Fused Silica Research at University of Tokyo

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Abstract

■Activity at Univ. of Tokyo

- Direct investigation of the intrinsic loss in bulk fused silica

■Experimental Procedure

- Nodal support technique

■Results

- Systematic comparison of mechanical losses
- High Q measured : $Q_{Max} = 4.3 \times 10^7$
- Reduction of loss by annealing
- Information about sources of loss

Contents

1.Introduction

2.Procedure

- Principle of nodal support technique
- 13 kinds of fused silica samples

3.Results

- Qs of Heraeus, Corning, Tosoh and Shin-etsu silica
- Annealing in vacuum
- Frequency dependence of measured loss

4.Summary

1. Introduction

■What should be investigated for mirror thermal noise

●If you want to estimate thermal noise at mirror resonance...

⇒ Measure quality factor of *suspended mirror* in GW detector

Source of dissipation at resonance : loss occurring at whole volume including loss due to suspension and attached mechanics

●If you want to estimate thermal noise in the **observation band**…

⇒ Measure intrinsic loss of *bulk mirror substrate* & coating

Source of dissipation in observation band: loss occurring near beam spot

Our Approach

- **Most likely choices for test masses**
  - *Fused silica* (for room temperature)
  - Sapphire (for cryogenic temperature)

- **Direct evaluation of intrinsic loss in fused silica**

  This is what we should have done.

  - Use of reliable measurement system
  - Elimination of external losses that obscure intrinsic loss
  - Active development of new fused silica in the future

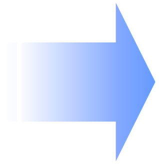
2. Procedure

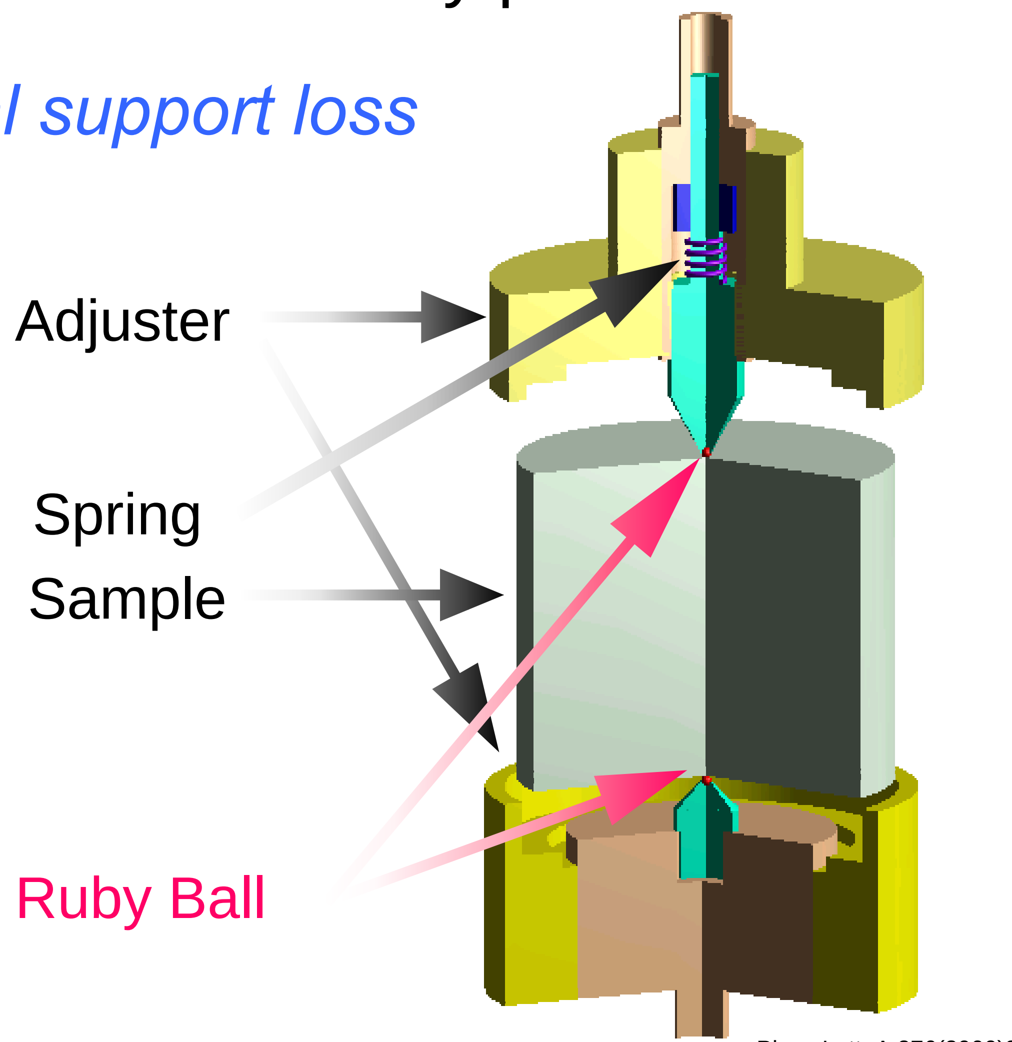
■Principle of experiment to measure intrinsic loss

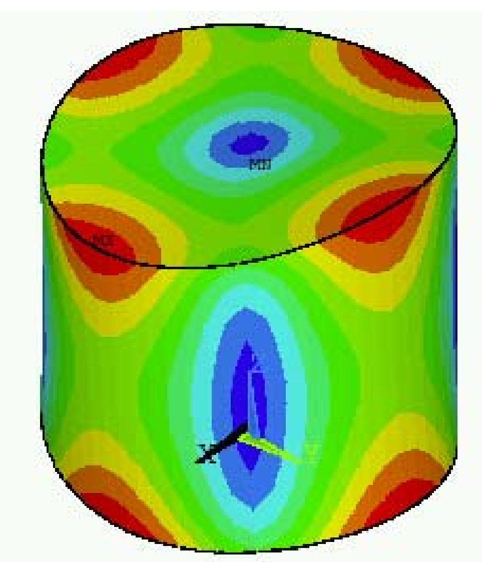
Support at the nodes of the vibrational mode by point contacts

Elimination of external support loss

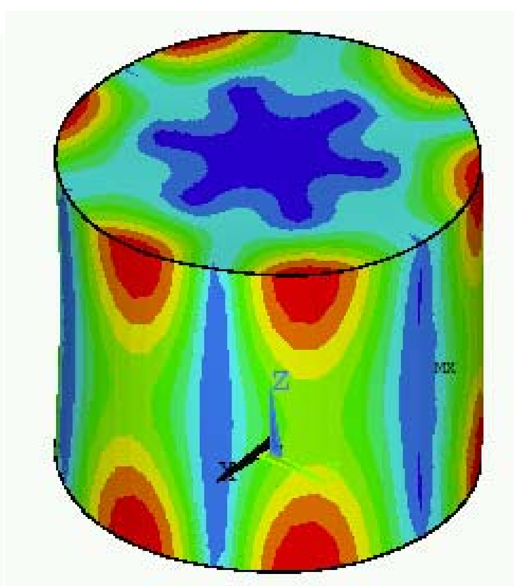
- Bulk cylindrical sample
- Higher order (*n*>1) mode







n=2, odd



n=3, even

Phys. Lett. A 276(2000)37
Phys. Lett. A 284(2001)162

Fused Silica Samples

■Commercial products

Company	Trade name	Type	Bubble class	Striae grade	Direction of homogeneity	Homogeneity of refraction index(x10^-6)	OH content (ppm)	Project
Heraeus	Suprasil 1	III	0	A	3D	5	1000	GEO(NM,EM)
	Suprasil 2	III	0	A	1D	5	1000	GEO(RM)
	Suprasil 311	III	0	A	3D	3	200	VIRGO,GEO(BS)
	Suprasil 312	III	0	A	1D	4	200	VIRGO(NM,RM)
	Herasil 1	II	0	A	1D	4	150	VIRGO(EM)
Corning	7980 0A	III	0	A	1D	1	800-1000	LIGO
	7980 0F	III	0	A	1D	5	800-1000	
	7980 5F	III	5	A	1D	5	800-1000	
Tosoh	ES	III	-	A	1D	-	1300	
	ED-A	V	-	A	3D	-	100	
	ED-C	V	-	A	3D	-	1	
Shin-etsu	Suprasil P-10	III	0	A	3D	2	1200	TAMA
	Suprasil P-30	III	0	C-D	3D	20	1200	

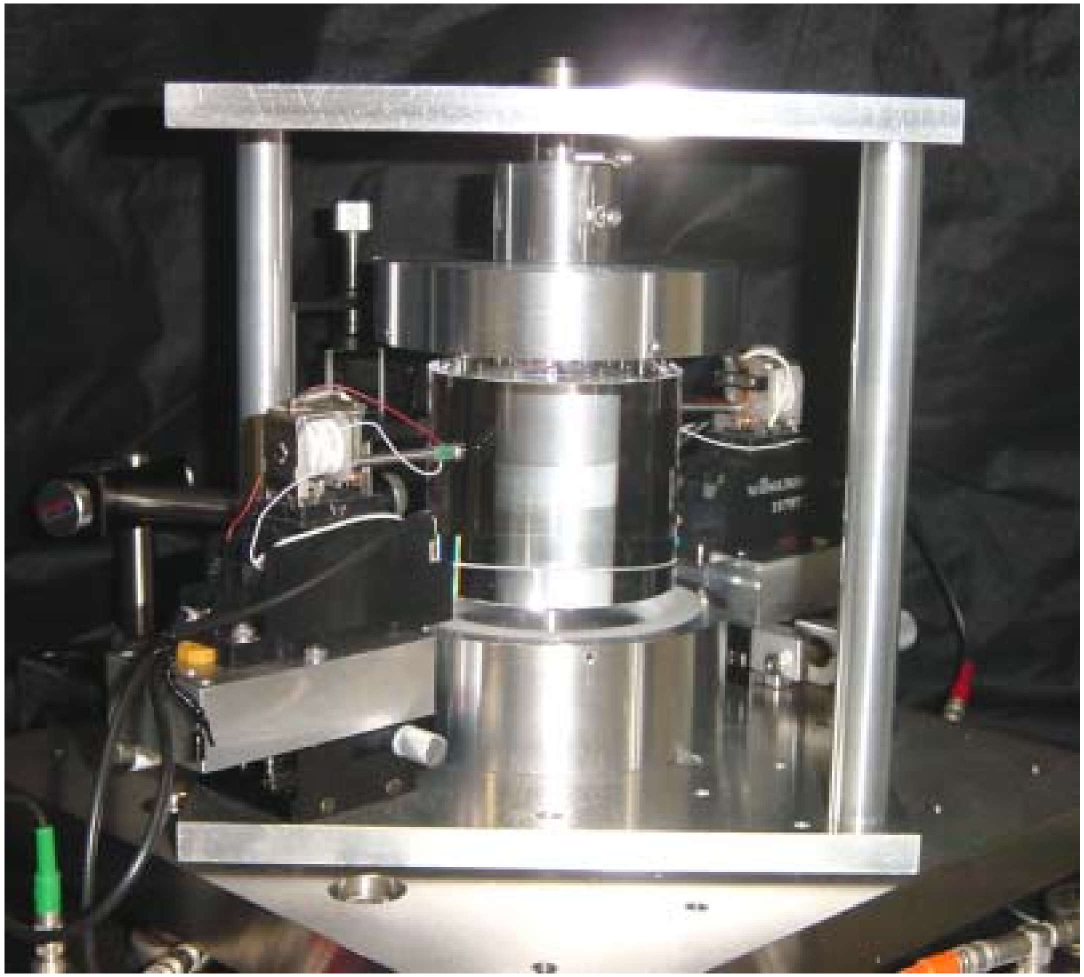
*VIRGO and GEO use custom made Suprasil called SV grade.

- Intrinsic Qs of 13 kinds of fused silica were measured.
- Each of them has different properties.
- 5 samples of them were annealed in vacuum.

Photograph – Setup

Nodal support system

- 2-mm ruby balls
- Simple system
- High precision in machining
- Vacuum
- PZT for excitation
- Interferometer for readout



Photograph – Sample

■Measured sample

- Cylindrical samples*
- Height : 6cm, Diameter : 7cm
- Commercially polished
  by the same company
- 50 resonances below 100kHz
- 25 higher order modes
- 45-deg. beveling

*We have also tried a block sample. Cylindrical shape is not a necessary condition for our support system.

3. Results

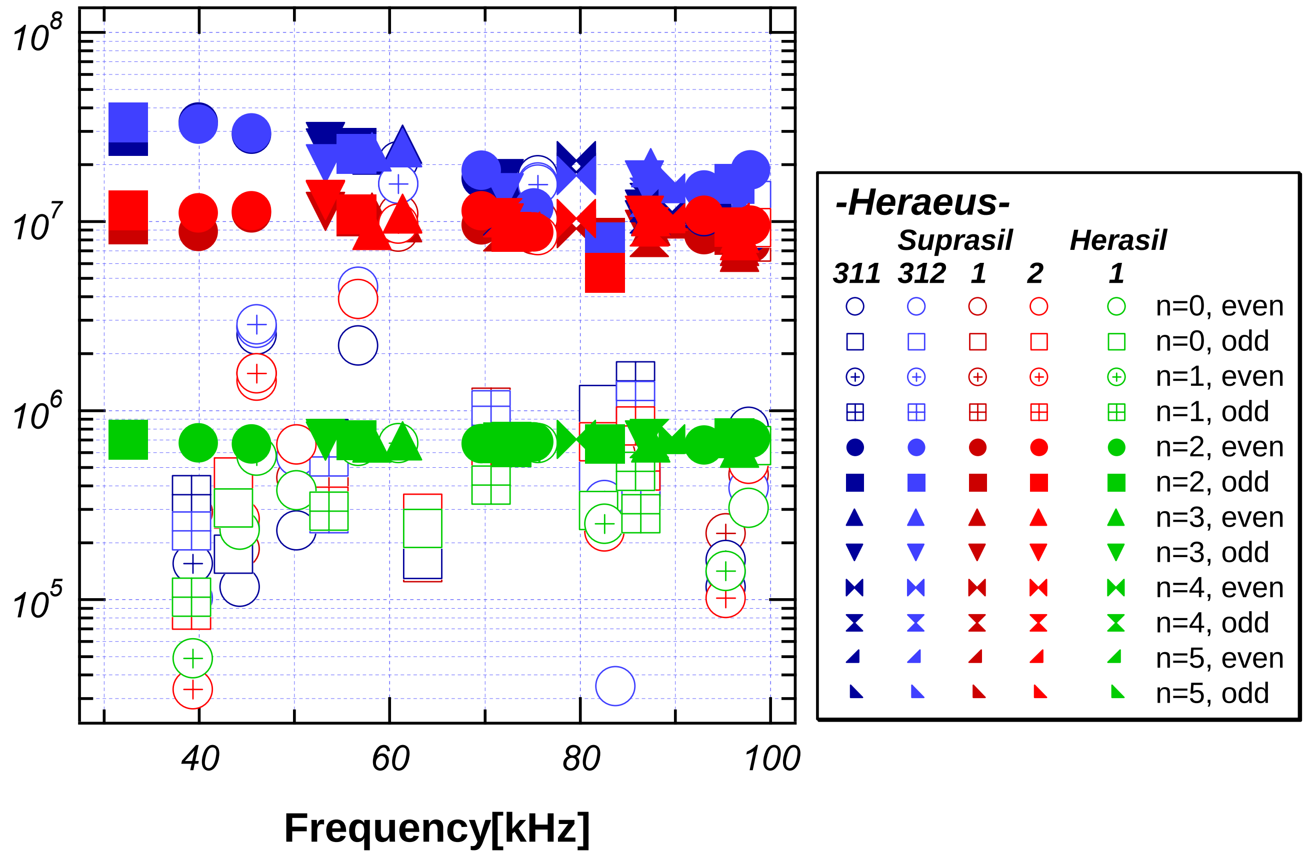
- Heraeus
- Corning
- Tosoh Quartz
- Shin-etsu Quartz Products

- Annealing in vacuum
- Comparison with each other
- Origin of measured frequency dependence

Heraeus

■World highest Qs among bulk fused silica

- Suprasil-311, -312
  $$Q_{Max} = 3.4 \times 10^{7}$$
- Suprasil-1, -2
  $$Q_{Max} \approx 1 \times 10^{7}$$
- Herasil-1
  $$Q_{Max} = 7.2 \times 10^{5}$$



(Except for Herasil)

The Qs were observed to be lower at higher frequency.

Corning

CORNING

■Similar mechanical-losses in different grades

- ●7980-0A*
- ●7980-0F
- ●7980-5F

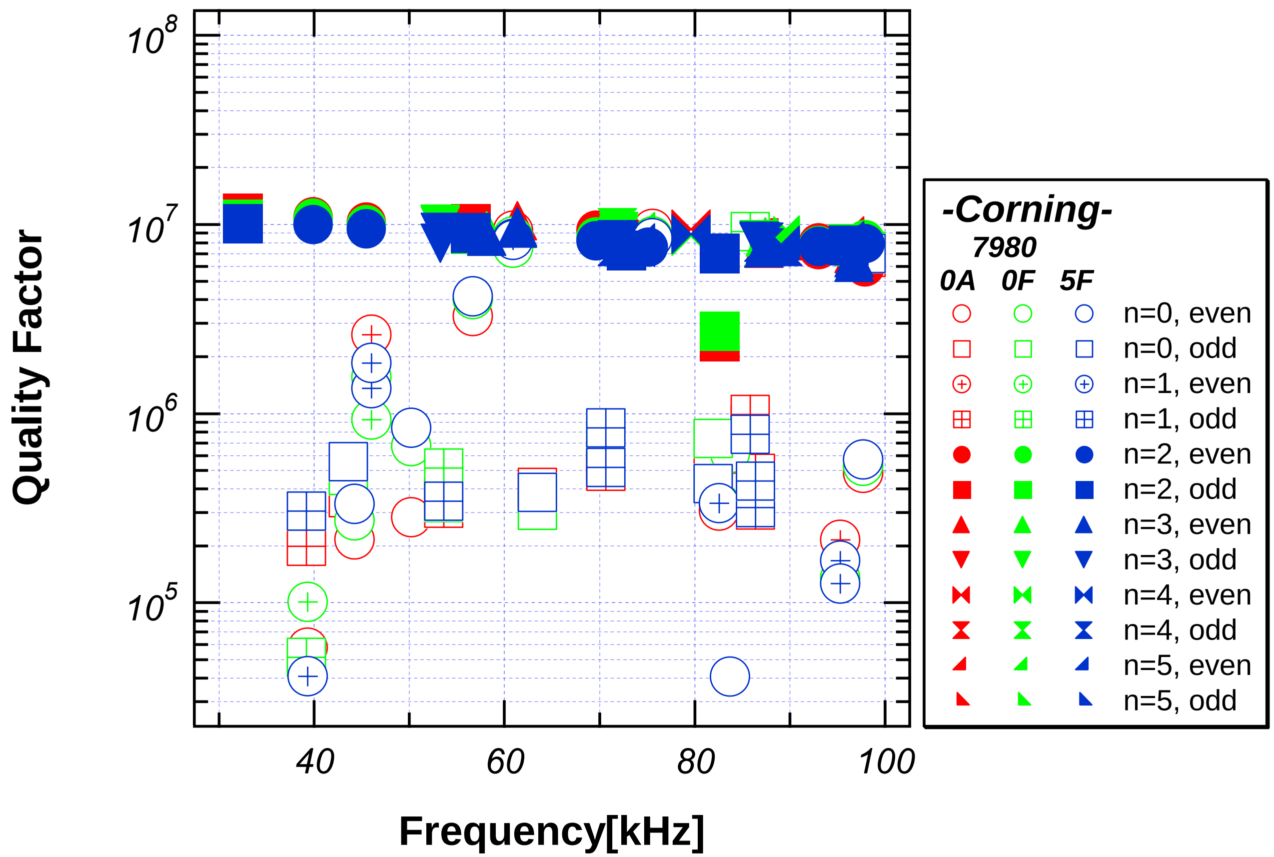
✓TYPE III, OH 800-1000ppm

✓Same chemical contents

✓Different homogeneity of refraction index and bubble class

$$Q_{Max} \approx 1 \times 10^7$$

Degraded with increase in frequency



*All of them are standard grade.

Tosoh Quartz

■Different quality factors obtained

●ED-A (VAD*: OH 100ppm)

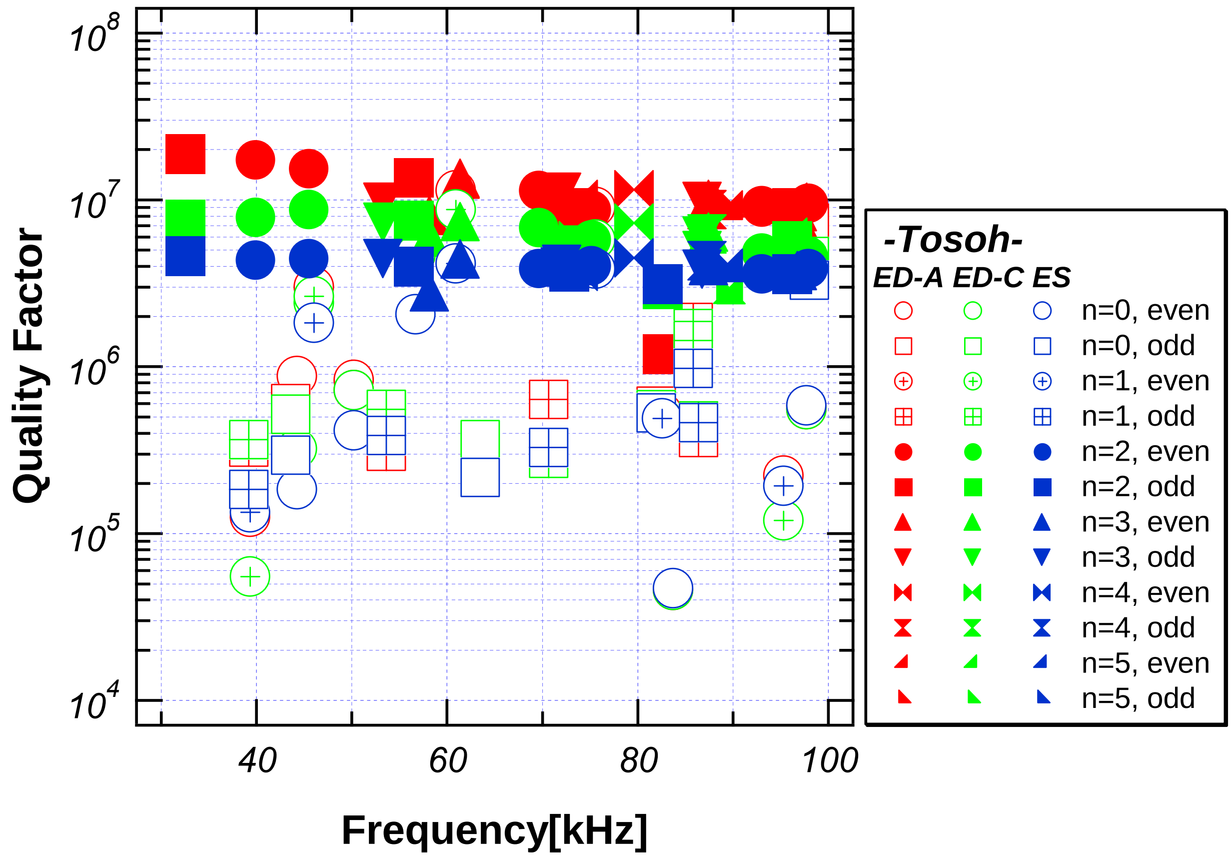
$$Q_{Max} = 1.9 \times 10^7$$

●ED-C (VAD*: OH 1ppm)

$$Q_{Max} = 8.8 \times 10^6$$

●ES (TYPE III: OH 1300ppm)

$$Q_{Max} = 4.6 \times 10^6$$



Amount of OH is not a only factor that dominates intrinsic loss

*Vapor-phase Axial Deposition method

Shin-etsu Quartz Products

■Lower quality factors observed than other samples

●Suprasil P-10

✓TYPE III, OH 1200ppm

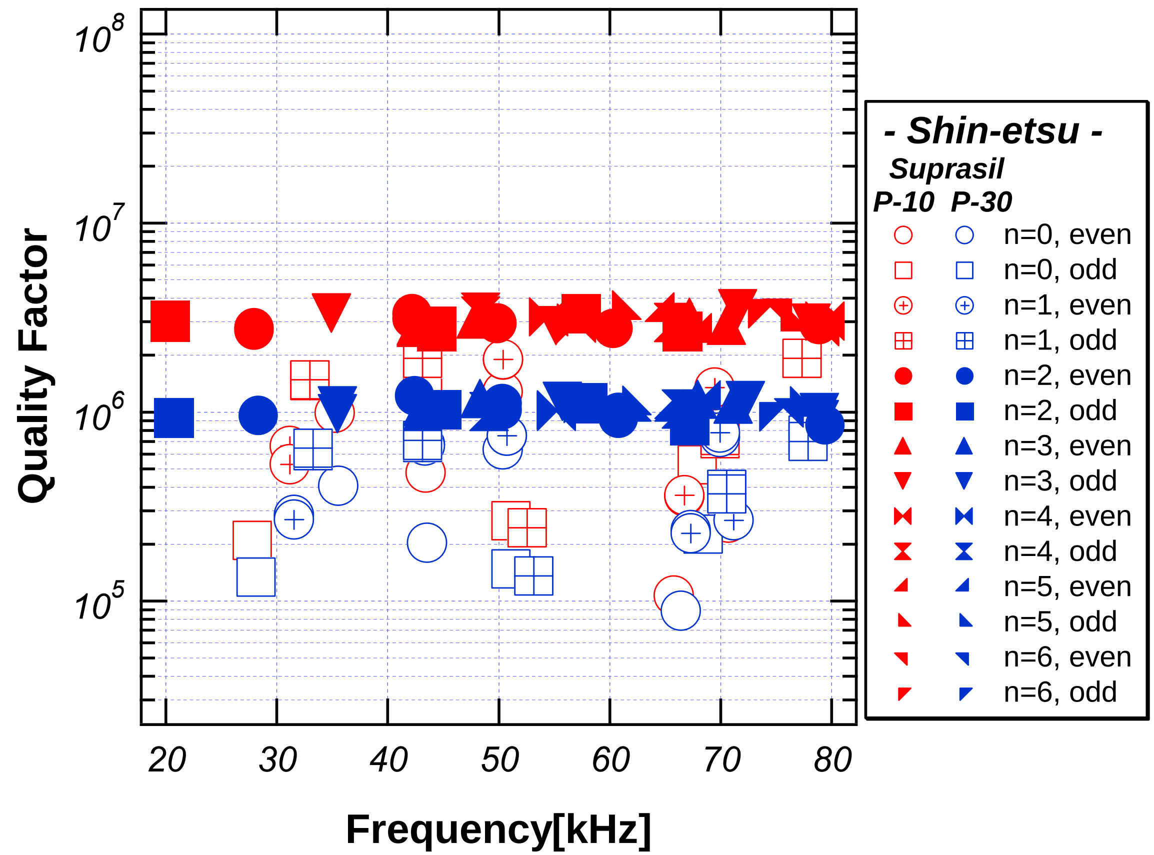
$$Q_{Avg} = 3.0 \times 10^6$$

●Suprasil P-30

✓TYPE III, OH 1200ppm

✓Glass with most striae

$$Q_{Avg} = 1.0 \times 10^6$$



(Diameter : 10cm, Height : 6cm)

Qs of TYPE III silica ranged from 10^6 to over 10^7

Annealing in Vacuum

■Increase in Qs observed in every annealed sample

●7980-5F

$$Q_{Before} = 1.0\times10^{7}$$

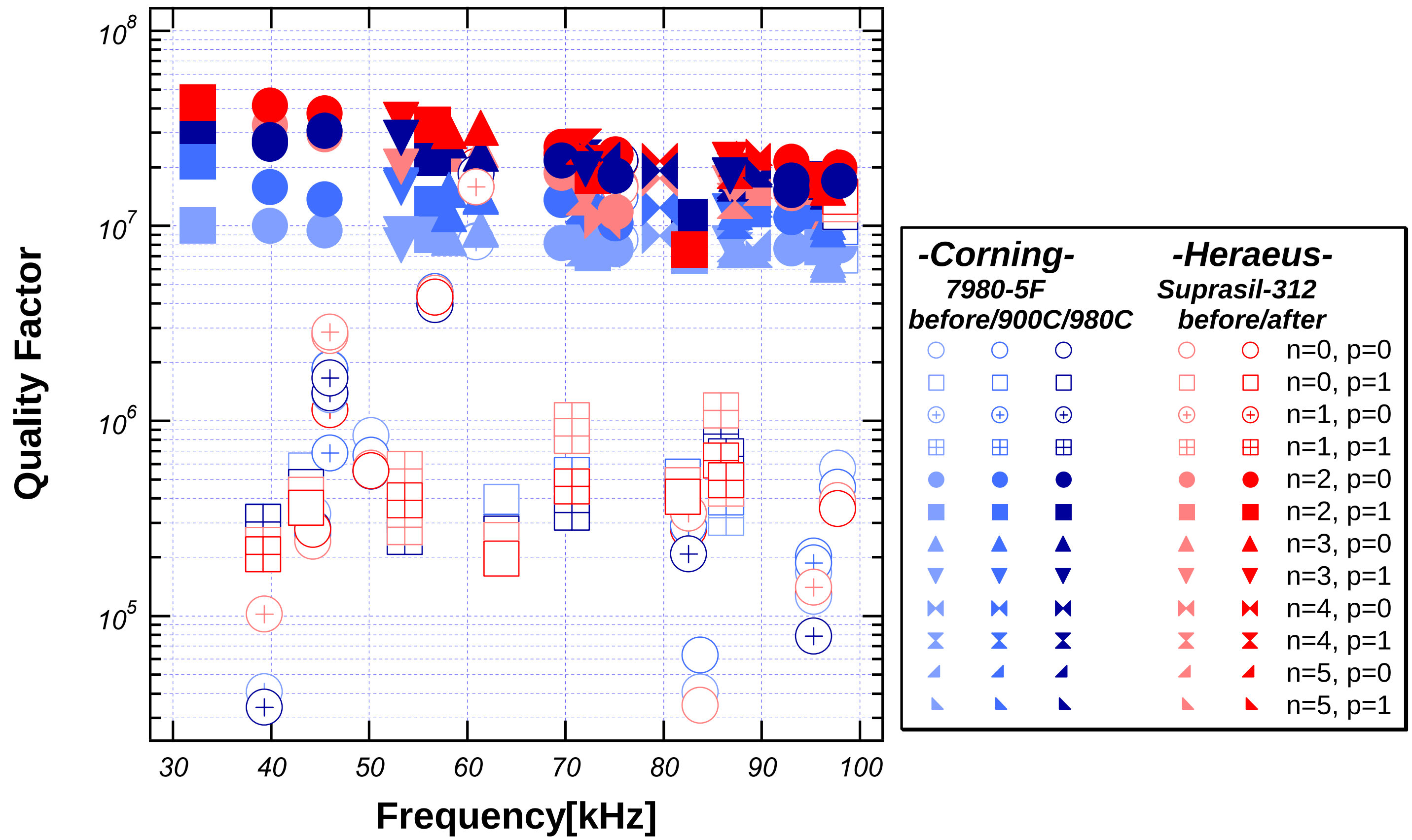
900°C $Q_{After} = 2.1\times10^{7}$

980°C $Q_{After} = 3.3\times10^{7}$

●Suprasil-312

$$Q_{Before} = 3.4\times10^{7}$$

980°C $Q_{After} = 4.3\times10^{7}$



Thermal treatment is important and promising.

Comparison with Each Other

■Intrinsic loss and optical properties

Company	Trade name	Type	Bubble class	Striae grade	Direction of homogeneity	Homogeneity of refraction index(x10^-6)	OH content (ppm)	Maximum Q (before anneal)	Maximum Q (after anneal)
Heraeus	**Suprasil 1**	III	0	A	3D	5	1000	1.1x10^7	
	Suprasil 2	III	0	A	1D	5	1000	1.3x10^7	2.1x10^7/3.3x10^7
	Suprasil 311	III	0	A	3D	3	200	**3.4x10^7**	**4.1x10^7**
	Suprasil 312	III	0	A	1D	4	200	**3.4x10^7**	**4.3x10^7**
	Herasil 1	II	0	A	1D	4	150	7.2x10^5	9.7x10^5
Corning	**7980 0A**	III	0	A	1D	1	800-1000	1.1x10^7	
	7980 0F	III	0	A	1D	5	800-1000	1.1x10^7	2.1x10^7
	7980 5F	III	5	A	1D	5	800-1000	1.0x10^7	2.1x10^7
Tosoh	**ES**	III	-	A	1D	-	1300	4.6x10^6	
	ED-A	V	-	A	3D	-	100	1.9x10^7	
	ED-C	V	-	A	3D	-	1	8.8x10^6	
Shin-etsu	**Suprasil P-10**	III	0	A	3D	2	1200	3.0x10^6	
	Suprasil P-30	III	0	C-D	3D	20	1200	1.0x10^6	

- Difference of TYPE (raw material, manufacturing process, etc.) is crucial.
- TYPE III tend to show higher Qs, if OH content is less.
- Bubble class, direction of homogeneity do not affect Qs.
- Homogeneity of refraction index doesn’t affect Qs.
- Qs could be degraded by the amount of striae.

Origin of Frequency Dependence

■Several possibilities

- Loss due to support
  - ✓We have measured Qs of 1×10^8 in silicon, 6×10^7 in sapphire.
  - ✓No frequency dependence of support loss has been observed in lower order modes.
- Loss due to surface
  - ✓This effect is strongly dependent on each modal shape, not on resonant frequency.
  - ✓The polish for curved surface was good enough. (next slide)
- Loss due to beveled edge
  - ✓This effect is also dependent on each modal shape rather than the resonant frequency.
  - ✓Beveled block gave the same results as the edge-rounded cylinder (next slide)
- Frequency-dependent material intrinsic loss
  - ✓Possible, because no one has observed directly real intrinsic loss in material.

Loss due to Beveled Edge

■Removal of beveling

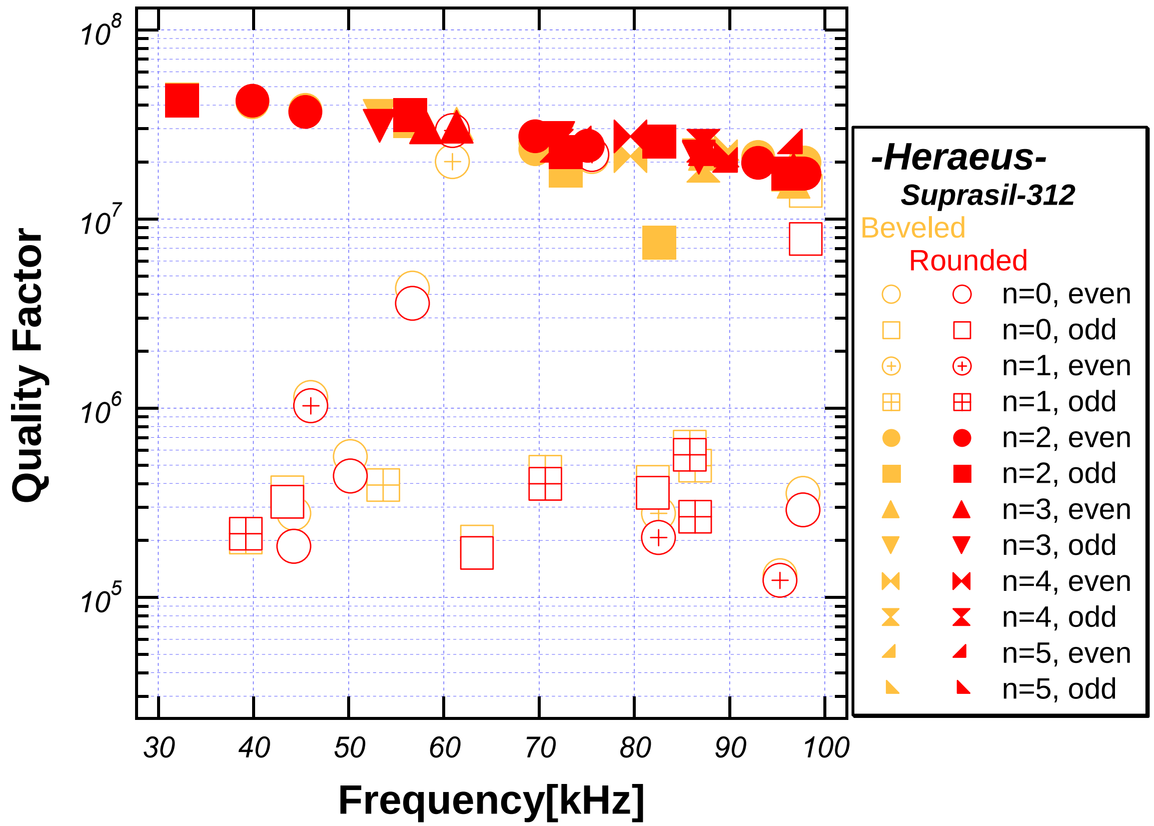
- ●No significant change observed

✓Before

(beveled edge)

✓After

(rounded edge)



Existence of edge is considered unimportant.

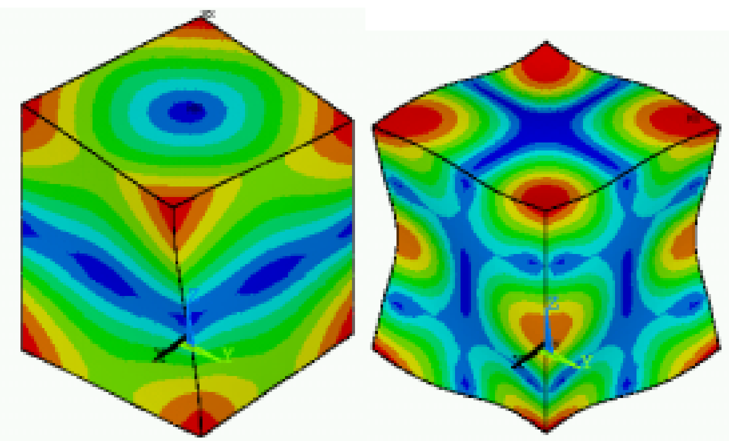
Effect of Edge & Curved Surface

■Comparison with block sample*

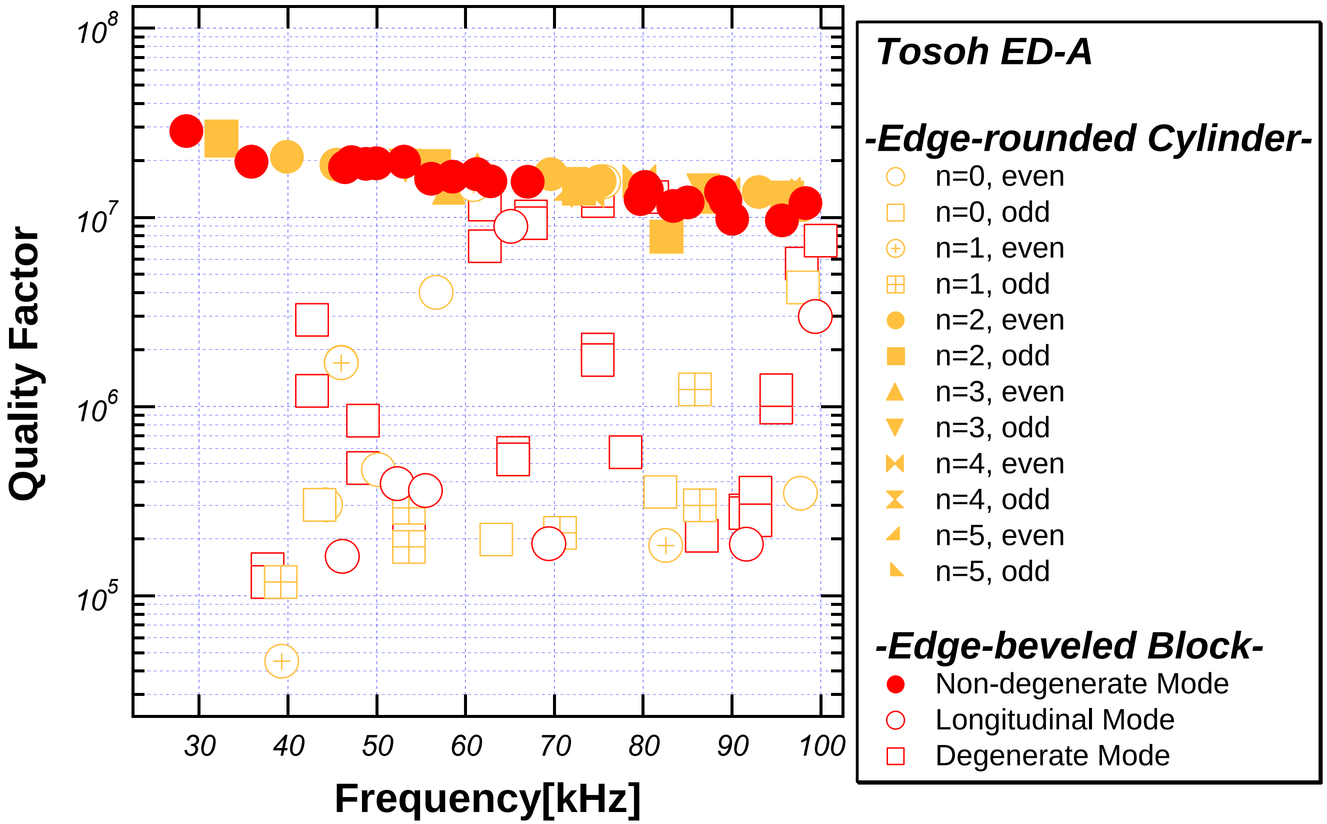
- ●Virtually no difference observed

*5cmx5cmx6cm

✓Non-degenerate modes



28.6kHz 80.2kHz



Curved surface is not a limiting factor.

Freq-dependent intrinsic loss is the most convincing.

4. Summary

■Our approach

- ●Resultant Q does not matter for mirror thermal noise.
- ●Our prime concern should be an intrinsic loss in material.
- ●Fused silica is the most promising at room temperature.

■Nodal support technique

- ●The best way to measure intrinsic loss by now
- ●Removal of support loss that has been a serious problem
- ●Reliable measurement based on a simple principle
- ●Measured Qs distributed on a straight line

Conclusion & Future Work

■Measurement of 13 kinds of bulk fused silica

- First systematic comparison of various kinds of fused silica
- Clear differences were observed in different grades.
- Maximum Q reached 4.3×10^7 after vacuum annealing.
- Knowledge about sources of loss was expanded.
- Circumstantial evidences support freq-dependent intrinsic loss.

■Future work

- Identification of sources of loss (use of spectroscopy etc.)
- Thermal treatment, expansion of measurement band...
- Active development of new fused silica