Optical disk resonators with micro-wave free spectral range for optoelectronic oscillators

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Outline

- Choice of the material
- Resonator fabrication
- Experiments
- Results
- Conclusion

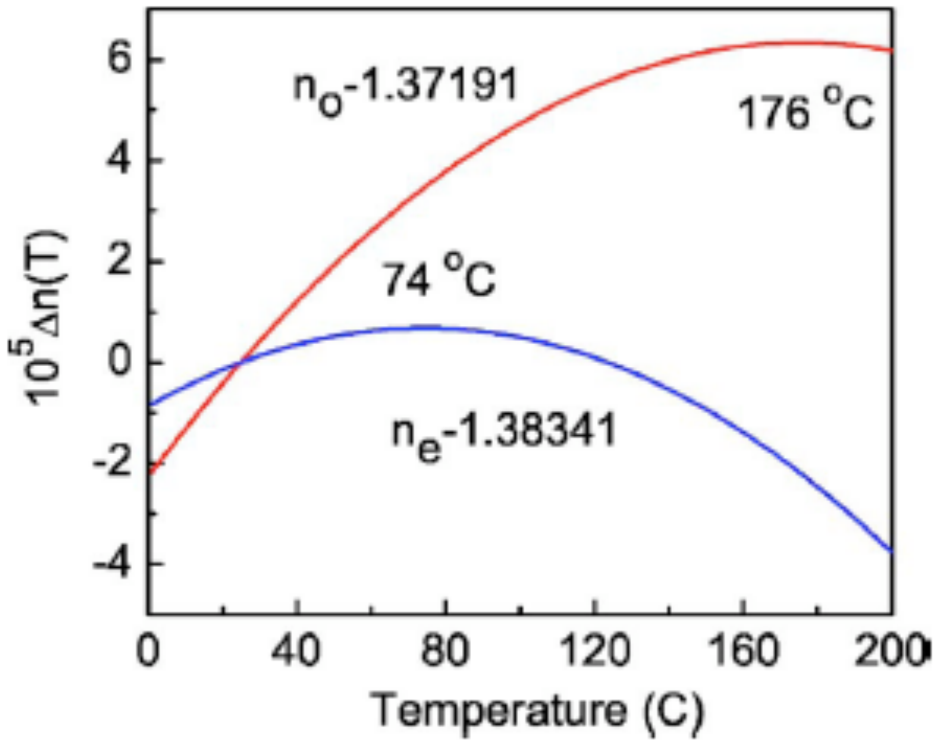
Optical materials

- **Q = 6 x 10^{10}** demonstrated with CaF_2 disk (I. Grudinin).

	MgF2	CaF2	Fused silica	Quartz
Transparency range	0.12 to 8.5 μm	0.2 to 9 μm	0.18 to 2.5 μm	0.19 to 2.9 μm
Refractive index @ 1550 nm	no = 1.37 ne = 1.38	n = 1.42	n = 1.44	no = 1.54 ne = 1.53
Hardness (Mohs)	6	4	6-7	7
Crystal Class	Tetragonal	Cubic	noncrystalline	Hexagonal
H2O pollution	Good	Good	Bad	Bad
Mechanical shock	Good	Bad	Good	good

I. S. Grudinin, V. S. Ilchenko, and L. Maleki, Phys. Rev. A 74, 063806(9) (2006).

MgF2 inversion point relates to Pound stabilization



Whispering-gallery-mode resonators as frequency references. II. Stabilization

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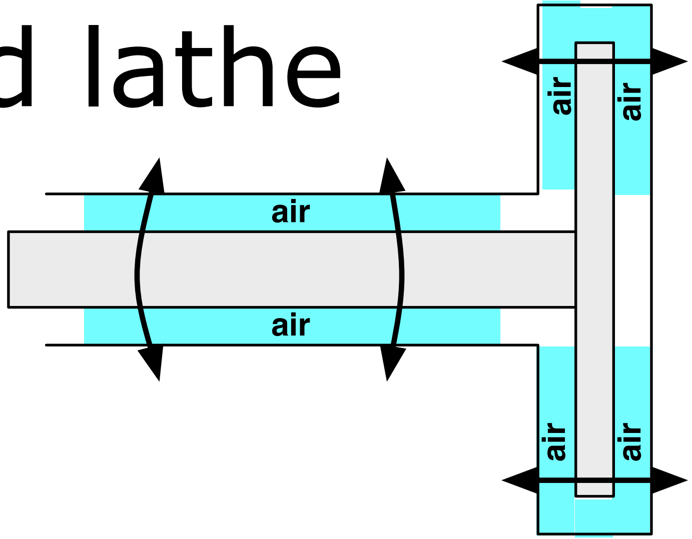
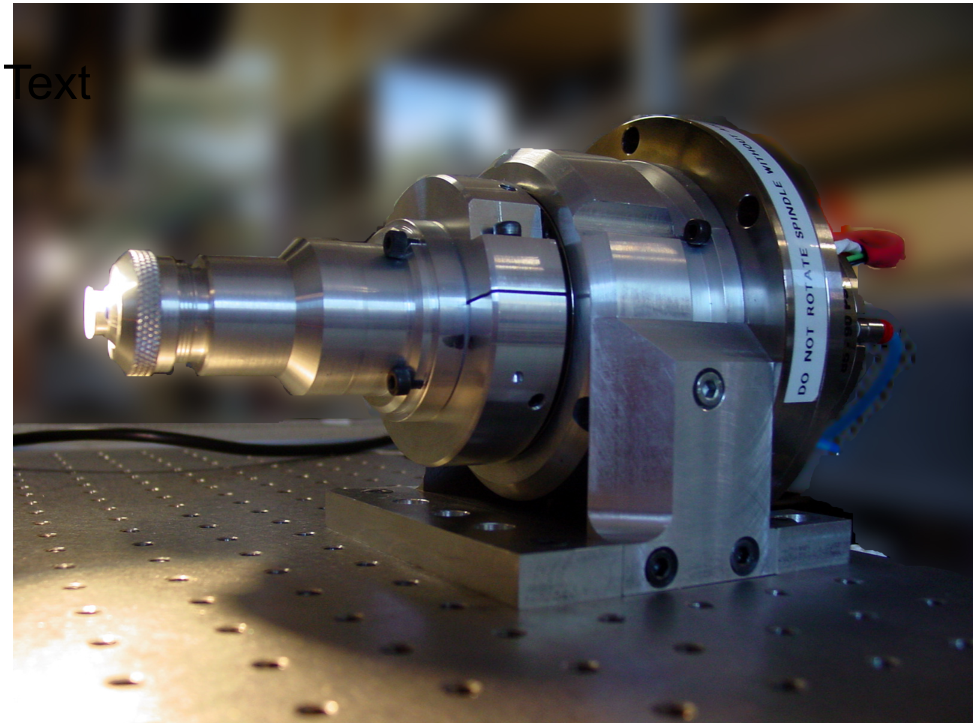
Dedicated lathe



- Brushless motor.
- Air-bearing to guarantee low vibrations.
- Small eccentricity error (200 nm).
- Precision collet to position the resonator holder.

Text



Derives from hard-disk test equipment

Can you figure out what a hard disk is?

3.5” & 7200 rpm => ~ 200 km/h

1 (µm)^2 bit area, 50 nm head–disk distance

Resonators preforming

- Stick a 6 mm MgF_2 optical window on a metal holder (0.5 - 1 mm thick).
- Correct for the centering error by grinding with several diamond grains size (40 - 20 μm).
- Create two 20° bevels to get a thin edge (about 30 μm, depending on crystal splinters).

Manual polishing step

- Several polishing powders in decreasing grains size (diamond, colloidal silica, cerium oxide, alumina) diluted in distilled water (6 μm to 30 nm).

- Polishing baize used as powder holder.

- Rotation speed depends on grain size.

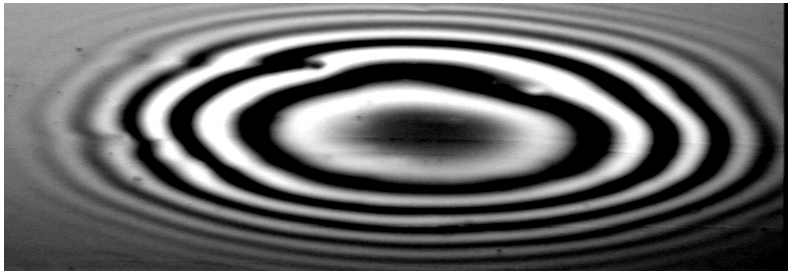
Newton rings

- White light phase-shifting microscope with 1 nm of resolution.

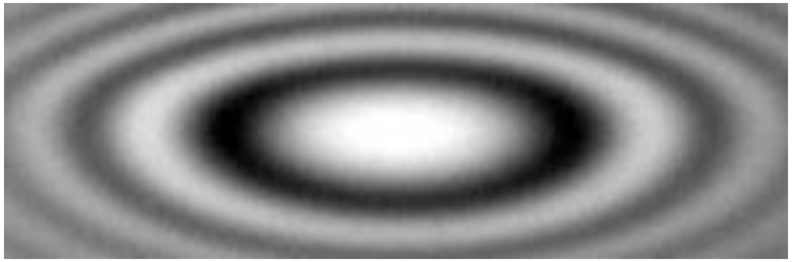
(FEMTO-ST instrument, based on the idea of phase-contrast microscope)

- Interference fringes as contour curves. Smooth contour curves indicates roughness less than 20 nm.

200 nm surface roughness

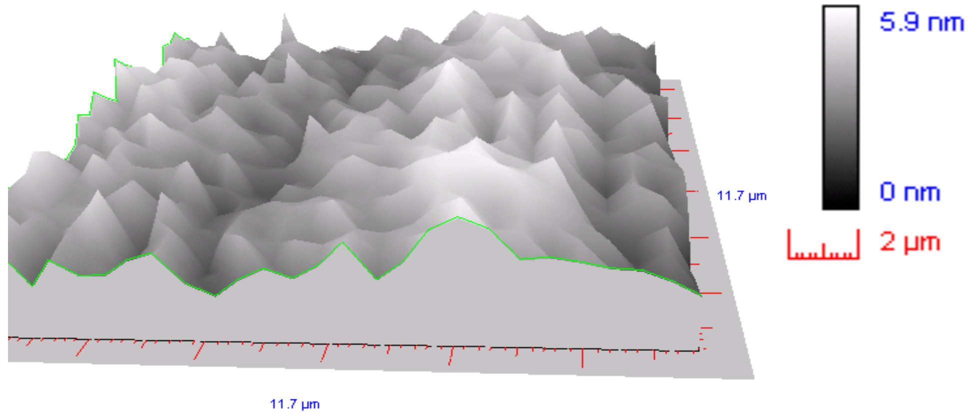


< 20 nm surface roughness

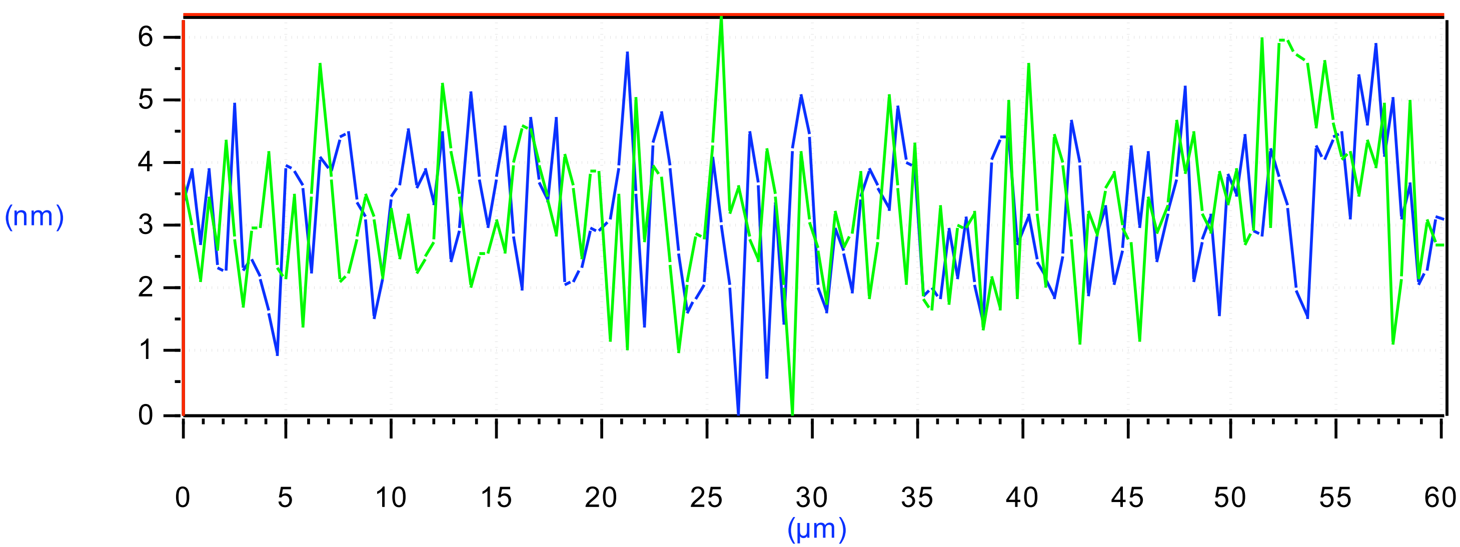


Roughness measurement

White light phase-shifting microscope with piezo control, after scan and image processing



3D surface of the disk



Rt	5,857	6,344
Ra	0,917	0,923
Rq	1,106	1,172
Rsk	-0,089	0,266
Rku	2,563	3,041
Rp	2,652	3,119
Rv	3,205	3,225
Rz	4,309	4,816
Rtm	4,309	4,816

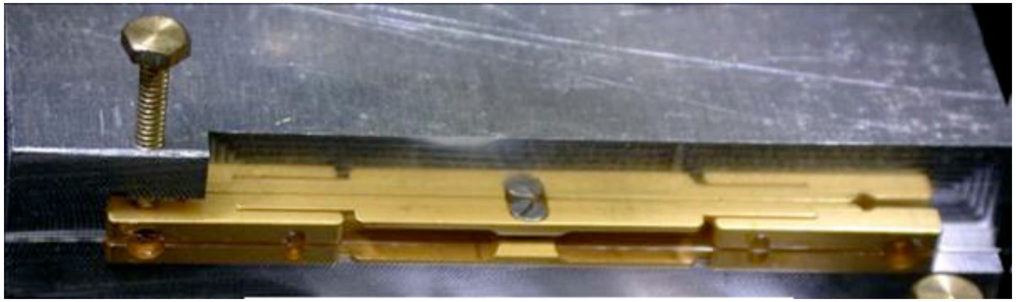
Roughness: **6 nm** peak-to-peak, **0.92 nm** rms.

Taper coupling

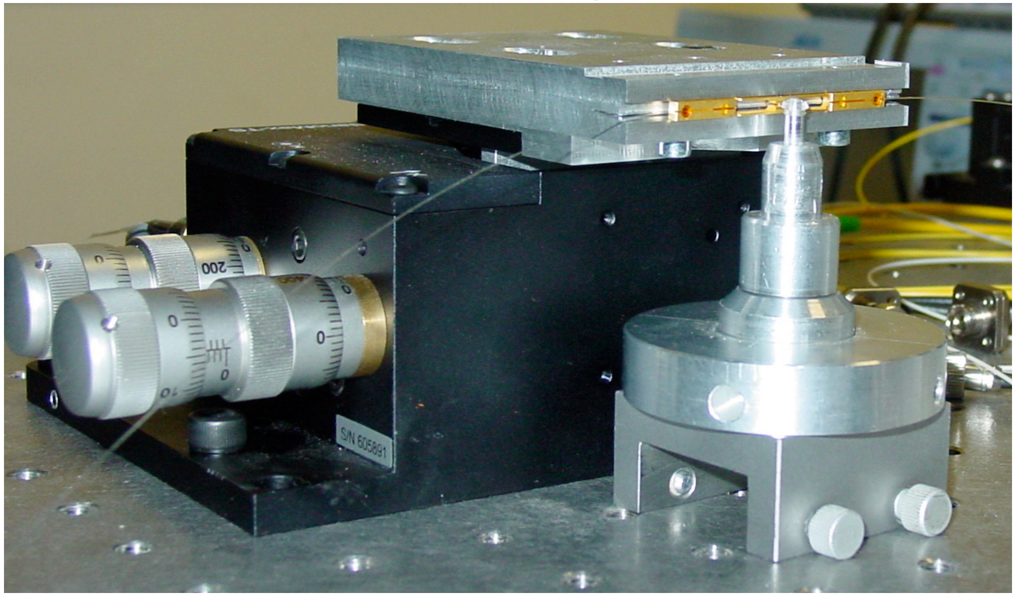
- Tapered SMF28 fiber glued on the holder.
  Manufactured by LASEO (Lannion, FR)
- For lowest stress, holder geometry and alloy match the thermal expansion of glass.
- Waist $< 3\ \mu m$.
- 3-axis nano-positioning with 20 nm resolution.

Advantages vs. prism-shaped fiber:
+ higher modal selectivity
+ clean mechanical design
+ one coupler serves as in/out

Taper glued on the holder

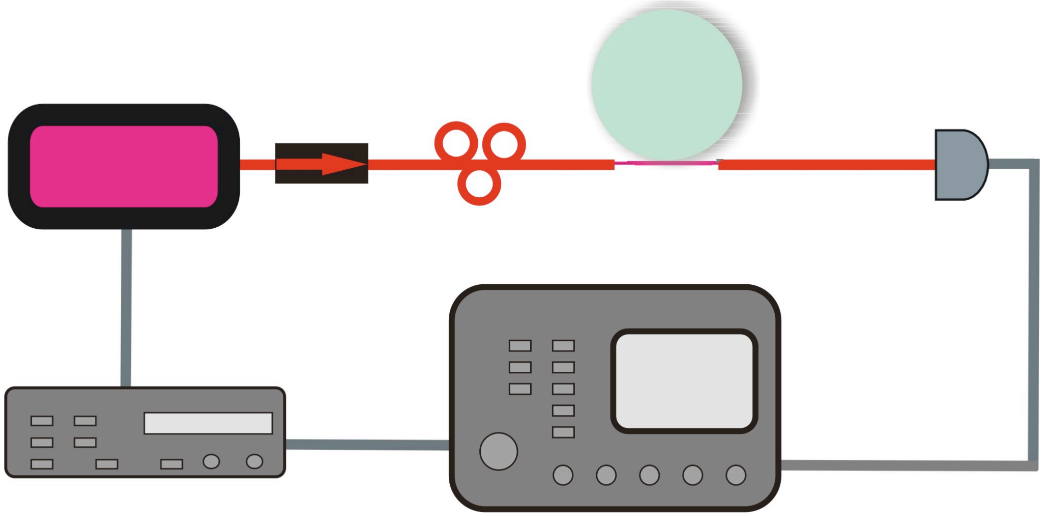


Nano-positioning system



Resonance measurement

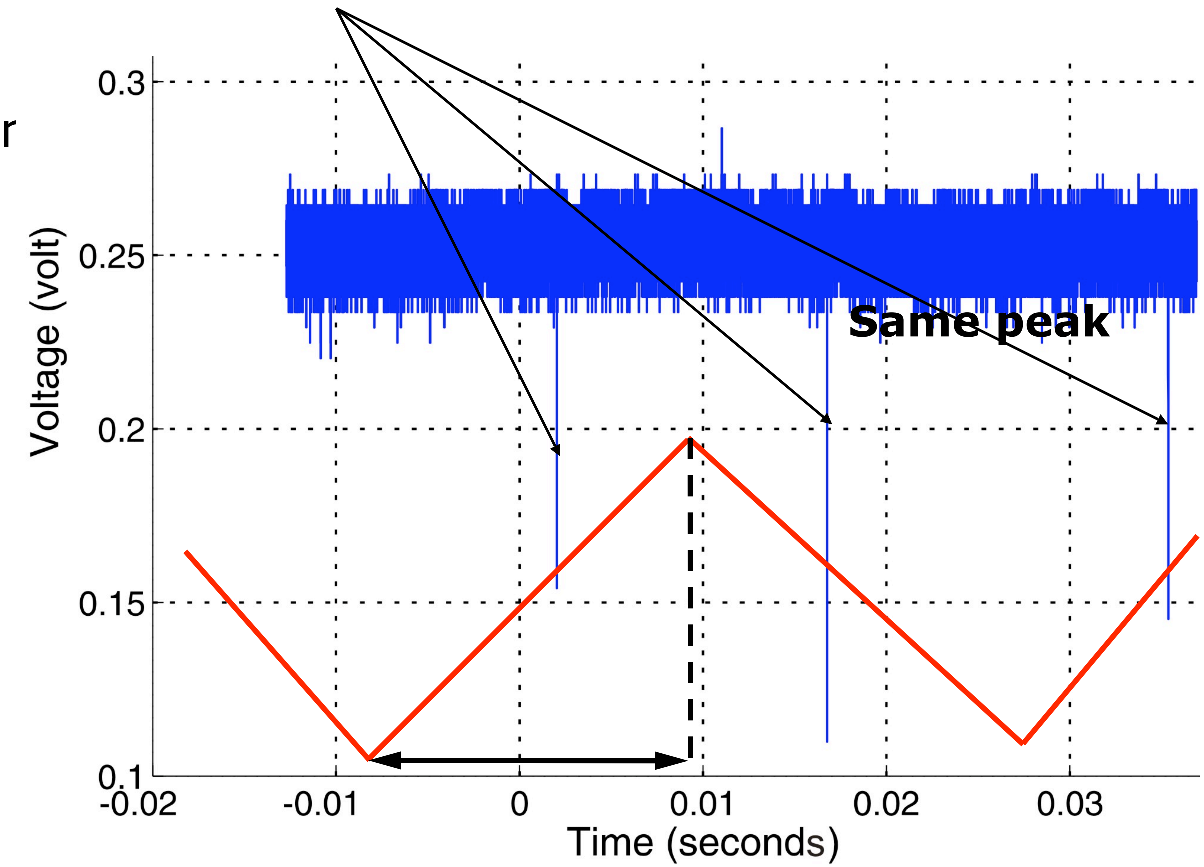
- 1550 nm erbium laser (3 mW power).
- 50 pm wavelength sweep (6 GHz).
- High resolution oscilloscope to analyze very sharp phenomena as peak resonance.



Tunics @ 1550 n

Detection of the resonance peak

- Single mode excitation:
  - Small taper size selects a thin excitation region.
  - Needs polarization controller.
- Wavelength span too small to scan a full FSR.
- Scan rate 50 Hz



Q factor measurement

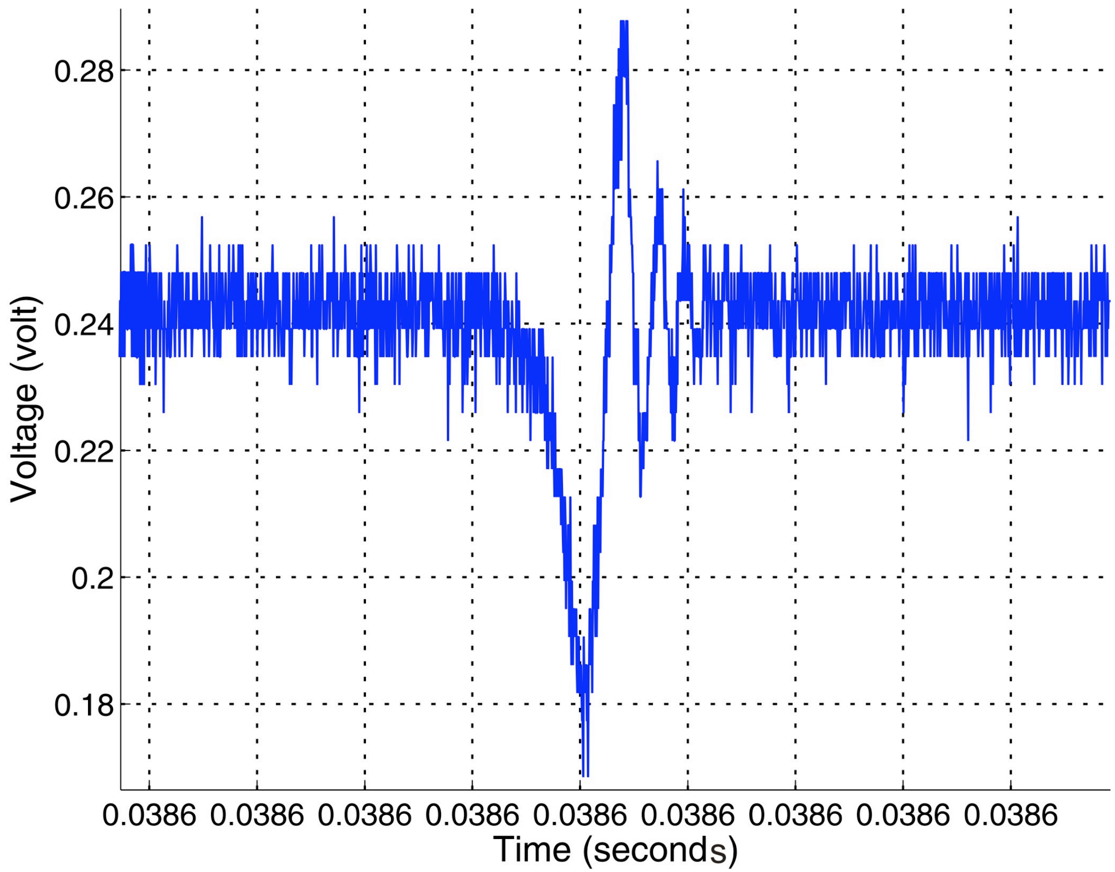
- Self-homodyne method.

- Increasing wavelength triangle scan.

- 400 Hz scan rate.

- Oscillation damping gives:

  Q=3.4 x 10^8



J. Poirson, F. Bretenaker, M. Vallet, and A. Le Floch, J. Opt. Soc. Am. B 11, 2811 (1997).

Thermal effect

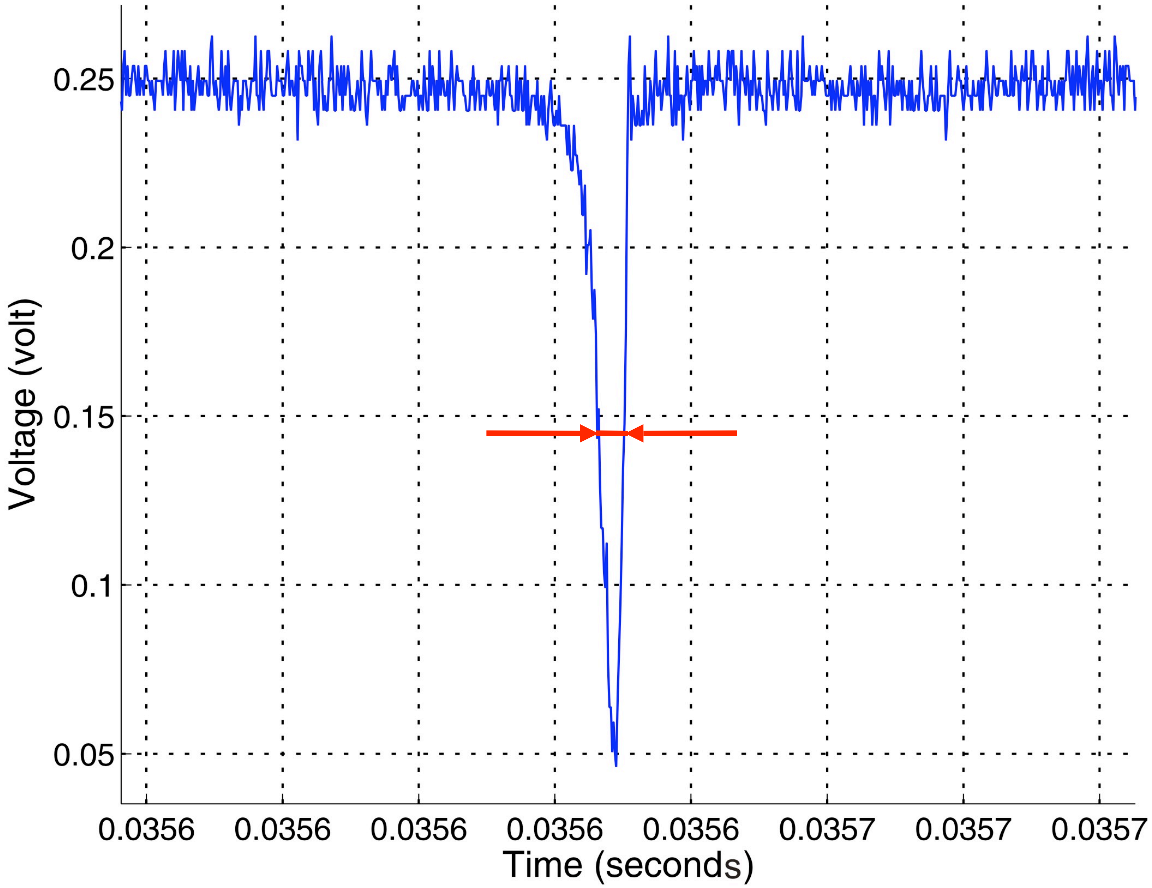
- Asymmetric shape.
- Positive TC (λ) of the

  resonance.
- Triangle sweep.
- First half of resonance shape: the carrier increasingly heats the energy region.

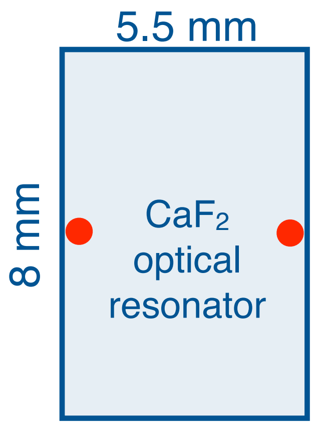
The resonance tracks the carrier.

- Second half: heating decreases.

The resonance steps back

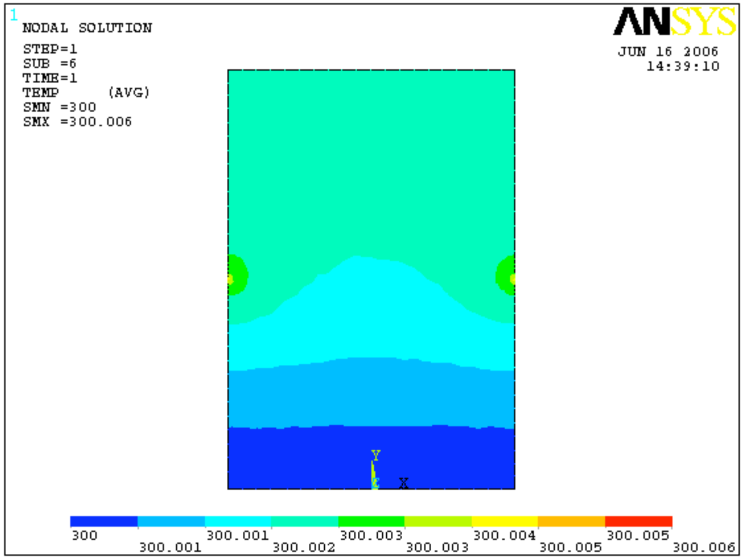


Thermal effects
example of CaF2 resonator

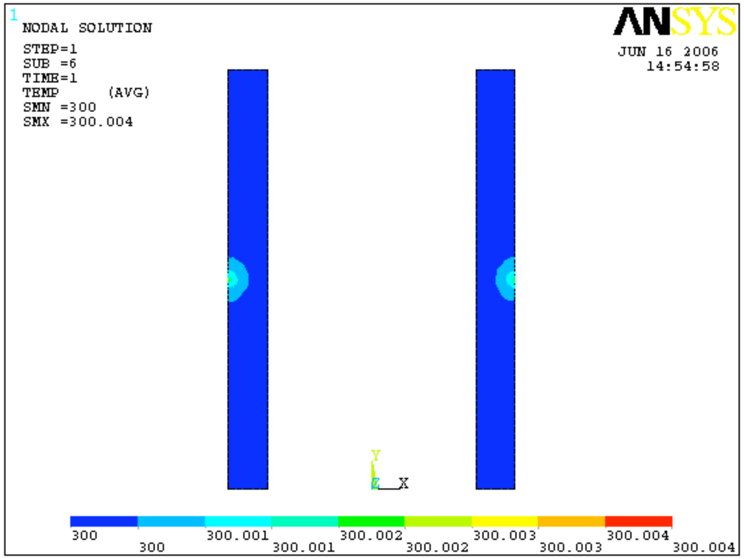


- cross section of the field region 1 μm^2
- CaF_2 thermal conductivity 9.5 W/mK
- dissipated power 300 μW
- wavelength 1.56 μm
- air temperature 300 K
- still air thermal conductivity 10 W/m^{2}K
- simplification: the heat flows from the mode region is uniform

bottom plane at a reference temperature



inner bore at a reference temperature



finite-element simulation and data refer to another resonator
because with a single taper we can't measure the resonator dissipated power

Thermal effects : CaF2 example

thermal expansion yields a frequency change

$$\frac{\Delta\nu}{\nu_0} \simeq \frac{dL}{L\,dT}\,\Delta T$$

the thermal expansion coefficient of CaF_2 is

$$\frac{dL}{L\,dT} \simeq 1.85\times10^{-5}$$

take a frequency change of 1.13 MHz at 192 THz (1560 nm)

$$\Delta T \simeq 3.2\times10^{-4}\ \mathrm{K}$$

A factor 10 is missing, vs. finite-element calculus.

Of course, the mode ring is constrained by the cold crystal around.

High temperature gradient

Conclusion

- Design and implementation of a dedicated lathe with 200 nm eccentricity error and low vibrations.

- A few 5.5 mm MgF_2 resonator implemented.

- Preforming and polishing process gives surface roughness of 0.92 nm rms on the 60 μm polished edge.

- First demonstration of the microwave-FSR resonator with taper coupling.

- Stable coupling over > 1 week.
- Preliminary result: $Q = 3.4 \times 10^8$.

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