Efficient Fiber-Laser-Pumped Ho:YLF Oscillator and Amplifier Utilizing the Transmitted Pump Power of the Oscillator

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Abstract: We present a novel scheme for a compact and robust pulsed fiber-laser-pumped Ho:YLF oscillator and amplifier system, where the pump power transmitted by the oscillator is utilized to pump the amplifier.
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1. Introduction

High energy 2 µm laser sources are of great interested for applications in remote sensing, medicine and defense. Ho:YLF is an attractive laser material to use since it has a very longer upper laser level lifetime (~14 ms) and higher emission cross section than Ho:YAG, which makes it ideal to produce high energy pulses. In addition, the very weak thermal lens on the σ polarization helps to deliver diffraction limited beams even under intense end pumping. However, the Ho:YLF has a somewhat stronger quasi-three-level nature. In order to reach transparency at the 2065 nm line, 22% of the Ho ions need to be pumped into the upper laser level (at room temperature). On the other hand, it already reaches transparency at the 1940 nm pump wavelength with only 56% of the Ho ions in the upper laser level. In addition, the pump absorption cross section at 1940 nm is relatively low and strongly polarized. Due to these constraints, a careful design is required with a trade of between efficient pump absorption and low threshold.

The traditional approach for a fiber-laser pumped Ho-laser system with amplifier is to split the unpolarized pump beam with a polarizing beam splitter and to use the two polarized beams to pump the oscillator and amplifier. In our approach, we use the full unpolarized pump beam to pump a relatively short oscillator crystal, which absorbs roughly half the pump power under lasing conditions. The transmitted pump power is then used to pump the amplifier crystal. The c-axis of the two crystals are orientated perpendicular to each other, in order to optimally utilize the unpolarized pump light and to facilitate lasing on the σ-polarization in the oscillator while amplifying on the stronger π-polarization. The distances between the pump fiber collimator and the crystals were kept short to minimize water absorption at 1940nm.

2. Experimental set-up and results

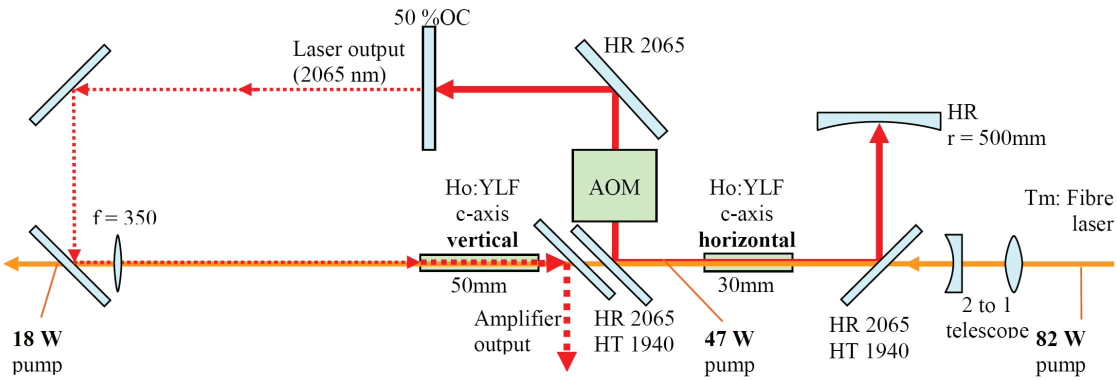

Fig. 1: Schematic diagram of the oscillator/amplifier Ho:YLF system.

A schematic diagram of our experimental setup is illustrated in Figure 1. We used an 80W 1940 nm Tm:fiber laser from IPG Photonics to pump both oscillator and amplifier crystals. The pump beam radius entering the 30 mm 0.5% doped Ho:YLF oscillator crystal was 0.56 mm. The cavity had a length of 340 mm and consisted of a 500 mm CV back-reflector and a flat 50% output-coupler. Two 45° mirrors, which had a high transmission coating for the pump light, were used to couple the pump light in and out of the resonator. The resonator mode had a ~0.6mm radius in the crystal, which was relatively independent of the thermal lens strength.

The oscillator crystal was oriented such that the c-axis (π polarization) is horizontal. The 45° mirrors were coated to reflect vertical polarized light at 2065 nm and therefore selected the σ polarization (⊥c-axis). The σ polarization has a lower gain cross section ($\sim 0.8 \times 10^{-20}$ cm^2) but also a much lower thermal lens, which reduces thermal aberrations in the resonator and so maintains beam quality. The oscillator had a threshold of 31 W (17 W absorbed), an overall slope efficiency of 25% and a maximum average output power of 12.4 W.

The oscillator was then pulsed with a fused-silica AOM operating at 100 W RF power. A minimum repetition rate of 1 kHz was used, which resulted in a maximum pulse energy of 10.9 mJ, as indicated in Figure 2. The calculated 33 mJ intra-cavity energy was below the damage threshold of the two 45° mirrors, which was ~35 mJ as previously observed in a similar setup.

The pulsed output of the oscillator was then coupled back into a 50 mm 0.5% doped Ho:YLF amplifier crystal. The pump beam radius entering the amplifier crystal was 21% smaller than in the oscillator crystal due to pump bleaching. The oscillator output beam (the seed) therefore had to be reduced using a f = 350 mm focusing lens. The amplifier crystal was orientated with its c-axis vertical, so that the amplification would take place on the π-polarization with its stronger emission cross section of $\sim 1.3 \times 10^{-20}$ cm^2. The much stronger (negative) thermal lens of the π-polarization is not critical in the single-pass amplifier. This was confirmed by a beam quality of the amplified beam of M^2 better than 1.1. In addition, this orientation maximizes the absorption of the remaining pump light.

After passing through the amplifier crystal, the slope efficiency of the system almost doubled from 25 to 47%. The maximum pulse energy at 1 kHz was 23.7 mJ and had a pulse length of 74 ns. This gain factor of 2 was confirmed by small signal gain measurements. Measurements below 1 kHz were not attempted in order to prevent optical damage to the oscillator.

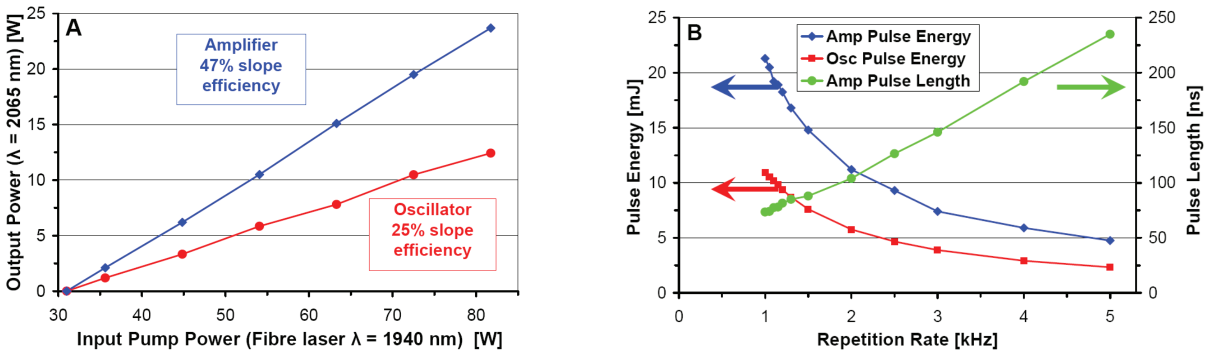

Fig. 2: The CW and pulsed performance of the oscillator and amplifier is shown in (A) and (B) respectively

3. Conclusion

We have demonstrated that a Ho:YLF oscillator and amplifier system can be designed in a compact setup where the pump power from an unpolarized fibre laser utilized efficiently. The system produced more than 20 mJ energy per pulse at 1 kHz, while maintaining a M^2 better than 1.1. This system only utilized single pass pumping of the oscillator and amplifier crystals, with 18 W of pump power which was not absorbed. This excess pump power can be carefully back aligned into the amplifier and oscillator, but we opted not to do this for fear of damaging the fiber pump laser. The seed can also be passed multiple times through the amplifier crystal. Our initial calculations show that by implementing both these measures it is possible to extract even higher energy pulses from this system. This proof of concept architecture therefore shows great promise of delivering highly efficient 2 µm pulsed output with excellent beam quality.