Low-threshold Fiber-coupled Erbium Microlasers on a Chip

Lan Yang, Deniz Armani, Kerry Vahala

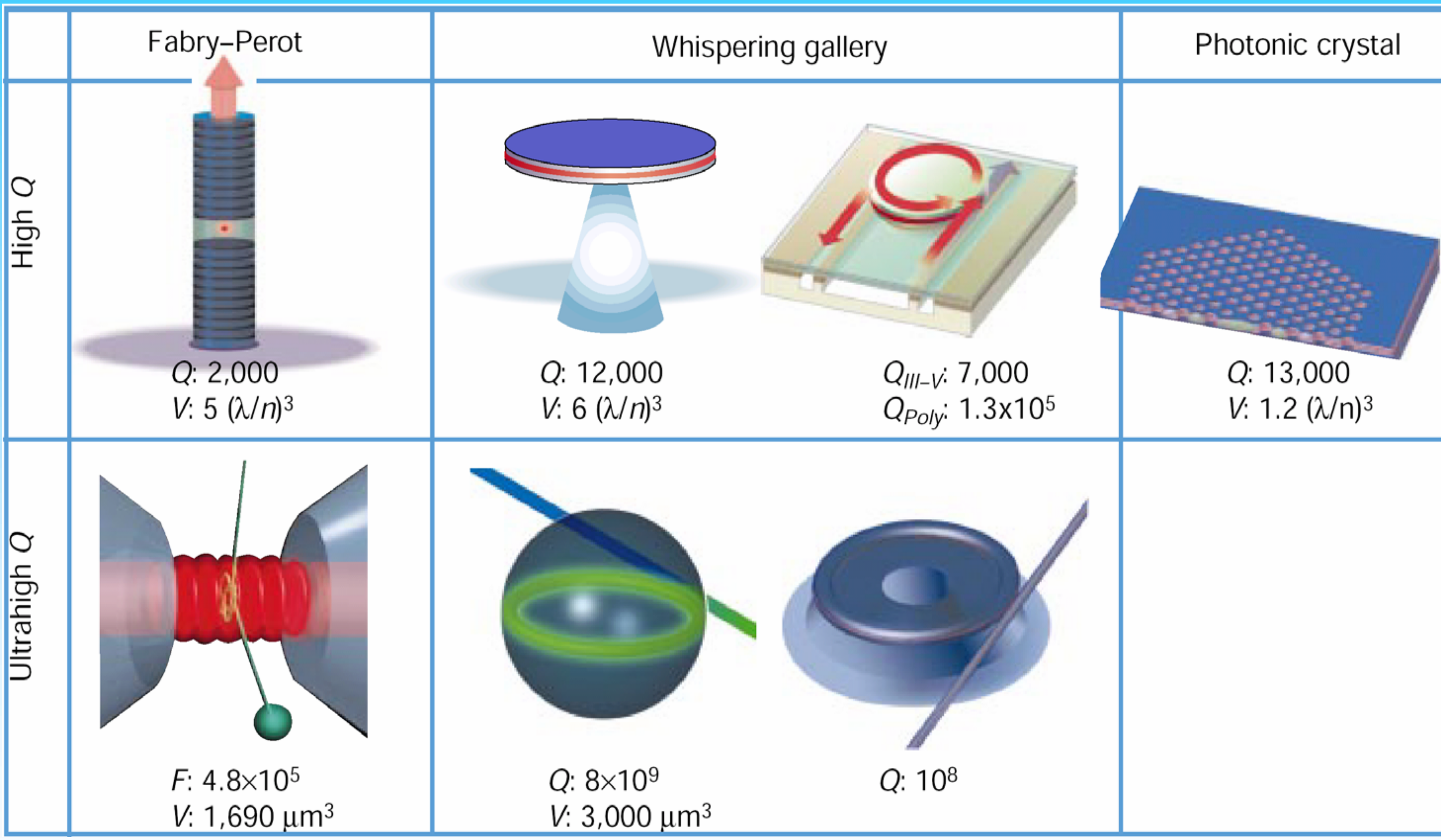
Department of Applied Physics
California Institute of Technology

http://www.its.caltech.edu/~vahalagr

Outline

- **Introduction**
  - **Background and motivation**
- **Experimental results**
  - **Process flow for ultra-high-Q planar microcavities**
  - **Sol-gel technology and surface functionalization of a microcavity on a chip**
  - **Laser performance of the microlasers**
- **Future work**

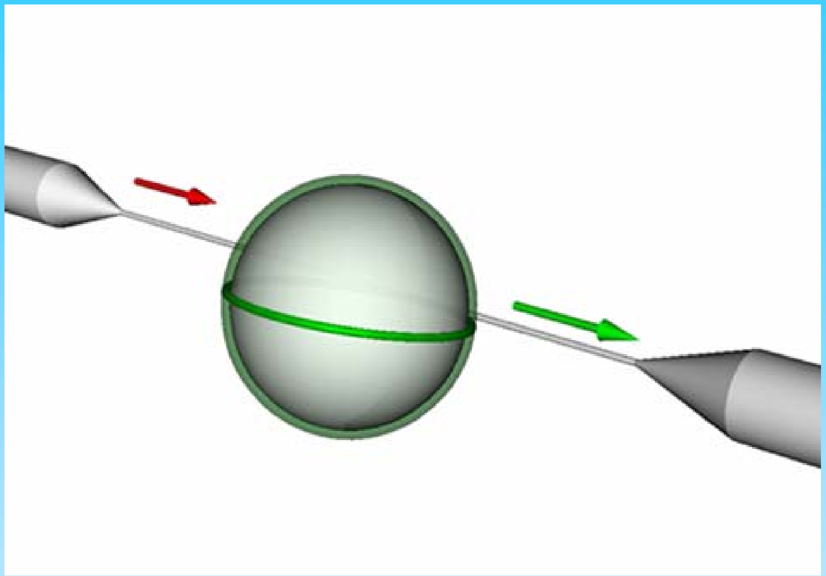
Introduction to Microcavity



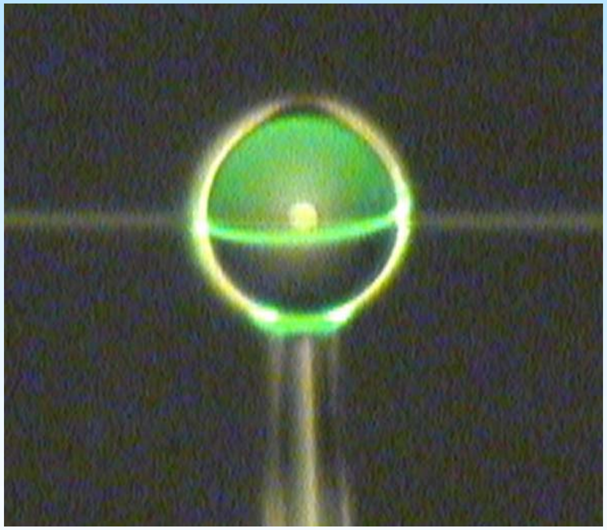
"Optical microcavities", *Kerry Vahala,* Nature, Vol. 424, pp. 839, 2003

http://www.its.caltech.edu/~vahalagr

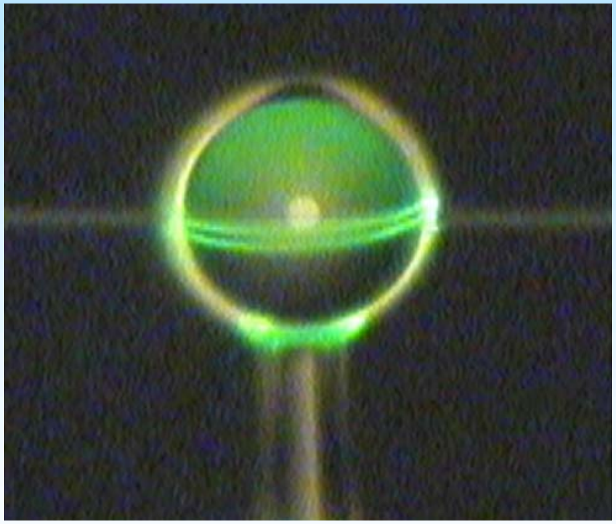
Previous work



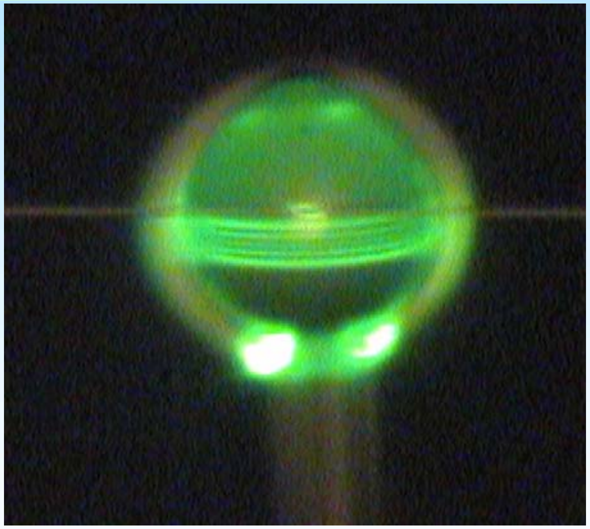
- **Surface functionalization: Er-doped sol gel thin film coated microsphere**
- **Both doping concentration and thickness could be adjusted, so that both cw and pulsed operation are possible**



m=l



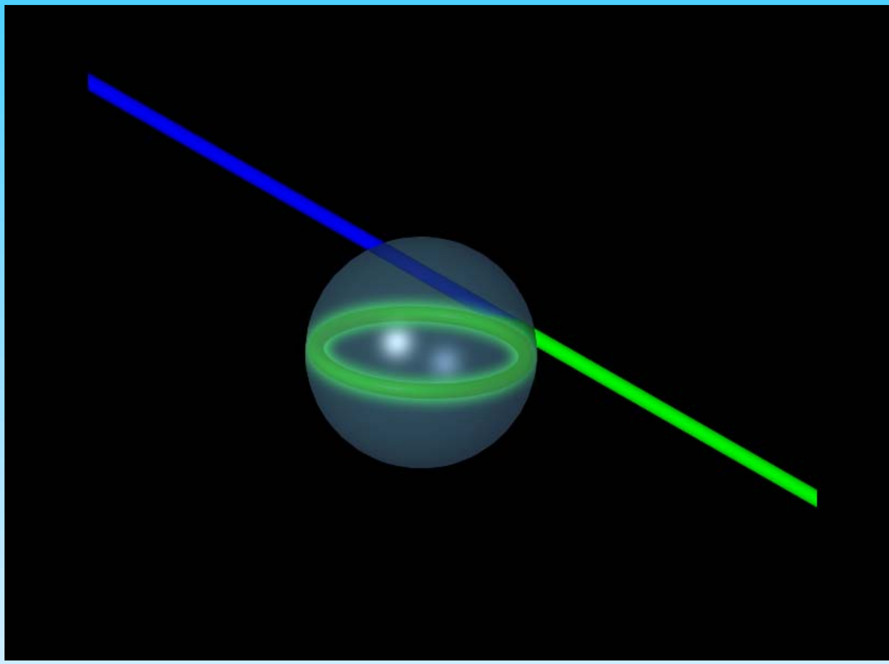
m=l-1

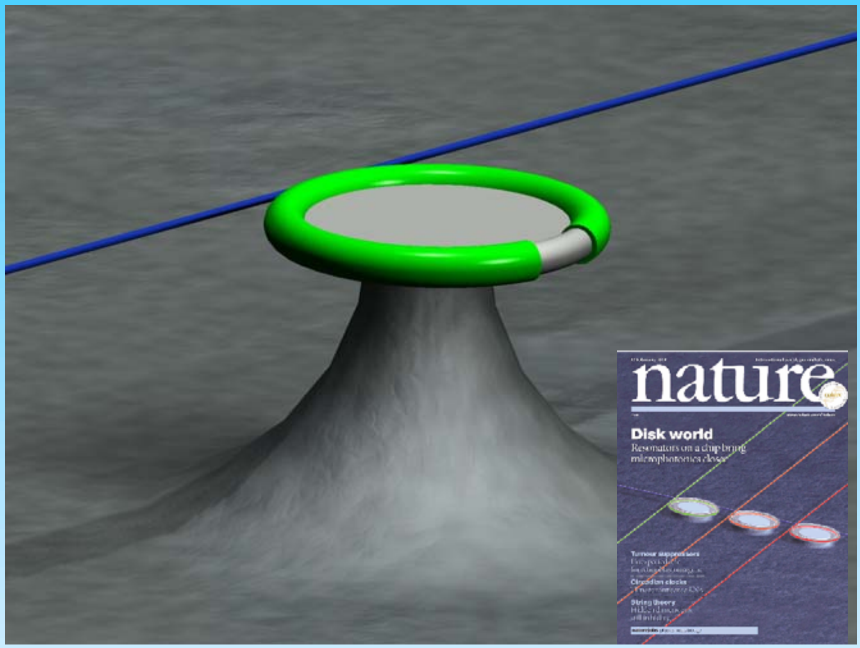


m=l-4

http://www.its.caltech.edu/~vahalagr

Motivation





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

- **Chip-based microcavities are integrable with other optical or electronic components**
- **Simplified mode spectrum compared with microsphere cavities**

http://www.its.caltech.edu/~vahalagr

Surface Functionalization of Microtoroid

Fabrication of microtoroids

Preparation of sol gel

↓

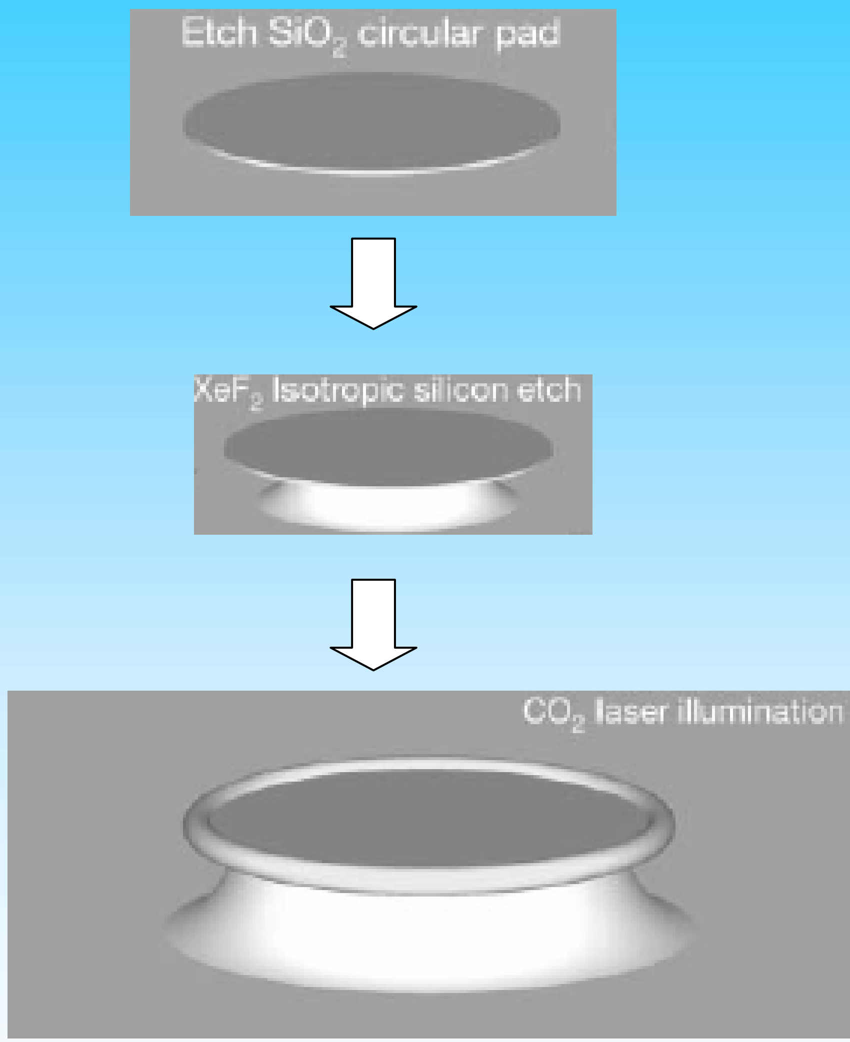
Surface functionalized microtoroids

↓

Microlasers on a chip

http://www.its.caltech.edu/~vahalagr

Process Flow for Ultra-high-Q Microcavity



Steps:

1. Use XeF_2 etch to remove Si,
   (SiO_2 disks act as etch mask during the XeF_2 etching process)
2. Selectively heat and reflow the undercut SiO_2 disks using a CO_2 laser(10.6 microns)
   (SiO_2 has a strong optical absorption at 10.6 microns)

Ultra-high-Q planar microcavity

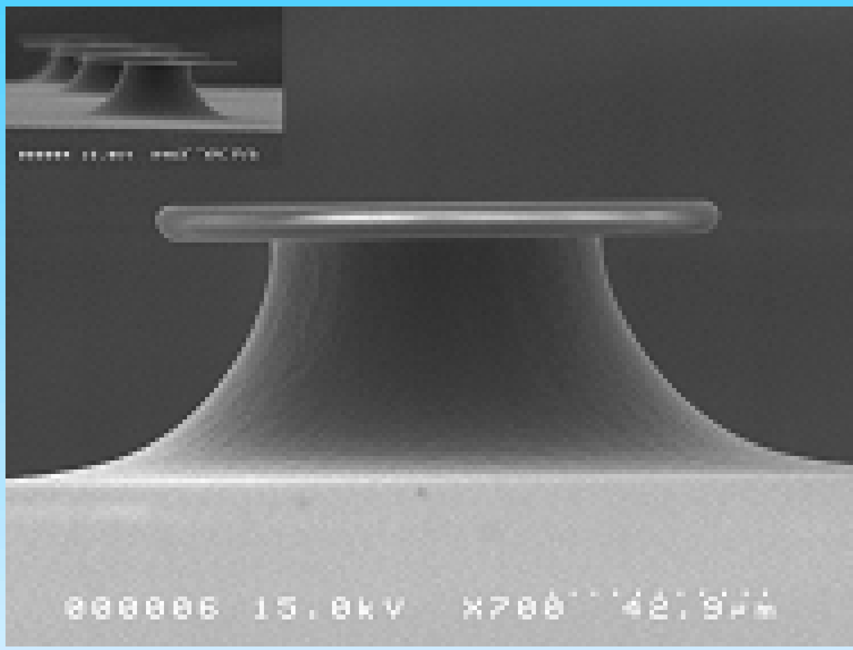
http://www.its.caltech.edu/~vahalagr

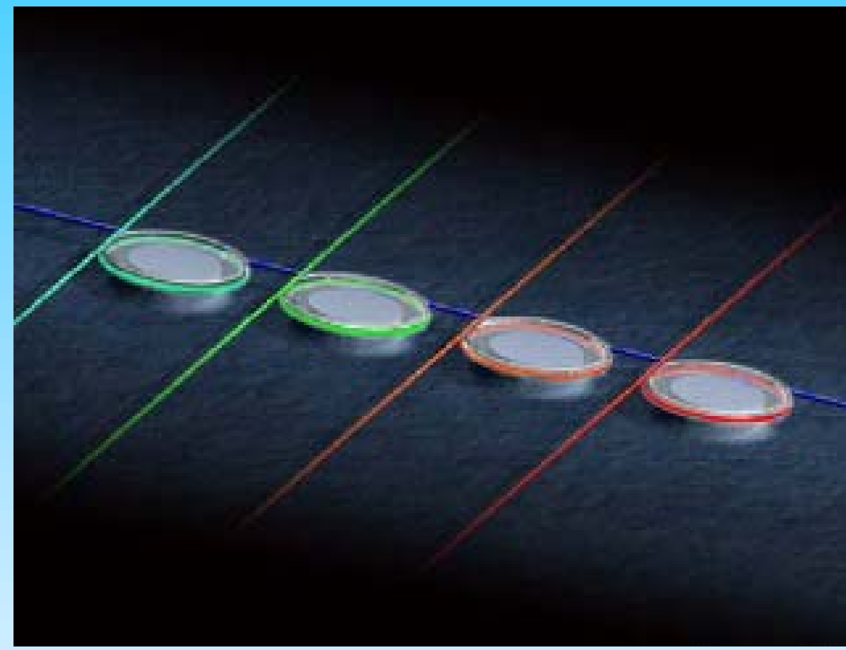
Silica Reflow Process

- SiO_2 has a strong optical absorption for CO_2 laser
- Si pillar under the silica disk works as a thermal sink
- Typical laser intensity ~100 MW/m^2

http://www.its.caltech.edu/~vahalagr

Ultra-High-Q Microcavity on a Chip





Advantages:

- **Fabricated in parallel using wafer-scale processing methods**

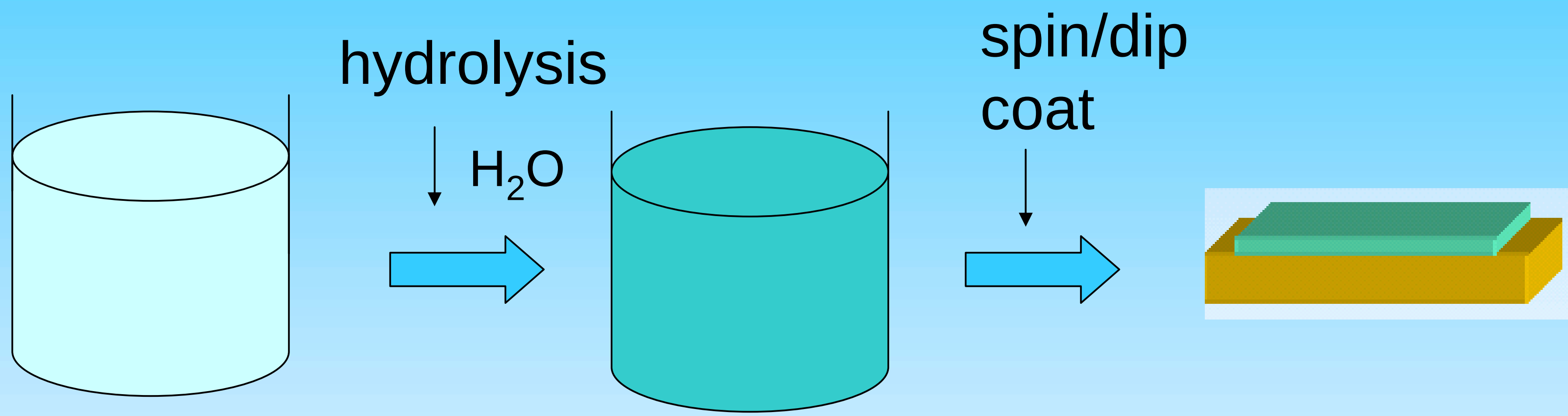
"Ultra-high-Q toroid microcavity on a chip", *Deniz Armani, Tobias Kippenberg, Sean Spillane and Kerry Vahala,* Nature, Vol. 421, 925-929, 2003

http://www.its.caltech.edu/~vahalagr

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

Sol-gel solution

Microtoroid

Dip coating

Heating at 160°C

Multiple process

Reflow and densification

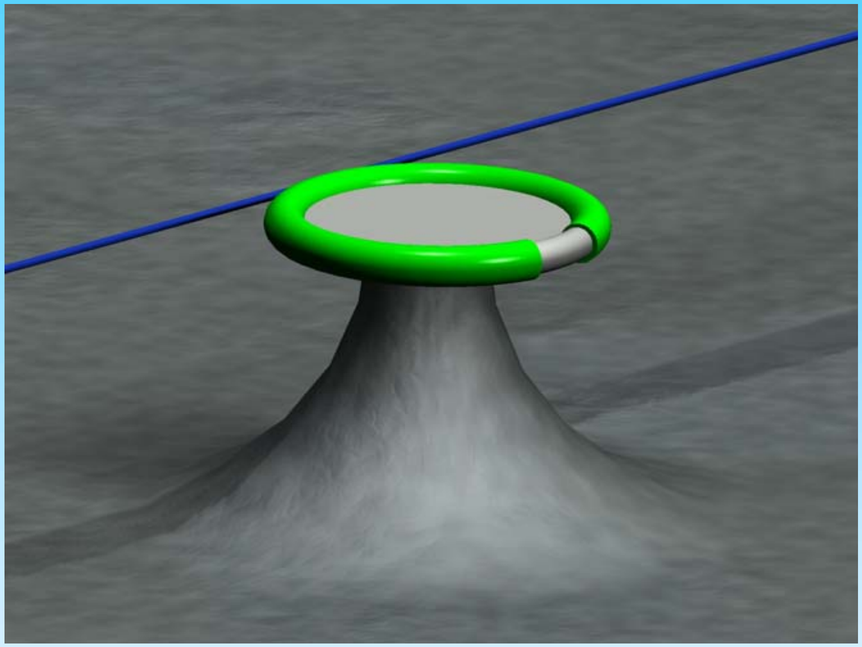
CO_2 laser processing

Etching in buffered HF

Surface functionalized Microlaser on a chip

http://www.its.caltech.edu/~vahalagr

Microlaser on a Chip



- Surface functionalized microtoroid cavity ⇨ Microlaser on a chip

"Fiber-coupled erbium microlasers on a chip", *Lan Yang, Deniz Armani, and Kerry Vahala,* Appl. Phy. Lett., Vol. 83, 825-826, 2003

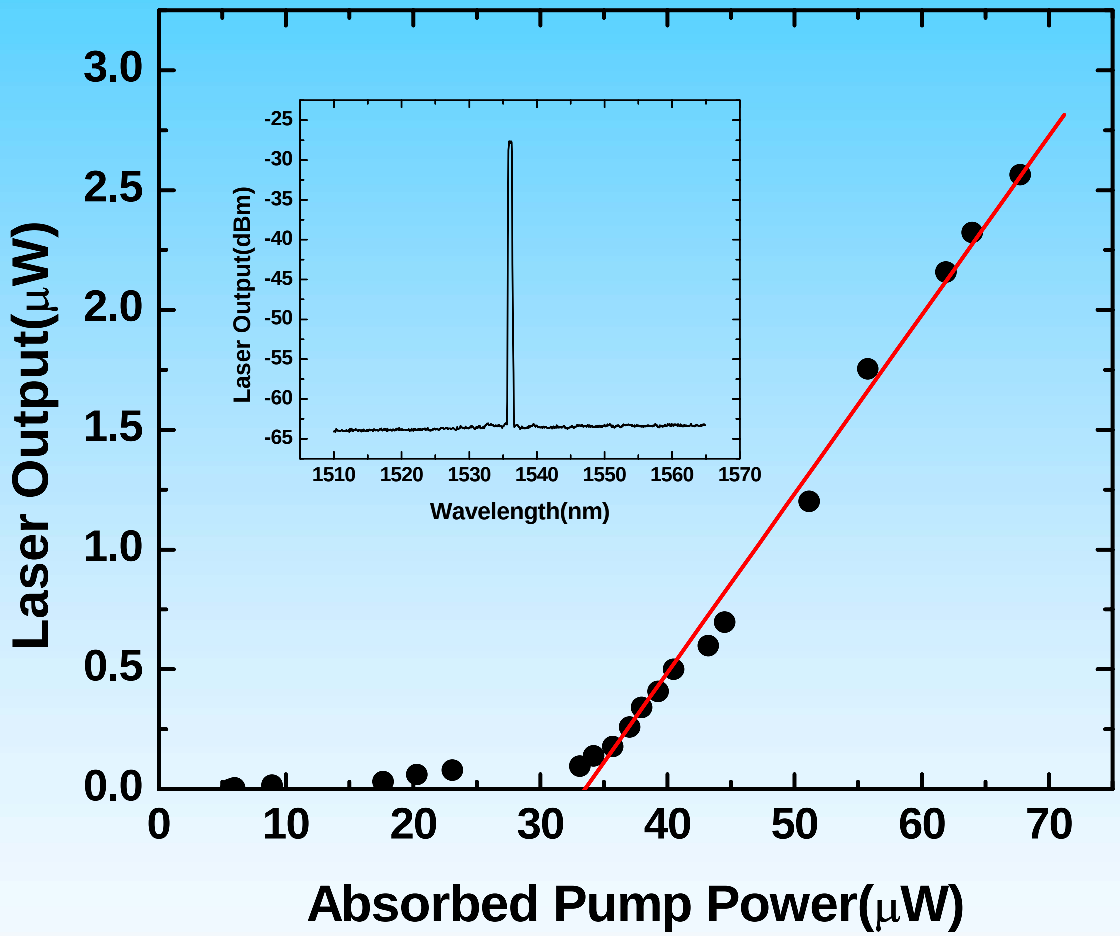
http://www.its.caltech.edu/~vahalagr

Achieve Low Threshold

Limiting Factors	Our solutions
Materials loss	Low loss medium
Surface scattering	CO_2 reflow process
Large mode volume	Highly confined mode
Low coupling efficiency	Efficient fiber taper coupling scheme

http://www.its.caltech.edu/~vahalagr

Laser Performance



- Toroid diameter is 80-μm
- Pump wave is in the 980-nm wavelength band
- Differential quantum efficiency:

$$\eta = \frac{P_{laser}}{P_{pump} - P_{th}} \frac{\lambda_{laser}}{\lambda_{Pump}} \sim 11\%$$

http://www.its.caltech.edu/~vahalagr

Future Work

- **Investigate on factors that affect the coupling efficiency between microtoroid and taper:**
  - **Air gap between resonators and coupling taper**
  - **Phase matching and field overlap between taper and resonators modes**

- **Study variations on surface functionalization:**
  - **Doping concentration**
  - **Different doping ions: Er-Yb codoped, Nd, etc**

- **Integration with other electronic and optical components**

Summary

- Surface functionalization of ultra-high-Q microcavity on a chip
- First chip-based erbium microlasers demonstrated
    - single mode
    - ultra-low threshold
- Future work: further characterization of the laser performance

http://www.its.caltech.edu/~vahalagr

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

Thanks for your attention!