High efficiency 70W 1908nm Tm-doped Fiber Laser System.

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Abstract: Achieving efficient operation from 790nm-pumped Tm-doped fibers at wavelengths <1.95µm requires careful attention to fiber and device design. Here we present a high-efficiency MOPA producing 70W at 1908nm with 53% slope efficiency from the power amplifier stage.

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1. Introduction

For cladding-pumped Tm-doped fibres operating below about 1.95µm, signal reabsorption losses are a significant design concern. Agger and Povlsen recently showed that the signal reabsorption in aluminosilicate Tm-doped fibres rapidly increases below 1.95µm [1]. For core-pumped systems, reabsorption is less significant however schemes such as cascaded pumping (Er:Yb pumped Tm) can not achieve the same quantum efficiencies as pumping at 790nm due to the absence of the cross-relaxation process [2].

Key to obtaining high efficiency in cladding pumped Tm-doped fibres at shorter wavelengths therefore involves minimizing the number of active ions present within the optical path. This is generally achieved through the use of large core-to-clad ratios. However, in fibres where high active ion concentrations are desirable to maximize inter-ion energy transfer (such as Er:Yb and 790nm-pumped Tm), large core-to-clad ratios can lead to fiber thermal management concerns. Fiber design therefore must take into consideration a combination of factors including core composition, core-to-cladding ratio, cladding diameter and the implied core diameter.

2. Experiment

For this experiment, the laser system utilized a master oscillator-power amplifier (MOPA) architecture, as shown in Fig. 1. The master oscillator (MO) was based upon a simple end-pumped Fabry-Perot cavity in single-mode fiber. This was used to seed the main power amplifier comprising a counter-pumped large mode area (LMA) high concentration fiber specifically designed for operation at shorter wavelengths.

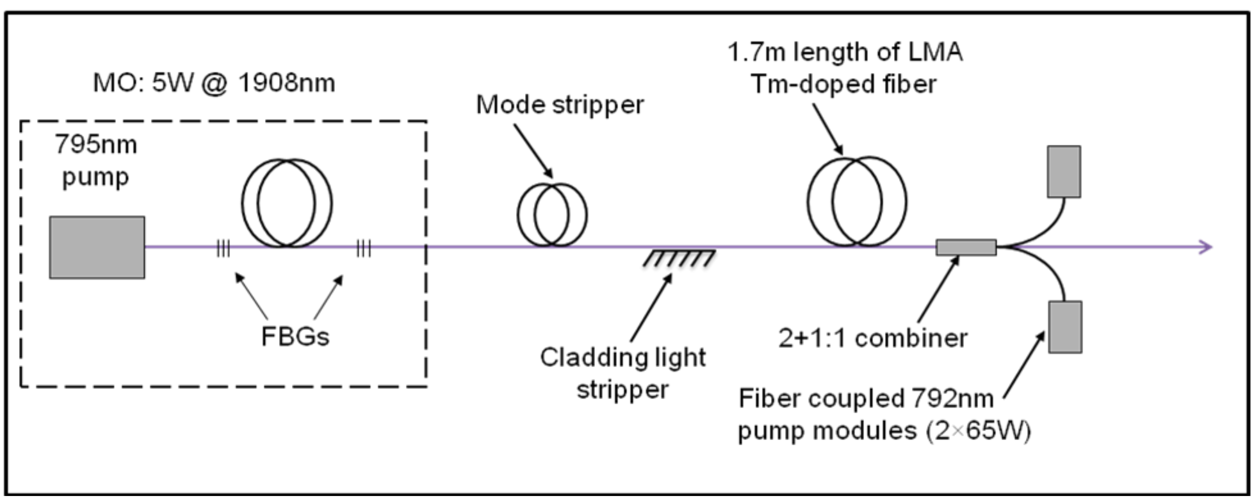

Fig. 1. Schematic of laser system.

2.1 Master oscillator

The Tm-doped fiber used in the MO had a mode-field diameter of 10.2µm, LP11 mode cut-off wavelength of 1.96µm and absorption of ~2dB/m @ 790nm. It was end-pumped with a fiber-coupled 795nm diode. At full power, it was capable of producing up to 10W at 1908nm.

We recorded the output spectrum of the MO with a 500mm monochromator installed with $300mm^{-1}$ grating blazed at 2µm and 50µm slits. Calibration was performed by observing the 3rd diffraction order of a HeNe beam. We recorded a centre wavelength of 1907.4nm with <0.5nm FWHM as shown in Fig. 2. This wavelength corresponds well to the peak absorption of Ho:YAG.

The ouput signal from the MO was launched into a passive fiber which had been mode-matched to the LMA active fiber of the amplifier. Since this fiber theoretically supported two transverse modes when uncoiled, it was coiled to remove any induced higher order modes which were stripped from the cladding before delivering the signal to the amplifier. The cladding stripper also served to remove any residual unabsorbed pump from the counter-pumped amplifier stage.

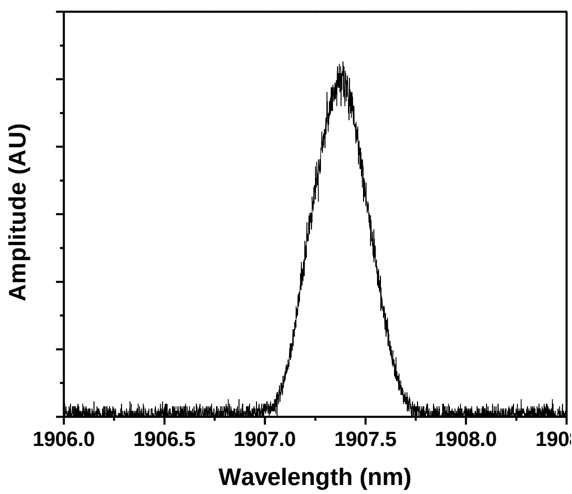

Fig. 2. Spectral output from the MO.

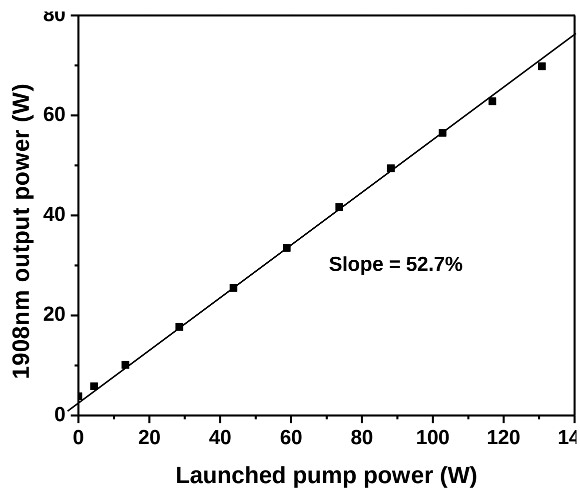

Fig. 3. Slope efficiency of the amplifier stage.

2.2 Power amplifier

2.2.1 Fiber design.

Taking into consideration both the brightness of economically available pump sources and the desired output power of >50W we selected a pump cladding size of 250µm. Whilst employing as large a core-to-clad ratio as possible is beneficial to reducing reabsorption losses, practical considerations such as thermal management, mode control (beam quality) and operating threshold place an upper limit on suitable core size.

Accounting for these factors we designed the core to have a fundamental mode field diameter of around 22µm. To aid cross-relaxation, relatively high concentrations of Tm^{3+} and Al^{3+} were incorporated [3]. A raised refractive index 'pedestal' was deposited around the core to lower its effective NA, so as to maintain near diffraction limited beam quality [4]. The measured pump absorption for the fibre was ~6dB/m.

2.2.2 Amplifier Configuration

Through experimentation, the best efficiency and stability was observed when counter-pumping 1.7m (~10dB pump absorption) of active fiber. The output from two 792nm pump diodes, each delivering up to ~65W into 200/220 0.22NA fiber, were coupled into the amplifier using a 2+1:1 pump/signal multiplexer.

Considering the relatively high absorption of the fiber, careful attention to thermal management was essential for maintaining reliability and efficiency. The effect of optical efficiency with respect to fibre temperature for 790nm-pumped Tm fibers has been shown in the past [5]. A 90mm diameter mandrel with a helically cut 'U-shape' channel ensured highly effective heat removal and provided sufficient mode control to ensure excellent beam quality. Whilst, as shown in Fig. 3, some deviation from linearity was observed in the slope efficiency it was determined by altering diode temperature that this was due to diode wavelength variation rather than thermal roll-off. For this fiber, the peak absorption was measured to be 788nm, hence the pump diodes tended to move off the absorption peak at higher powers and temperatures. Indeed thermal modeling suggests that power scaling to above 100W should be possible before degradation of the fluoro-acrylate polymer outer cladding is observed.

Conclusion

1908nm is a key wavelength used as a low quantum defect pump source for Ho:YAG lasers [9]. However most high power demonstrations of 790nm-pumped Tm lasers have to date been at wavelengths exceeding2.04µm [6,7,8] where reabsorption effects are relatively mild. Here we have demonstrated that through careful attention to fibre and device design, high power and highly efficient operation is also possible at shorter wavelengths.

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