Optical Wavelength Selection and Amplification by Silica Microcavities and Erbium Doped Fiber

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***Abstract*—In this paper we describe how circular silica micro disk resonators can be coupled to erbium doped fiber to create a desired emission spectrum. This approach could lead to very compact and inexpensive multiple wavelength lasers. We demonstrate here a selective erbium emission at a single wavelength using a silica microcavity.**

I. INTRODUCTION

Very high performance step index optical microcavities have attracted a lot of interest recently. Research on very high quality optical micro resonators started with silica micro spheres [1]. Recently, researchers have modified the spherical micro resonator into a more workable form, the planar micro disks [2]. More suited to conventionnal microfabrication processes and much easier to integrate into complex systems, the micro disk resonators have many advantages over spherical geometries. These resonators offer exceptional performance due to their extremely high quality factor [2]. Very high quality microcavities can be used in a variety of optical systems, such as telecommunication filtering [2], bio-chemical detection [3], [4], and quantum electrodynamics [5]. The cavity's filtering ability can be used to modify signals, and the behavior of active components, such as erbium doped fiber. Coupled to an erbium doped fiber amplifier or laser, the cavity can select the emission spectrum of the doped fiber. With the development of dense wavelength division multiplexing (DWDM), the need for narrow multi wavelength and cost effective laser sources has emerged. In this paper, we propose the basis for a technology that has the potential for a multiple wavelength source and individual optical modulation all in one compact device. We will demonstrate the possibility of selecting the emission spectrum of an erbium doped optical fiber using a micro disk resonator to filter an input broadband signal.

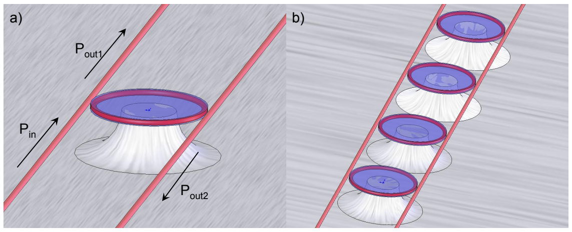

Fig. 1. a) Schematic of the coupled micro disk cavity. b) Schematic of the proposed multiple wavelength system

II. SILICA MICROCAVITIES

Silica disk microcavities use the step in index of refraction between itself and the surrounding media to guide light by total internal reflection. Light trapping in the microcavity is regulated by the geometrical properties of the disk, allowing specific wavelengths to resonate according to specific trajectories or modes. The most useful modes are the whispering gallery modes because they allow a very high level of confinement and thus a very high quality factor (Q). This high Q value translates in very narrow resonant peaks in the resonant spectrum, providing these cavities extremely interesting filtering capabilities.

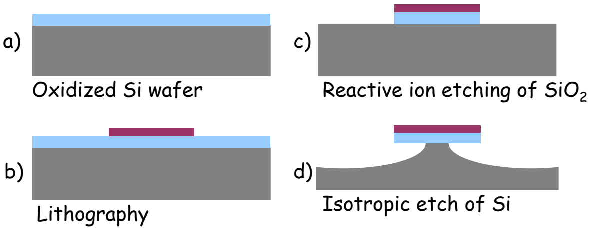

Fig. 2. Schematic of the microfabrication process

We use a simple fabrication process to machine these silica micro disks, as shown in Fig. 2. Using a conventional UV lithography process (Fig. 2b), we transfer a micro disk pattern to an oxidized silicon wafer (Fig. 2a). We then etch the silicon oxide by reactive ion etching (RIE) (Fig. 2c) to ensure good verticality of the side walls. The disk is then released by performing an isotropic etch of the silicon underneath (Fig. 2d). Once the microcavity is fabricated, a tapered optical fiber with a diameter of 1.2 μm is brought to close proximity in order to achieve optical coupling of light with the micro disk. A piezoelectric translation stage is used to optimize the distance between the taper and the edge of the disk. The fabricated circular silica microcavities can be used to select a wavelength in a broad band or multi wavelength signal in order to extract the resonant wavelengths from the input signal [2]. Furthermore, by coupling a second tapered fiber on the other side of the cavity, it is possible to collect these filtered wavelengths as shown in Fig. 1a [6]. The coupling of resonant wavelengths into a second fiber was achieved experimentally and Fig. 3 presents the power spectrum collected by both input

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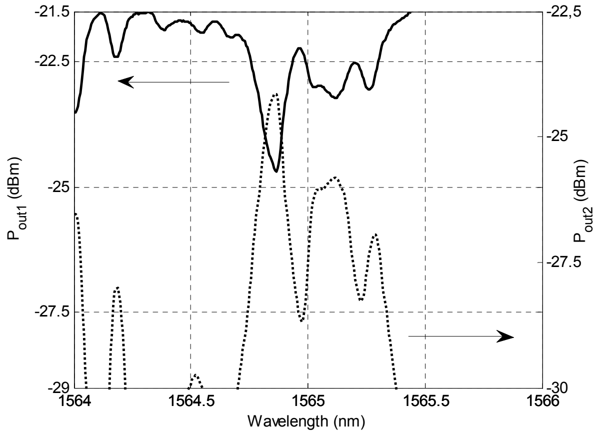

Fig. 3. Output power spectrum of both tapered fibers P_{out1} and P_{out2} as seen in Fig. 1a.

and output tapers. Note that the powers are offset du to losses in the tapers. This demonstrates clearly that the optical signal collected from the second taper does indeed correspond to the cavity's resonant spectrum. Although it is important to note that the addition of a second taper causes additional loss to the cavity, lowering the Q factor and broadening the resonant peaks. Also, the presence of secondary peaks suggests that the cavity used in this experiment is not single mode.

III. ERBIUM EMISSION SELECTED BY MICROCAVITY FILTERING

The very high quality factor of these cavities implies that the light collected out of it is highly coherent. This coherent signal can then be amplified using an Erbium doped fiber amplifier (EDFA) to generate a stimulated emission with narrow linewidth centered on the resonant wavelength of the microcavity. Figure 4 presents a schematic of the optical setup used to filter and amplify a broadband ASE (amplified spontaneous emission) source into a narrow coherent emission. To amplify the filtered signal, we use a five meter Erbium doped fiber optically pumped by a 980 nm laser diode.

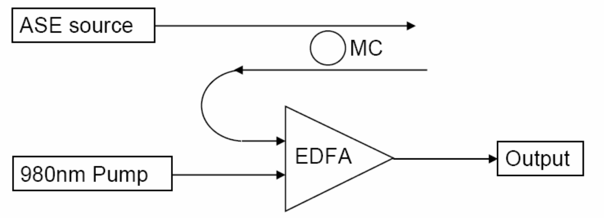

Fig. 4. Schematic of the optical filtration and amplification setup

Figure 5 presents the filtered output previously discussed, before and after its amplification. This shows maximum gain on the highest and thinnest peak of the filtered signal. The emission peak is perfectly aligned with the maximum of the filtered spectrum at 1564.85 nm. This emission has a linewidth (FWHM) of less than 0.06 nm. 8 dB amplification is observed between the filtered and amplified peaks. But, looking at the peak at 1565.29 nm, we note 11 dB of attenuation. As a consequence, the total effective amplification is more than 20dB. The large attenuation observed is due to a loss in the amplification setup. By reinjecting this amplified signal into the input, it would be possible to generate a fiber laser which would increase the output power and emission selectivity. Furthermore, the linewidth of the emission would be much narrower. Finally, by introducing multiple cavities in such a system it will be possible to create a multiple wavelength source.

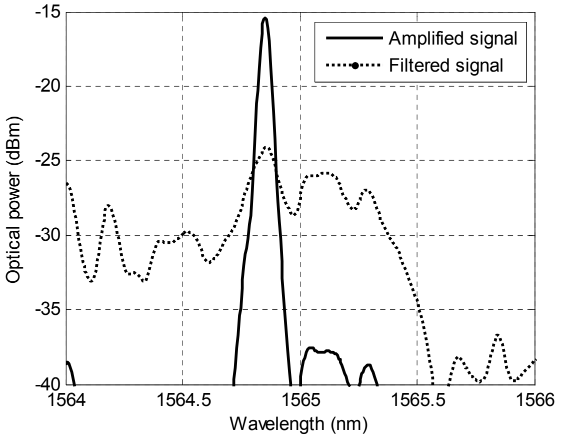

Fig. 5. Emission spectrum of the filtered signal before and after amplification

IV. CONCLUSION

We have shown that it is possible to control the emission spectrum of an erbium doped fiber amplifier by using the filtering ability of a silica micro disk resonator. We have obtained an emission wavelength of 1564.85 nm which corresponds to one of the resonant modes of the microcavity that was used in this experiment. This emission peak has a linewidth smaller than 0.06 nm. This approach could lead to very compact and inexpensive multiple wavelength lasers.

REFERENCES

[1] M. L. Gorodetsky, A. A. Savchenkov and V. S. Ilchenko, "Ultimate Q of optical microsphere resonators", *Opt. Lett.*, Vol. 21, no. 7, pp. 453-455, 1996.

[2] T. J. Kippenberg, S. M. Spillane, D. K. Armani and K. J. Vahala, "Fabrication and coupling to planar high-Q silica disk microcavities", *Appl. Phys. Lett.*, Vol. 83, no. 4, pp. 797-799, 2003.

[3] F. Vollmer, D. Braun, A. Libchaber, M. Khoshsima, I. Teraoka and S. Arnold, "Protein detection by optical shift of a resonant microcavity F.", *Appl. Phys. Lett.*, Vol. 80, no. 21, pp. 4057-4059, 2002.

[4] A. M. Armani, R. P. Kulkarni, S. E. Fraser, R. C. Flagan and K. J. Vahala, "Label-Free, Single-Molecule Detection with Optical Microcavities", *Science*, Vol. 317, pp. 783-787, 2002.

[5] V. Lefkvre-Seguin, S. Haroche, "Towards cavity-QED experiments with silica microspheres", *Mater. Sci. Eng.*, Vol. 48, pp. 53-58, 1997.

[6] H. Rokhsari and K. J. Vahala, "Ultralow Loss, High Q, Four Port Resonant Couplers for Quantum Optics and Photonics", *Phys. Rev. Lett.*, Vol. 92, no. 25, p. 253905, 2004.