Injection seeded/Phase-conjugated 2-μm laser system

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Abstract: For the first time, beam quality improvement of 2 μm laser using a fiber based phase conjugation mirror has been demonstrated. Single frequency operation is necessary to lower threshold. The reflectivity of PCM is ~50%.

OCIS codes: (140.3070) Infrared and far-infrared lasers, 190.5040 Phase conjugation.

1. Introduction

Holmium doped lasers operating around 2 μm wavelength have many applications in wireless communications, atmospheric surveillance, weather forecast, range-finding, guidance, and medical diagnosis/therapy. The fact that it is eye-safe and the ability to produce high energy pulses make it especially suitable for long range lidar applications. Most commercially available lasers operate in the visible to near infrared spectrum from 0.4 to 1.4 μm. This waveband is usually called as the retinal hazard region because the laser light might cause damage to the retina resulting in a blind spot in the fovea. The laser light outside the retinal hazard region, the ultraviolet between 0.29 and 0.40 μm or mid to far infrared between 1.40 and 10.60 μm spectrum, will not focus on the retina. It could cause damage to the cornea or to the eye lens, but the damage threshold of the cornea or eye lens is higher than that of the retina. The maximum permissible exposure (MPE) in the mid-infrared spectrum is much higher.

Erbium doped laser is also attractive in terms of eye-safety. Er-doped fiber lasers can generate output at 1.55, 1.65, 2.7 or 3.45 μm, but the performance is not very impressive in terms of efficiency or energy output [1]. Thulium doped fiber lasers operating in the wavelength of 1.9 μm have been commercially available with output over 100 watt. However, the lower effective stimulated emission cross-section is unfavorable for the energy extraction of Q-switched oscillator and pulsed amplifier. The drawbacks restrict their applications in lidar and remote-sensing. Holmium doped lasers on the other hand have a larger effective stimulated emission cross-section. It is good for the energy extraction of Q-switch oscillator and pulse amplifier.

In recent years, great progress has been made in the research and development of Holmium doped and holmium-thulium co-doped lasers. Q-switched output at 1.1 J/pulse at a 2.053 μm wavelength has been achieved in a diode-pumped Ho:Tm:$LuLiF_4$ master oscillator-pulsed amplifier (MOPA) system [2]. The total system efficiency reaches 5% and 6.2% for single- and double-pulse operations, respectively. This system produces a 1.4 times diffraction-limited laser beam.

2. Experimental setup

The experimental setup is schematically shown in Fig.1. The oscillator and amplifier laser crystals are cooled by water. The pump diodes are conductively cooled. The water temperature is set between 10-15ºC. The cavity length is 3 m. For reducing system volume, the ring-cavity oscillator is composed by two concave mirrors with 4 m radius of curvature and four flat mirrors. In one round trip, the beam path has 8 bounces. The active medium of the oscillator is a $Ho_{.453\%}$:$Tm_{6\%}$:$LuLiF_4$ rod 21 mm in length and 4 mm in diameter. A piezoelectric transducer (PZT) mounted mirror is used to adjust the cavity length to establish the seed wavelength resonation. The fiber-coupled seed laser is a single-frequency solid-state laser. The Faraday isolators inserted between the seed laser and oscillator are to protect the seed source. For 10 Hz pump pulse 100 ms in duration and 540 mJ in energy, the Q-switched pulses have 80 mJ in energy and 200 ns in width. Due to the thermal birefringence of $LuLiF_4$ crystal, the output beam has an elliptical cross section. The measured thermal focal lengths at the a-axis and c-axis are -2.8 m and -5.0 m, respectively. A 2 m focal lens is used to couple the oscillator beam. The amplifier crystal is a 40 mm long $Ho_{.453\%}$:$Tm_{6\%}$:$LuLiF_4$ rod with a diameter of 5 mm. The c-axis of the oscillator crystal is perpendicular to the c-axis of amplifier crystal. In this way, the thermal birefringence of the amplifier can be partially compensated by that of the oscillator. The remaining thermal birefringence of the amplifier is corrected by a cylindrical lens of 1.09 m focal length after the amplifier. The single pass amplified beam is coupled to the large-core silica fiber by a 35 cm focal length lens. The fiber with a 0.22 numerical aperture and a 400 μm diameter is used as the phase conjugated mirror (PCM). The polarizer and quarter wave plate inserted between the cylindrical lens and 35 cm focal lens are to measure the reflectivity of the phase conjugated mirror. The Faraday rotator and polarizer inserted between the oscillator and amplifier is to eject the double-pass amplified beam and avoid feedback of the amplified beam to the oscillator. The double-pass amplified beam will be reflected to the diagnostic equipment measuring the beam quality, pulse energy, frequency shift.

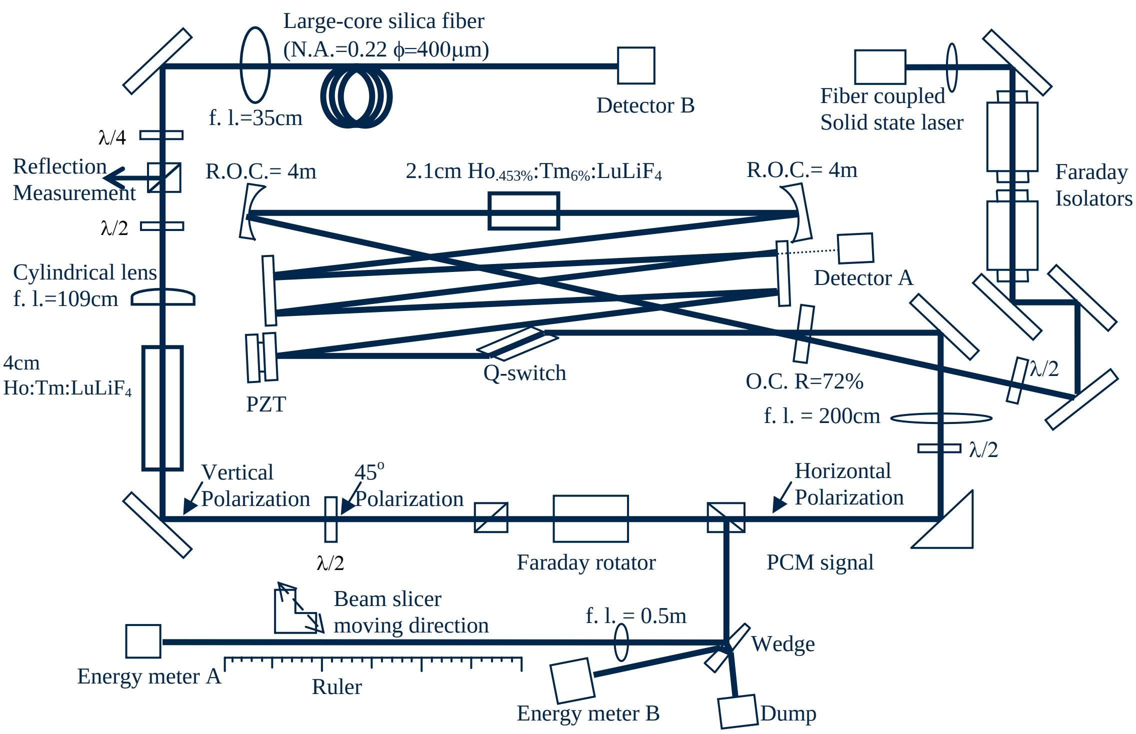

Fig.1. Experimental setup.

3. Experimental results

The injection seeded Ho:Tm:$LuLiF_4$ oscillator operates in single transverse mode and single longitudinal mode. The central wavelength of the seed laser is 2.0533 μm. The seeding success rate is almost 100% after making the mode matching between the oscillator and seed laser. When the oscillator operates at 10 Hz, the pulse width and energy are ~200 ns and ~80 mJ. The spectral width of single frequency pulse is less than 5 MHz. The single-pass amplification of the amplifier is around 2 times. To avoid damaging of fiber surface, only a 100 mJ pulse is coupled to the large core silica fiber as PCM. The maximum reflectivity of PCM is about 50%. For a single frequency pulse, the threshold of PCM reflection is lower. Fig. 2 shows the profiles of incident, reflected and transmitted pulses of 1 m silica fiber. The center wavelength of the PCM reflected pulse is 2.05345μm. The wavelength shift related to the input wavelength of 2.0533μm is 0.15 nm. The corresponding frequency shift is 9 GHz. The beam qualities of the double-pass amplified pulse with PCM are shown in Fig.3, where M^2=1.264 horizontally and M^2=1.177 vertically. If the PCM is replaced by an ordinary flat mirror, the beam qualities of double-pass amplified pulse are that M^2=1.44

horizontally and M^2=1.24 vertically. In this setup, the principal optical component damaging the beam quality is the Faraday rotator between the oscillator and amplifier.

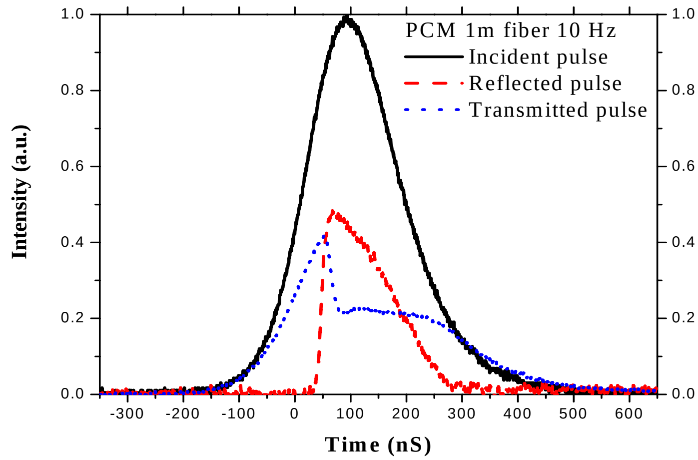

Fig.2 The profiles of PCM incident, reflected and transmitted pulses

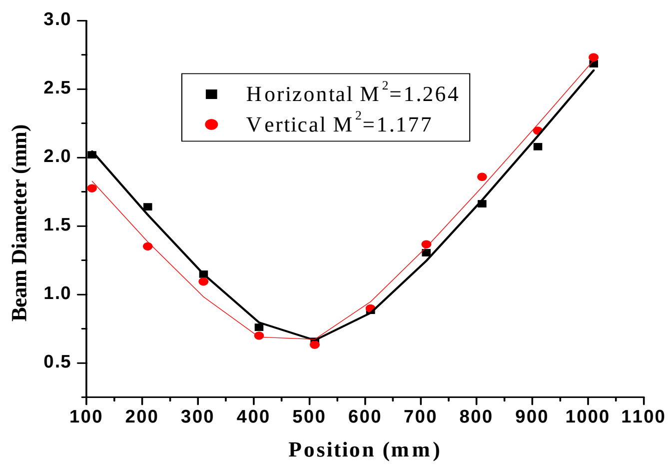

Fig.3 The double-pass amplified beam profile with PCM.

4. Conclusion

The injection seeded and phase-conjugated 2 μm laser system is first demonstrated in NASA Langley Research Center. So far, commercially available 2 μm Faraday rotators degrade the beam quality. For the PCM, the reflectivity of silica fiber is not high enough for field deployment. There are two approaches for increasing the reflectivity of PCM. One is to seek material with lower PCM threshold. The other is to increase the damage threshold of the fiber end surface, such as using a bulk glass bounded fiber.

References

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