Method of fabricating high transmission optical tapered fiber

Yohei Ogawa (B4)

Optical tapered fiber is an essential tool for measuring the optical characteristics of microcavities. In this paper, we describe the fabrication of the tapered fiber that transmits 70% of the input power and that provides a 20 dB evanescent light. We confirmed the results both theoretically and experimentally.

Keywords: Tapered fiber, Optical waveguide, Evanescent light

1. What is optical tapered fiber?

In recent years, optical microcavities have been intensively researched. The $Q$ factor is often used to show the performance of the microcavity system. When measuring the $Q$ factor we must couple light into a microcavity by evanescent light. An optical tapered fiber is an ideal tool because it can excite evanescent light.

Optical tapered fiber is shown schematically in Fig.1.

We can fabricate tapered fiber by pulling heated single mode fiber (SMF) until its diameter is about 1 μm. Because the fiber diameter is about the same as the optical wavelength 1.55 μm, a large part of the mode leak outside the fiber core and excite evanescent field. We can use this light to excite the whispering gallery mode of microcavities.

In this paper, we first estimated the amount of the leakage of the evanescent light into the air in respect to the fiber diameters. Then I show the fabrication of an ideal tapered fiber.

Fig. 1. Schematic illustration of tapered fiber.

2. Estimating taper diameter

To fabricate optical tapered fiber, we need to determine its shape. And we must obtain the diameter of the tapered fiber at a particular point. First, we consider only a small region, which is heated with an LPG flame. When the state $k$ (at time $t$) changes to $k+1$, at a constant volume, we obtain

$$\pi r_k^2 L = \pi (r_k + \Delta r)(L + \Delta l)$$ \hspace{1cm} (1)

where $r_k$ is the fiber radius, $L$ is the length of the region that the flame crosses, and $\Delta r, \Delta l$ is the difference between $r$ and $L$. Formula (1) is deformed to

$$r_{k+1} = r_k + \Delta r = r_k \sqrt{\frac{L}{L + \Delta l}}$$ \hspace{1cm} (2)

If $t$ is not continuous, cylinders will be formed whose radius is $r_k$ and whose length is $\frac{\Delta l}{2}$. This is shown in Fig. 3. Because the pull time $t$ is continuous, the shape of the tapered fiber is as shown in Fig. 1. We used a pulling speed $v = 240 \mu m/s$, a heating length $L = 3$ mm and a step time $t = 0.1 s/step$. These values lead to $\Delta l = vt = 24 \mu m/step$. After comparing experimental results, we chose the $L = 3$ mm graph for our method. We estimate the pull time needed to fabricate an arbitrary diameter using this function.

Fig. 2. Heated region of tapered fiber. Radius and length change is described.

Fig. 3. Image of tapered fiber according to eq. (2).

Fig. 4. Minimum radius of optical tapered fiber versus pull time.

Next, we performed a mode propagation simulation with RSoft BeamPROP. The light power near the tapered fiber is shown in Fig. 5. According to Fig. 5, a tapered fiber with $d = 600$ nm can provide a 40% evanescent light from the input light. This is sufficient to introduce light into a microcavity when our target was to fabricate $d = 600$ nm tapered fiber.
3. Construction of flame temperature

When fabricating optical tapered fiber, the temperature of the flame used in the process is an important factor. The temperature of an LPG flame can be estimated from the LPG and O₂ gas flow rates and from the mixture rate of the two gases. According to previous reports [1,2], the glass processing temperature is 1900 ~ 2100 K. To achieve this flame temperature requires an LPG and O₂ molecular ratio of 2.8:5 [3]. When LPG is burnt at this ratio CO and CO₂ are generated but not soot. In this work, the LPG pressure was 0.0686 MPa and the pressure was 0.1 MPa. These pressures and molecular ratios result in a 7:10 flow ratio. We adopted this ratio for the LPG and O₂ gas.

4. Fabrication optical tapered fiber

The equipment for fabricating optical tapered fiber is shown in Fig. 6. A schematic diagram is shown in Fig. 7. The optical fiber is heated by an LPG burner located in the center and pulled at a constant speed by an automatic sample stage.

We fabricated the optical tapered fiber while observing the laser transmission. The gas ratio was set as discussed in section 3. The LPG pressure was 0.0686 MPa, the flow rate was 14 ml/min, the O₂ gas pressure was 0.1 MPa, and the flow rate was 20 ml/min. If we want to fabricate d = 600 nm tapered fiber, when the pulling speed is set at v = 240 μm/s, the estimated pull time is t = 150 s from Fig. 4. With this requirement we observed light transmission λ = 1550 nm while optical tapered fiber fabrication, described in Fig. 8. It shows that optical tapered fiber can be stably fabricated and the transmission loss is about 2 dB.

Fig. 9 shows the transmission loss when the optical tapered fiber touches the slide glass. The observed 10 dB loss shows that a lot of light escapes from the tapered fiber.
5. Conclusion

In this paper, I showed how to fabricate optical tapered fiber for measuring microcavities and described the optical characteristics of optical fiber.

6. References