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A Master-Oscillator-Power-Amplifier 2-micron Laser Using Fiber Phase-conjugate Mirror

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Abstract: For the first time, a 2-micron master-oscillator-power-amplifier laser using a fiber based phase conjugation mirror has been demonstrated. The beam quality improvement and 56% of the PCM reflectivity have been achieved.

1. Introduction

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 of 1.2 J/pulse at 2.053 μm wavelength has been achieved in a diode-pumped Ho:Tm:LuLiF₄ master-oscillator-power-amplifier (MOPA) system [1]. The fact that it is eye-safe and the ability to produce high energy pulses make it especially suitable for coherent wind lidar applications. As a coherent wind lidar transmitter there is a stringent beam quality requirement to achieve efficient heterodyne detection. The beam quality of a high power and/or high pulse energy laser system usually suffers mainly due to thermal introduced wave front distortion. There is a need to study the phase conjugate mirror to compensate any static or dynamic aberration in such a high gain MOPA system.

It is well established that the phase conjugate mirror (PCM) technique can be used effectively to improve the laser beam quality [2]. The phase conjugated mirrors have been applied to laser systems with broad wave-length range, practically for near infrared 1.06 micron lasers. Many nonlinear physical mechanisms generate optical phase conjugation of coherent laser beams. Among them, the Stimulated Brillouin Scattering is an efficient way for self-pumped phase conjugation generation [3]. SBS phase conjugate mirrors are robust, reliable, and have a simple design. The generation of a phase conjugate wavefront arises from the third order material nonlinearity. A wide variety of nonlinear materials can be used to generate the phase conjugate effect, such as high pressure gases, liquids and solids. In addition to technical specifications required by particular measurements, space-borne laser lidar systems also need to meet the safety, rigidity and reliability requirements. Therefore, the solid materials are preferred due to their favorable properties. In this paper, we discuss the demonstration of an optical fiber based phase conjugate mirror that applied to a high energy 2-micron MOPA system.

2. Experimental setup

The experimental setup is schematically shown in Fig.1. The system consists of an oscillator and an amplifier in double pass amplification format. Phase conjugating SBS mirror can be easily applied to laser MOPA system [4-6]. The 2-micron oscillator is in a ring cavity configuration suitable for generating TEM₀₀ transverse mode output. For highly coherent light the SBS has the lowest threshold of all nonlinearities inside a long optical fiber [7]. To obtain a low SBS threshold, it is very important to have the laser operating at single frequency with narrow bandwidth. To achieve single frequency operation, the master oscillator is injection seeded by a 2-micron seed laser. The seed laser is a fiber-coupled single-frequency continuous-wave solid-state laser. A mirror mounted on piezoelectric transducer (PZT) is used to adjust the cavity length to establish the seed wavelength resonance, where the Q-switching is triggered. The Faraday isolators inserted between the seed laser and oscillator protect the cw seed source. The injection seeded oscillator produces 80 mJ Q-switched pulses with 200 ns in width at 10 Hz operation. The output is a diffraction limited single frequency beam with bandwidth of ~2MHz. Due to the thermal birefringence of LuLiF₄ 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-meter focal lens is used to couple the oscillator beam into the amplifier. The c-axis of the oscillator crystal is aligned perpendicular to the c-axis of amplifier crystal. In this way, the thermal birefringence of the amplifier can be partially compensated each other. The

remaining thermal birefringence of the amplifier is corrected by a cylindrical lens of 1.09 m focal length after the amplifier.

The SBS as a self-pumped phase conjugation generation is normally achieved by focusing the laser beam into the SBS medium. The single pass amplified beam is coupled into the large-core silica fiber by a 35 cm focal length lens. This fiber is used as the phase conjugated mirror. The phase distortions induced in the oscillator beam during its first pass through the amplifier are compensated by reflecting that beam off the fiber phase conjugate mirror, and then passes through the amplifier for the second time. The final amplified output shall have the beam quality as the initial oscillator beam through this double pass MOPA architecture.

Here the all-solid state fiber with low OH concentration is used as the preferred phase conjugate medium. Optical fibers have long interaction lengths so the SBS threshold can be reduced to very low values. The fiber is a fused silica multimode fiber with a 0.22 numerical aperture and a 400 μm diameter. The light is scattered in the medium at a self-induced acoustic wave grating. The stimulated scattering arises from the spontaneous Brillouin scattering.

The polarizer and quarter wave plate inserted between the cylindrical lens and 35 cm focal lens are used to measure the reflectivity of the phase conjugated mirror. The Faraday rotator and polarizer inserted between the oscillator and amplifier ejects the double-pass amplified beam and prevents 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 etc.

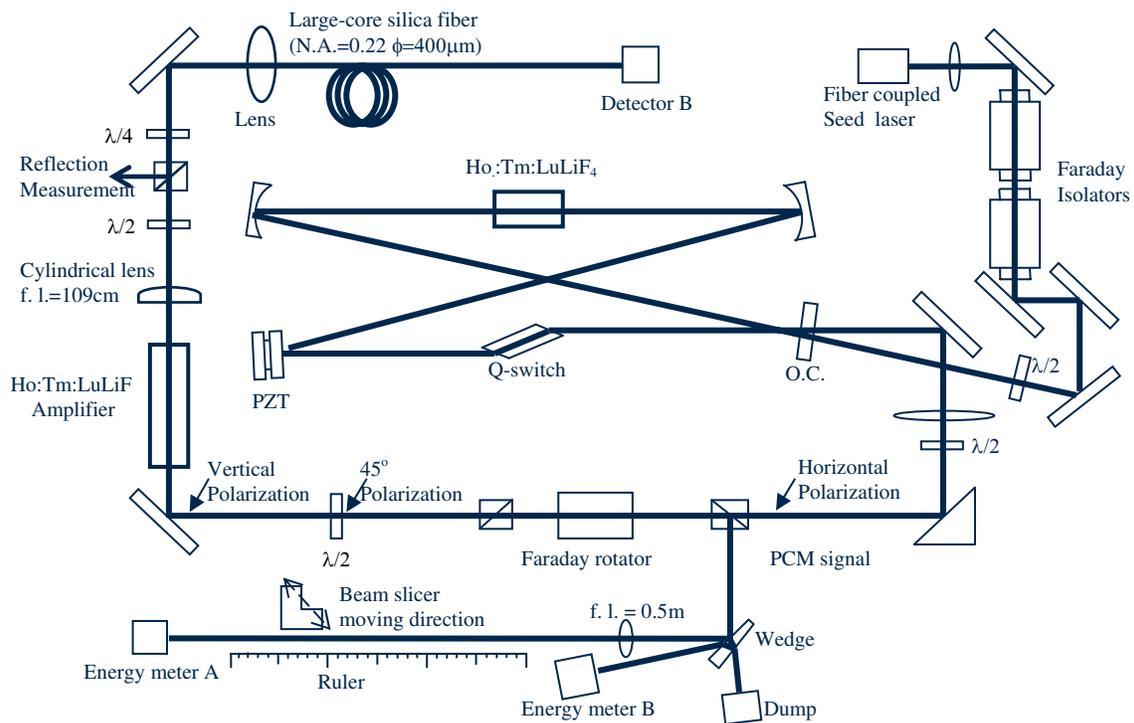


Fig.1. Experimental setup.

3. Experimental results

The single-pass amplification gain of the amplifier is around 2 times. One of the problems to use fibers as phase conjugate mirrors is the fiber end face damage. To avoid such a damage, the amplifier gain and the input oscillator pulse energy is adjusted such that less than 100 mJ pulse is coupled to the large core silica fiber. For a single frequency laser 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 phase conjugate Stokes pulses are stable in amplitude and shape. The reflected pulse exhibit a sharp leading edge. The leading edge is also delayed relative to the input pulse. This delay is responsible for the establishment of the stimulated Brillouin scattering.

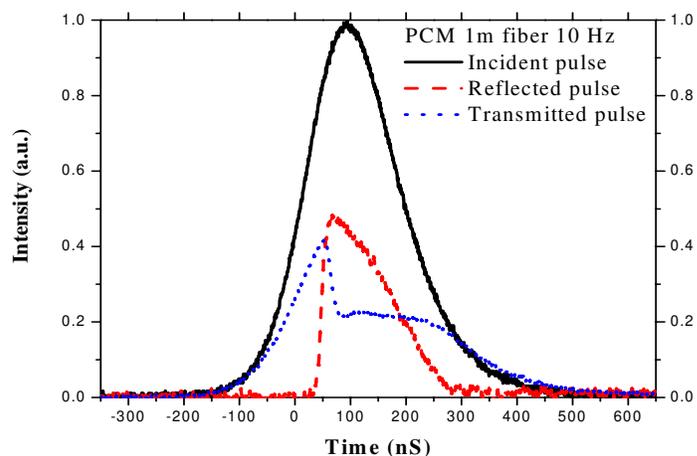


Fig.2 The temporal profiles of PCM incident, reflected and transmitted pulses

The energy reflectivity is a function of the pulse energy and the pulse duration of the incident pump light. The threshold occurred at ~ 10 mJ. The maximum reflectivity of the fiber PCM is achieved at 56% with 120 mJ incident energy at 175 ns pulse width. The interference due to the incident and spontaneous scattered light generates a traveling acoustic wave that modulates the material refractive index through the elastic optic effect. Phase conjugating SBS mirrors are based on backward scattering. Only Stokes component exists in the Brillouin spectrum. Because of the moving acoustic grating, the retro-reflected Stokes wave is shifted by the Doppler effect corresponding to the sound velocity. The typical range of this frequency shift depends on the SBS material properties. In the case of solid state fused silica fiber, the wavelength shift related to the input center wavelength is measured at 0.15 nm. The corresponding frequency shift is 9 GHz, which is the normal frequency shift of this solid state material.

The beam qualities of the double-pass amplified pulse are measured using the setup shown in Fig. 1. M^2 value of 1.264 and 1.177 are obtained for the horizontal and vertical direction, respectively. 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. The output beam image also displays nicer beam shape in the PCM system compared to that in using regular retro mirror system. In the PCM system, the output beam is in circular shape. In the regular retro mirror system, the beam shape is elliptical.

4. Conclusion

The injection seeded and phase-conjugated 2-micron laser MOPA system has been demonstrated. To our knowledge, this is the first time that an all solid-state fused silica fiber acts as a phase conjugate medium in a 2-micron laser MOPA system. It demonstrated the phenomena of a phase conjugate mirror. The system operates stable and reliable.

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