Surface-functionalized Silica Microsphere Lasers

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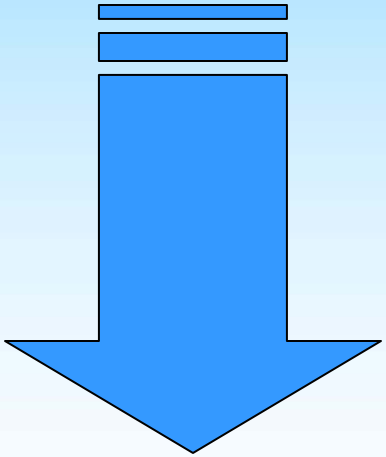
Outline

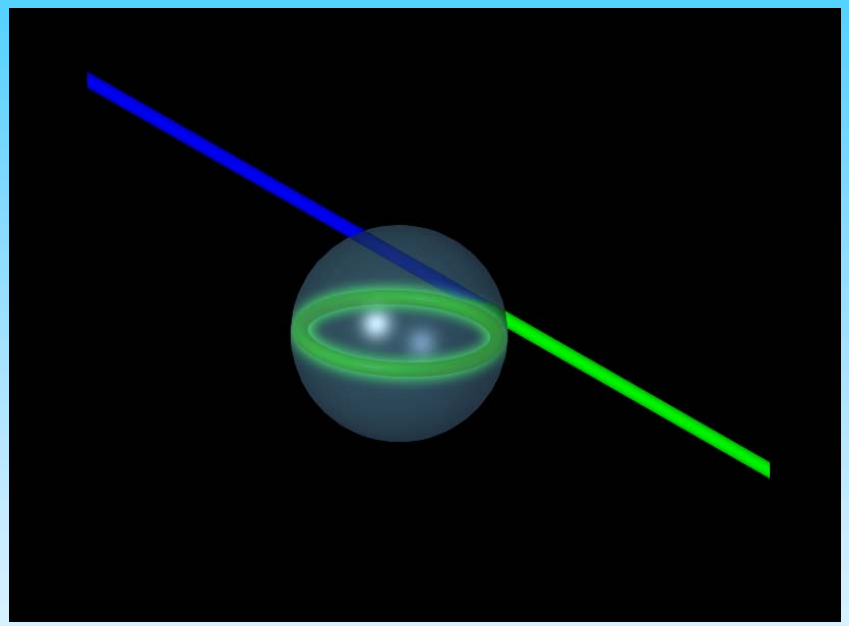
- Introduction
  - Background and motivation
  - Sol-gel technology and surface functionalization
- Experimental results
  - Spatial mode selection
  - Analysis for laser operation dynamics
  - Pulse and CW operation
- Summary

Background for Functionalization

Why surface functionalize the silica microsphere resonator ?



Whispering Gallery Mode Microsphere Lasers



The resonator modes are strongly confined just within the inside surface by continuous total internal reflection.

- **Radial direction: Spherical Bessel**
- **Polar direction: Associate Legendre Polynomial**

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Previous Work on Rare-earth Doped Microsphere Lasers

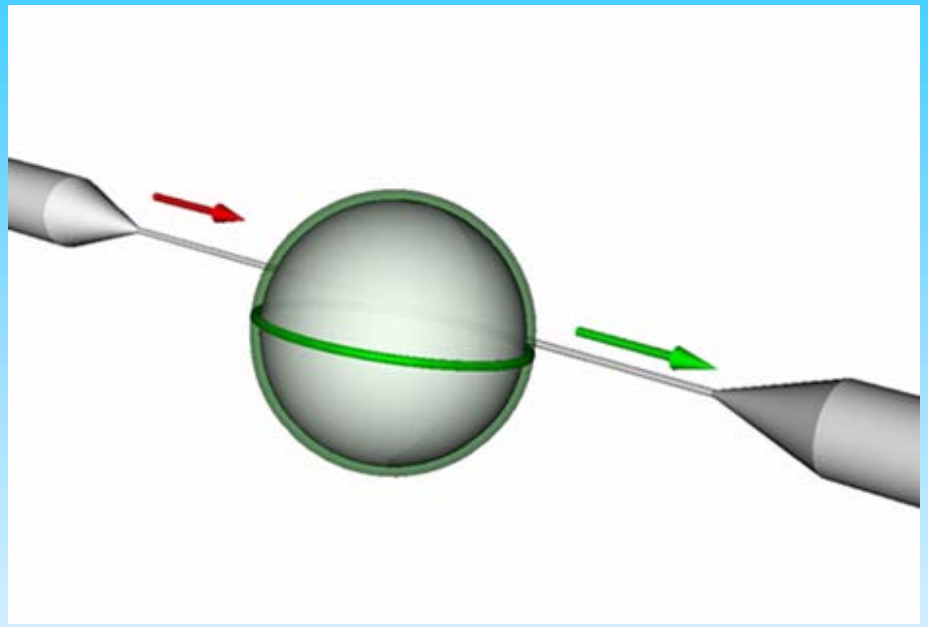
Very low threshold WGM Nd^{3+} doped silica microsphere lasers (V.Sandoghdar, F. Treussart, J. Hare, V. Lefevre-Seguin, J.M.Ramond, and S. Haroche, Phys. Rev. A 54, 1777(1996))

- **Threshold: 200 nW**
- **Laser output: 150 pW**
- **Quantum efficiency: 0.035%**

Low threshold Er^{3+} doped phosphate microsphere lasers (M. Cai, O. Painter, K. J. Vahala and P. C. Sercel, Opt. Lett. 25, 1430 (2000))

- **Threshold: 60 μW**
- **Laser output: 3 μW**
- **Quantum efficiency: 2.5% (Improved by taper coupling scheme)**

Motivation

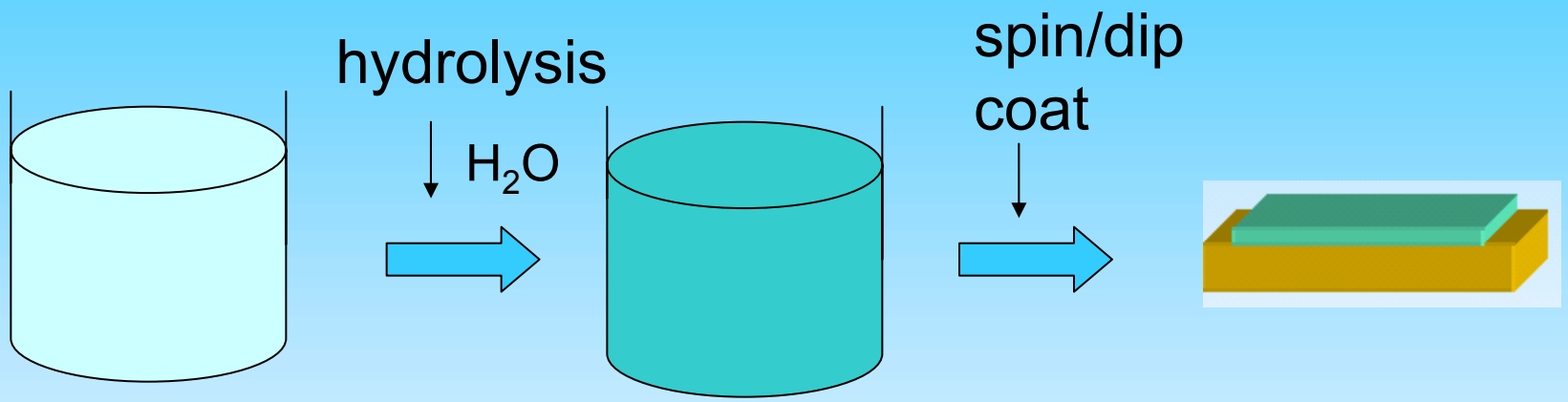


- The WGM's in glass microsphere are confined in the 'film region'
- More flexible because multiple dopants are available
- Investigation of pulsation behavior

Advantages of Sol-gel Method

- Involves liquid chemical synthesis of homogeneous materials
- Versatile method to deposit thin films on non-planar surfaces
- Low cost and simple procedure
- Environmentally safe, versus other processes such as chemical vapor deposition (CVD)

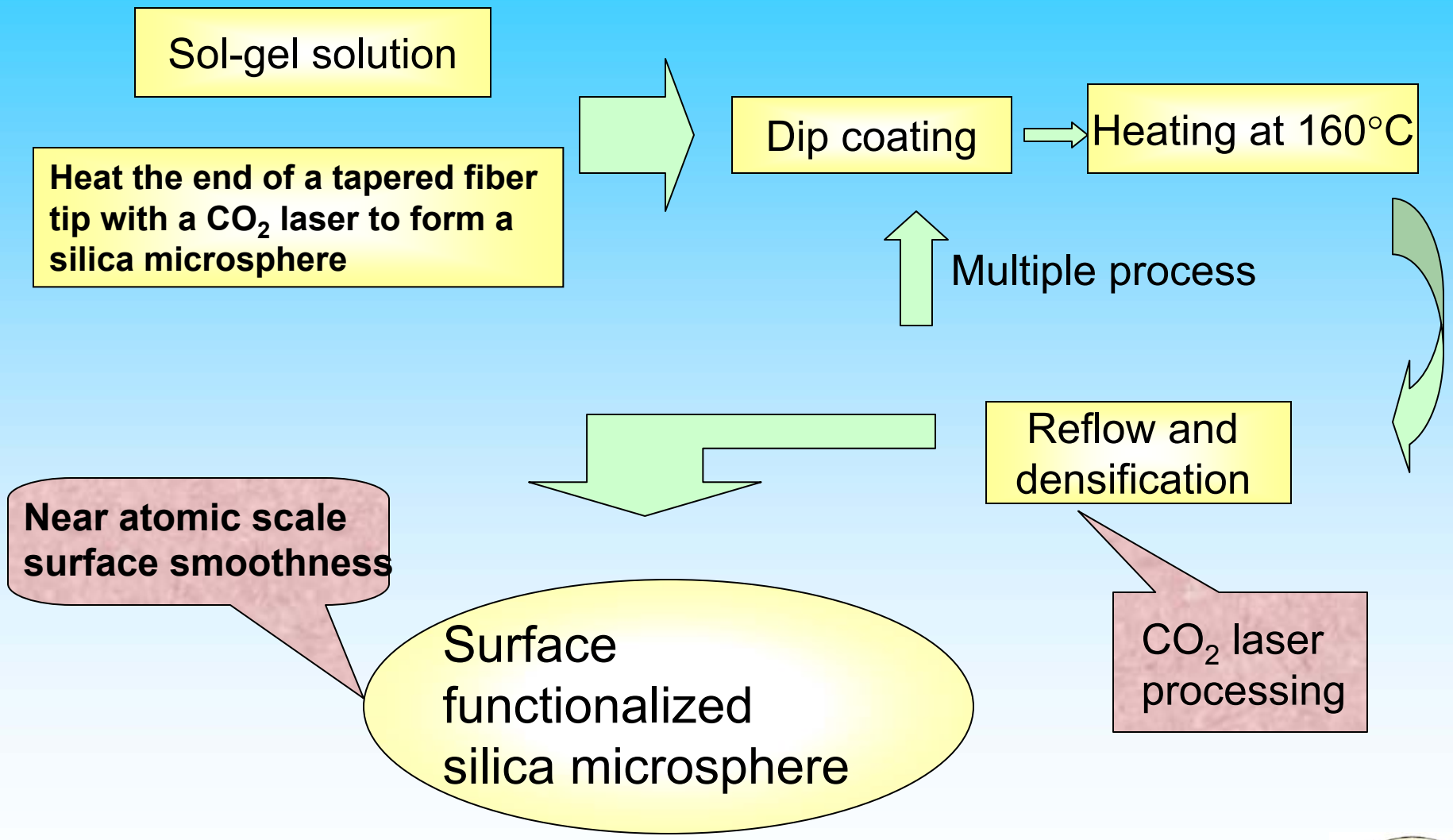
Sol Gel Process



organometallics
+dopants
in alcohol solvents

viscous gel

Process Flow



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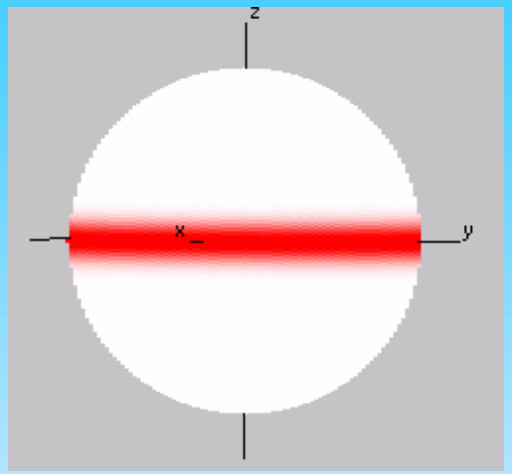
Equatorial WGM's



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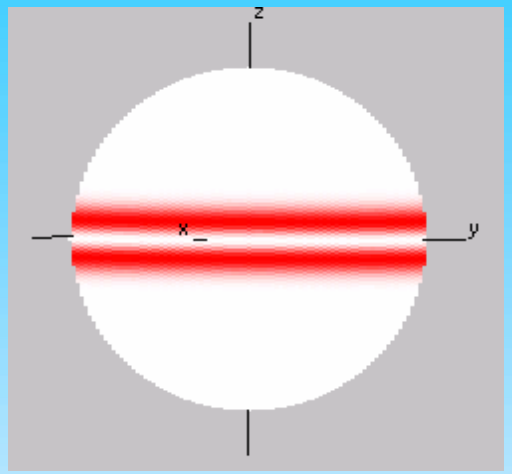

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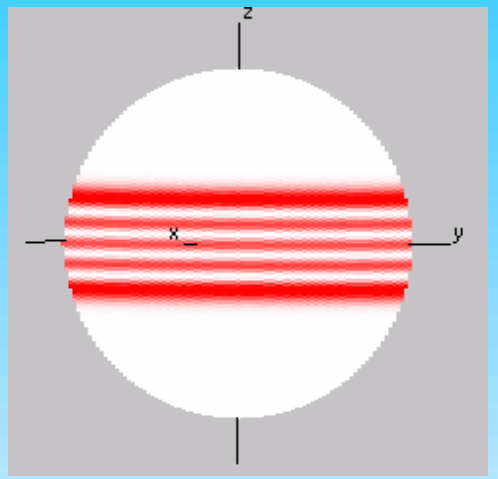

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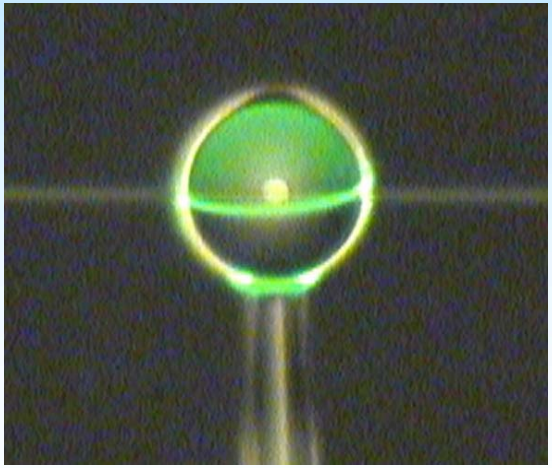

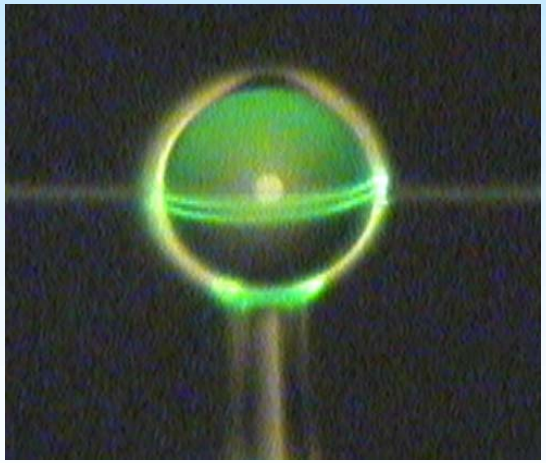

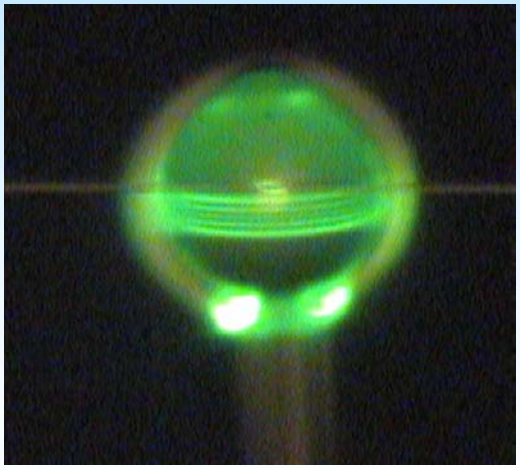

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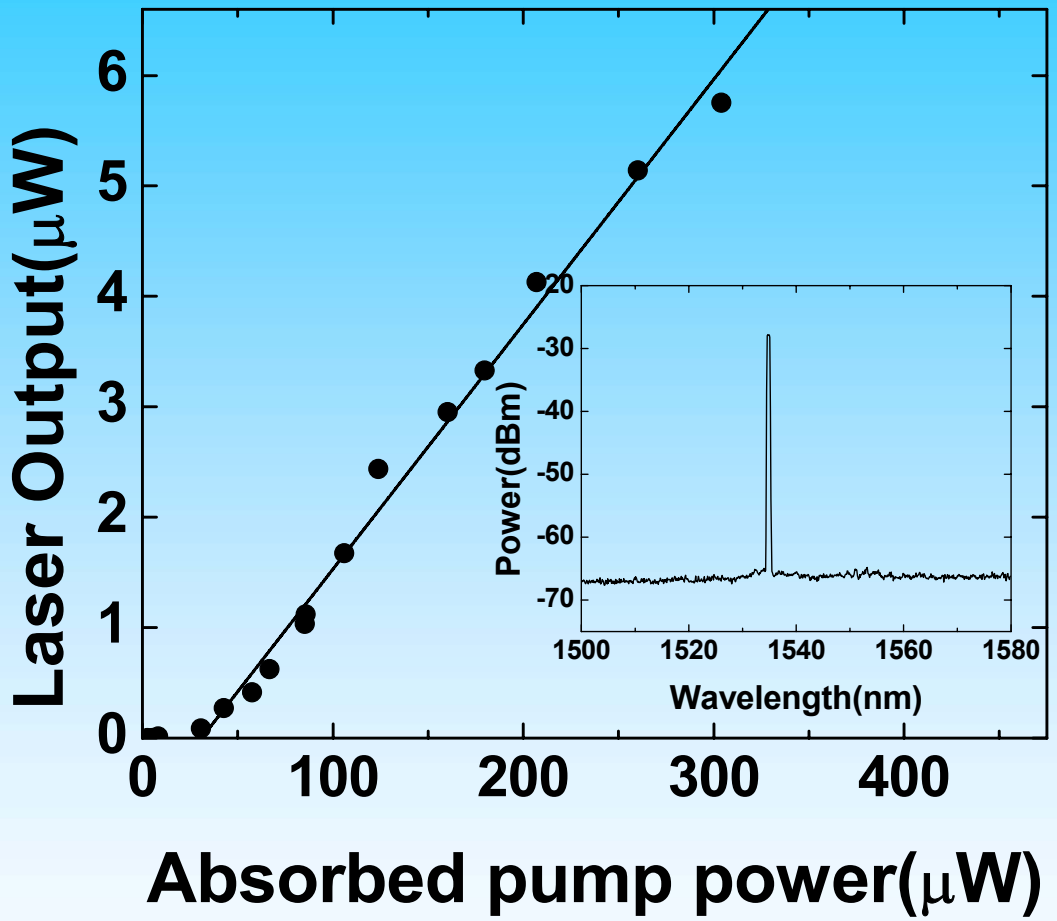
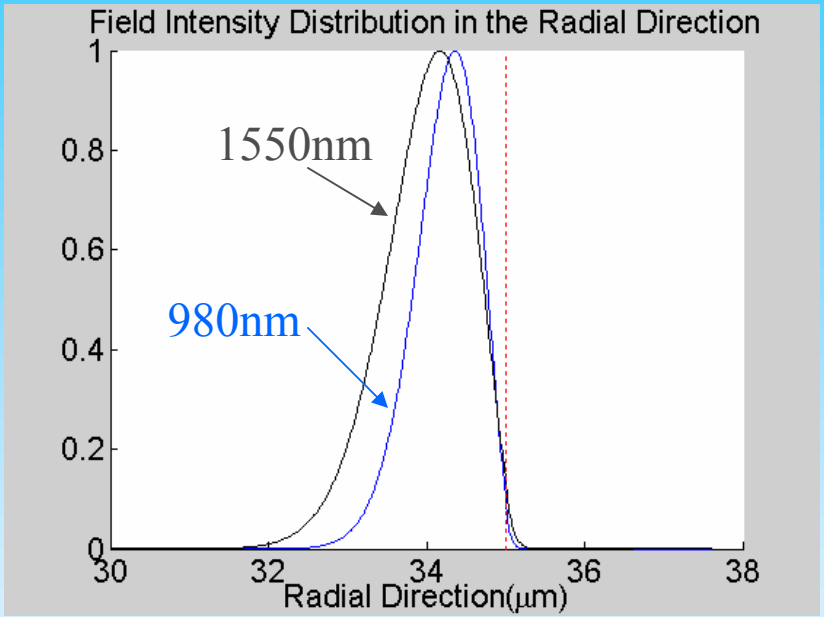
Laser Performance

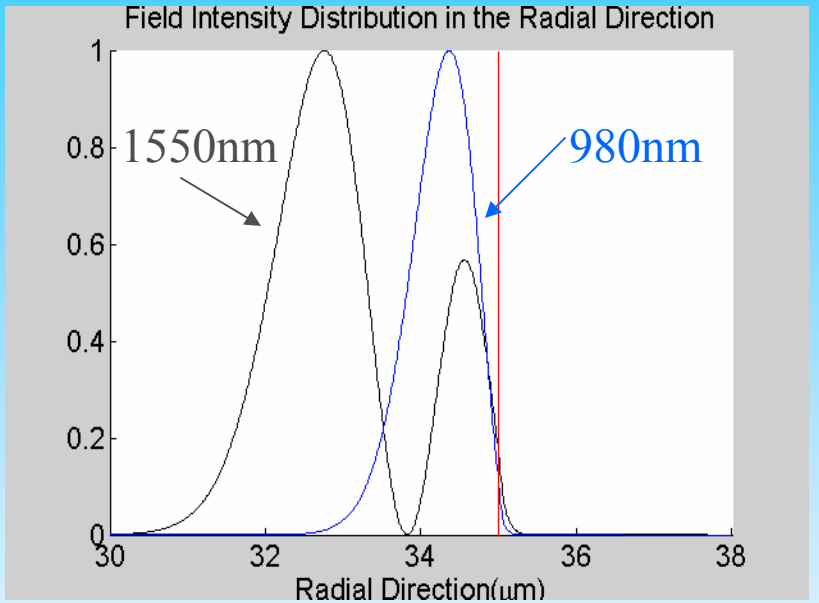


Contributing factors for low threshold performance:

- Low loss medium
- CO_2 reflow process
- Highly confined mode volume
- Efficient fiber taper coupling scheme

Mode Selection Mechanisms





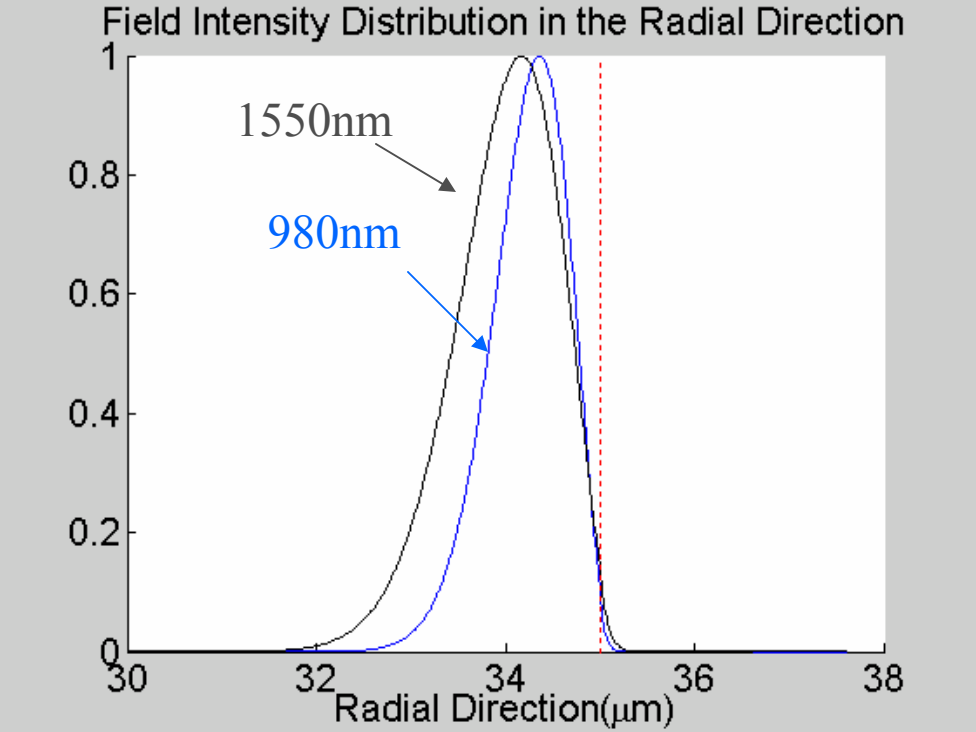
Overlap of pumping and lasing modes

Suppression of higher order radial modes:

- Fundamental radial WGM's have best spatial overlap with fiber taper
- Fundamental radial WGM's have best overlap with active surface region

Similar mode selection mechanism also works for azimuthal WGM's

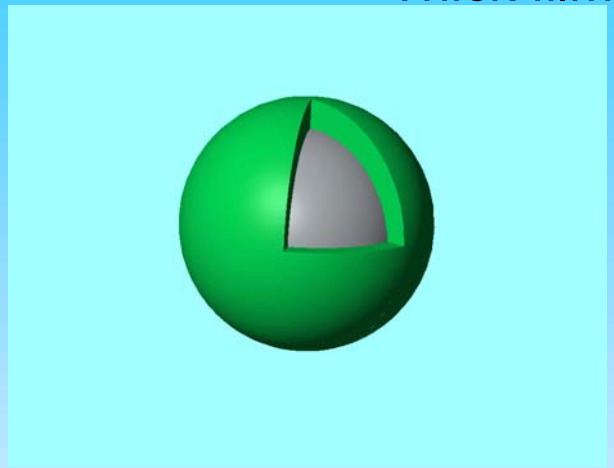
Effect of Film Thickness on Laser Dynamics



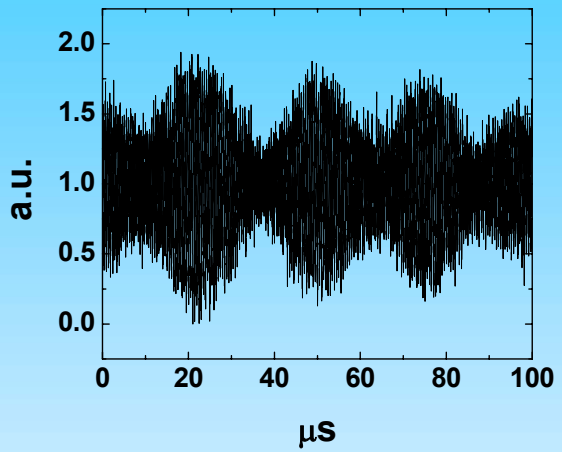
- Un-pumped region works as intracavity saturable absorber and permits pulsation mode generation

CW v.s. PM Operation

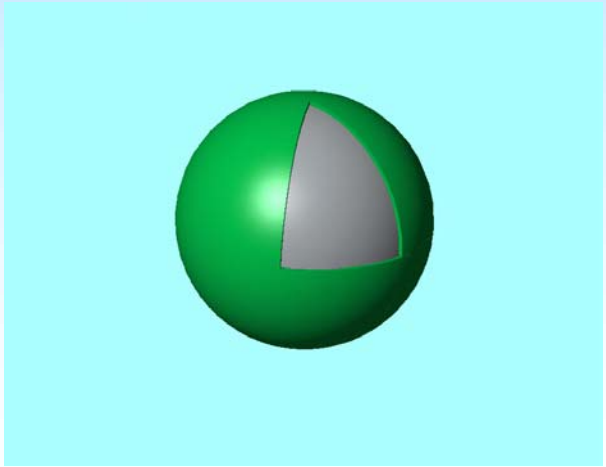
Thick film



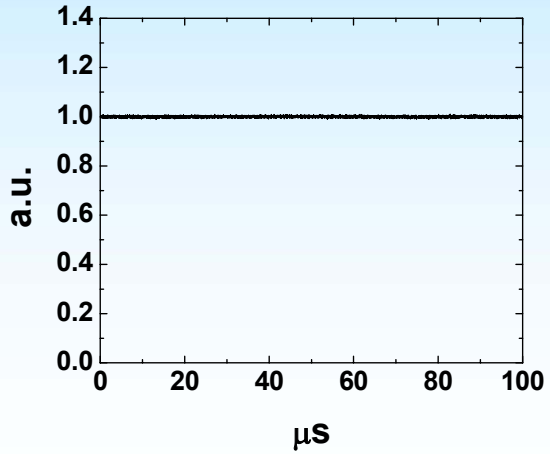
Pulsation Operation



Thin film



CW Operation



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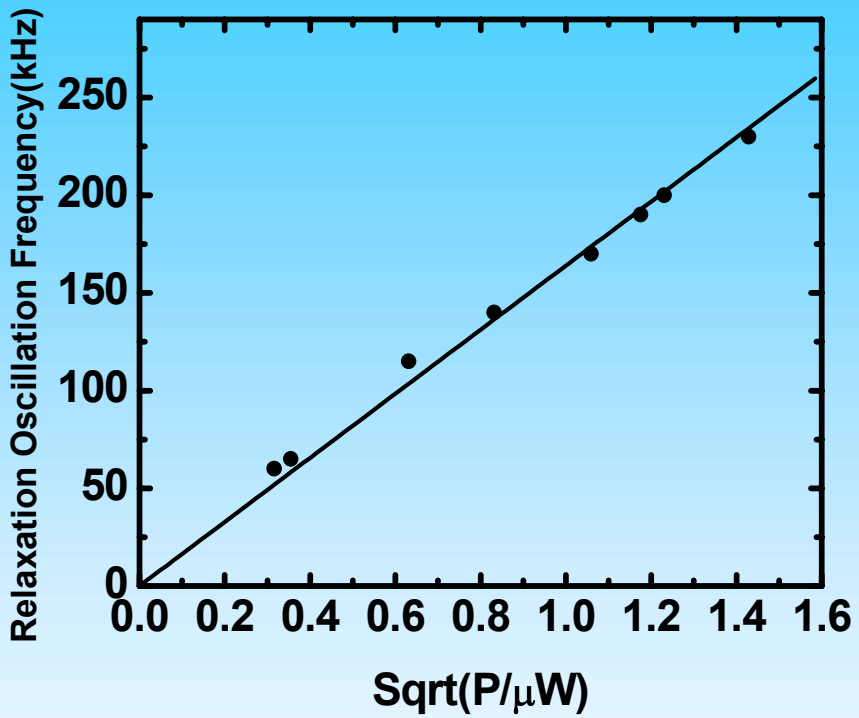
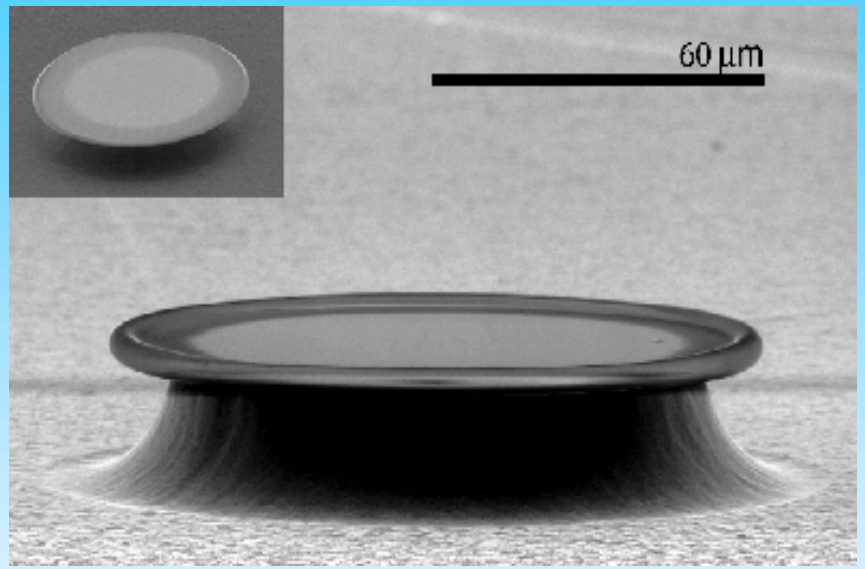
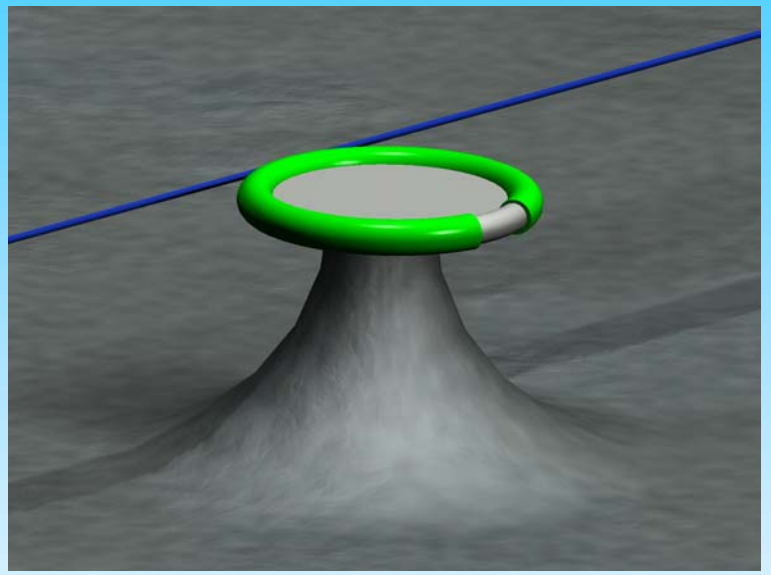
Relaxation Oscillation vs. Laser Output Power



- Sphere diameter is 60-μm; doped sol-gel shell thickness is 5-μm
- Relaxation oscillation frequency has a linear relationship with the square root of the laser output power

Future Work





- Surface functionalized microtoroid cavity ⇒ Microlaser on a chip

"Ultra-high-Q toroid microcavity on a chip", *Deniz Armani, Tobias Kippenberg, Sean Spillane and Kerry Vahala,* Nature, Vol. 421, 925-929, 2003

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Summary

- Low threshold surface gain functionalized silica microsphere lasers are achieved*
- By varying the thicknesses of the doped sol-gel layer,we can alternate between:
  - Pulsed operation
  - CW operation
- Future work: surface functionalize microcavity on a chip

*Lan Yang and Kerry Vahala Optics Letters, vol. 28, No. 8, 592-594

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Presentation will be available at http://www.its.caltech.edu/~vahalagr

Thanks for you attention!

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