Long-term Operation of High-power 3 µm Fiber Lasers

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Abstract: We report GeO_2 endcapping on high-power 3 µm-class fluoride fiber laser cavities which minimizes fiber tip degradation and enables their long-term operation.

OCIS codes: (060.3510) Lasers, fiber; (060.2340) Fiber optics components; (140.3070) Infrared and far-infrared lasers.

1. Introduction

There has been considerable progress lately in mid-infrared fluoride fiber lasers thanks to defect-free, low-loss fluoride fibers, and advances in fiber components such as fiber Bragg gratings (FBGs), splices and endcaps. Laser radiation near 3 µm has a great potential for many applications in defense, medicine, and spectroscopy [1]. However, output power scaling of fluoride-based fiber lasers near water's fundamental stretch resonance brings different challenges calling for innovative solutions. One of these major challenges is thermal runaway of fiber tips due to OH migration inside glass, which leads to catastrophic damage and limits the maximum operation time of the lasers [2]. Recently, we have demonstrated a 42 W splice-less fluoride fiber laser cavity operating at 2824 nm, which suffered from fiber tip degradation over time [3]. The same problem also occurred in other high-power demonstrations [4,5]. In this research, we fabricated for the first time oxide-based GeO_2 endcap components for 3 µm high-power fluoride fiber laser systems and investigated their ability to mitigate fiber tip degradation under 20 W cw laser radiation. This is the first report of a 20-W-level 3 µm fiber laser operating for 100 h without undergoing catastrophic damage.

2. Experimental setup

The schematic of the experimental setup is shown in Fig. 1. A 20 W fiber laser setup with a central wavelength of 2.8 µm was used for the fiber tip degradation experiments. The laser cavity is similar to the one reported in [3], and is made of a 6.5 m long double clad 7 mol. % erbium-doped fluorozirconate (Er^{3+}:ZrF_4) fiber (15/250 µm, 0.12 NA, *Le Verre Fluoré*). It is bounded by two intracore FBGs written through the polymer of the fiber using femtosecond pulses, as described in [6], with high reflectivity (HR-FBG) and low reflectivity (LR-FBG) of >99% and 8%, respectively. It was pumped by a multimode diode bundle (240/242 µm, 0.46 NA) delivering a combined pump power of 92 W at 976 nm, which enabled an output power of 21 W and a slope efficiency of 23% with respect to the launched pump power. The remaining pump signal at the end of the active fiber was removed via a residual pump stripper (RPS). The Er^{3+}:ZrF_4 fiber was spooled on an aluminum spool for passive cooling. At the output of the system, a single-mode passive ZrF_4 fiber was spliced to the laser cavity to carry out multiple degradation tests. Short GeO_2 endcaps (L≈400 µm, $ø_{core}$=230 µm) from two different suppliers (*Le Verre Fluoré (LVF)* and *Infrared Fiber Systems (IFS)*), along with an AlF_3 *endcap (Fiberlabs, L*≈400 µm, $ø_{core}$=200 µm) were spliced on the output face of the passive ZrF_4 fiber using a Vytran GPX splicer and a Vytran LDC cleaver. The images of the manufactured endcaps are shown in Fig. 2 (b) and (c). They were fixed in a copper V-groove to ensure efficient heat conduction. The degradation over time of GeO_2 and AlF_3 endcaps was monitored by measuring their output face temperature with a thermal camera (*Jenoptik*, Variocam) equipped with a close-up lens.

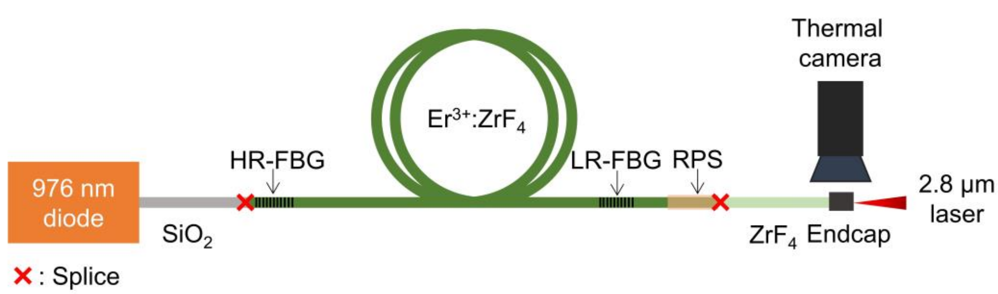

Fig. 1. Schematic of the experimental setup used to monitor fiber tip degradation over time.

3. Results and discussion

Figure 2 (a) shows the measured temperature of the different endcaps under 20 W of incident radiation at 2.8 µm over a 100 h time period. The initial temperature for both GeO_2 endcaps is around 50 °C and increases of to 100 °C and 80 °C for the IFS and LVF fibers, respectively. No catastrophic failure was observed during the tests with GeO_2 fibers. On the other hand, the initial temperature of the well-known AlF_3 endcap is close to that of the GeO_2 endcaps, yet its tip degraded in less than 7 hours of operation. The endface image of the AlF_3 and GeO_2 tips after the degradation tests are shown in Fig. 2 (d) and (e), respectively. Observable catastrophic damage on the AlF_3 endcap face is clearly seen in Fig 2 (d), while no damage was observed on the GeO_2 endcap face, thus enabling high-power long-term laser operation near the liquid water absorption peak. Although the increase in temperature during the test shows that there is still degradation related to ambient water vapor diffusion within the GeO_2 glass matrix, they are more robust to OH contamination and clearly outperform the AlF_3 endcaps. In fact, the initial temperature rise of the GeO_2 endcap is 1.4 °C/W, which would lead to a temperature between 140-218 °C at 100 W of output power. This temperature range is sustainable since it is lower than the transition temperature of ZrF_4 fibers (i.e. 270 °C [7]). On the other hand, the main drawback of GeO_2 material is its high refractive index (n=1.83) compared to that of ZrF_4 (n=1.49) fibers, which causes high reflection at the splice and GeO_2-air interface. Advances in fusion splicing techniques have also recently enabled fluoride fiber splicing to other types of oxide-based low refractive index fibers such as fused silica (n=1.42). Experiments with SiO_2 endcaps will be conducted in the near future to study and compare their performances.

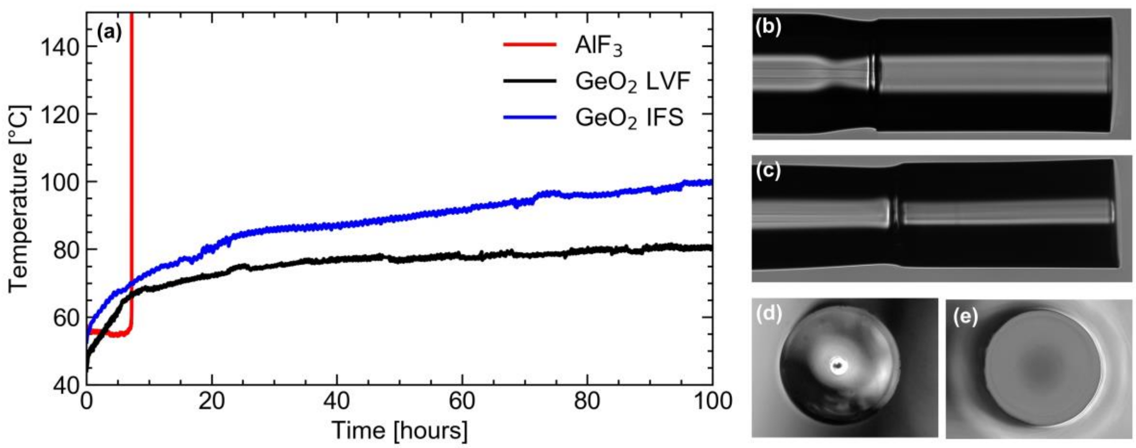

Fig. 2. a) Measured temperature of the endcap faces as a function of time at 20 W of average power, image of b) AlF_3 and c) GeO_2 endcaps, optical microscope image of d) AlF_3 and e) GeO_2 tips after degradation.

4. Conclusion

In this work, oxide-based GeO_2 endcaps were manufactured and used for the first time in a high-power 2.8 µm fluoride fiber laser to minimize fiber tip degradation due to OH diffusion. No damage was observed when the system was operated at 20 W over 100 h, while common AlF_3 endcaps failed in less than 10 hours. Therefore, GeO_2 endcaps are clearly a better alternative than AlF_3 for long-term and stable operation of high-power 3 µm-class fluoride fiber lasers and pave the way for future power scaling demonstrations.

5. References

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