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FBG Reflected Wavelength and Fiber Gain Matching on a Continuous Wave Monolithic Tm³⁺, Ho³⁺-Doped Fiber Laser

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Abstract: We present the optimization of a 2 μm CW monolithic single-oscillator laser in terms of output power and efficiency by the adaptation of the FBG reflected wavelength to the maximum gain wavelength of the fiber. © 2022 The Author(s)

1. Introduction

In the last ten years, the development of all-fibered monolithic fiber laser sources at 2 μm has been particularly challenging. All-fibered single oscillator architectures offer the compactness and the robustness required by most of the 2- μm laser applications, as surgery, LIDAR or directed countermeasures. However, the use of fiber components give birth to new problematics. Indeed, the splices between active and passive fibers with different geometries lead to some power losses and degradations of the output beam profile, as highlighted by Simakov et al. in 2015 [1]. Moreover, the Fiber Bragg Grating (FBG) used to build the fiber laser cavity can be very sensitive to the power. Thus, the FBG heating implies a spectral degradation characterized by a broadening and shifting of the laser output spectrum. This effect was particularly observed in the monolithic single-oscillator thulium-doped fiber laser source emitting 567 W at 1.97 μm , developed by Walbaum et al. in 2016 [2]. These issues can be resolved by implementing a cladding light stripper and by using new-generation FBGs with lower thermal slope, respectively. Nevertheless, the absorption/emission phenomenon occurring in the gain medium is also responsible for some behavior we need to pay attention to. As the free-running (without FBG) emission wavelength of the laser depends on the maximum gain of the active fiber, the length of the fiber is a key parameter that can impact the laser operation. Traditionally, the fiber length is chosen in order to maximize the pump absorption. However, a longer fiber length implies a higher maximum gain wavelength. The development of a single-oscillator fiber laser source can then be accompanied by the presence of a parasitic cavity that depends on this maximum gain wavelength, as mentioned in Ref. [3].

In this communication, we study the power and spectral evolution of an all-fiber laser source based on a Tm³⁺, Ho³⁺-codoped fiber emitting at 2 μm in continuous wave regime in several configurations of match and mismatch between the maximum fiber gain and the FBG reflected wavelengths. The comparison of these configurations shows that the matching of these two parameters improves the performance and the stability of the laser source.

2. Experimental setup

The laser setup, shown in Fig. 1, consists of a silica double-clad PM fiber with a Tm³⁺, Ho³⁺-codoped core of 20 μm diameter and a cladding of 300 μm diameter (“Thulium-Holmium Doped Fiber”, THDF). The THDF, cooled by deionized water at 18 °C, is symmetrically pumped by four high-power 793-nm fiber-coupled laser diodes (LD) fusion-spliced to two (2+1) \times 1 fiber pump combiners (FPC) which directly inject a maximum total pump power of 540 W into the THDF. The high reflectivity (HR) mirror of the laser cavity is a Fiber Bragg Grating (FBG) reflecting intracavity light. The output coupler (OC) consists of the FPC passive fiber cleaved at 0° in order to benefit from the 4-% Fresnel reflection. Three configurations are compared, using different couples of FBG and fiber length (Table 1).

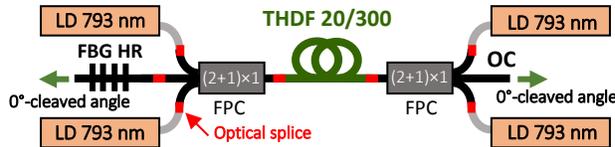


Fig. 1: Schematic of the setup.

Configuration	THDF length	FBG wavelength
#1	10 m	2.09 μm
#2	5 m	2.09 μm
#3	10 m	2.12 μm

Table 1: Description of the three laser configurations.

3. Results

In configuration #1, the 2- μm power measured at the OC and at the FBG outputs (part of light transmitted by the FBG) as a function of the pump power at 793 nm is shown in Fig. 2a. At the OC, a maximum power of 146.1 W was obtained

(efficiency: 31%; threshold: 21.2 W). On the FBG side, a maximum 2 μm power of 43.4 W was measured. Moreover, a nonlinear evolution of the 2- μm power is observed on both sides. The spectrum measurements showed that most of the light transmitted by the FBG (95%) is emitted at 2115 nm. 34% of the light at the OC is also emitted as multi-peaks around this wavelength (Fig. 2b). This wavelength corresponds to the maximum gain of the 10-m piece of THDF, as verified in the free-running configuration without FBG (Fig. 2c). These results suggest that a mismatch between the laser emission wavelength (induced by the FBG) and the wavelength corresponding to the gain peak (defined by the active fiber length) gives rise to two competing laser oscillations at different wavelengths.

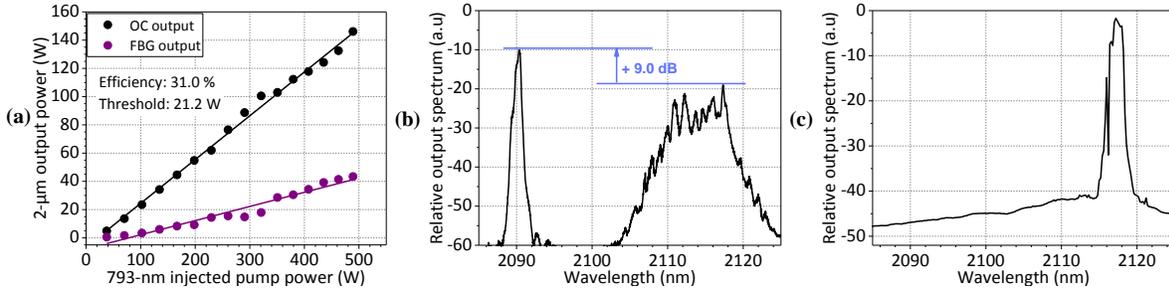


Fig. 2: 2- μm power measured on the OC (black dots) and FBG (purple dots) sides versus 793-nm injected pump power (a) and relative output spectrum measured at the maximum output power (b) in configuration #1; (c) Relative output spectrum of the free running-cavity fiber laser (with 10-m piece of THDF) around its laser emission power threshold.

A study of the fiber gain matching to the FBG reflectivity was performed by reducing the active fiber length from 10 m to 5 m in order to correspond to a maximum gain at 2.09 μm . As shown in Fig. 3a, in this configuration #2 a maximum power of 179.1 W at 2 μm was obtained at the OC (efficiency: 40.2%; threshold: 39.2 W). Meanwhile, a maximum power of 12.9 W at 2 μm was measured at the FBG fiber output. By matching the fiber length and the FBG, this configuration exhibits a more linear evolution of the output power and a suppression of light emitted around 2115 nm, as confirmed in the spectrum measured on the OC side at the maximum output power (Fig. 3b).

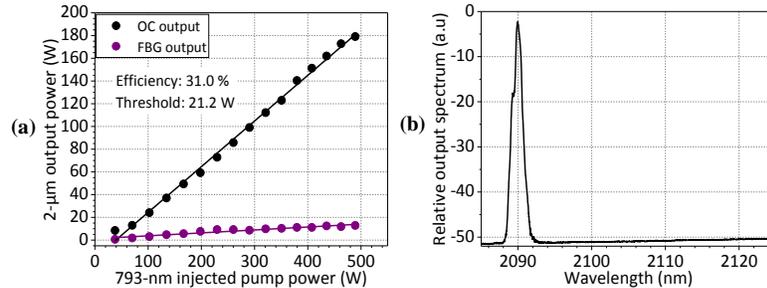


Fig. 3: 2- μm power measured on the OC (black dots) and FBG (purple dots) sides versus 793-nm injected pump power (a) and relative output spectrum measured at the maximum output power (b) in the configuration #2.

The configuration #3 in which the first FBG is replaced by another FBG centered at 2.12 μm in order to correspond to the maximum gain of the 10-m piece of THDF will also be presented in this communication.

4. Conclusion

In conclusion, we showed that matching the active fiber gain to the FBG reflectivity allowed the monolithic single-oscillator Tm^{3+} , Ho^{3+} -codoped fiber laser source to take advantage of an amplification exclusively at the 2.09 μm wavelength imposed by the FBG. It results in an increase of 33 W of power emitted at 2 μm at the OC of the laser and in an improvement of the efficiency (+9 points) to reach 179 W and 40.2%, respectively.

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