Constructing a laser reflow system and fabricating silica toroid microcavities

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In this work, we constructed a system for performing a laser reflow process, which is an important part of silica toroid microcavity fabricating process. Furthermore, we successfully fabricated a silica toroid microcavity by performing a laser reflow process on a disk structure fabricated in a clean room. As a result, we have been able to use the cavities for various applications.

Key words: Silica toroid microcavity; laser reflow; CO₂ laser.

1. Introduction

Recent progress on the technology used to fabricate optical micro cavities has made it easy to fabricate ultra-high $Q$ cavities. As the light is strongly confined in such a cavity, an interaction between the light and matter can be easily obtained. As a result, we can use various optical nonlinear effects efficiently within the cavities.

A silica toroid microcavity was proposed by Vahala’s group in 2003 [1]. The characteristic of this kind of cavity is an ultra-high $Q$ and the highest reported value is $4 \times 10^9$ [2]. This is a much higher $Q$ than can be obtained with a silicon microring resonator ($Q=1.43 \times 10^6$) [3] or a photonic crystal ($Q=1.43 \times 10^6$) [4]. Although silica microsphere cavities have much higher $Q$ value of $\geq 10^9$ [5], a toroid cavity has a superior capacity for integration on a chip because it can be fabricated on a Si chip. So it has been used for many applications related to lasers, sensors and cavity quantum electro dynamics (QED).

In this work, we constructed a system for performing a laser reflow process, which is an important part of the procedure used for fabricating silica toroid microcavities, in order to study the application of the cavity. We successfully achieved the trial fabrication of a silica toroid microcavity, and we are now ready to study its application.

2. Fabricating process of a silica microcavity

This section details a method for fabricating a silica toroid microcavity. First, a silica pad is fabricated on silicon on insulator (SOI) chip by photolithography. Then, Si under the pad is selectively removed by XeF₂ dry etching. After that a silica disk on a silicon pillar is obtained as shown in Fig. 1. Although this disk structure can be used as an optical cavity, laser reflow is performed on the structure to achieve a much higher quality factor. Laser reflow is a process whereby the fringe area of the silica is melted with a CO₂ laser. The silica disk shrinks during this process and a silica toroid microcavity is realized. The entire process is shown in Fig. 1.

![Flow diagram illustrating the process used to fabricate silica toroid microcavities](image)

The fringe area of the silica disk can be selectively melted because 1) silica has a much larger absorption coefficient than Si in a wavelength of 10.6 µm and 2) Si has a larger thermal conductivity than silica. While the CO₂ laser is focused on the disk structure, a large amount of heat is generated in the silica disk due to its large absorption coefficient. Although the heat generated in the central area of the disk flow through the Si pillar, which has large thermal conductivity, heat generated in the fringe area of the silica disk accumulates because the area is thermally isolated by the surrounding air. Therefore, only the fringe area is heated toward its melting point, and this causes it to shrink.

To feed light into the cavity, a tapered optical fiber is brought near the cavity until it is less than 1 µm from it. Subsequently, the light in the evanescent field is inputted into a torus-shaped part of the cavity and looped circularly within the cavity. This loop is the principle to confine the light in the silica toroid microcavity. Although there is surface roughness on the silicon microring cavity or photonic crystal caused by the etching process, a silica toroid microcavity has a smooth surface because laser reflow is performed after etching and surface tension makes the surface very smooth. So the surface scattering loss decreases greatly and the $Q$ of the toroid cavity increases greatly. Therefore, laser reflow is a very important process for obtaining an ultra-high quality factor.
3. Construction of laser reflow system

This section describes the laser reflow system that we constructed. As mentioned in the previous section, we employed a CO\textsubscript{2} laser as a light source. Although the light emitted from CO\textsubscript{2} laser is invisible because of its wavelength of 10.6\,\mu m, a guide laser emitting at a wavelength of 780 nm is attached to coincide with the optical path of the CO\textsubscript{2} laser. Furthermore, the wave shape is modulated to an arbitrary frequency up to 15 kHz by a connected function generator.

The entire optical path within the system is shown in Fig. 2. The beam outputted from the laser is first attenuated down to an appropriate power level through a variable optical attenuator. The beam is then focused on a chip through a ZnSe beam combiner and a ZnSe aspheric lens. As the diameter of the disk structure on the chip is approximately 100\,\mu m, the highly precise alignment of the positions of the disk structure and the laser spot is necessary. Thus, we employed an XYZ automatic stage with a resolution of 100 nm in the xy directions and 10 nm in the z direction.

To confirm that the laser spot is focused precisely on the disk structure, we constructed the imaging system shown in Fig. 2. In this system, a CCD can capture the reflected light on the chip, so a clear image can be obtained. Furthermore, as the focal length of the ring-shaped lighting is designed to coincide with that of the ZnSe aspheric lens, the emitted light is efficiently concentrated on the chip. The captured image is shown in Fig. 3(a).

Note that light scattered from a chip is unsafe because of the high power CO\textsubscript{2} laser used for laser reflow. Therefore, we enclosed the stage holding the chip in an aluminum box as shown in Fig. 3(b). In addition to maintain the safety, this box has an additional purpose, which is to increase the air-tightness in the box. It is known that hydroxyls adhere to the surface of the silica toroid microcavity as a result of laser reflow in the air, and so the $Q$ of the cavity is decreased [5]. Considering this effect, we plan to conduct the laser reflow in a N\textsubscript{2} atmosphere in the future. This aluminum box is an important step in this respect.

4. Fabrication of silica toroid microcavity

This section describes the fabrication of a silica toroid microcavity. Figure 4(a) shows a scanning micro electron microscope (SEM) image of the disk structure prior to laser reflow. This disk structure was made by wet etching for 30s with a mixture ratio of HF : HNO\textsubscript{3} : CH\textsubscript{3}COOH = 3 : 5 : 3 and its diameter was 94.8\,\mu m. A SEM image of the structure after the laser reflow is shown in Fig. 4(b). We used an 8 W rectangular laser pulse with a width of 0.75 ms. A comparison of the images obtained before and after laser reflow shows that the fringe area has shrunk and the diameter has decreased from 94.8 to 84.4\,\mu m. From this result, we can conclude that we successfully fabricated a silica toroid cavity with our laser reflow system.

In this section, we discuss some of the problems with our laser reflow system. The most significant problem is the distortions of the shape after the laser reflow caused by the invisibility of the CO\textsubscript{2} laser beam spot. We used a guide laser spot to match the spot of the CO\textsubscript{2} laser and the disk structure. However, there was a slight disagreement between the optical path of the CO\textsubscript{2} laser beam and the guide beam, so a situation where the CO\textsubscript{2} laser spot is not perfectly centered on the disk can easily occur. This small error seriously affects the shape after the laser reflow because the disk diameter of approximately 100\,\mu m is very small. As a result, the toroid shape is distorted and this can be the main cause of a decreased $Q$ factor. There is an additional problem, namely that hydroxyls and contaminants on the toroid reduce the $Q$ value because we conduct the laser reflow in air. Thus, the measured $Q$ of the toroid cavity we fabricated is $3 \times 10^5$ and this is a much smaller than the previously reported value [2]. To improve the $Q$ factor, next year we will conduct the laser reflow in a N\textsubscript{2} atmosphere.
5. Conclusion

We constructed a system that can perform a laser reflow process for a silica toroid microcavity. Furthermore, we successfully fabricated a silica toroid microcavity by using this system. Next year, we intend to improve the accuracy of the reflow system and study the application of the silica toroid microcavity.

References