Cladding-Pumped Nested-Ring Tm Fiber Laser with 131 W Single-Mode Output at 1907 nm

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INTRODUCTION

Hybrid Tm fiber-laser-pumped Ho:YAG lasers provide an attractive platform for generating mid-infrared output via the pumping of an optical parametric oscillator. High power sources emitting in the mid-infrared regime are required for use in laser materials processing, medical surgery and various defense applications. However, achieving single-mode output at power levels beyond 100 W from Tm fiber lasers at the 1907 nm absorption peak in Ho:YAG is very challenging. In this paper, we explore a novel fiber design incorporating a highly-doped ring of Tm material nested within an undoped core. The nested-ring fiber has demonstrated high lasing efficiency with heat loading distributed over long fiber device lengths, critical for high power 1907 nm operation.

Figure 1. (a) Refractive index variation in the nested-ring Tm fiber. Inset: end-face image of the fabricated nested-ring fiber. (b) Power curve for the nested-ring fiber with the corresponding slope efficiency with respect to absorbed power, η . Inset: Laser emission spectrum and beam intensity profile at 131 W of 1907 nm output.

As Tm-doped silica fiber lasers operate as quasi-three-level gain media, high fractional population inversions are essential in order to achieve laser action at 1907 nm. The high inversions demand a sufficiently large overlap factor between the pump light and the Tm-doped core, which is difficult to achieve in a cladding-pumped configuration. However, cladding-pumping the active fiber with high power 790 nm laser diodes is an important route for high power fiber laser operation. Attempts to unify cladding-pumping and the need for high fractional Tm population inversions have often relied on small cladding-to-core area ratios, large mode area cores, lower Tm dopant concentrations or reduced fiber lengths. As a result, access to 1907 nm output powers exceeding 100 W is often achieved by sacrificing the laser efficiency or the beam quality. Laser performance beyond 100 W at 1907 nm has been demonstrated in master oscillator power amplifiers (MOPAs)¹, multimode laser oscillators² and pedestal-fiber single-mode laser oscillators.³ However, the MOPA is unsuitable for free-space cavity pumping due to high back-reflection sensitivity of the amplifier stage, whilst multimode laser oscillators suffer from degraded beam quality. Single-mode 1907 nm laser oscillators have demonstrated over 100 W using device lengths up to 2.3 meters and with slope efficiencies up to 53% with respect to absorbed pump power³, limiting power scalability.

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In this paper, we demonstrate a novel pedestal-free single-mode 1907 nm Tm fiber architecture optimized for high power emission, as illustrated in Figure 1a. This nested-ring fiber core features a circular band of Tm dopant, which is embedded within the rest of the undoped core glass. A classical 1907 nm Tm fiber uses a uniformly-doped low-concentration ($<2\text{wt}\%$) core, sacrificing the two-for-one cross-relaxation and high slope efficiency for an increased device length. For the nested-ring fiber, we implement a high Tm doping concentration ($\sim 4\text{wt}\%$) without excessive pump absorption due to the small doped area. With the dopant material surrounding the center of the fiber core, there is a reduced interaction between the fundamental-mode 1907 nm signal light and the doped region. Signal reabsorption is therefore suppressed, permitting further device length increases and enhanced output power generation.

Figure 2. Tm-doped fiber (TDF) cavity, wavelength-locked for 1907 nm operation. The diode protection filter (DPF) is used to prevent high power backwards 2 μm light causing diode damage if the FBGs were to lose wavelength locking.

EXPERIMENTAL RESULTS

The nested-ring fiber was fabricated by MCVD (modified chemical vapor deposition) and solution-doping to create the fiber profile as illustrated in Figure 1a. Once drawn, the fiber had a 8.2 μm diameter core with 122 μm flat-to-flat octagonally-shaped cladding. The core diameter is selected to ensure robustly single-mode emission. The chosen fiber dimensions ensure that the mode field diameter and the fiber cross-sectional area are matched to a passive 10 $\mu\text{m}/0.15$ NA fiber. Laser operation was achieved using a pair of 1907 nm fiber Bragg gratings (FBGs) spliced onto 6 meters of nested-ring Tm fiber (Figure 2). A 10 meter length of coreless 125 μm fiber was spliced to the high reflectivity (HR) FBG to reduce broadband feedback from the input cleave face. A 300 W 790 nm pump diode source was free-space launched through the coreless fiber. The output coupler (OC) FBG was bonded to an anti-reflection (AR) end cap for further feedback suppression. In Figure 1b we see that for 222 W of launched pump power, the nested-ring fiber laser demonstrated 131 W of 1907 nm output power. The emission was limited by available pump power. The laser emitted 15.8 W of unabsorbed pump, with an 11.5 dB pump absorption. Figure 1b indicates a 64.5% slope efficiency with respect to absorbed power and a 60.0% slope efficiency with respect to launched power. The spectrum in Figure 1b (inset) indicates the absence of parasitic lasing and amplified spontaneous emission at 131 W output. The beam profile was consistently single-mode at all output powers (Figure 1b, inset) and there were no transverse modal instabilities observed. The minor roll-over in the 1907 nm emission power curve suggests that multi-hundred Watt emission from the nested-ring fiber could potentially be achieved with more robust thermal management.

CONCLUSION

To the best of our knowledge, this is the most efficient 1907 nm single-mode Tm fiber laser capable of operating beyond 100 W. The robustly single-mode beam quality and laser oscillator configuration make the nested-ring fiber highly suited for pump delivery to bulk Ho:YAG, in comparison to existing high power 1907 nm sources. At 131 W of 1907 nm single-mode output and 64.5% slope efficiency with respect to absorbed pump power, the use of a nested-ring Tm fiber architecture presents a viable opportunity for significant mid-infrared power scaling.

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