Yb^{3+}-doped Silica WGM Milled Microrod laser

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Abstract: A fast and versatile fabrication method for high Q milled microrod resonators, directly on rare-earth doped fibers, is demonstrated using a pulsed CO_2 laser. Evanescently pumped WGM microlaser with ~9μW output power has been achieved.

OCIS codes: (140.3460) Lasers; (140.4780) Optical resonators; (060.2310) Fiber optics; (230.3990) Micro-optical devices

1. Introduction

Whispering Gallery Mode (WGM) microresonators are intriguing structures for realization of low threshold and narrow linewidth microlasers owing to their high Q and small mode volume. Methods have been developed to fabricate lasers based on different microresonators, such as microsphere [1, 2] and microstub resonators [3], directly from rare-earth-doped fibers [3-5]. However, most of the devices rely on fiber-tip melting [4, 5] or splicing of small active-fiber stubs [3], and to large extend they are not controllable or reproducible. Material processing with CO_2 laser has been of great interest in recent years. Continuous wave lasers have been employed to fabricate microspheres [5] and to surface-reflow microtoroids [6] in order to achieve ultra-high Q's. These processes rely on heating up and melting the material. Here, we demonstrate a new method to fabricate WGM microrod resonator lasers directly on rare-earth doped silica fibers. We use a pulsed CO_2 laser in order to achieve controlled ablation of the fiber surface and form a WGM microcavity, similar to microstub resonators [3], without the need though of extra laborious splicing steps. In this method, precise control of the cavity length and sub-micron ablation depth in a very short fabrication time, as a simplified one-step process, are achievable. High Q and control on the cavity geometry, which are essential parameters in microlasers, are achieved by additional fire-polishing.

2. Fabrication

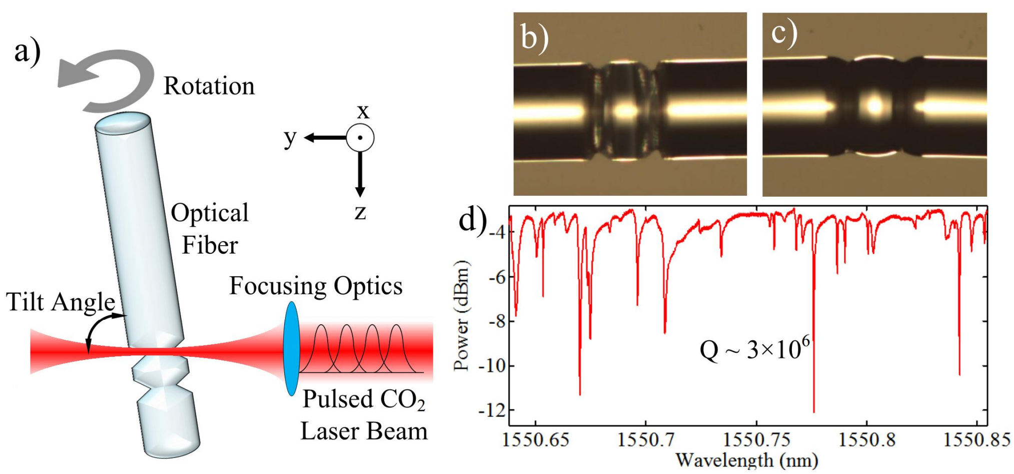

Figure 1. a) Fabrication setup. CO_2 laser-milled resonator b) before and, c) after fire-polishing. (d) Resonance spectrum of the microresonator after fire-polishing.

An Yb^{3+}-doped fiber, provided by Heraeus Quarzglas GmbH, with 200 μm-diameter active core and 240 μm cladding diameter is used. The fabrication setup is schematically shown in Fig. 1(a). A pulsed CO_2 laser at 9.6 μm wavelength with 100 W power is focused onto the fiber using optical lenses. The position of the fiber with respect to the laser beam waist is controlled using an XYZ stage, and the fiber axis can be tilted for precise alignment. A DC motor provides rotation around fiber axis with a controllable speed. A sequence of pulses with a certain width and repetition frequency is used at a tilt angle of 162˚ resulting in a maximum ablation depth of 20 μm (Fig. 1(b)). The fiber tilt was introduced in order to improve the tapering at the edges of the microrod resonator. In order to improve the surface roughness of the milled edges the structure was fire-polished by applying controlled electrical arcs. This has the added benefit of diffusing the Yb^{3+} ions into the cladding and therefore increasing the WGM/dopant overlap. On the other hand, surface tension smoothens out and improves the optical quality of the resonator edges, giving it characteristics of truncated microbottle resonator [7]. The resonator before and after fire-polishing is shown in Fig. 1(b) and 1(c), respectively. Fire-polishing improved the Q-factor from ~10^{+4} to ~$3\times10^{+6}$ (see Fig. 1(d)), and enabled lasing.

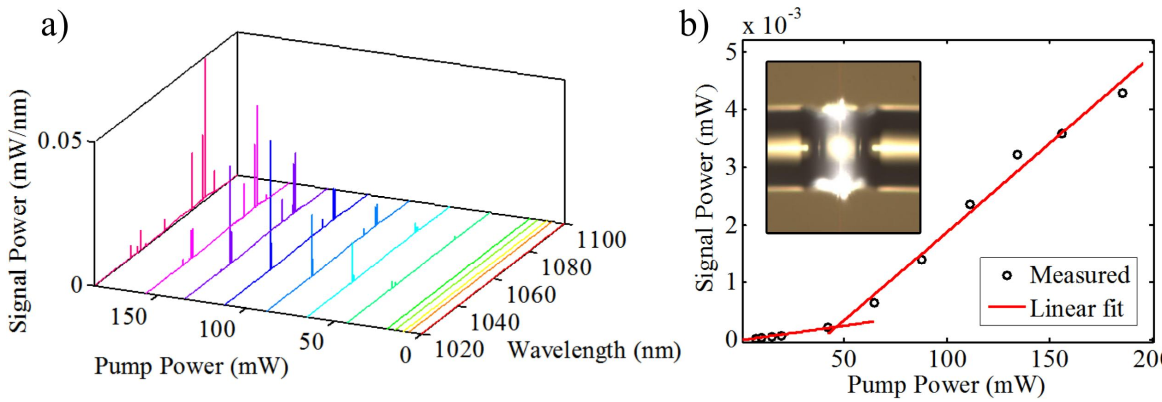

Figure 2. a) Spectra of signal as a function of launched pump power, and b) total measured signal as a function of launched pump power (inset shows the light scattered at 70 mW pump power).

3. Results and Conclusions

The resonator is in-contact and evanescently coupled to a 2 μm-diameter tapered silica fiber. A laser diode pump with center wavelength at 974.5 nm and ~1 nm linewidth is launched into the tapered fiber and evanescently excites pump WGMs. The generated signal is collected through the same tapered fiber and monitored by an optical spectrum analyzer. Lasing peaks corresponding to WGM resonances, located in the 1040 nm-1100 nm wavelength range, are observed. Fig. 2(a) shows the measured signal spectra as the launched pump power through the tapered fiber increases. The total signal power, calculated by summing up all individual lasing peaks, is plotted in Fig. 2(b). The total lasing power is linearly dependent to the launched pump power for the powers above a threshold of ~40 mW (corresponding to absorption of ~1 mW). Since lasing action happens along both forward and backward directions, measured values are about half the actual lasing power. The optical-to-optical efficiency with respect to absorbed pump power was ~0.1% (by taking into account both forward and backward propagations). The threshold and efficiency can be further improved by fiber design and optimizing the overlaps between the doped area and pump, and signal depths.

We have presented a new method of fabricating high quality milled microrod resonators, directly on a large-area Yb^{3+}-doped fiber, using a pulsed CO_2 laser. Subsequent fire-polishing has resulted in Q's in excess of $3\times10^{+6}$, comparable with microbottle resonators [7]. We have evanescently pumped the fire-polished microrod resonator and observed lasing in well-defined WGM resonances in the 1040 nm-1100 nm band. The laser threshold, optical spectra and efficiency of the milled microrod resonators depend on the resonator length and results will be presented at the conference. Also, polishing can be done by the CO_2 laser itself [8], thus eliminating the current additional fire-polishing step. This can enable large number of identical microresonators in one-fabrication-step process. The fiber tilt and controlled CO_2 exposure results in minimum ablation depths and does not compromise the fiber strength. Such microresonator structures, with two fiber stems attached naturally to the resonator ends, will enable a variety of future robust sensing applications and tunable telecommunication devices.

4. References

[1] V. Sandoghdar, F. Treussart, J. Hare, V. Lefèvre-Seguin, J.-M. Raimond, and S. Haroche, "Very low threshold whispering-gallery-mode microsphere laser," Phys. Rev. A 54(3), R1777–R1780 (1996).

[2] G. S. Murugan, M. N. Zervas, Y. Panitchob, and J. S. Wilkinson, "Integrated Nd-doped borosilicate glass microsphere laser," Opt. Lett. 36, 73–75 (2011).

[3] G. S. Murugan, S. Bakhtiari-Gorajoobi, C. A. Codemard, M. N. Mohd Nasir, G. Y. Chen, A. Langner, and M. N. Zervas, "Optical microstub resonator lasers," Proc. SPIE 8960, Laser Resonators, Microresonators, and Beam Control XVI, 896018 (2014).

[4] C. Grivas, C. Li, P. Andreakou, P. Wang, M. Ding, G. Brambilla, L. Manna, and P. Lagoudakis, "Single-mode tunable laser emission in the single-exciton regime from colloidal nanocrystals," Nat. Commun. 4, 2376 (2013).

[5] Y. Ruan, K. Boyd, H. Ji, A. Francois, H. Ebendorff-Heidepriem, J. Munch, and T. Monro, "Tellurite microspheres for nanoparticle sensing and novel light sources," Opt. Express 22, 11995-12006 (2014).

[6] D. K. Armani, T. J. Kippenberg, S. M. Spillane, and K. J. Vahala, "Ultra-high-Q toroid microcavity on a chip," Nature 421, 925–928 (2003).

[7] G. Senthil Murugan, J. S. Wilkinson, and M. N. Zervas, "Selective excitation of whispering gallery modes in a novel bottle microresonator," Opt. Express 17, 11916-11925 (2009).

[8] S. B. Papp, P. Del'Haye, and S. A. Diddams, "Mechanical control of a microrod-resonator optical frequency comb," Phys. Rev. X3, 031003 (2013).