Fabrication of High-Q Microresonators using Femtosecond Laser Micromachining

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Abstract: We report a novel technique to fabricate microdisk resonators using femtosecond laser micromachining. The resonators had suppressed higher order modes with a measured Q-factor as high as 7.8×10^6.

OCIS codes: (140.3390) Laser materials processing; (230.5750) Resonators.

1. Introduction

Microresonators exhibiting whispering gallery modes (WGM) are interesting for a number of important applications such as Raman lasers [1], bio-sensing [2], laser reflectors [3] and, more recently, optical frequency combs [4]. There have been a number of fabrication techniques reported in the literature [5-7] that allow the creation of microresonators with different sizes and shapes. Microspheres are perhaps the easiest to fabricate since the formation process is based on surface tension induced flow in a glass melt. Record high Q-factors have been shown in fused silica microsphere resonators, but this structure also support a large number of higher order modes making the resonant mode structure complex and difficult to selectively excite. Microtoroids fabricated by photolithography and CO_2 laser heat reflow [6] have a simpler resonant mode structure due to the reduced symmetry. However, the fabrication process requires clean room processing and is limited to only a narrow range of materials and sizes. Here, we introduce a new fabrication technique based on femtosecond laser micromachining which allows the formation of microdisk resonators with controlled dimensions. The advantage of this technique is that a wide range of materials and sizes can be applied.

2. Femtosecond machining of the microdisk structure

The primary fabrication was performed with an amplified femtosecond Ti:Sapphire laser system which produces 100fs pulses with a pulse energy of 1μJ. The repetition rate is 1 kHz which minimizes thermal heating accumulation when the beam is interacting with the sample. The laser was focused on the rotating working sample by a microscope objective with an NA of 0.2. The whole setup resembles a microlathe with the mechanical cutting tool replaced by a focused femtosecond laser beam.

To demonstrate this concept we used a short segment of a standard single mode optical fiber as the sample. The fiber had 125μm fused silica cladding, and was prepared by removing some of polymer coating from the fiber followed by cleaning and cleaving to leave only a few millimeters of exposed fiber. The rotating fiber was brought into the focus of the femtosecond laser with it axis perpendicular to the laser beam. When the high intensity focused spot of the laser interacted with the glass it caused optical breakdown through multi-photon ionization [8]. This breakdown ablates the material forming a channel around the fiber. The rotating fiber was translated along its axis to result in a microdisk shape (Fig. 1.a).

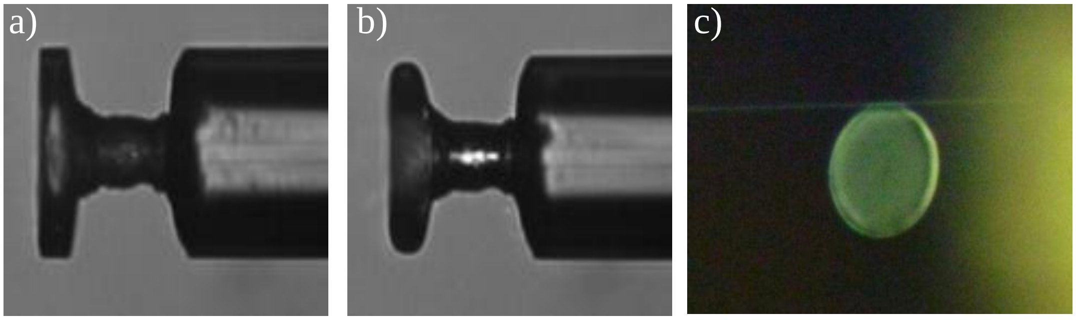

Fig 1: a) Freshly machined microdisk resonator b) microdisk resonator after exposure to electric arc; c) microdisk resonator coupled to fiber taper for Q-measurement.

3. Post-processing of microdisk structure to enhance resonator Q-factor

The primary femtosecond micromachining fabrication process left residual surface roughness which would lead to optical loss. The ablated surface was further processed by exposing it to the high temperature electric arc of an optical fiber fusion splicer to enhance the surface smoothness of the microresonator. The electric arc was produced by an Ericsson FSU995 fusion splicer where the arc time and intensity could be adjusted. Under optimal conditions, the thermal treatment process maintained the dimensional integrity of the microdisk (Fig. 1.b).

4. Experimental characterization of microresonators

Light from a tunable laser is coupled into the microresonators by means of a tapered optical fiber [9]. The microresonator is affixed to a piezo-actuated positioning stage and is brought near to the tapered optical fiber (Fig. 1.c). The Q-factor is determined by sweeping the tunable laser and making linedwidth measurements of the resonances (Fig. 2). A wide range of arc durations (0.1s to 1.5s) and arc currents (5mA to 29mA) were explored, and the transmission was measured for various microdisk resonators after each exposure to the electric arc. We have found that low arc duration (0.1s) with an arc current of ~ 20mA are the most effective parameters for reflowing the microdisks in an efficient and repeatable fashion. A typical Q-factor for the femtosecond micromachined microdisk resonators was 1×10^6. We observed good suppression of higher order WGMs, with the mode structure consisting mainly of fundamental resonant modes (Fig. 2.a). The maximum Q-factor of resonators created with this machining process was 7.8×10^6, greatly exceeding that of most other planar resonators. It is also comparable to the record value of 1.25×10^8 for a planar micro resonator [6].

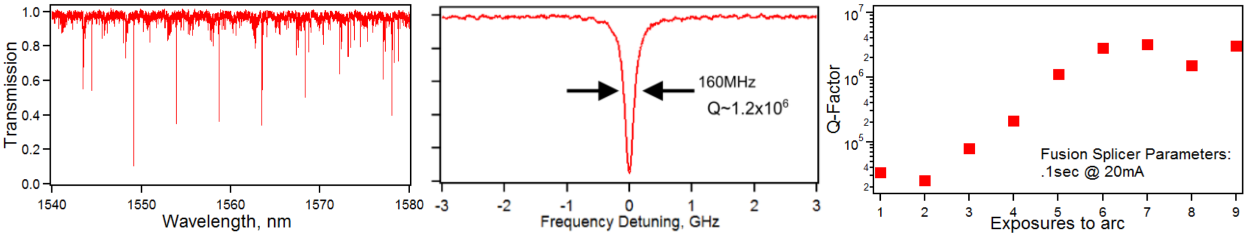

Fig 2. a) Transmission of microresonator over 40 nm after four exposures to electric arc; Q-factor of 1.1×10^6. b) Zoom-in view of a single resonant mode, the Q-factor is ~ 1.2×10^6. c) Q-factor of a microresonator as a function of exposures to electric arc.

In summary, we demonstrated a fast prototyping technique for the fabrication of high-Q microdisk resonators. It has the advantage of providing for the creation of microresonators with simple, low mode density resonant structures using a wide range of materials. We are also exploring the possibility of creating microresonators with large sizes (centimeters) or non-circular shapes (e.g., elliptical) using this technique for a variety of applications.

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5. References

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