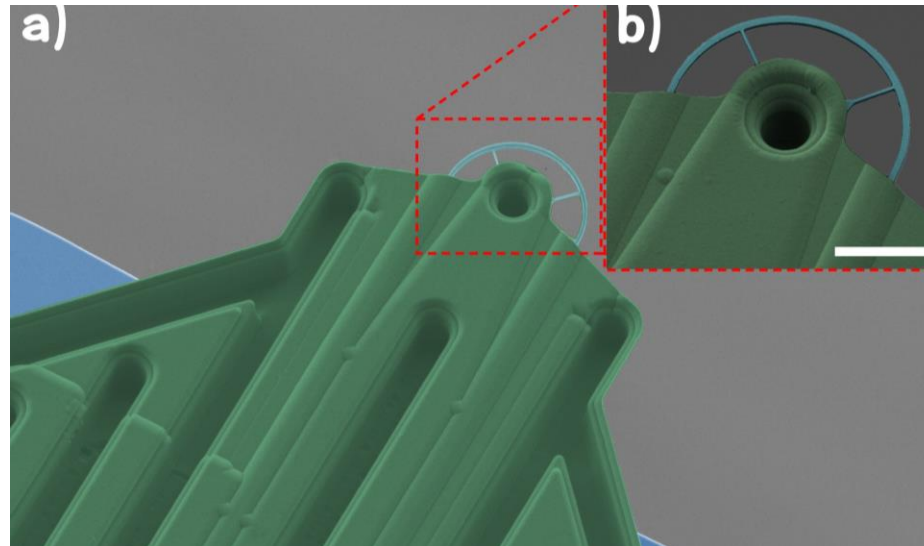


# Microfabricated Photonic Probes

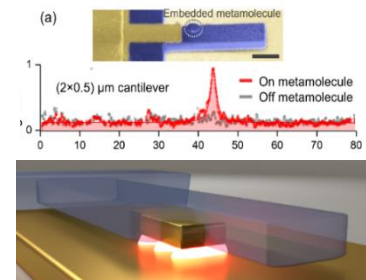


Vladimir Aksyuk  
Physical Measurement Laboratory

FCMN 2019

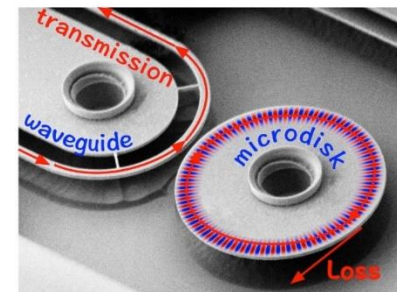
## ■ Experiment on chip

- Implement custom multiphysics coupling
- Study a specific effect



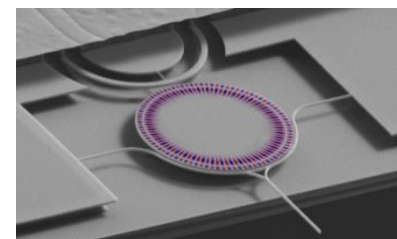
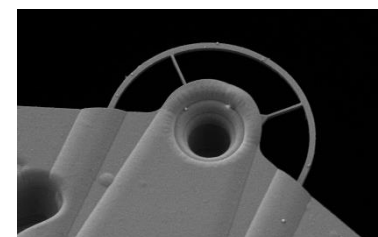
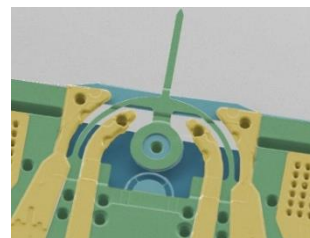
## ■ Technology block or platform development

- A specific function useful for multiple applications
- Develop fabrication process sequences and designs
- Optimize functional performance



## ■ Instrument on chip

- Leverage a technology platform
- Create and demonstrate a new measurement capability
- A resource useful for others
- Potential technology transition / commercialization



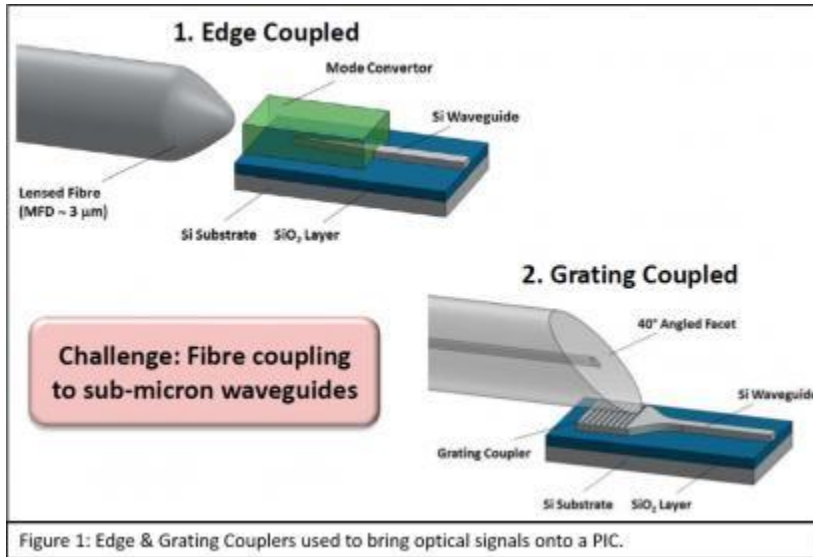
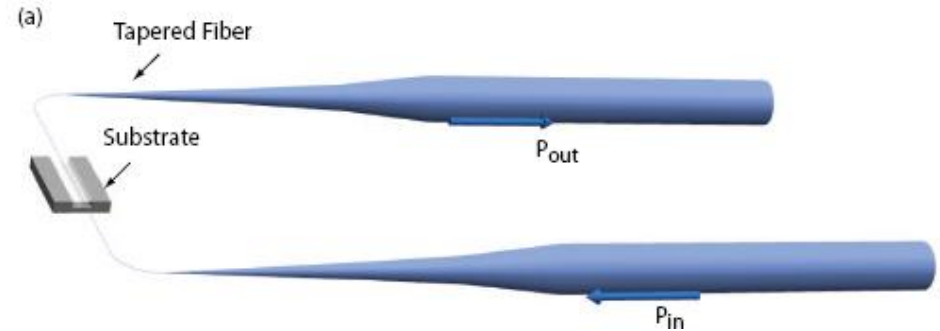
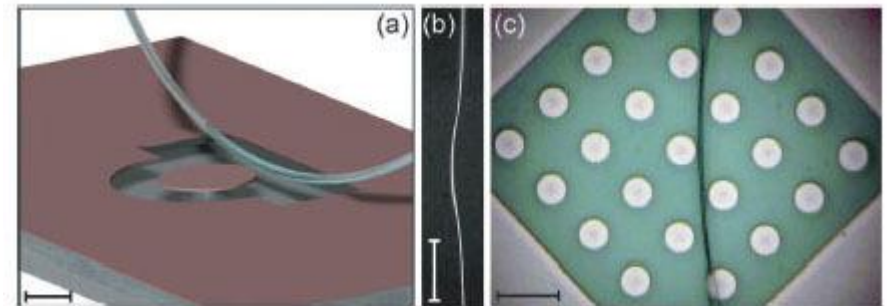


Figure 1: Edge & Grating Couplers used to bring optical signals onto a PIC.

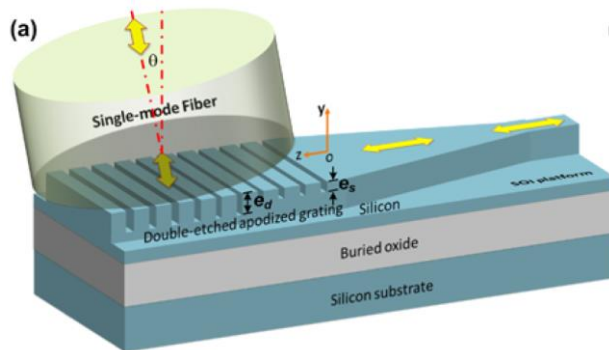
M. Heins, "Mind The Gap - Boarding the Silicon Photonics Packaging Train", SemiWiki.com (2016)



Opt. Express **17**, 10542-10563 (2009)



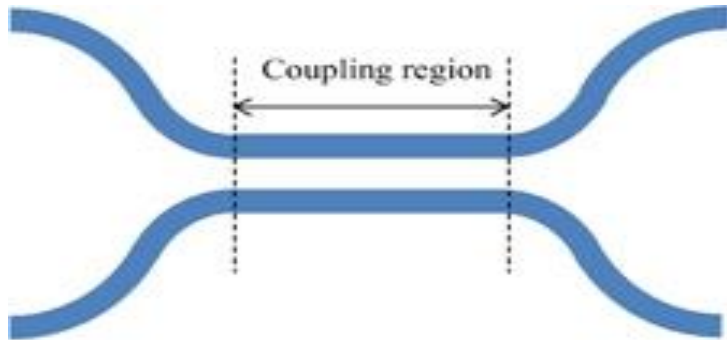
Opt. Express **15**, 4745-4752 (2007)



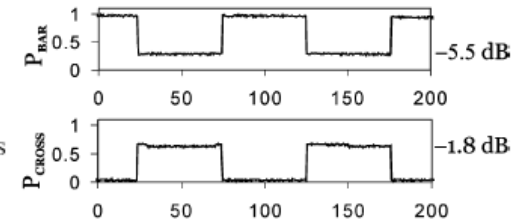
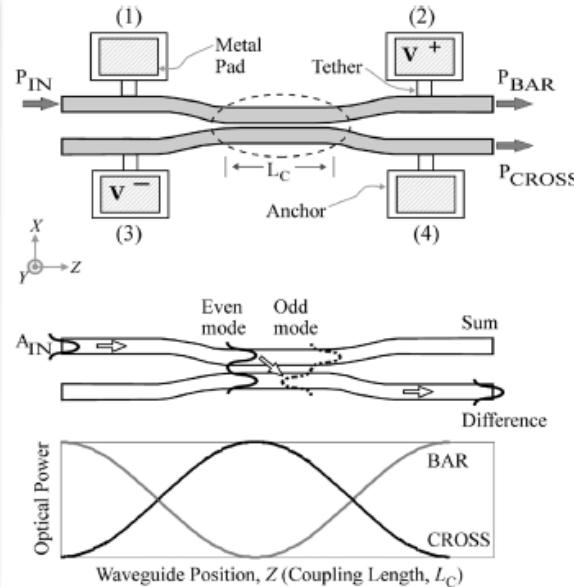
Opt. Express **21**, 7868-7874 (2013)

- Edge coupling requires edge access
- Grating coupling requires gratings
- Fiber tapers are
  - large, flexible, fragile – hard to position
  - low-index – loss into photonics cladding

# On-chip optical connection: evanescent coupling **NIST**

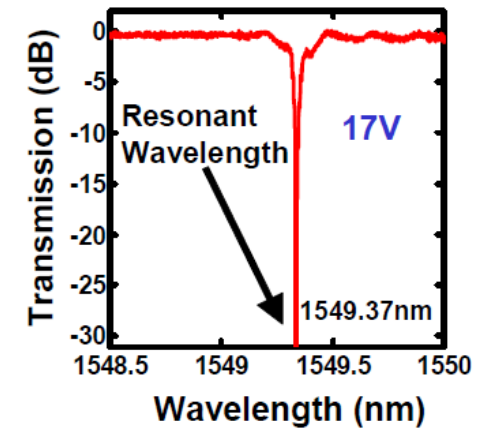
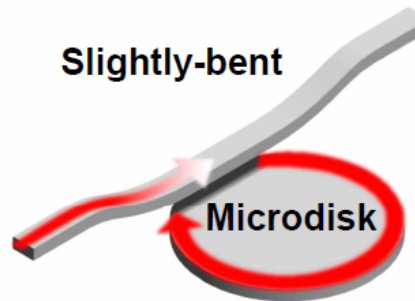
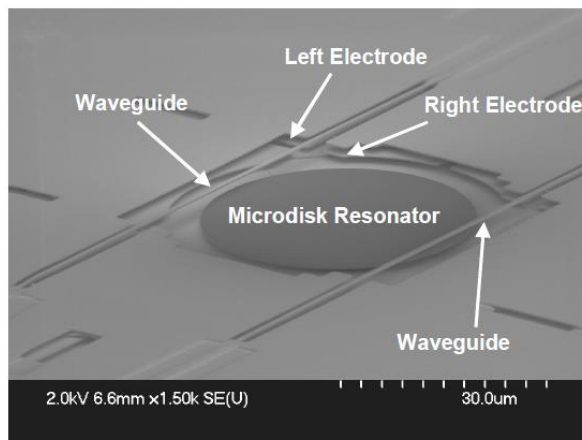


2017 Jpn. J. Appl. Phys. 56 04CA01  
doi:10.7567/JJAP.56.04CA01



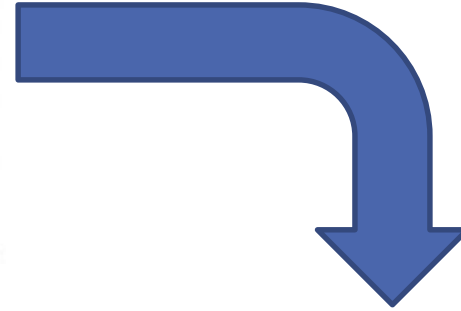
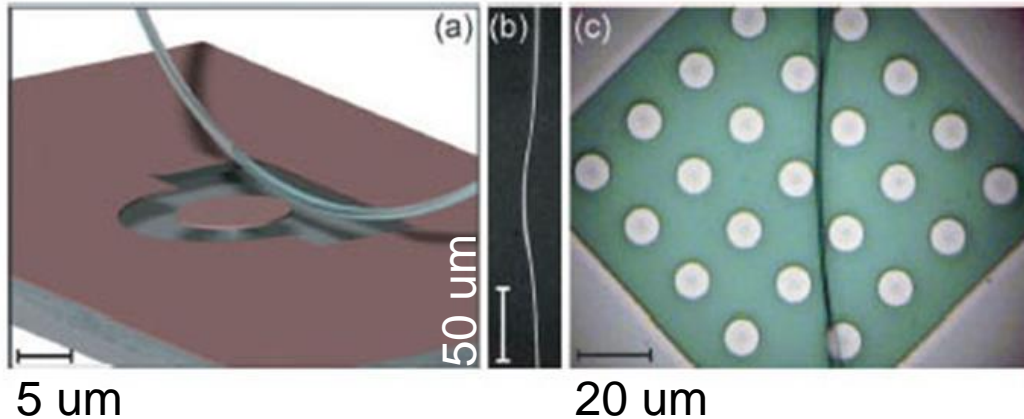
J. MEMS, v. 14, no. 5 (2005)

**Electromechanically tunable**

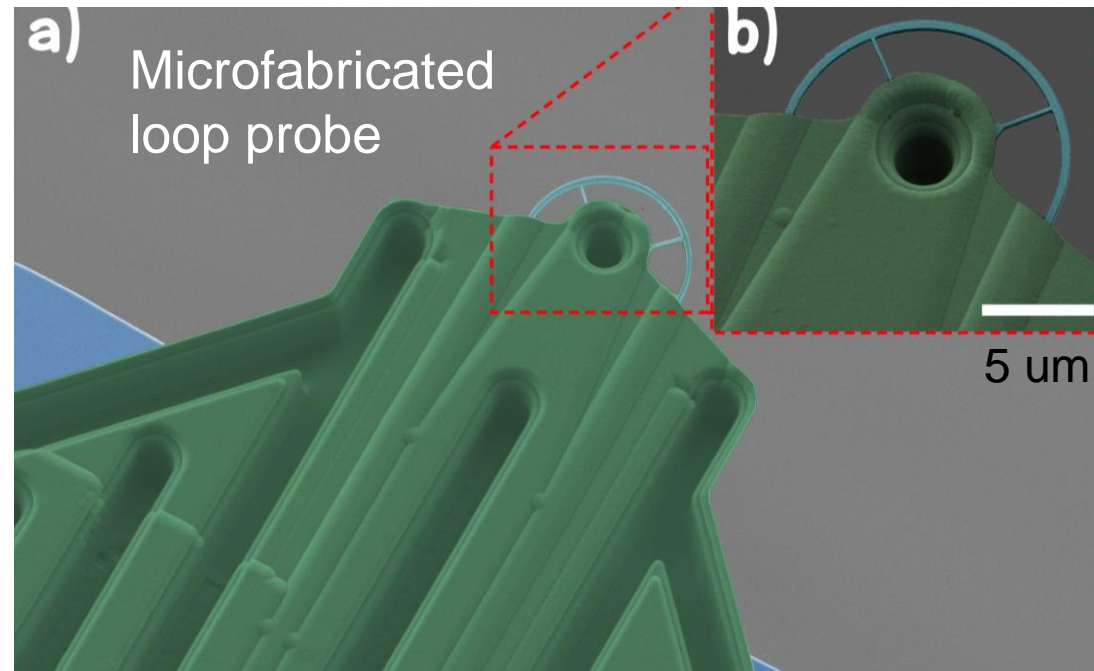


OPTICS EXPRESS Vol. 14, No. 11, 4703 (2006)

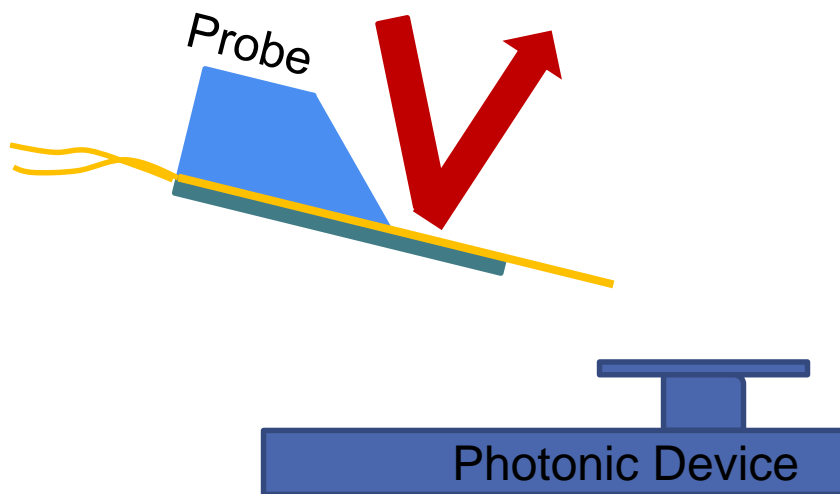
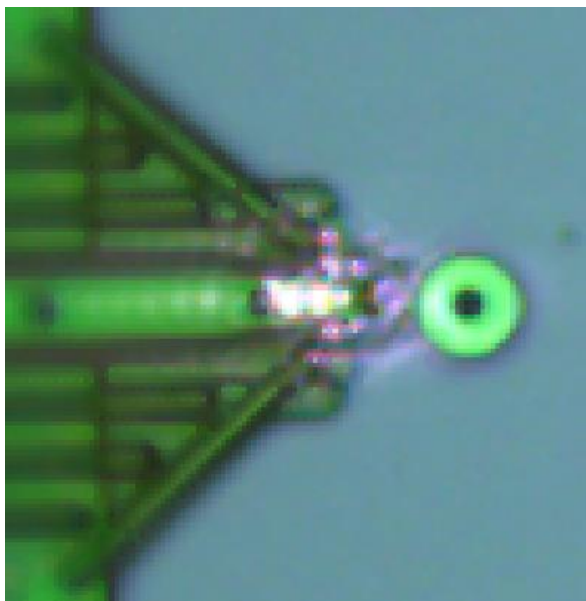
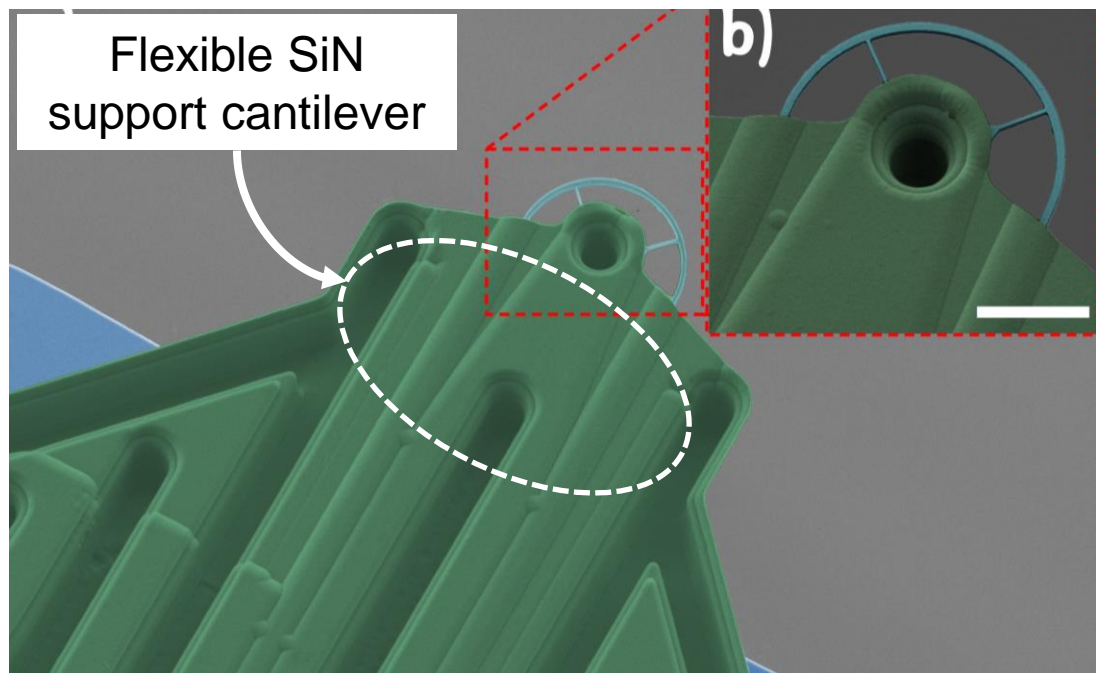
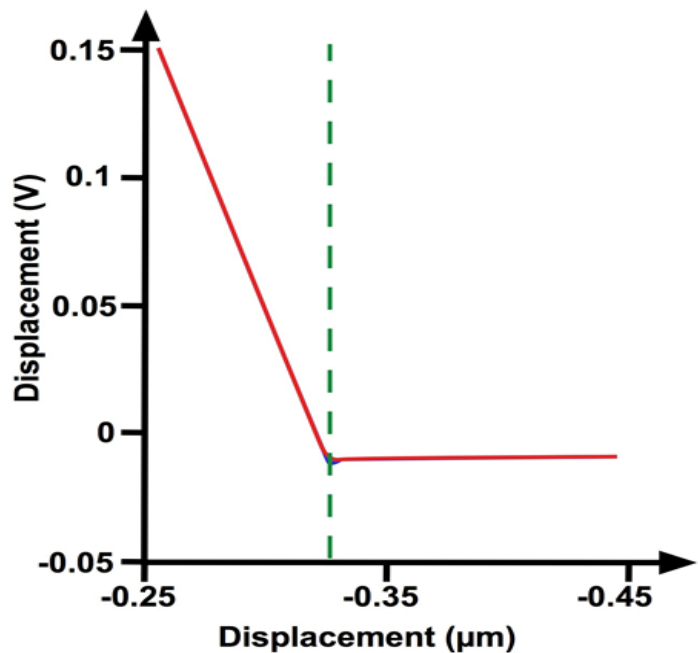
Opt. Express **15**, 4745-4752 (2007)

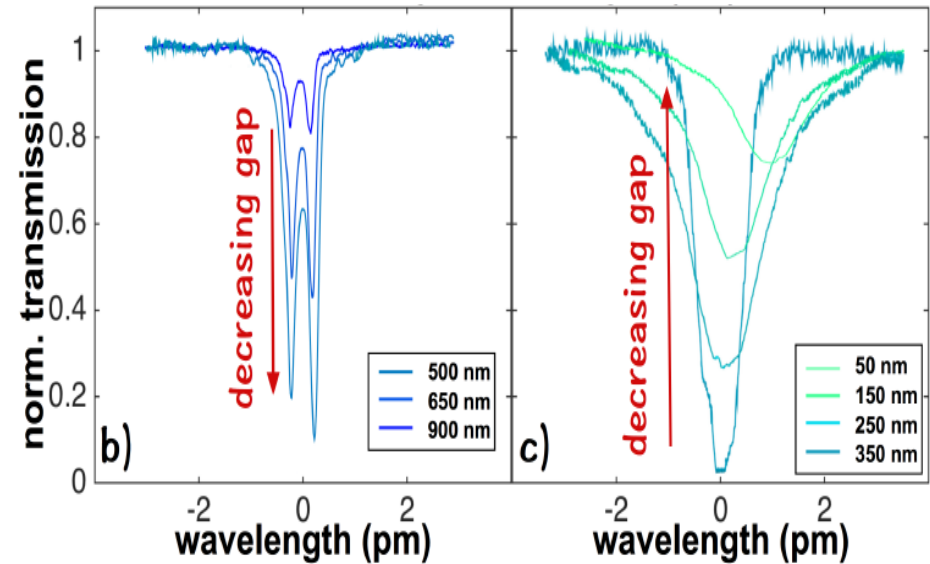
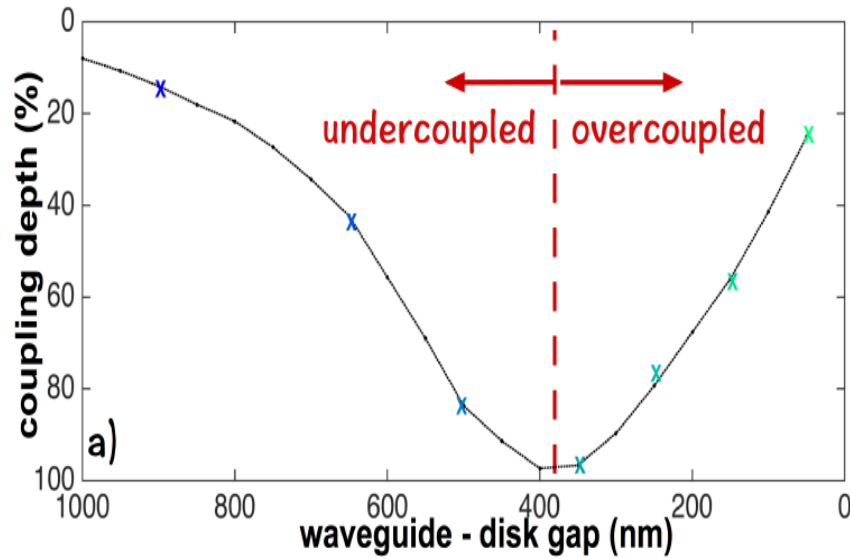


- High-index waveguide
  - No cladding loss
- Small, stiff, robust
  - Fast positioning/scanning
  - No mechanical noise
- Lithographically defined
  - Desired index, optical properties
  - Custom-tuned coupling



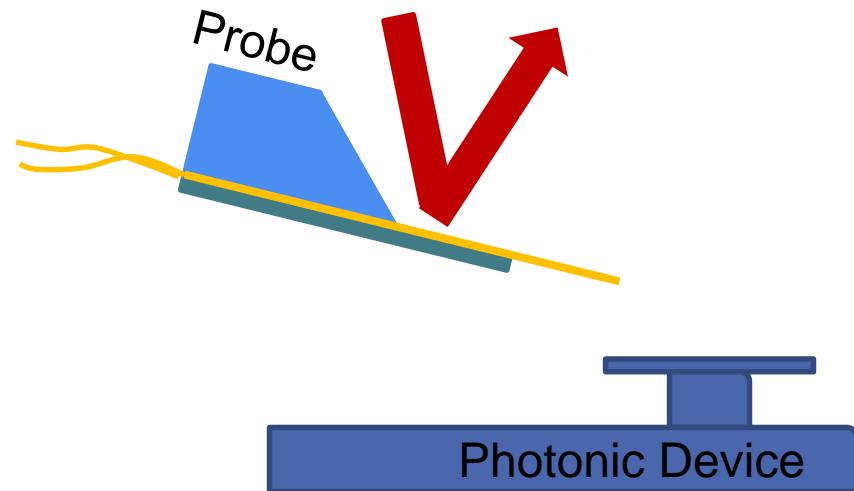




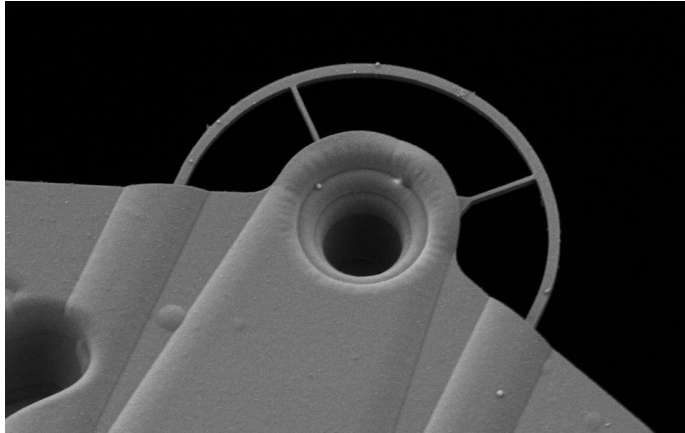


IEEE PHOTONICS TECHNOLOGY LETTERS, VOL. 29, NO. 8, (2017)

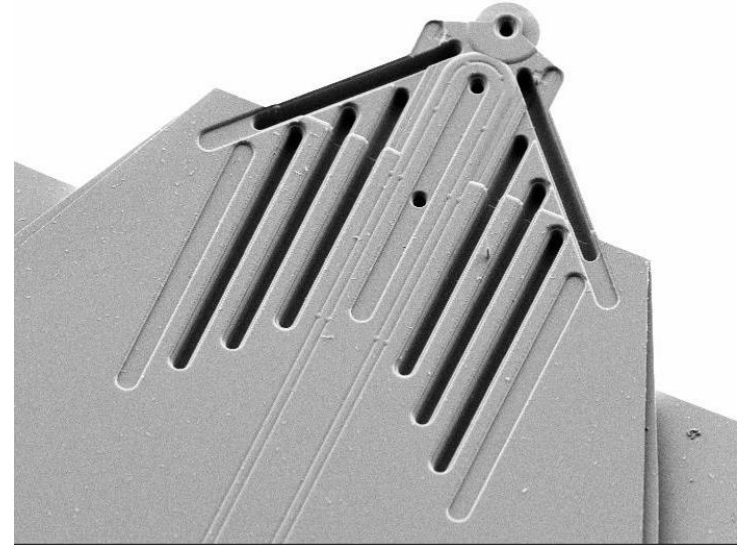
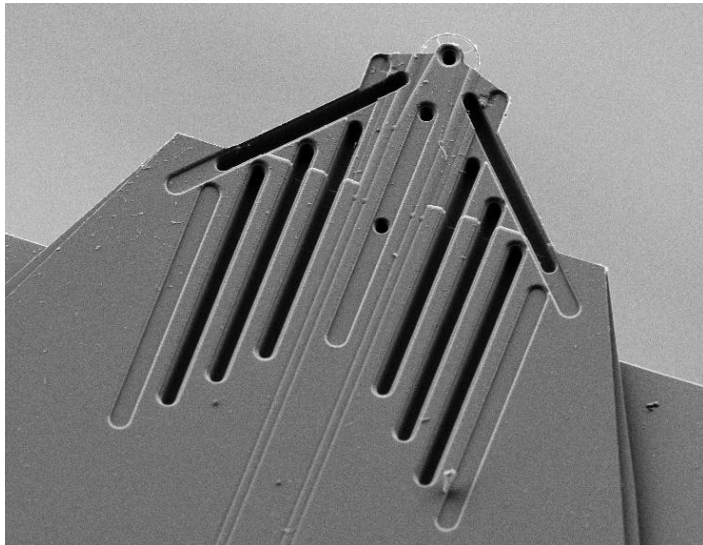
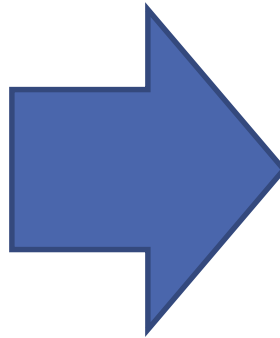
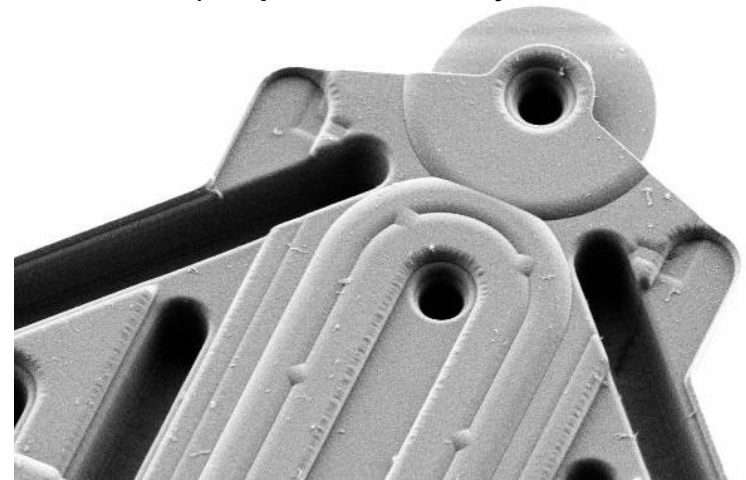
- Fine distance control
- Deep coupling
  - Matching polarization
  - Matching coupling rate



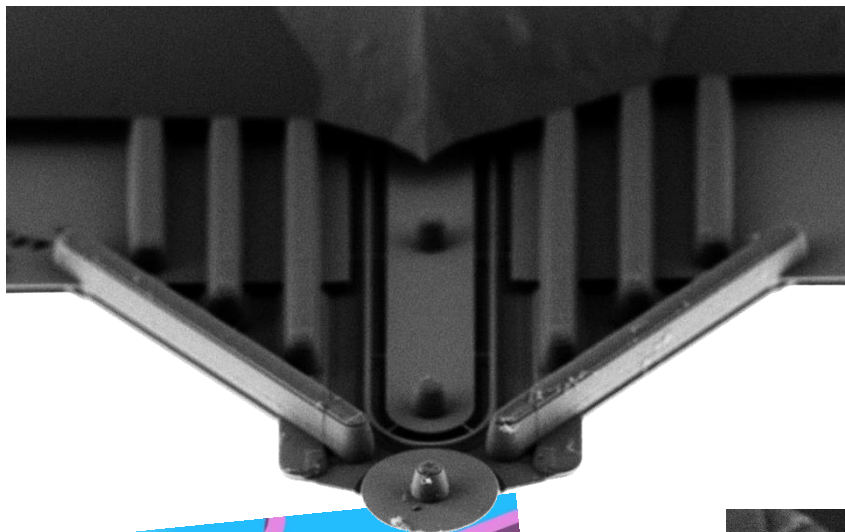
Waveguide Loop



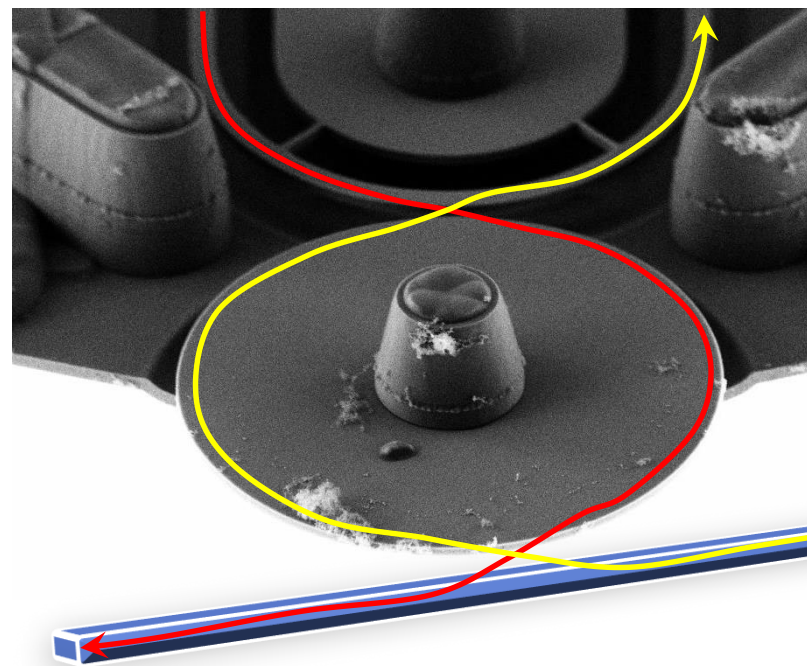
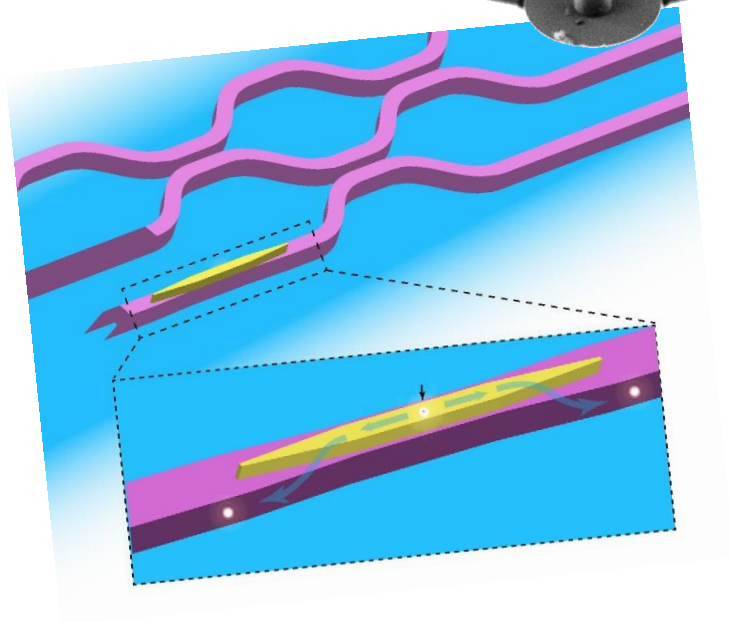
Microdisk resonator  
(or photonic crystal resonator)





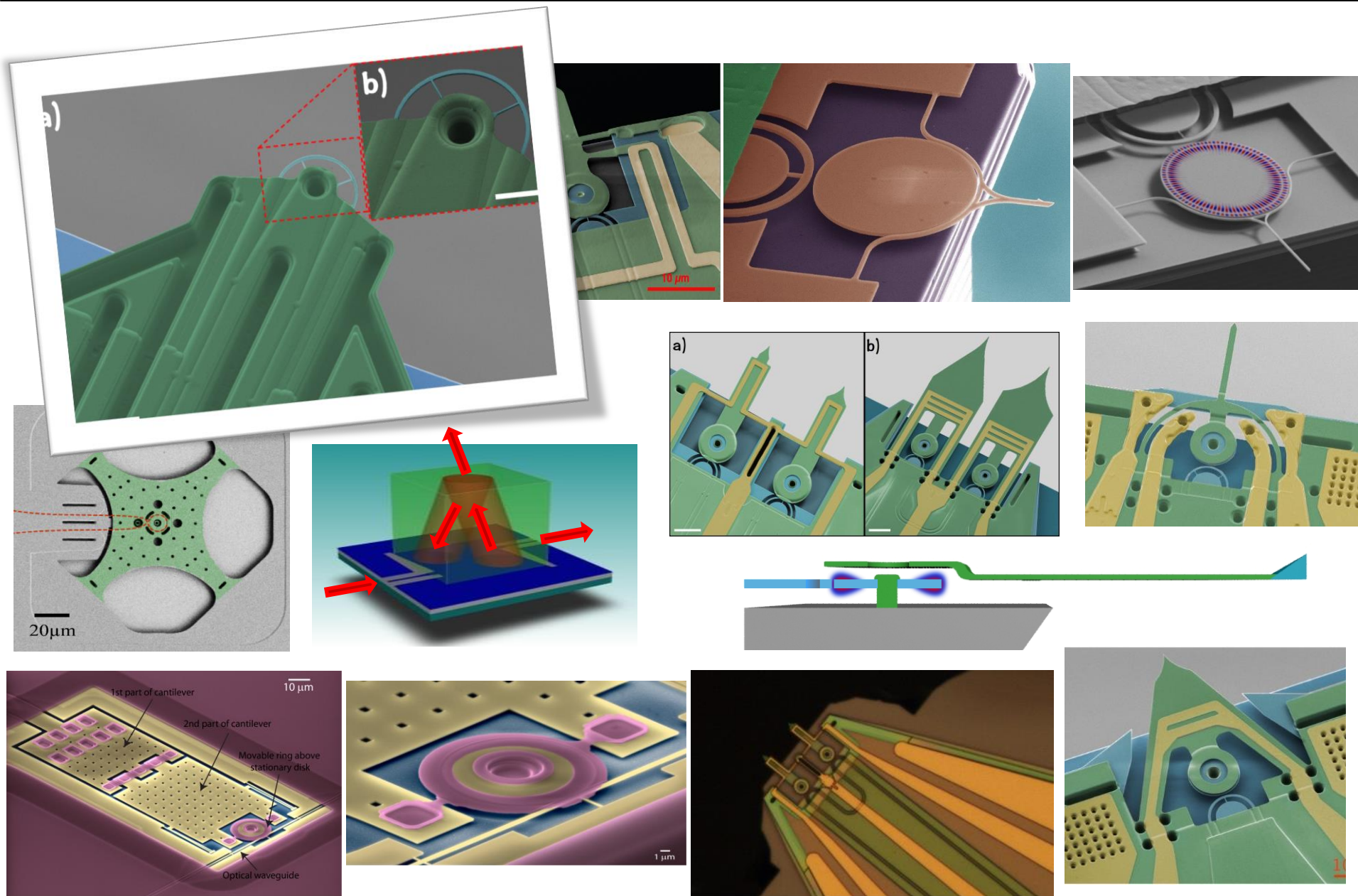


- Wavelength-specific
- Stronger coupling
  - Higher efficiency
  - More local
  - Through thin cladding



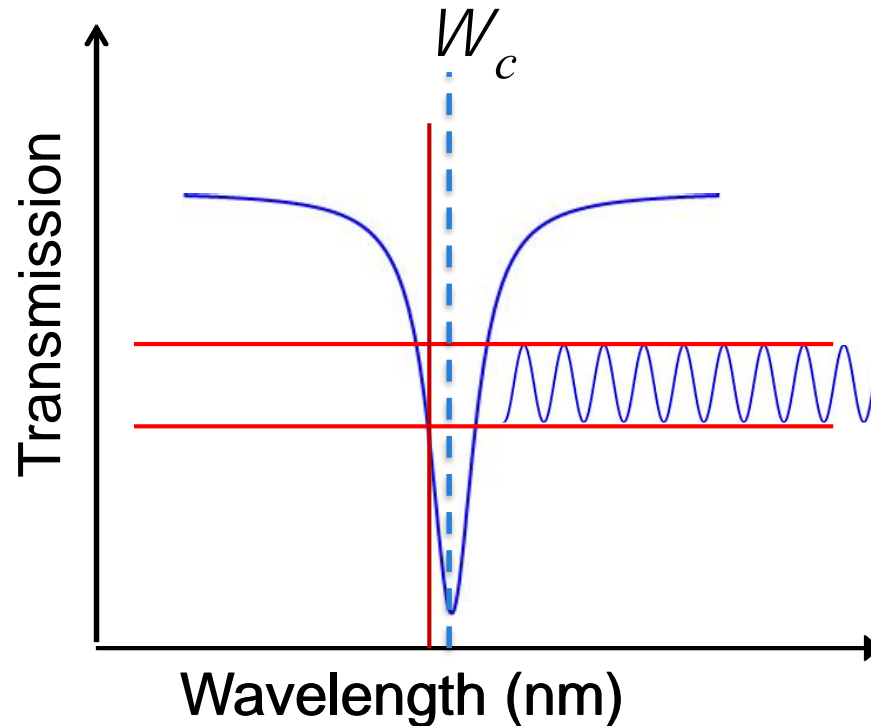
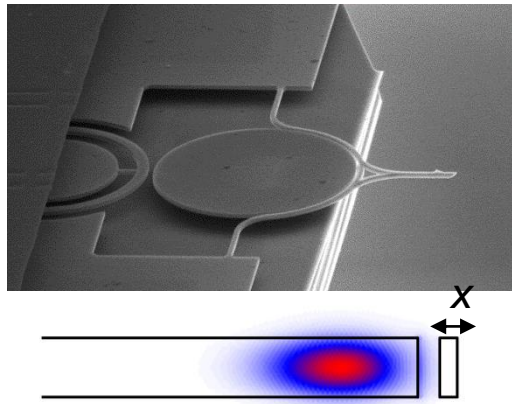
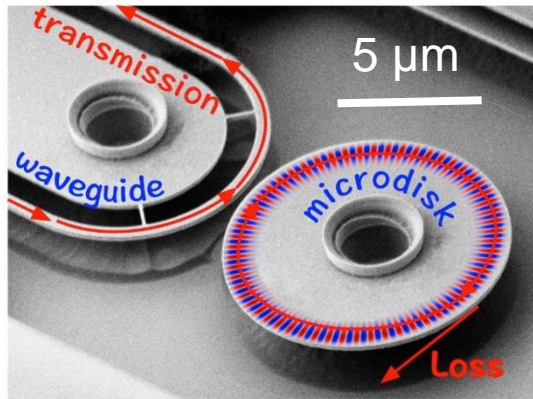
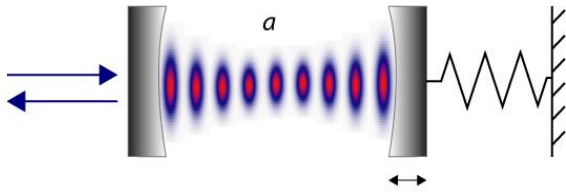
- Microfabrication benefits
  - Lithographically defined shape
  - Small and stiff
  - Batch fabrication possible
- High effective index, controlled by design
  - Local, broadband, deep coupling
- Micromechanical cantilever integrated
  - Mechanical compliance to avoid damage
  - In-contact measurements simplified
- AFM integration
  - Accurate and rapid positioning
  - Accurate separation control
- Electrical tuning (in the future)

- Testing of photonic devices at wafer level
  - Packaging is expensive
  - Use of known good die
- In-line testing
  - Actual photonic elements / circuits
  - Dedicated test structures
  - *No gratings or large area couplers*
- Can couple to Si, SiN on/in SiO<sub>2</sub>
- Can move rapidly and accurately in commercial AFM/SPM
  - Wafer-scale AFM instruments
  - Planar fiber pigtailling + micromechanical cantilever
- Multiple test points possible:
  - multiple individual probes
  - array probes





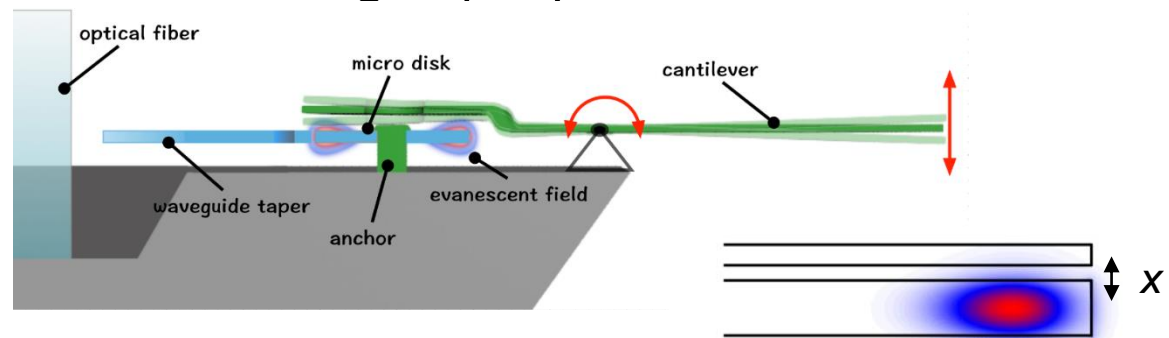
# Cavity-optomechanical motion sensing



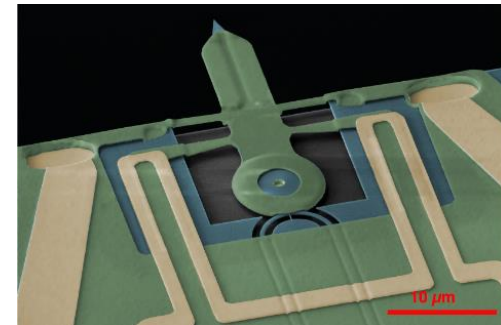
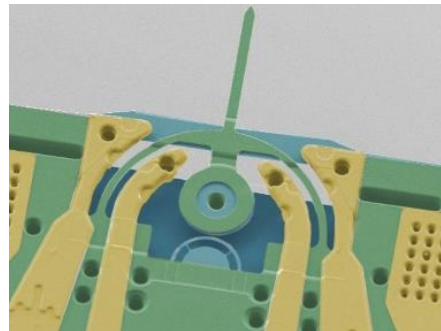
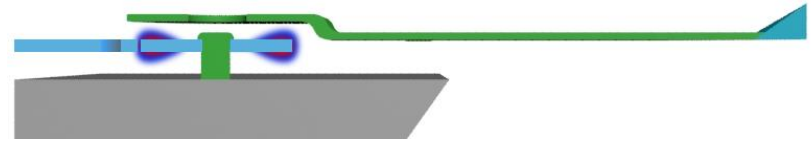
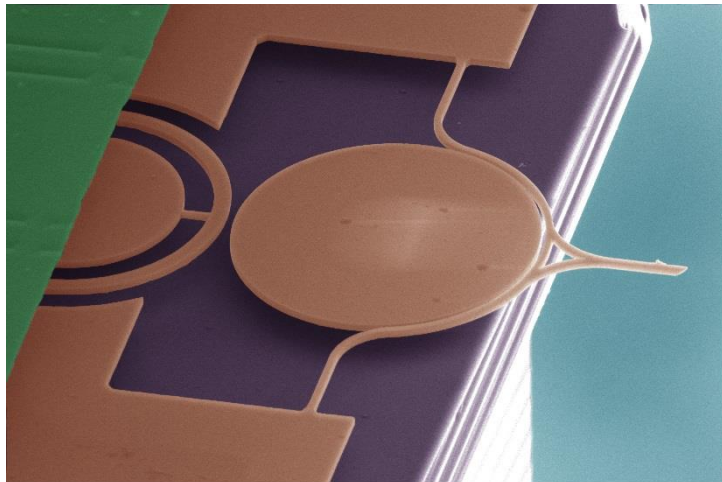
$$g_{OM} = \frac{d\omega_c}{dx}$$

$$\delta\omega_c = \omega_c / Q$$

Displacement  
signal

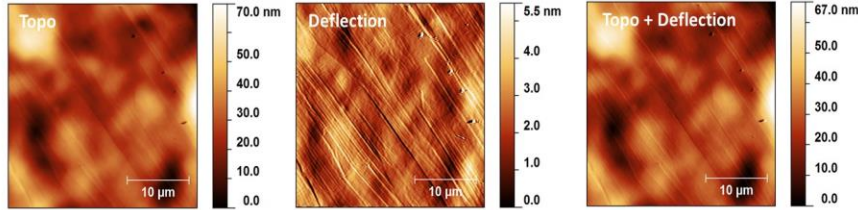


- **FAST**: measure motion at up to 100 MHz to 1 GHz mechanical frequency
  - Optical Q:  $10^4$  to  $10^6$
- **SENSITIVE**: sense  $\approx 1$  pm motion in 1  $\mu$ s (1 MHz)
  - $g_{om} = 1$  GHz/nm to 30 GHz/nm; noise level (0.5 to 5) fm / $\sqrt{\text{Hz}}$
- Self-aligned and stable
- Compact, fiber connectorized, practical
- Electrostatic and thermo-electric actuation and tuning

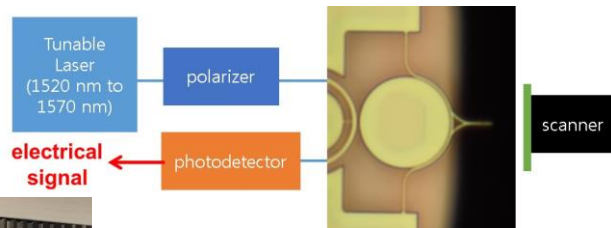
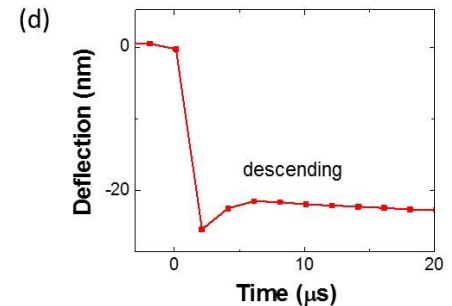
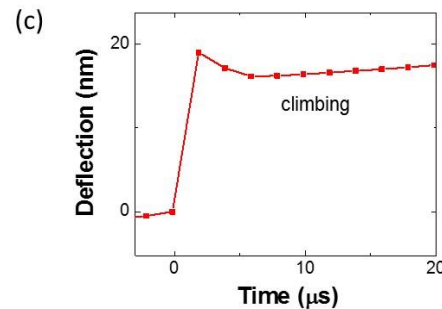
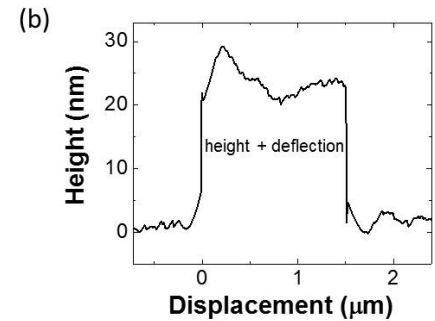
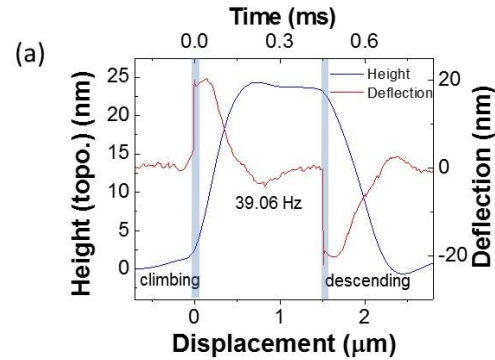
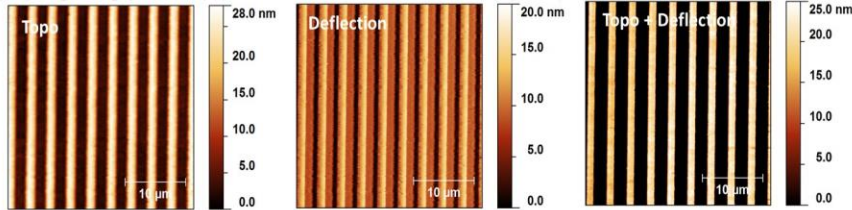


# Fast, low noise contact-mode AFM

(a) HOPG (30 x 30  $\mu\text{m}$ , 39.06 Hz, 2.93 mm/s, 512 x 512 pixels)

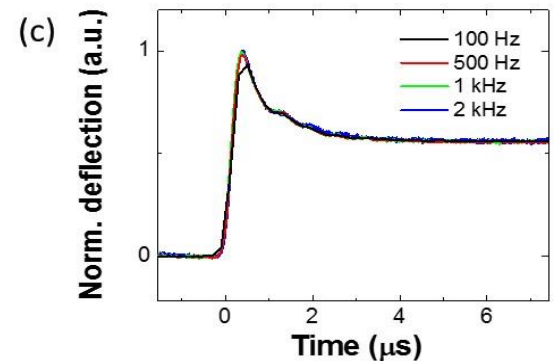


(b) 3  $\mu\text{m}$  grating (30 x 30  $\mu\text{m}$ , 39.06 Hz, 2.93 mm/s, 512 x 512 pixels)



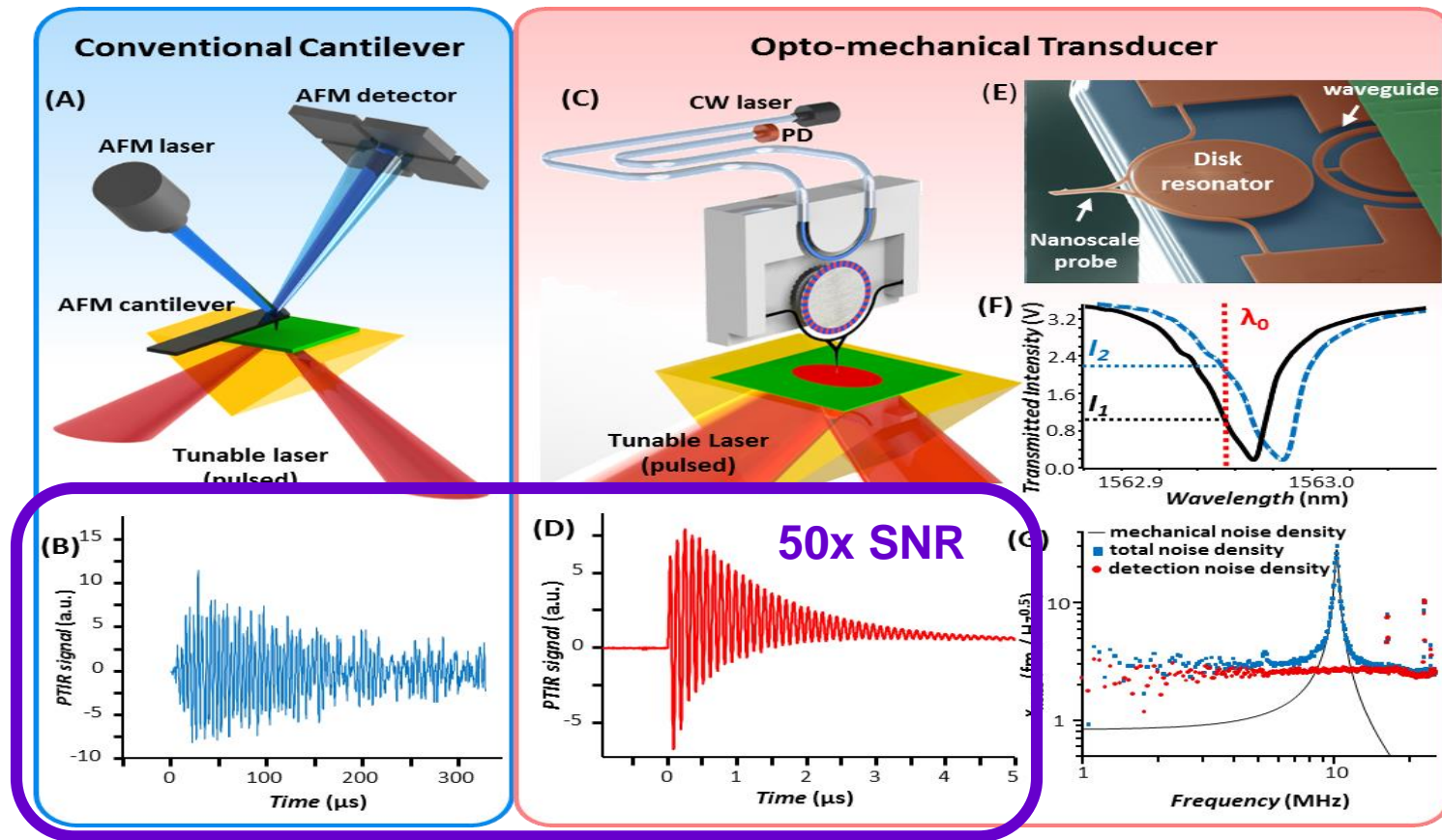
- Microsecond response time
- Few  $\text{fm}/\text{Hz}^{0.5}$  displacement noise
- < 20 pm RMS per point (2  $\mu\text{s}$ )
- Approx. 5 nN force

Toward HD, video-rate AFM



# Dynamic nano-AFM probe: enabling advanced PTIR

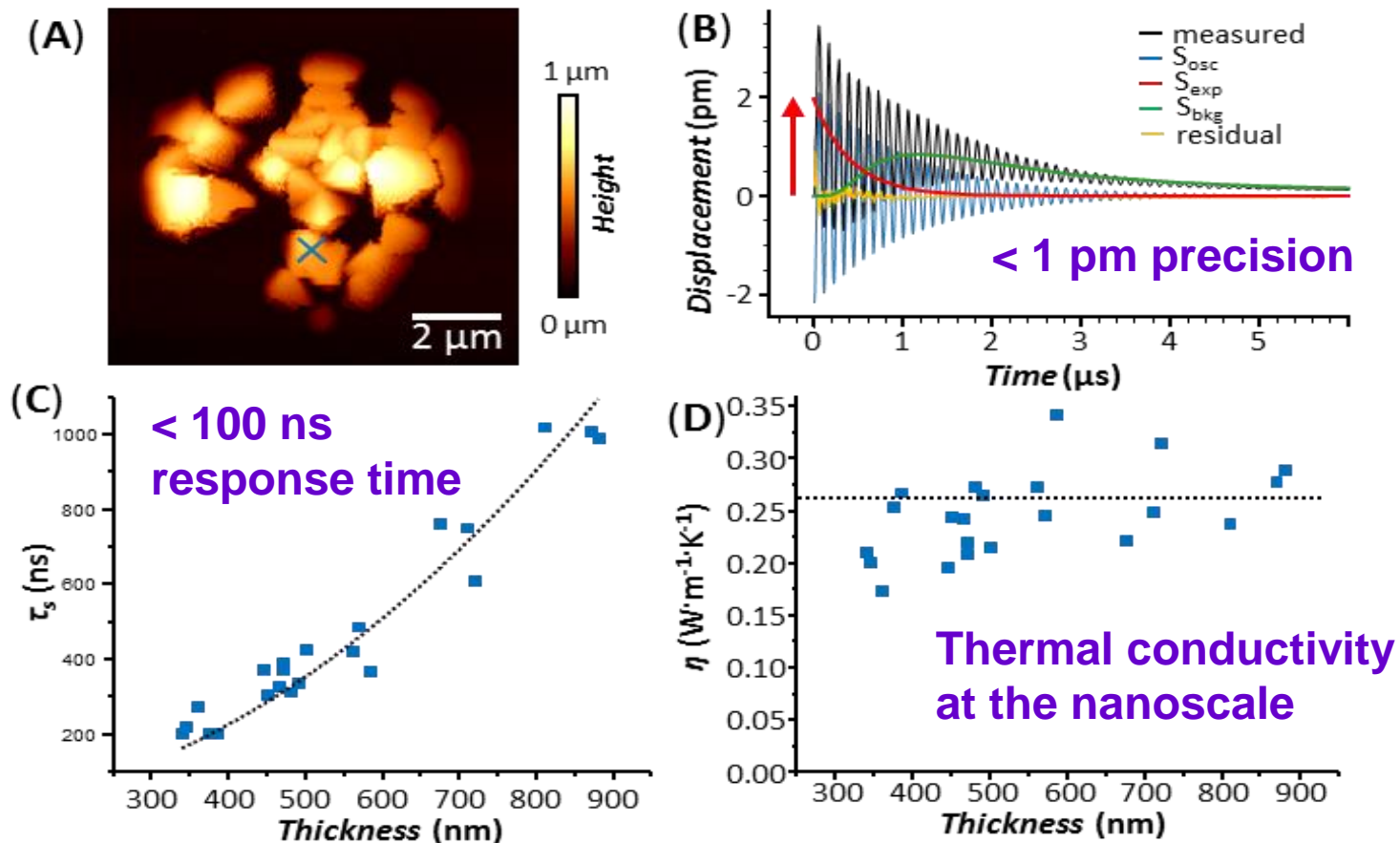
Photo Thermal Induced Resonance = IR spectroscopy with nanoscale resolution  
Chemical mapping  
Optomechanical probe = 50x increased sensitivity for thin samples



J. Chae, S. An, G. Ramer, V. Stavila, G. Holland, Y. Yoon, A. Alec Talin, M. Allendorf, V. A. Aksyuk, A. Centrone, Nano Letters **17** (9), pp 5587–5594 (2017).



## Speed + precision = nanoscale thermal expansion dynamics

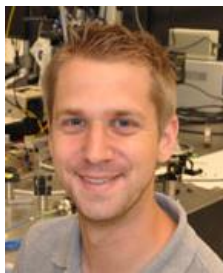


# Acknowledgements

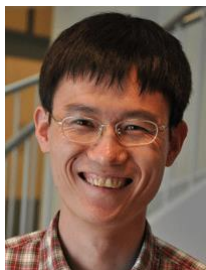
## Optical MEMS and NEMS Lab



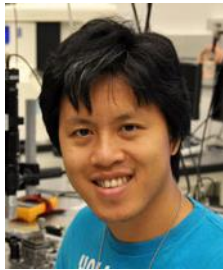
Sang Min An



Thomas Michels



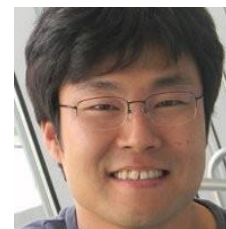
Houxun Miao



Jie Zou

## PTIR Lab

Andrea Centrone



Jungseok Chae



Georg Ra

## Nanophotonics Lab

Kartik Srinivasan

Marcelo Davanco

## Nanofabrication support

Daron Westly

Rob Ilic

## MOF Experts (Sandia National Labs)

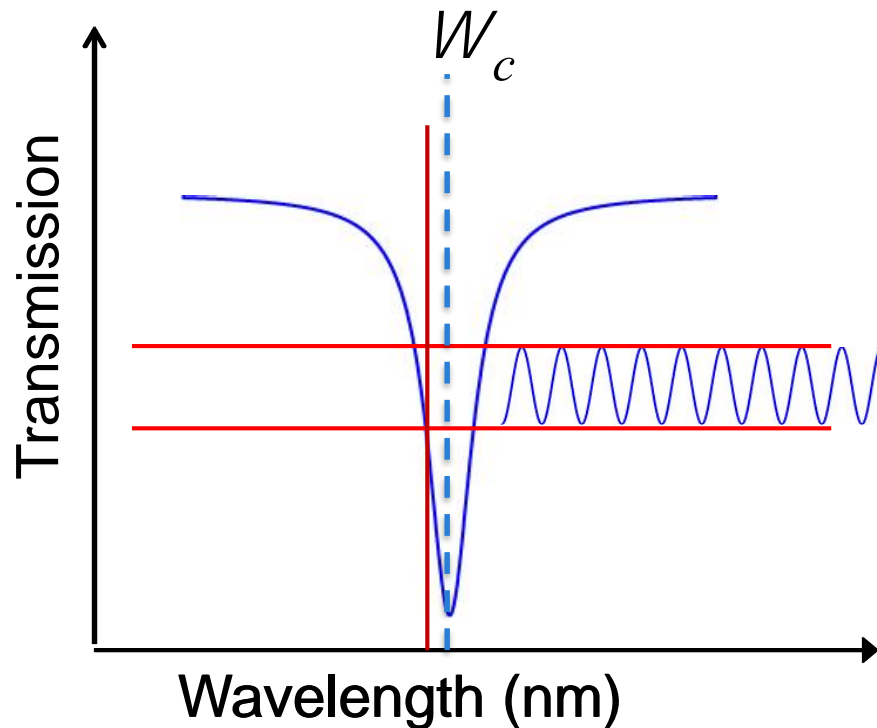
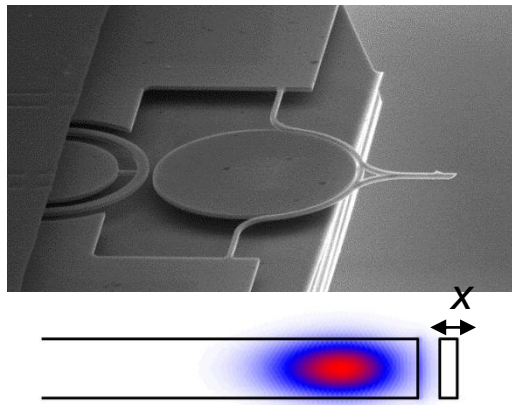
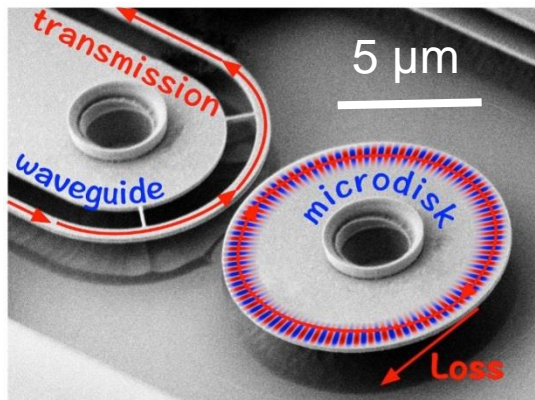
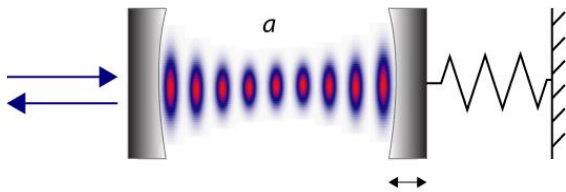
Alec Talin

V. Stavila

M. Allendorf



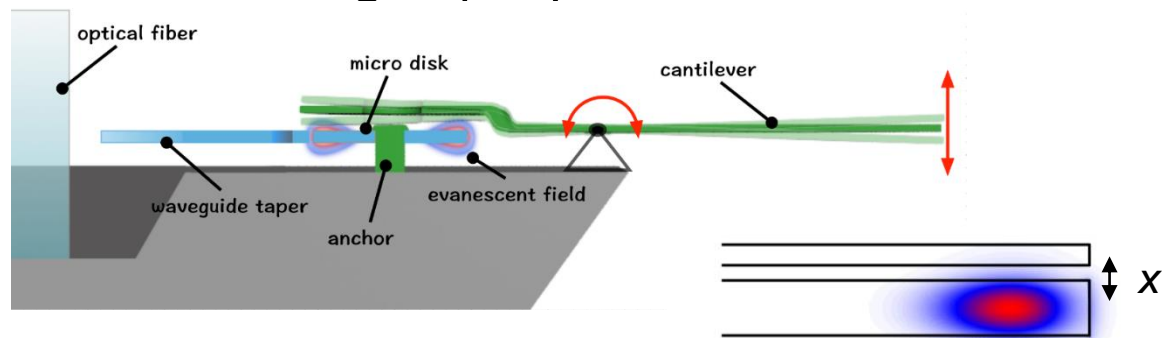
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Displacement signal





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