Optical Second Harmonic Generation in a Whispering Gallery Mode Resonator

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Outline

Motivation

Develop a quantum memory scheme.

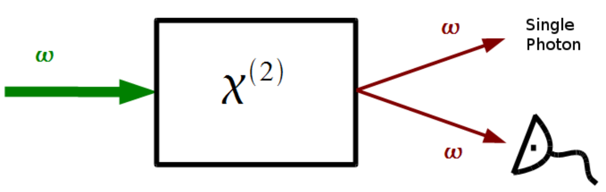
- Mapping states of light onto a gas of atoms.
- Light states are read back out at a later time.
- New source of single photons for storage.

Develop source of squeezed light.

- Produce squeezing from nonlinear processes.
- Improved interferometry.

Heralded Single Photon Source

- Send light into medium with nonlinear polarization.
- One photon is converted to two lower energy photons.
- Detection of one photon ”heralds” the presence of the other.

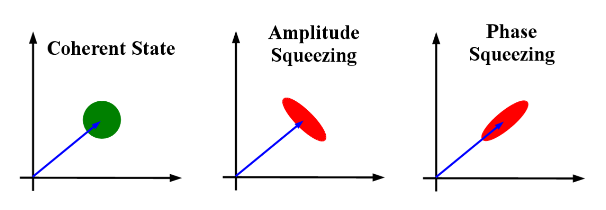


Squeezed Light

- Light amplitude & phase uncertainties are related.

$$\Delta x \Delta p \geq \frac{\hbar}{2} \tag{1}$$

- Uncertainty is reduced below this limit in one variable after nonlinear processes.
- Reduced uncertainty results in higher resolution.



Second Harmonic Generation

- Energy Conservation

$$\omega + \omega = 2\omega \tag{2}$$

- Momentum conservation

$$k_{2\omega} - 2k_{\omega} = \frac{2\omega}{c}(n(2\omega) - n(\omega)) = 0 \tag{3}$$

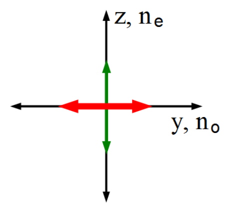
- Achieving $n(2\omega) = n(\omega)$ is called **phase matching**.

For example, $\lambda = 1064nm$ can be converted to $\lambda = 532nm$.

Phase Matching Methods

- Birefringent crystal ($n_o(\omega) \neq n_e(\omega)$)
- Type-I phase matching

$$n_o(\omega) = n_e(2\omega) \qquad (4)$$



Methods for satisfying Eq. 4

1. Critical (or angle) phase matching
2. Non-critical (or temperature) phase matching
3. Quasi-phase matching (via periodic poling)

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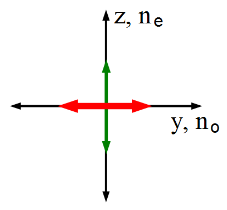

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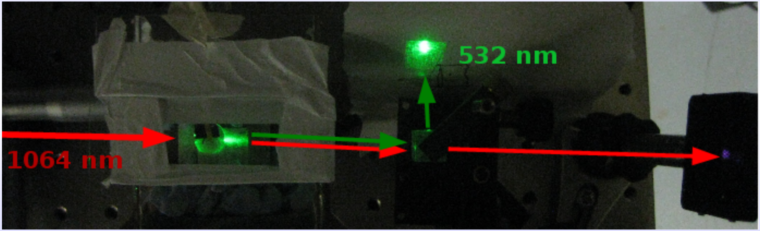
Single-pass SHG

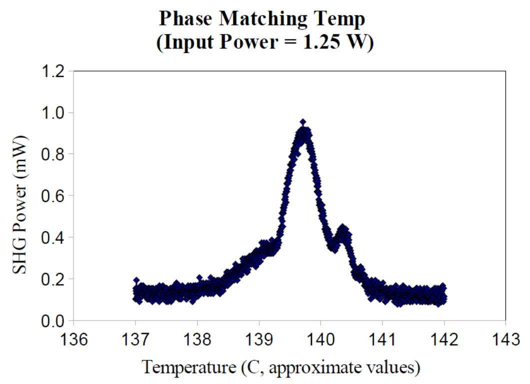
Sent a $\lambda = 1064nm$ laser through a lithium niobate crystal.



Adjusted temperature to produce SHG at $\lambda = 532nm$.

Single-pass SHG

Phase-matching temperature for our lithium niobate is $T = 140°C$.



For single-pass, conversion efficiency is very small ($\sim 0.1\%$).

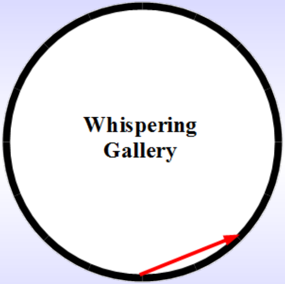
Why Whispering Gallery Mode Resonators?

- Optical nonlinear effects are small.
- High laser power.
- High quality cavity.

Solution: Use whispering gallery mode resonators.

Whispering Galleries

A whispering gallery is a circular cavity



that contains a field through total internal reflection (TIR).

The field contained inside is a *whispering gallery mode* (WGM).

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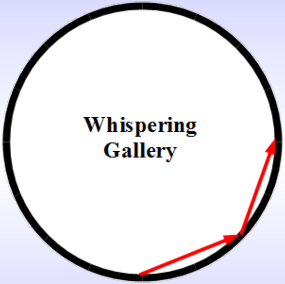

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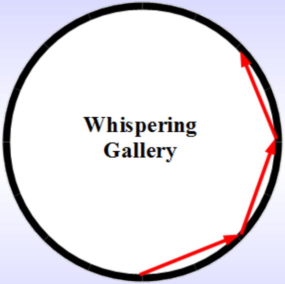

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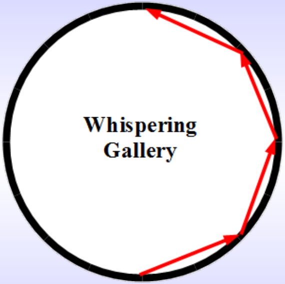

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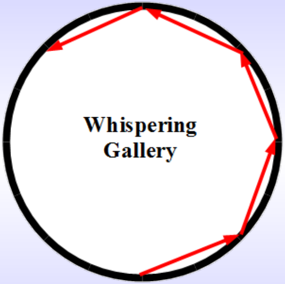

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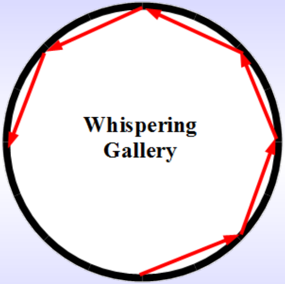

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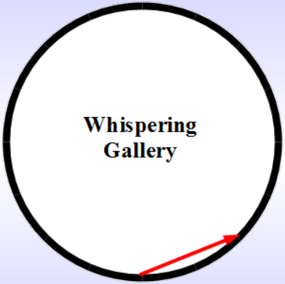

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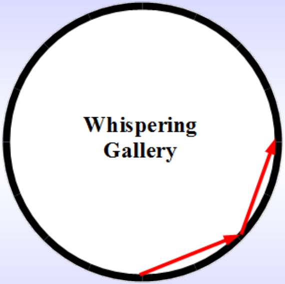

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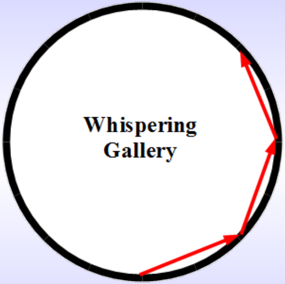

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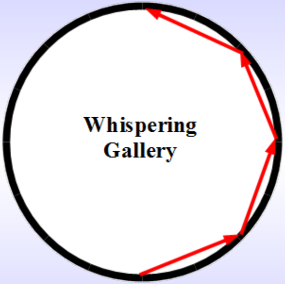

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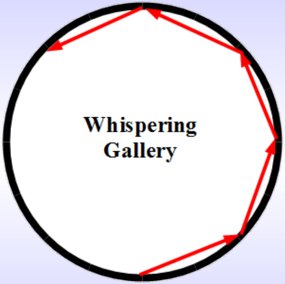

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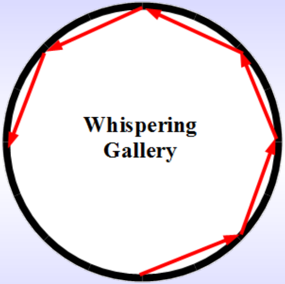

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WGMR Disk Production

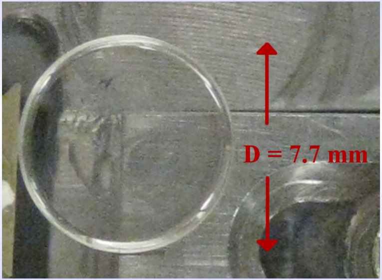
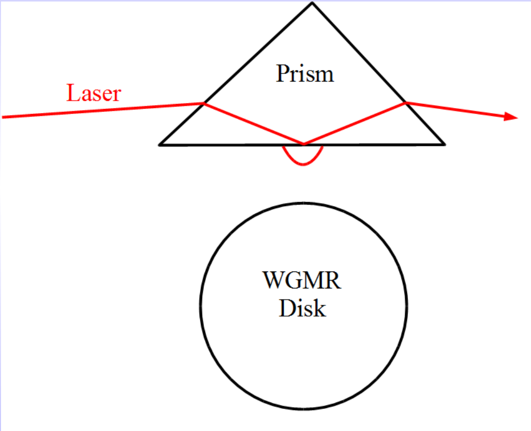


Figure: Lithium niobate resonator.

- Made from lithium niobate ($LiNbO_3$).
- Edge shaped with sandpaper.
- Polished with diamond lapping film.
- Polish quality affects quality factor (Q-factor).

Whispering Gallery Mode Excitation



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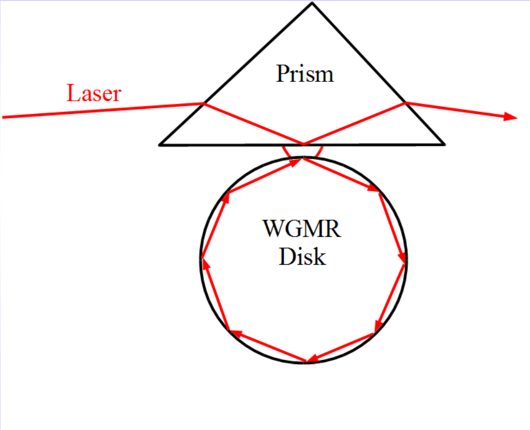
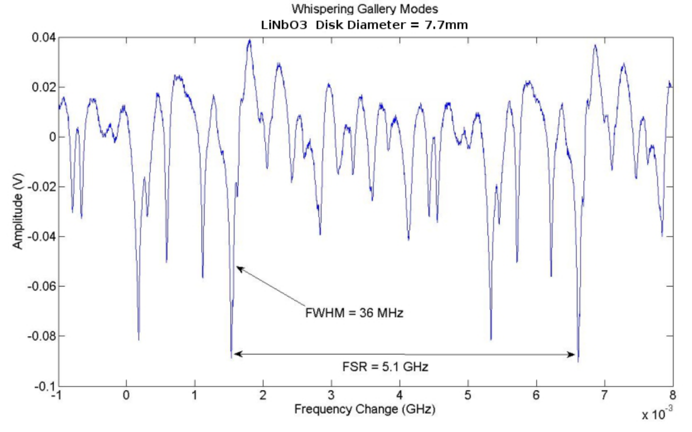


Whispering Gallery Mode Excitation

Frequency scanned output from our $LiNbO_3$ WGMR disk near 795nm, with a Q-factor of $Q = 10^7$.



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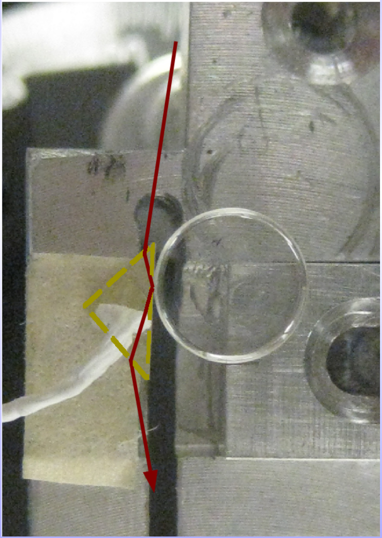
Whispering gallery mode resonators:

- have high quality factors and a small mode volume - reduced power requirements.
- are monolithic structures - better stability.

SHG in a WGMR

1064nm to 532nm noncritically phase-matched SHG inside a WGMR.



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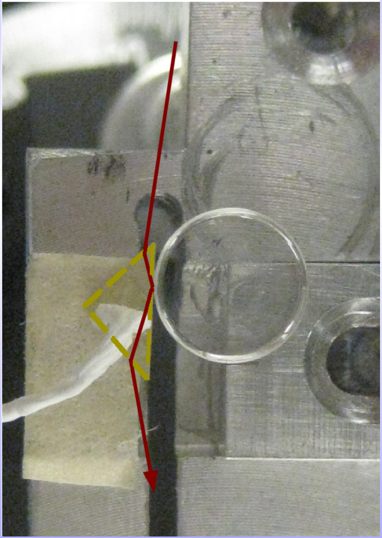

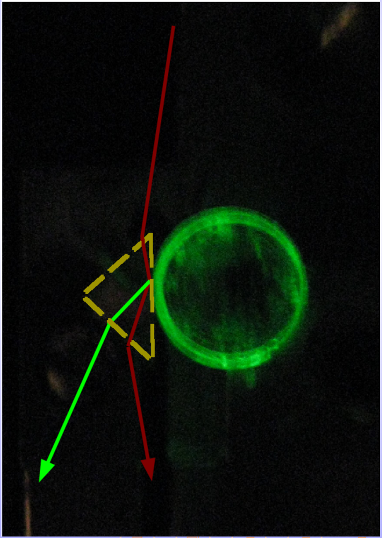

Summary

Developing nonclassical light sources for quantum information.

- Produced high quality factor WGMRs.
- Achieved phase matching for SHG in a WGMR.

Future plans:

- Optimize second harmonic generation.
- Achieve parametric down-conversion.
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Acknowledgements

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