Fabrication of whispering gallery mode cavities using crystal growth

○Hiroshi Kudo[1], Yohei Ogawa[1], Takasumi Tanabe[1], and Atsushi Yokoo[2, 3]
Keio Univ. [1], NTT Basic Research Labs. [2], NTT Nanophotonics Center[3]
E-mail: tnb@phot.elec.keio.ac.jp

Abstract

We fabricated whispering gallery mode (WGM) cavities made of crystalline material using a laser-heated pedestal growth (LHPG) method. Q -factor of our hexagonal sapphire resonator was 8.5×10^3, which can be increased according to our numerical analysis.

Background

Various applications of high - Q microcavities

・High-Q microcavities are used for sensing,[1] signal processing[2] and optical comb generations.[3]

$Q = \omega_0 \frac{U_{cav}}{P_{in}}$

photon density $\propto Q/V$

P_{in}: input power
U_{cav}: energy stored in cavity

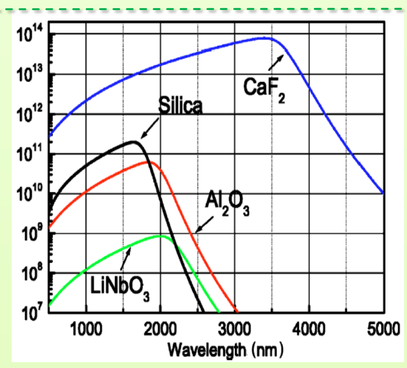
[1] F. Vollmera, S. Arnold, and D. Kengb, PNAS **105**, 2070120704S (2008)
[2] Takasumi Tanabe, et. al, Appl. Phys. Lett. **87**, 151112 (2005)
[3] T. J. Kippenberg, R. Holzwarth, and S. A. Diddams, Science **332** 555-559 (2007)

Quality factor in crystalline material

We can achieve much higher Q by using crystalline materials such as CaF_2 than silica.

However

Crystalline material is fragile and difficult to fabricate.

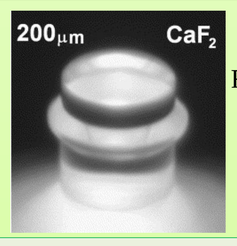


Calculated Q-factor obtained from material absorption coefficient for various materials

A. Savchenkov, V. S. Ilchenko, A. B. Matsko, and L. Maleki Phys. Rev. A **70**, 051804(R) (2004)

Microcavity fabrication by mechanical polishing

Diamond turning process



Fabricated WGM cavity

Ivan S. Grudinin, Andrey B. Matsko, Anatoliy A. Savchenkov, Dmitry Strekalov, Vladimir S. Ilchenko, Lute Maleki, Opt Commun **265** 33-38 (2006)

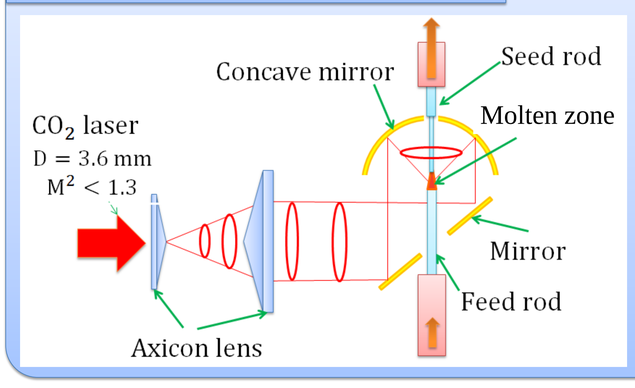
Small structure with smooth surface is difficult to fabricate.

Motivation

・We need to develop a novel method that can fabricate small WGM crystalline cavity with smooth surface.

・We apply laser heated pedestal growth (LHPG), which has been used for fabricating fiber laser.

Experimental setup



CO_2 laser power = 3.4～3.7 W
Power density on molten zone
$= 7.94 \times 10^8$ (W/m^2) (laser power = 3.7 W)

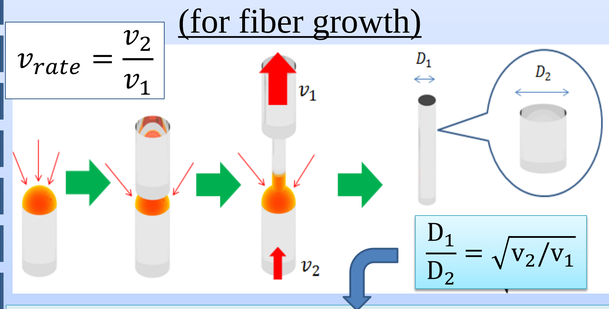
Velocity pulled upward (normal)
Seed rod: 0.12 mm/min
Feed rod: 0.72 mm/min
Velocity pulled upward (microcavity fabrication)
Seed rod: 0.12 mm/min
Feed rod: 0.36 mm/min

Material: sapphire

Modified laser heated pedestal growth (LHPG)

Standard LHPG
(for fiber growth)

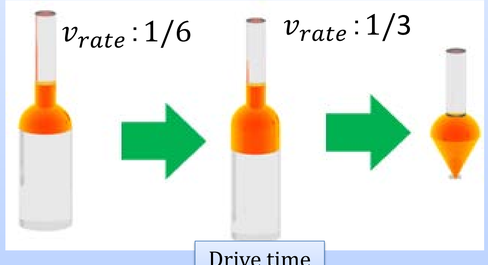
$v_{rate} = \frac{v_2}{v_1}$



The rod diameter can be controlled.

v_{rate} is fixed throughout the growth.

Modified LHPG
(for cavity fabrication)

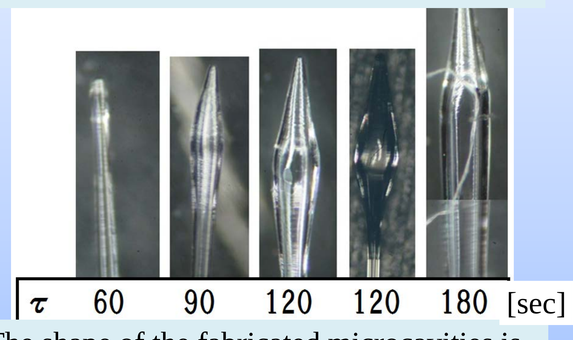


v_{rate} is changed during the growth.

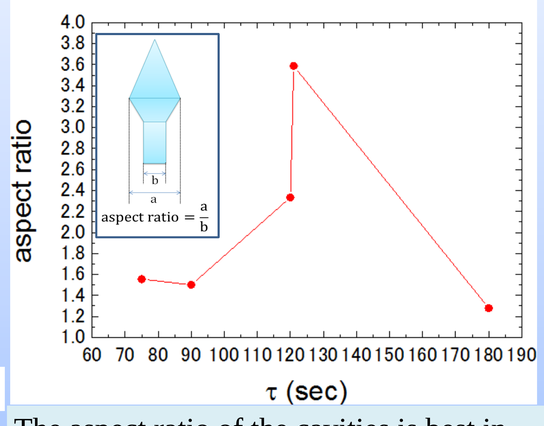
By changing v_{rate}, we can fabricate a bulge, which is used as a WGM microcavity.

Fabrication result

Fabricated resonators with differnt τ .



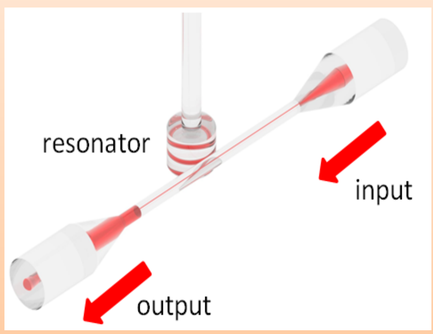
The shape of the fabricated microcavities is dependent on τ .



The aspect ratio of the cavities is best in τ =120 sec.

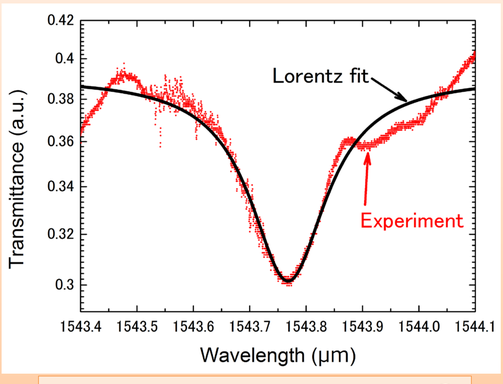
Transmission spectrum

Optical measurement setup



Parameter

Taper fiber diameter = 2~3 μm
Input power = 0 dB



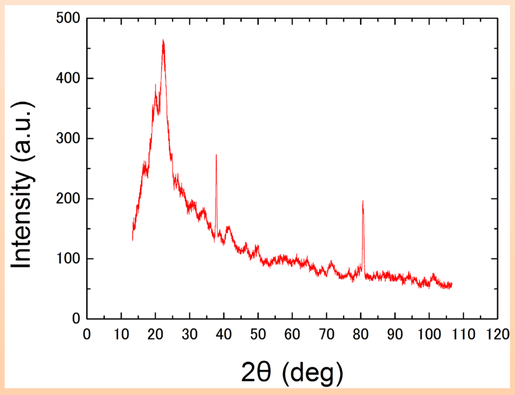
Q factor $= 8.5 \times 10^3$

High Q is successfully obtained with sapphire WGM cavity.

However, higher-Q should be possible considering the low material absorption of sapphire.

X-ray analysis

Three peaks correspond to the lattice constant of sapphire's a-axis (4.76 Å).

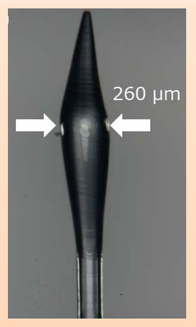


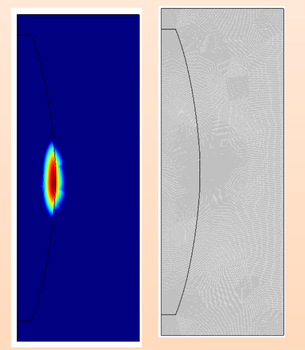
Crystalline of the fabricated resonator is maintained after the fabrication.

Crystalline is not the cause of the low- Q.

Shape and mode volume

Fabricated result

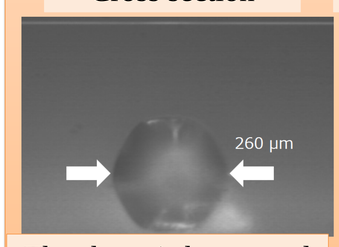




$V_{eff} = 8.1 \times 10^3$ μm^3

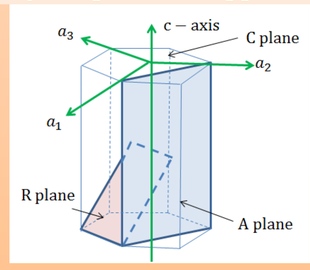
Well confined WGM is excited.

Cross section



The shape is hexagonal

Crystal plane of sapphire



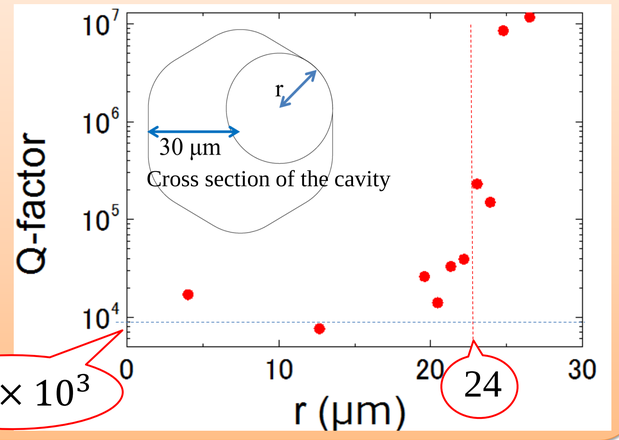
Careful investigation of the crosssectional shape vs. Q is needed.

FDTD calculation

Q factor dramatically decreases when r < 24 μm.

We must make the shape of our microcavities more round in order to acheive higher Q.

Relationship between Q factor and r



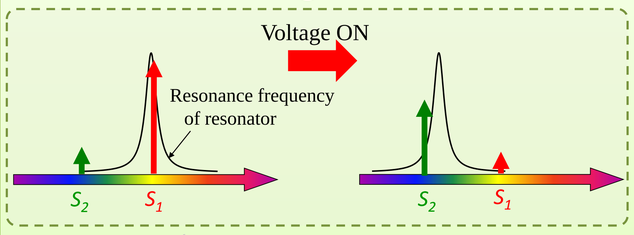
Conclusion

・We developed a new method to fabricate WGM cavitis by using LHPG method and achived a Q−factor of 8.5×10^3.

・We showed that higher Q can be achieved by smoothing the curvature radius of the edges.

Future directions

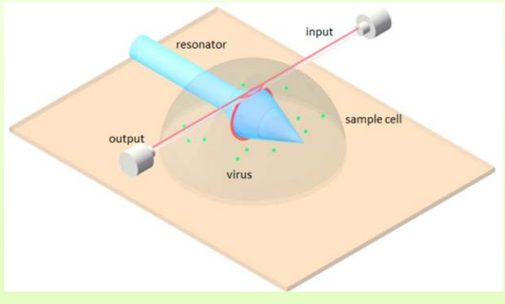
Modulation using Pockels effect



Resonance frequency changes when voltage is applied on the crystalline material such as $LiNbO_3$ or quartz , by Pockels effect.

Telecommunication

High sensitive particle detection



Resonance frequency changes when particles touch to a resonator.

Biosensing