New Perspectives for Mid-infrared Fiber Lasers

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Abstract: The latest achievements in terms of spectral coverage and output power from both cw and pulsed mid-IR fiber lasers are presented with special emphasis on their basic components as well as their possible applications.
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1. Introduction:

High power silicate glass-based monolithic near-infrared fiber lasers (FLs) have revolutionized the manufacturing sector due to their superior optical as well as mechanical performances, namely in terms of beam quality, ruggedness, compactness and long-term reliability. Although they have not yet reached the same level of maturity, mid-infrared (MIR) fiber lasers based on low-phonon energy glasses (e.g. fluoride) also hold great promise for several applications pertaining to the environment and the biomedical sectors [1]. Now most of these applications present high requirements in terms of average/peak power and pulse energy or in terms of emission spectrum, be it narrow or broad, fixed or tunable. As shown in Fig. 1, the general trend in the average output power of rare-earth-doped mid-IR FLs as a function of the emitted wavelength is a more or less regular decrease from the kW to the mW level over the 2-4 μm spectral region.

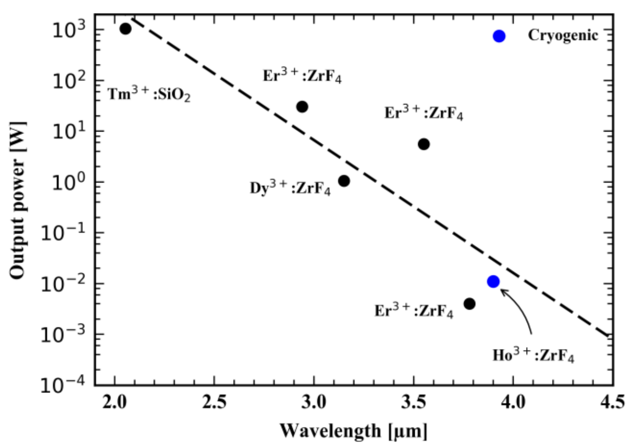

Fig.1 Highest reported cw output power from rare-earth doped fiber lasers over the 2.0-4.5 μm spectral region.

One major challenge related to laser emission at longer wavelength is related to multi-phonon decay, which increases exponentially with both temperature and wavelength. Fluoride glass optical fibers are key to postpone this detrimental effect but unlike silica they do not present high mechanical and thermal properties. Additionally, fluoride glass optical fibers are not yet offering the same broad set of optical components (e.g. pump combiners) than silica fibers, although some essential components, such as fiber Bragg gratings (FBGs), have been demonstrated [2].

2. High power emission in cw mode of operation:

To date, laser emission from mid-IR fiber lasers at wavelength longer than 2.5 μm were obtained from fluorozirconate glass optical fibers doped with either Er^{+3}, Ho^{+3} or Dy^{+3} rare-earth ions. In particular, the Er^{+3} ion has shown trend exceeding performances in the neighborhood of both 3.0 and 3.5 μm [3-4]. Accordingly, the availability of ultralow-loss double clad fluorozirconate fibers along with the all-fiber design provided by a pair of

FBGs were key in achieving 30 watts of output power at 2.94 μm, i.e. at the water fundamental absorption peak. The pair of FBGs used for this demonstration are shown in Fig. 2.

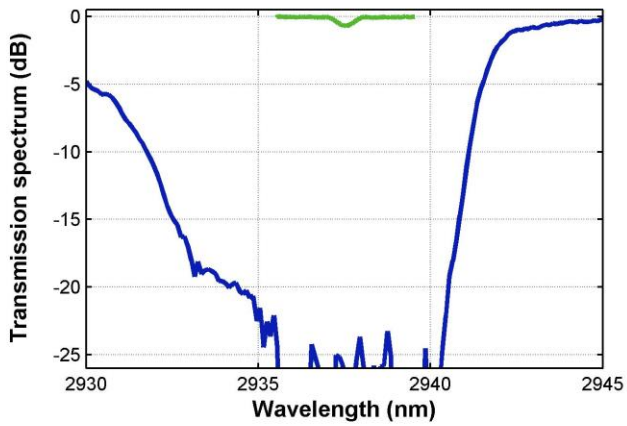

Fig. 2 Pair of FBGs inscribed in a fluoride glass fiber for the demonstration of a 30W fiber laser operating at 2.94 μm.

The use of FBGs has also been instrumental in the demonstration of a record 5.6 W output power from a monolithic dual-wavelength pumped FL operating near 3.5 μm. Although the long-term operation and the high power handling potential of fluoride glass fiber laser has been established at the two previous wavelengths, a specific power scaling problem related to fiber tip degradation, especially in the neighborhood of the O-H resonance peak, was identified and is currently being addressed.

3. Pulsed laser operation:

Several mid-IR applications can simply not be addressed with cw FLs and are calling for their pulsed counterparts. Accordingly, several pulsed regimes of operation of mid-IR FLs were recently investigated. Both Q-switched and gain-switched FLs were demonstrated, leading to pulsed operation in the ns regime near both 3.0 and 3.5 μm. Pulse energies approaching the 100 μJ level with an average power exceeding 10 W were namely produced from a rugged monolithic cavity operating at 2825 nm. Pulse energies in excess of 100 μJ were also produced in the sub-nanosecond regime based on an Ho^{+3}-doped fiber based amplifier scheme. The femtosecond regime was also studied via a fiber based ring laser cavity relying on the nonlinear polarization evolution mode-locked scheme and 207 fs pulses with 3.5 kW peak power near 2.8 μm were produced [5]. Such femtosecond FL was further used as a seed for an Er^{+3}-doped-fiber amplifier, resulting (via the soliton self-frequency shift process) in a watt level femtosecond fiber source tunable from 2.8 to 3.6 μm [6].

4. Conclusion:

Significant progresses were recently reported for both cw and pulsed mid-IR fiber lasers so that these sources can now address a growing number of applications that are specific to this spectral region. Further progress is also expected to occur in the near future in terms of both average power scaling (up to 100W) and wavelength coverage (up to 4 μm).

5. References:

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