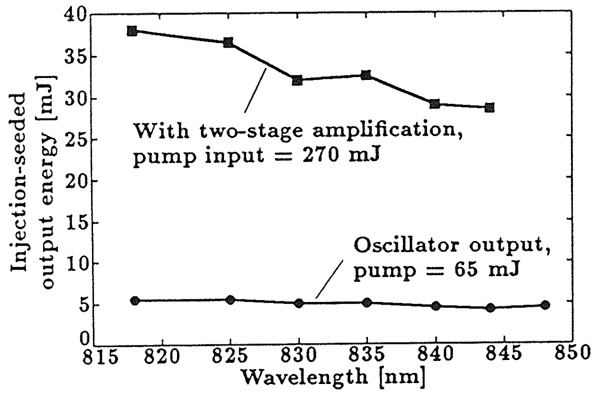


Fig. 5. Tuning characteristics of injection seeded Ti^{3+}:sapphire laser. Solid circles represent oscillator output and solid squares represent amplified output.

3 Application of a Fiber Grating for Cr^{3+}:LiSAF Laser

In case of a conventional grating, the first order reflectivity near grazing incidence is limited. This restricts the single-mode operation to a small tuning range. This limitation can be overcome by introducing a fiber grating to provide the required feedback[3)].

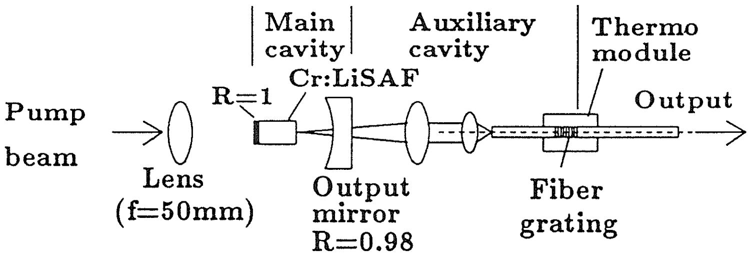


Fig. 6. Experimental setup.

Figure 6 shows the experimental setup with fiber grating. The grating was formed in a commercial germanosilicate single-mode fiber (cutoff wavelength 780 nm) by the side writing holographic technique using a KrF excimer laser (248 nm). The length of the grating formed was ≈4 mm and the reflectivity was measured to be 67% at a Bragg wavelength of 838 nm with a linewidth of 0.66 nm FWHM. When the fiber grating was used, due to narrow-band feedback, a spectrally narrowed output was obtained at 838 nm with a complete quenching of the free-running broad emission ranging from 830 to 840 nm.

Figure 7 shows a Fabry-Perot interference fringe pattern of the Cr^{3+}:LiSAF laser near threshold condition. Predominantly single-mode operation was observed, however sometimes weak secondary mode was also observed at 200 mW input. The FSR was 0.22 $cm^{-1}$and the spectral width was less than 0.025 cm^{-1}.

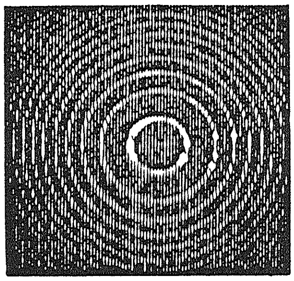


Fig. 7. Fabry-Perot interference fringe pattern of single-mode Cr^{3+}:LiSAF laser.

4 Conclusion

A high-power tunable single-mode injection-seeded Ti^{3+}:sapphire laser is developed using a tunable cw Cr^{3+}:LiSAF laser as an injection laser. Though the tuning range was limited between 818 and 848 nm, it can be broadened by improving the cavity design and by using a wavelength dependent optimized mirror-design based on the gain characteristics of the laser. In order to overcome limitation of a conventional grating and to obtain a wide tuning range, a cw Cr^{3+}:LiSAF laser is developed by using an externally coupled fiber grating.

References

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