Hybrid Diode-Microresonator Laser / FThO5

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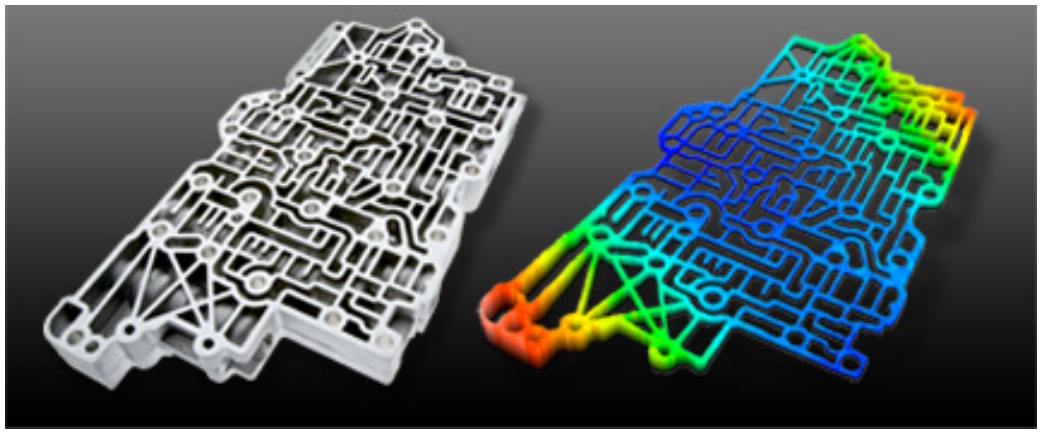
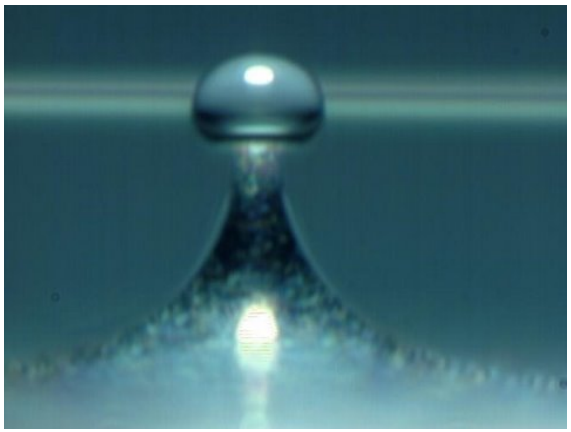
Motivation: Holographic Metrology

- Microcavity WGMs [1] are popular research topics.
- WGMs have only recently been incorporated into commercial products [2].
- Extend WGM to digital holographic metrology [3].



(a)



(b)

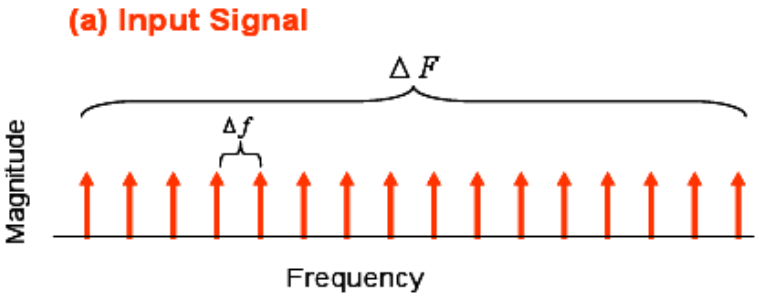
[1] V.B. Braginsky, M.L. Gorodetsky, V.S. Ilchenko, Phys. Lett. A, 137, 7, 1989; D.K. Armani et al., Nature 421, 6926, 2003

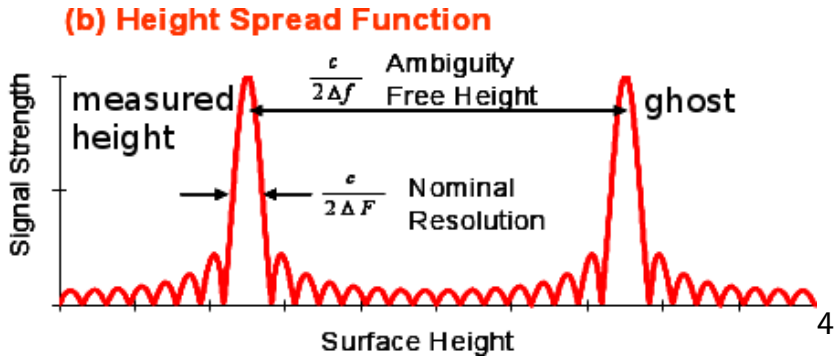
[2] OEwaves, Inc; L. Maleki, A.B. Matsko, A.A. Savchenkov, V.S. Ilchenko, J.M. Shoenfeld, D.J. Seidel

[3] C.C. Aleksoff, Proc. SPIE, 6311, 2006

Requirements

- Input is a set of peaks at different wavelengths.
- $20nm$ span, MHz linewidth, pm spacing between some lines - 12 lines.
- Fast scanning - from offline quality control to a moving assembly line.
- Lower cost.
- mW power.





[4] K.J. Gasvik, Optical Metrology, 3rd ed., Ch. 11; J.C. Marron and K.W. Gleichman, Opt. Eng., 2000; C.C. Aleksoff, Proc. SPIE, 6311, 2006

Current Technology

- External cavity diode lasers are used to tune among different frequencies - they have narrow linewidths and are excellent choices for continuous scans across wavelengths.
- But require grating/mirror system
- Scanning speed is limited:
  $10s$ to move grating
  $2min.$ per scan.

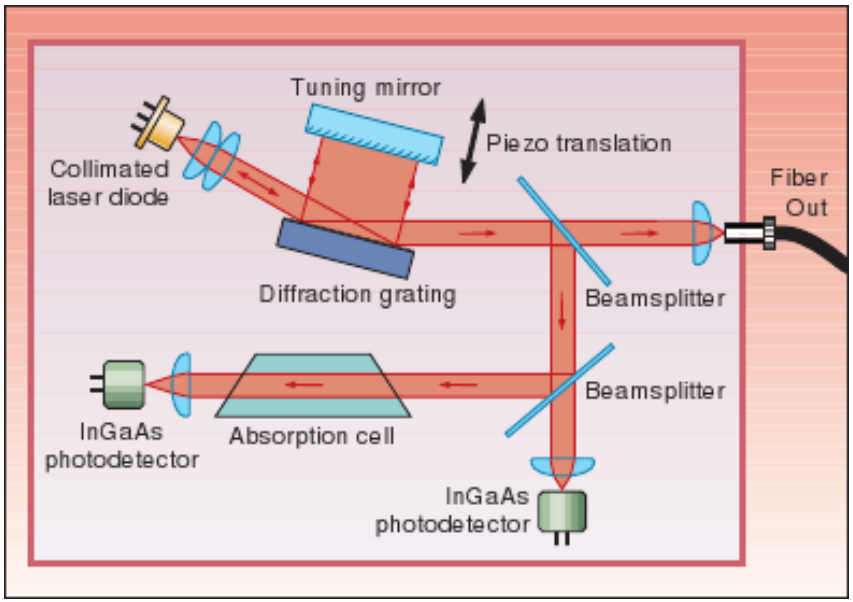


Image from Newport Corp.

New Concept: Use Diode-Pumped Microresonators

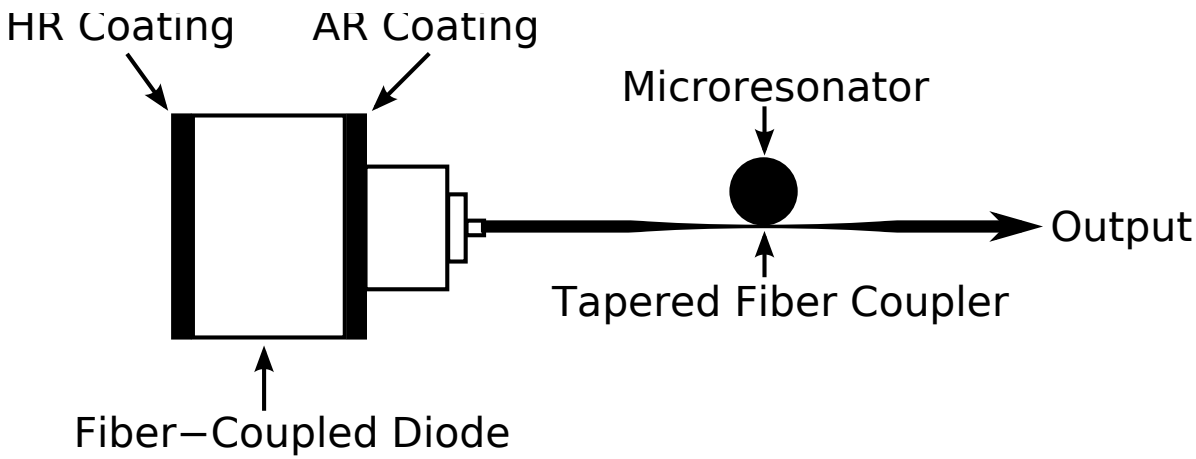
- Provide half of the required lines simultaneously via Raman scattering [5] using a diode pump.
- Use thermocoupler to shift lines pm to get the second half of the required lines.
- Line spacing is stable and determined by cavity resonance.
- Narrow linewidths on the order of Hz possible [6].

Steps	Current Method	Concept
1	λ1	λ1,λ2,λ3,...,λn
2	λ2+Δλ	λ1,λ2+Δλ,λ3+2Δλ,...,λn+(n-1)Δλ
3	λ3+2Δλ	
	...	
n	λ4+(n-1)Δλ	

[5] S.M. Spillane, T.J. Kippenberg, K.J. Vahala, Nature 415, 6872, 2002
[6] L. Yang, Phys. Rev. Lett., In Review, 2009

Experimental Setup

- Diode pump is the energy source and gain medium.
- Pump radiation is coupled into the microresonator via fiber taper [7].
- Feedback is caused by Rayleigh scattering in microresonator [8]
  narrow-band
  at the cavity resonance frequency due to multiple recirculation.

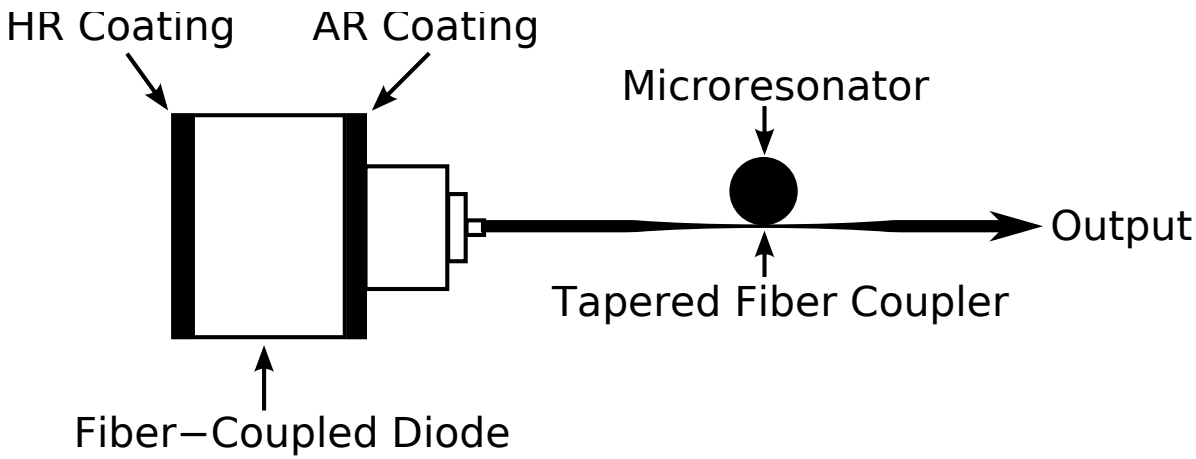


[7] S. M. Spillane et al., Phys. Rev. Lett. 91, 043902 (2003); M. Cai, O. Painter, and K. J. Vahala, Phys. Rev. Lett. 85, 74 (2000); Knight, J. C., Cheung, G., Jacques, F., and Birks, T. A. . Opt. Lett. 22, 1129–1131 (1997)

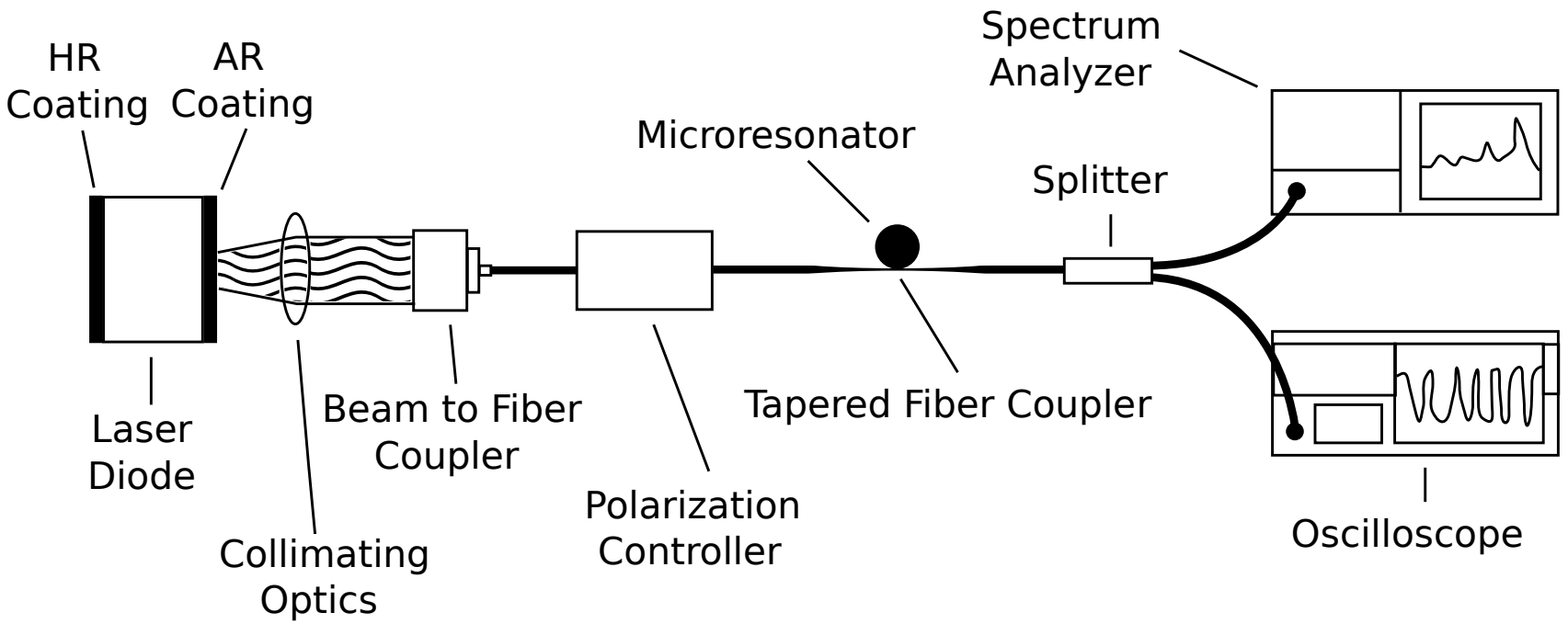
[8] V.V. Vasiliev, Opt. Commun., 158, 305, 1998; K. Kieu and M. Monsuripur, Opt. Lett., 32, 3, 2007

Experimental Setup

- Reflected light couples out through fiber taper and passes through diode gain material again.
- Light is amplified at the cavity resonance frequency.
- Forward-propagating Raman scattering couples through the fiber taper and is sent to a spectrum analyzer.

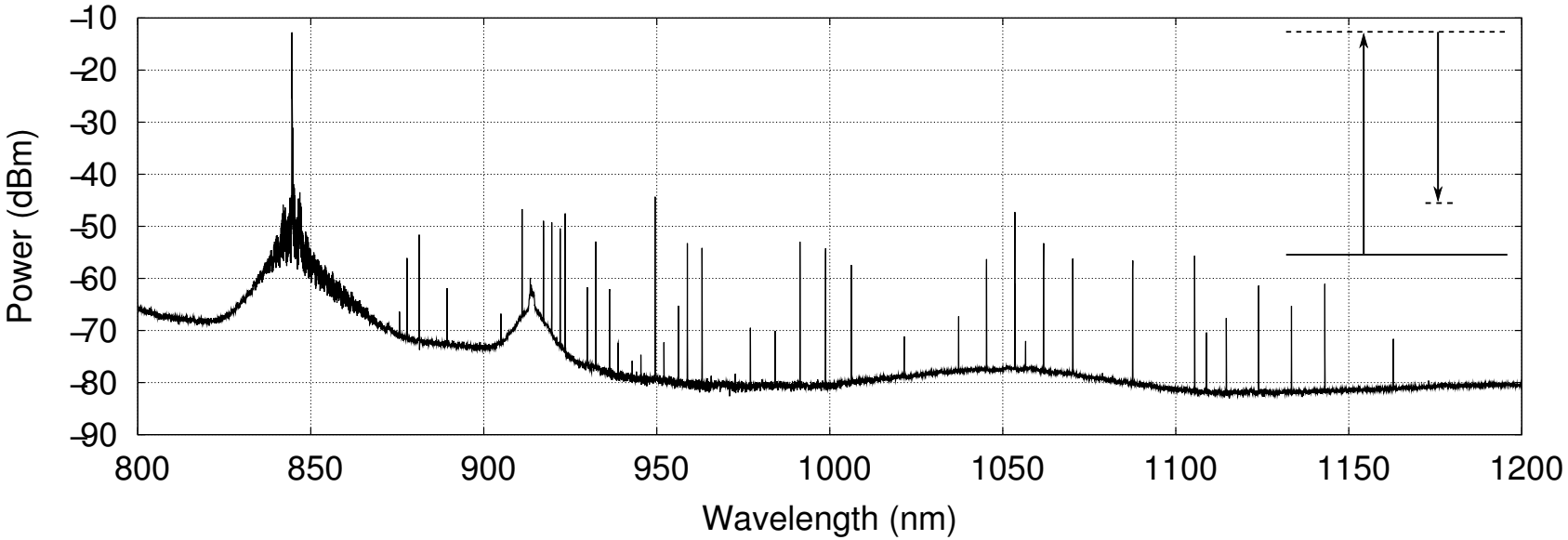


Setup


HR Coating
AR Coating
Spectrum Analyzer
Microresonator
Splitter
Laser Diode
Collimating Optics
Beam to Fiber Coupler
Polarization Controller
Tapered Fiber Coupler
Oscilloscope

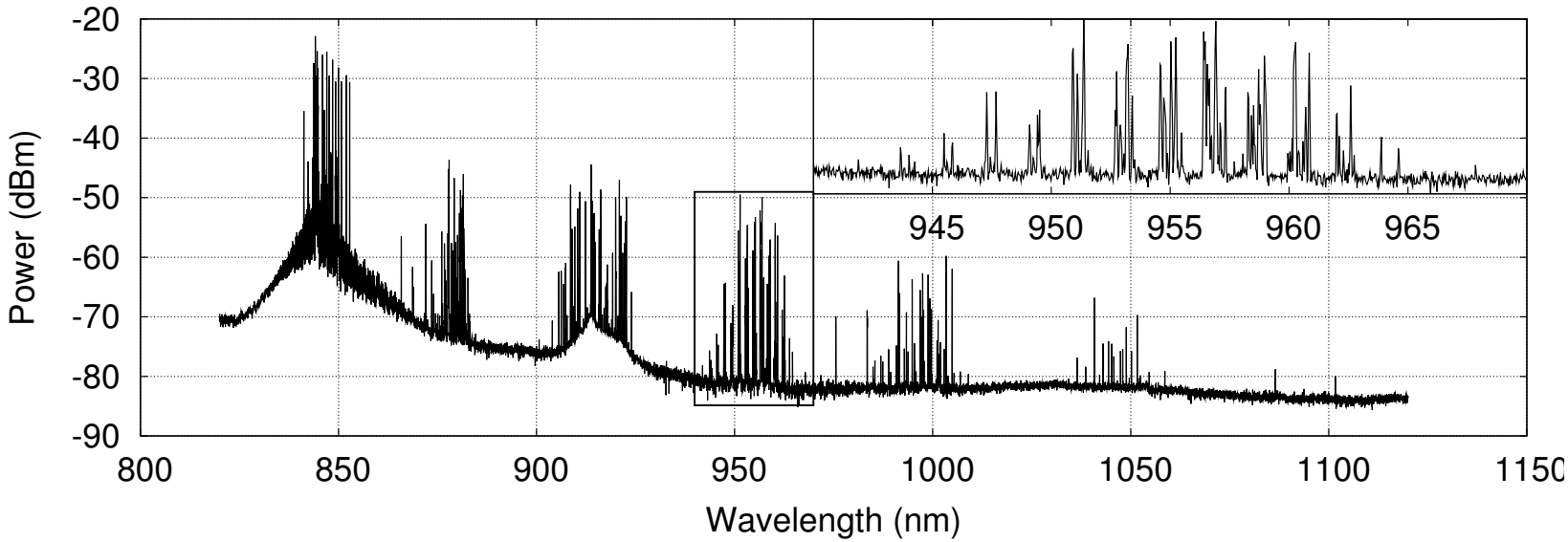
Experimental Results: Spectrum

- On-chip 29.3 μm silica sphere.
- 41 Raman peaks in 7 groups.
- Peak spacing, peak number can be designed upon request.



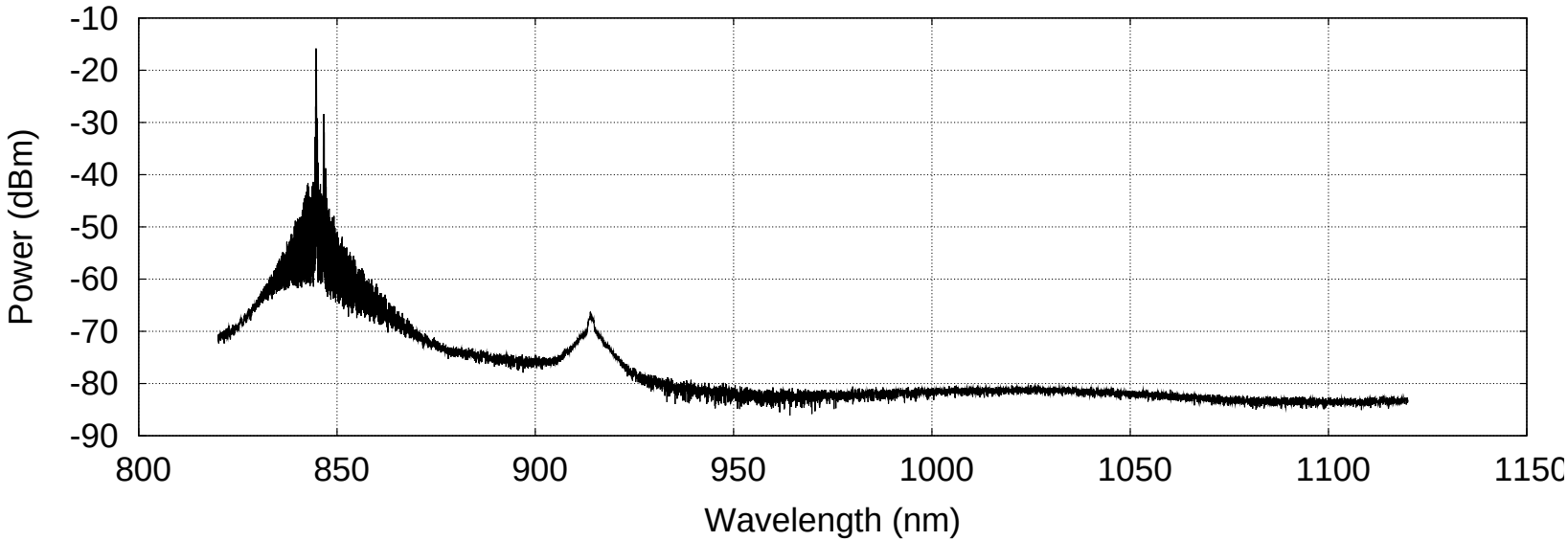
Experimental Results: Spectrum

- 90 μm silica sphere made by melting the tip of a tapered fiber.
- 170 Raman peaks in 6 groups.



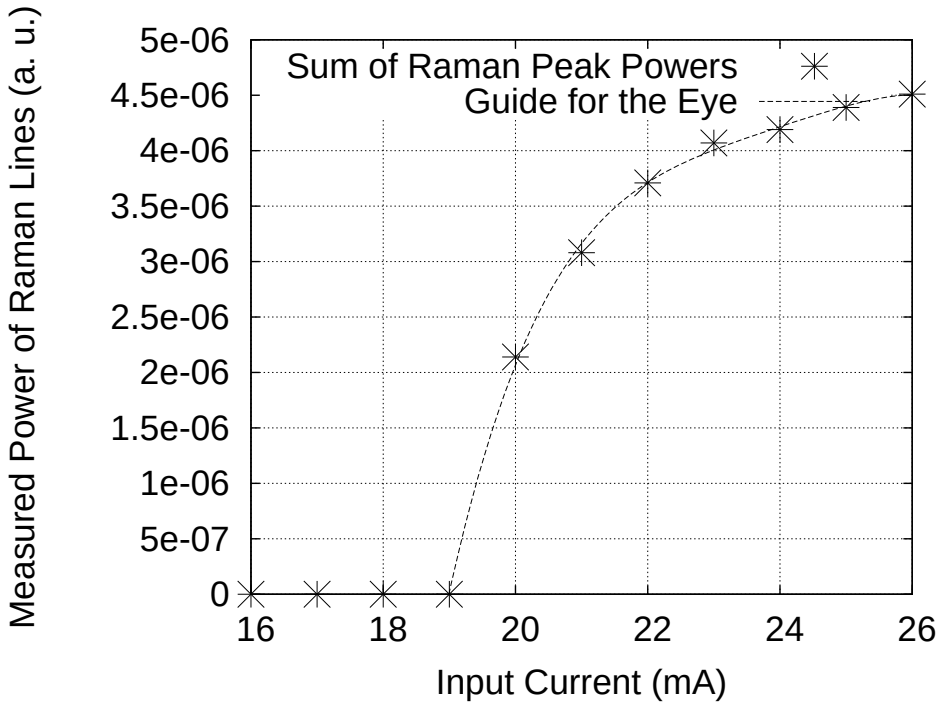
Experimental Results: Control Group

- Spectrum of the diode source alone.



Experimental Results: Power Dependency

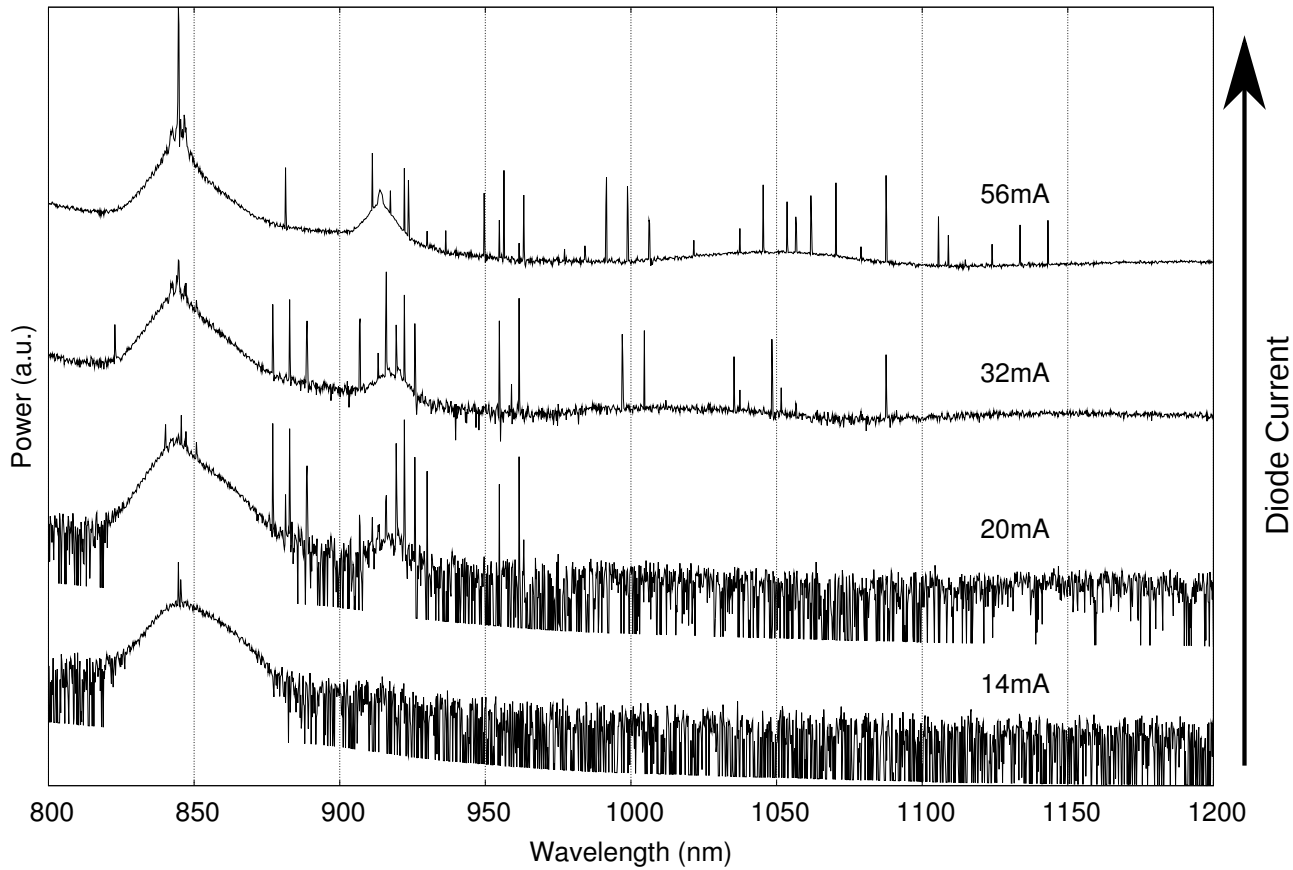
- Plot showing how total power of low-order Raman peaks in a $19.7\mu m$ on-chip microsphere changes with diode current.
- No Raman lines were visible at below $19mA$.
- In agreement with previous results [9].



[9] T. Kippenberg et al., IEEE J STQE, 10, 5, 2004; T. Carmon et al., Opt. Express, 13, 09, 2005

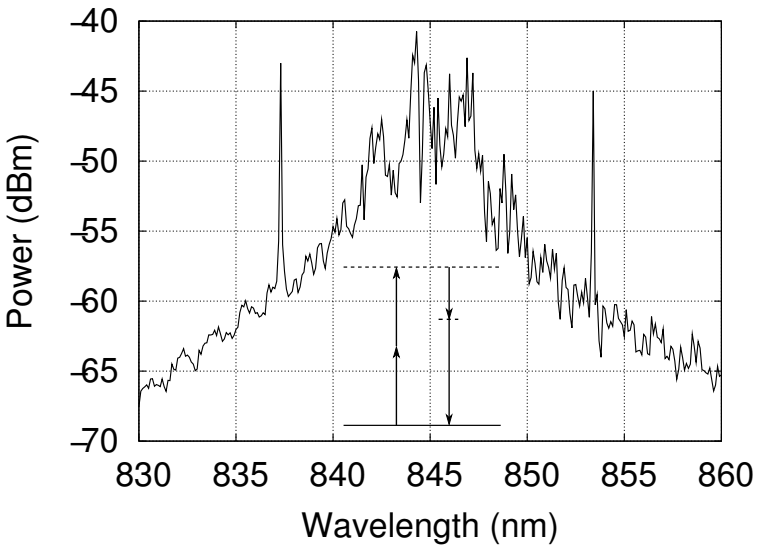
Experimental Results: Power Dependency

- Raman lasing in a 29.3 μm on-chip sphere at four different diode operating currents.



Experimental Results: Parametric Oscillations

- Parametric oscillations [10] in a $28\mu m$ on-chip microsphere (left) and uncoupled diode spectrum (right).
- Idler at $837.3nm$ and signal at $853.4nm$.



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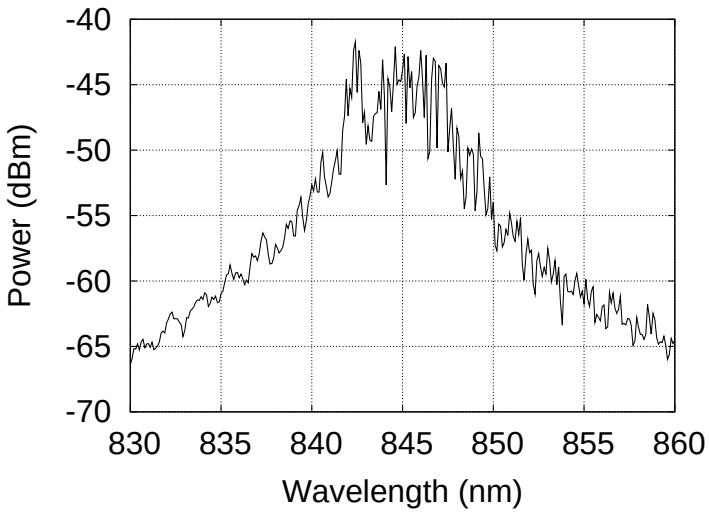
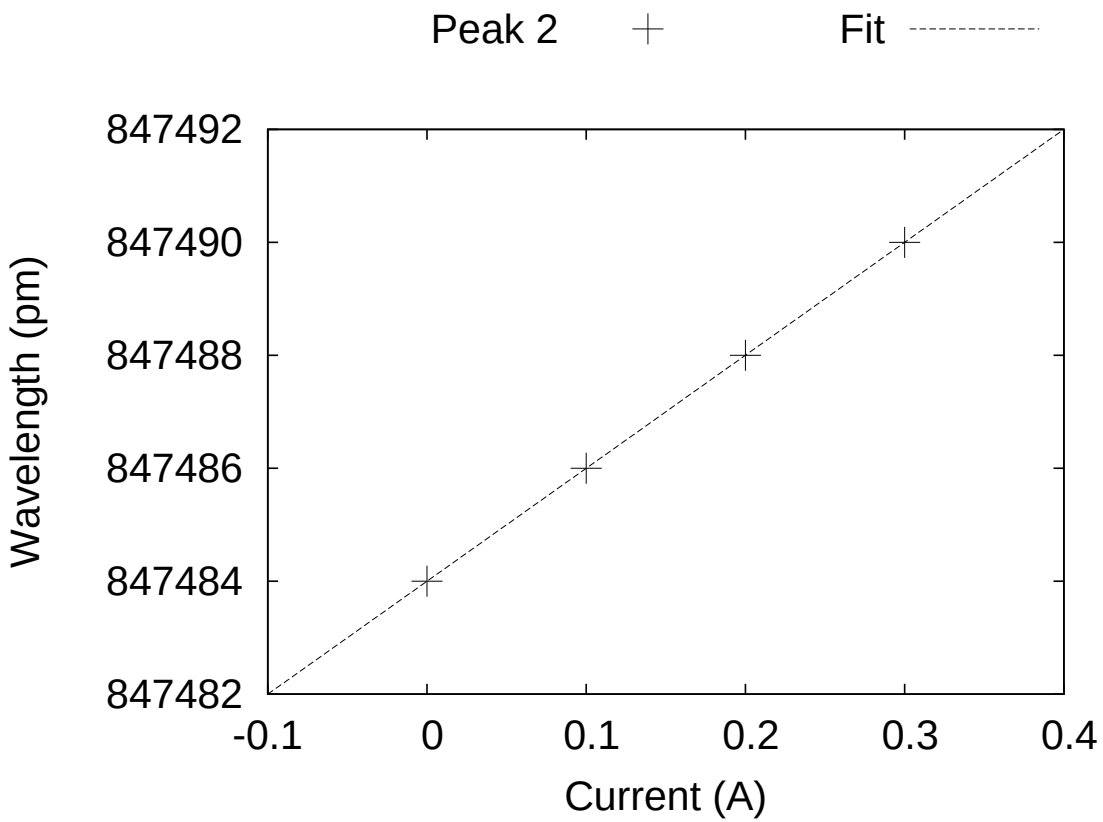


(d)

[10] T.J. Kippenberg, S.M. Spillane, K.J. Vahala, Phys. Rev. Lett., 93, 8, 2004

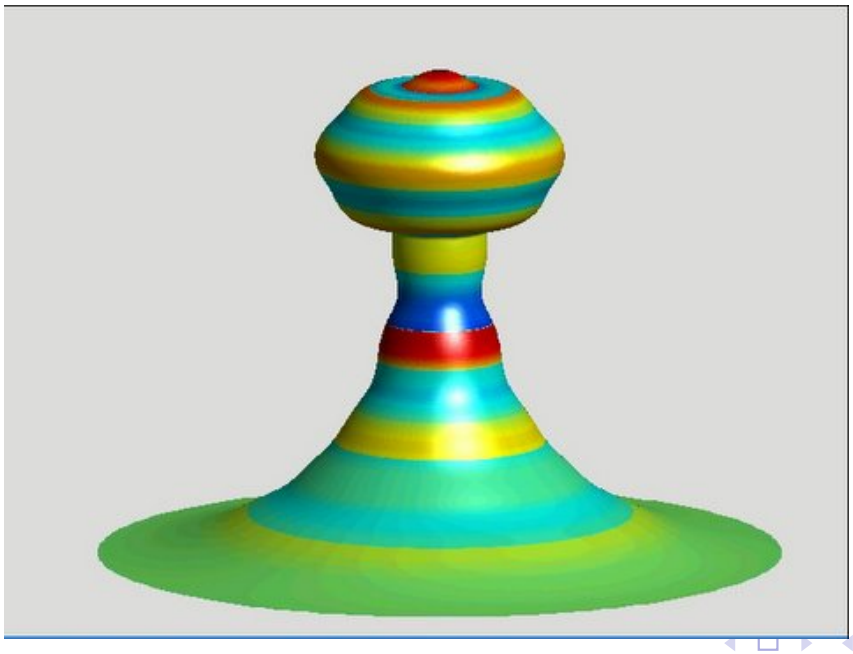
Preliminary Results: Thermal Shifting of Peaks

- Peaks can be shifted with pm spacing using standard thermoelectric heater.
- Thermal timescale of silica on the order of ms.
- Limited by spectrum analyzer to $1pm$ resolution.



Other Characteristics

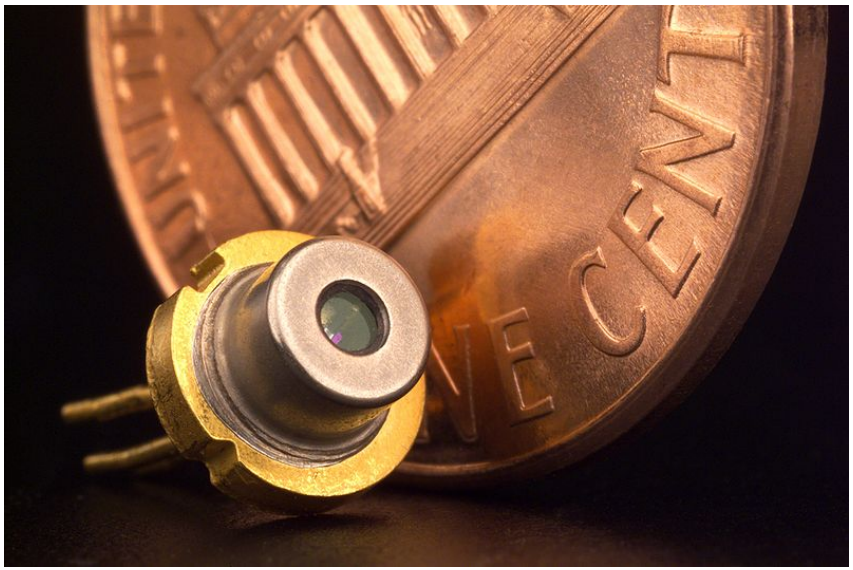
Oscillation	Origin	Our System
Mhz-GHz	Radiation-pressure induced vibration (T. Carmon et al., Phys. Rev. Lett., Vol. 94, No. 22, 2005)	Don't have; pump at zero detuning where mechanical gain is zero.
1-100kHz	Thermal instability (V.S. Ilchenko and M.L. Gorodetsky, Laser Phys., Vol. 2, No. 6, 1992)	Might have, not affecting holography since much narrower than MHz bandwidth.
	Feedback (T. Morikawa et al., Electron. Lett, Vol. 12, No. 17, 1976)	



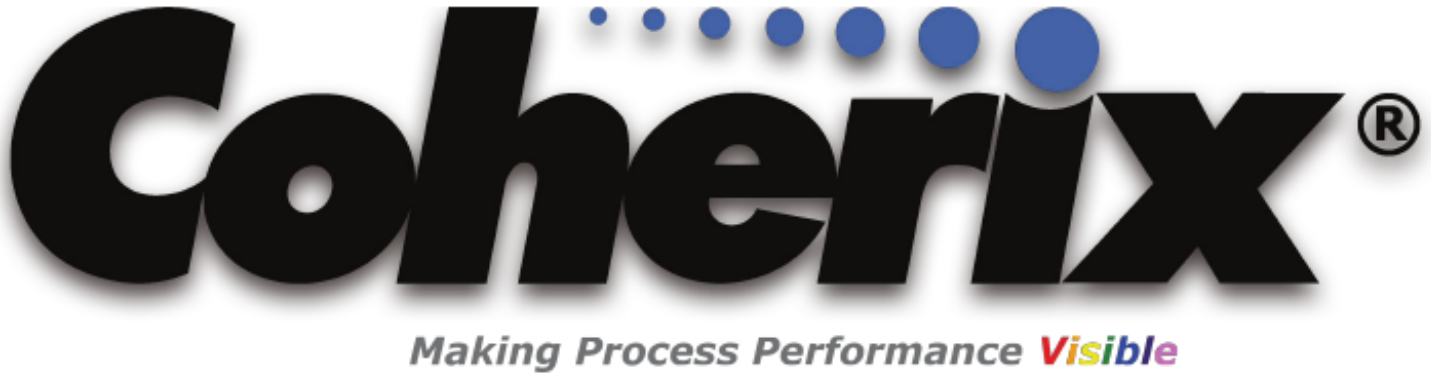
Conclusion

- Laser line requirements - 170 lines, $200nm$ span, Hz linewidth - ✔.
- Fast scanning requirement - two stages at ms each per scan vs 12 stages at $10s$ each - ✔
- pm spacing requirement - ✔.
- Lower cost requirement - $\$100s$ vs $\$10000s$ - ✔
- mW power - in progress.

- **Nonresonant pumping with a diode! ✔**



This project is generously supported by Coherix Corp.



Thank you for your attention.

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