Microrod Resonator Laser with Versatile Pumping Configurations

S. Bakhtiari Gorajoobi(1)*, G. Senthil Murugan(1), A. Langner(2) & M. N. Zervas(1)
(1) Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
(2) Heraeus Quarzglas GmbH, D-63450 Hanau, Germany
*sbg1u12@soton.ac.uk

Abstract: A new Yb^{3+}-doped silica WGM microrod resonator laser is demonstrated using different pump-delivery and signal-collection configurations, which include evanescently-coupled microtapers or direct side-pumping.

1. Introduction

High Q and small mode volume of Whispering Gallery Mode (WGM) microresonators make them excellent structures for realization of low threshold and narrow linewidth microlasers. Resonators such as microtoroids [1], microspheres [2, 3] and microbottles [4] are well explored as both passive and active devices. The most common coupling systems used for excitation and signal collection of these structures are based on tapered fiber coupling owing to their high coupling efficiency. Other methods rely on integrated waveguides [3], prisms [2] and/or collecting the scattered light [5]. As the spectrum and coupling efficiency highly depend on the excitation position, most of these coupling systems require precise alignment and complex packaging. Hence, providing a platform where the excitation and collection of light along with the WGM laser cavity are all integrated as a stand-alone device would be important in developing new, fully-functional and low-threshold lasers. Here, we demonstrate a completely new microrod resonator (MRR) laser based on WGMs micro-machined directly in an Yb^{3+}-doped optical fiber, where the pump excitation and/or signal collection can be achieved through the same fiber stem on either side of the MRR cavity, thus eliminating the conventional complex coupling systems. We use a pulsed CO_2 laser in order to micro-machine, through controlled ablation, the fiber surface and form a WGM microcavity directly on the rare-earth doped fibers in a very short time. This topology is reminiscent of the previously demonstrated microstub resonators [6], but without the need of extra laborious splicing steps.

2. MRR Laser Fabrication and Characterization

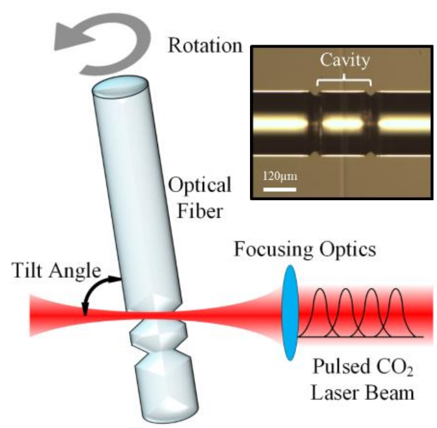

Fig. 1: MRR fabrication using pulsed CO2 laser.

An Yb^{3+}-doped silica fiber, provided by Heraeus Quarzglas GmbH, with 200 μm-diameter active core and 240 μm cladding diameter is used. MRRs are fabricated using our new technique based on high power pulsed CO_2 laser milling [7]. Two microgrooves are directly milled around the surface of the active fiber to shape the MRR with Q's close to 10^7 (see Fig. 1).

In the first MRR laser configuration, shown in Fig. 2(a), a micro-tapered fiber with a waist diameter of 2 μm is in contact with and evanescently-coupled to the MRR. A laser diode pump at 976 nm wavelength and ~1 nm linewidth is launched into the tapered fiber, and pump WGMs are evanescently excited. Due to the 20μm-deep undoped clad, the higher radial order pump WGMs should be excited in order to have significant overlap with the active core. This in turn enables excitation of high radial-order modes for the lasing signal. On the other hand, due to the limited depth of the macro-machined grooves, forming the MRR cavity, these modes can leak out into the adjacent fiber stems. This is similar to the leakage observed in micro-bottle resonators [8]. Side-leaked light is collected through a Multi-Mode Fiber (MMF) and monitored using an optical spectrum analyzer, simultaneously with the tapered fiber throughput. Figure 2(b) illustrates that for each lasing peak at 1080nm-1110nm wavelength range observed at the micro-taper throughput, there is a corresponding side-leaked peak. A closer look at the lasing peaks shows that the micro-taper throughput and side-leaked spectra occur at slightly different spectral positions and behave differently as the pump power increases. This implies that in most cases the two spectra are due to different radial- and/or axial-order WGMs. Furthermore, scanning across the cross-section of the fiber stem shows that both the pump and signal powers are located close to the edges of the fiber stem, indicating that both are in WGMs.

Figure 2(c) shows the variation of the total collected signal power as a function of the launched pump power, for three different micro-taper excitation positions (position 1: close to the MRR edge; position 2: half-way to the MRR center; position 3: at the MRR center). Collection from both the tapered fiber throughput and the side-leakage are shown. The total power of each signal is calculated by summing up all the individual lasing peaks. It is shown that shifting the micro-tapered fiber closer to the MRR center increases the laser efficiency. This is believed to be due to the predominant excitation of pump and signal WGMs with smaller overlap with the relatively rough micro-grooves and, therefore lower losses (higher Q's). However, with excitation at the MRR center (position 3) the microlaser output is observed to be unstable. This is believed to be due to stronger excitation of low axial order pump WGMs which are localized predominantly at the MRR center, leaving parts of the MRR edges under-pumped or partially unpumped. Such partially inverted cavities are known to result in unstable outputs. The side-leaked power shows similar dependence on the taper excitation position but it is always stable, reinforcing the idea that it is due to different WGMs.

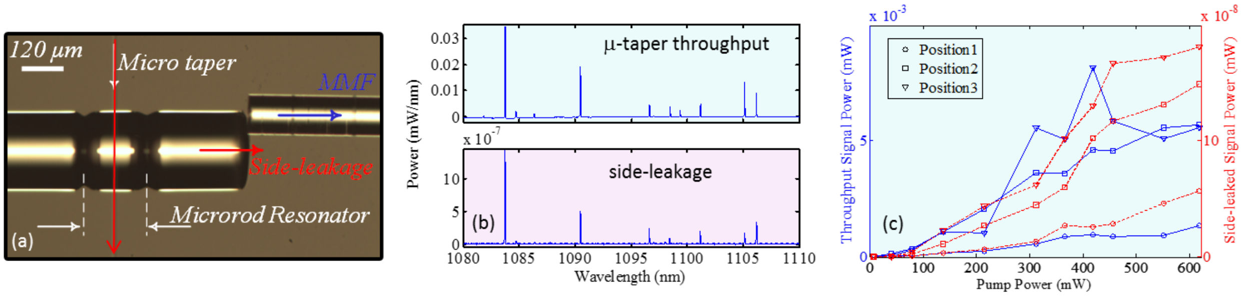

Fig. 2: a) MRR laser excited through a microtaper, b) output spectra obtained from micro taper throughput and side-leakage, and c) micro taper throughput and side-leaked signal powers as a function of pump power and position of the tapered fiber along the resonator.

Figures 3(a)&(b) show an alternative pumping configuration where the pump is launched to the doped core from the side. The pumping takes place through free space coupling of pump light from a single mode fiber to the fiber stem (coupling region). The signal WGMs and residual pump leak out are monitored through a collection fiber on the other side of the fiber stem. The spectra of the collected signals guided through the output fiber stem are plotted in Fig. 3(c). Lasing peaks corresponding to WGMs of the resonator are observed at 1060nm-1110nm wavelength range. Due to the more uniform pumping the output spectrum is robust and stable for all pump powers and excitation positions. The threshold, efficiency and spectra of the laser can be further enhanced and controlled by varying the length of the resonator. More results will be presented at the conference.

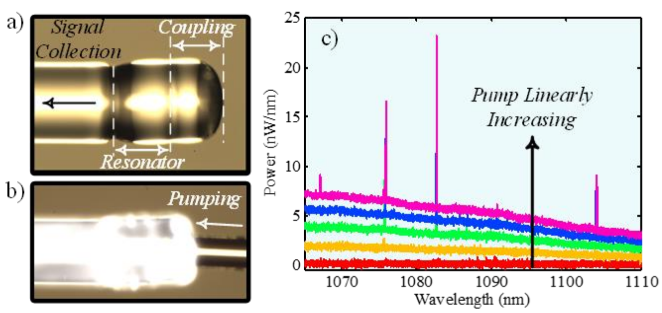

Fig. 3: a) Side-pumped MRR structure, b) MRR pumped from side through the core, and c) output spectra collected through the output fiber stem.

3. Conclusions

The proposed fabrication method provides production of large numbers of MRRs directly on rare-earth doped optical fibers in a controllable and cost effective one-step process at very short fabrication time. This work shows a promising route for fabrication of compact, stand-alone microlasers, without the need of additional microtapers. Pump launching and output laser power collection can be achieved through the stem fibers, which are integral parts of the MRR laser. The demonstrated MRR laser is extremely robust and the two integral fiber stems can be used for remote pumping and laser power/spectra monitoring. They can be easily integrated into advanced mechanical, temperature and chemical micro-sensors.

4. Acknowledgements: The work was partially supported by the EPSRC Centre for Innovative Manufacturing in Photonics.

4. References

[1] D. K. Armani, T. J. Kippenberg, S. M. Spillane, and K. J. Vahala, Nature 421, 925–928 (2003).
[2] V. Sandoghdar, F. Treussart, J. Hare, V. Lefèvre-Seguin, J.-M. Raimond, and S. Haroche, Phys. Rev. A 54(3), R1777–R1780 (1996).
[3] G. S. Murugan, M. N. Zervas, Y. Panitchob, and J. S. Wilkinson, Opt. Lett. 36, 73–75 (2011).
[4] G. Senthil Murugan, J. S. Wilkinson, and M. N. Zervas, Opt. Express 17, 11916-11925 (2009).
[5] G. S. Murugan, J. S. Wilkinson, and M. N. Zervas, Appl. Phys. Lett. 101, 071106 (2012).
[6] G. S. Murugan, S. Bakhtiari-Gorajoobi, et al, Proc. SPIE vol. 8960, 896018 (2014).
[7] S. B. Gorajoobi, G. S. Murugan, and M. N. Zervas, Conference on Lasers and Electro-Optics 2015, paper SF1H.7.
[8] G. S. Murugan, J. S. Wilkinson, and M. N. Zervas, Opt. Lett. 35, 1893-1895 (2010).