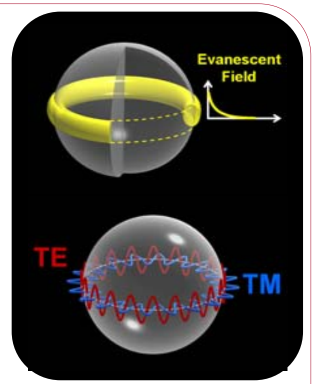
# Analysis of Molecular Transformations and Light Manipulation with Optical Microresonators

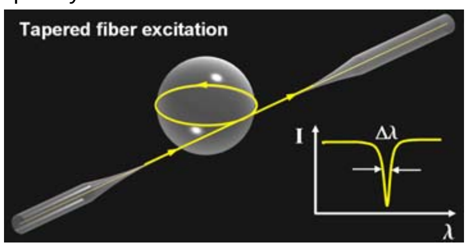

**Frank Vollmer and Juraj Topolancik**

*The Rowland Institute at Harvard, Harvard University, 100 Edwin H. Land Blvd., Cambridge, MA 02142*


## Optical Microcavities

- High-Q whispering gallery modes (WGMs) (Q~$10^6$).
- Highly sensitive to refractive index (polarizability) perturbations.
- Evanescent field probing of ultra-thin molecular layers.
- Two probing polarizations (TE and TM). Capable of probing optical anisotropies in molecular self-assemblies.
- Sensitive to molecular binding events and changes within the structure of immobilized molecules.
- Binding events and conformational changes conveyed as shift in resonant frequency of WGMs.



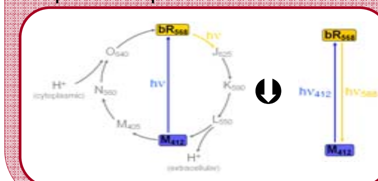

**Resonant shift:**

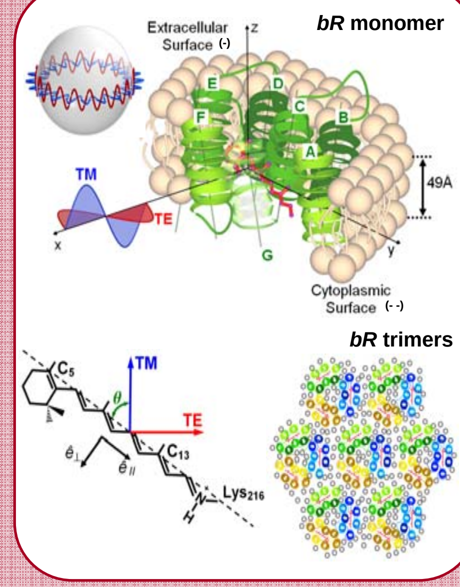
$$\frac{\Delta\lambda}{\lambda} \propto \frac{\sigma_{mol}\,\alpha_{mol}}{R}$$

$\sigma_{mol}$: molecular surface density
$\alpha_{mol}$: molecular polarizability
R: resonator size

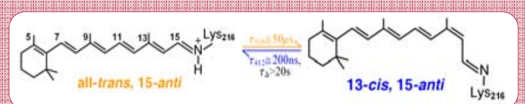
## Bateriorhodopsin

- Model biological membrane system.
- Known 3D structure. Highly oriented, optically anisotropic system. Large polarizability changes upon isomerization.
- Self-assembles as a monolayer.
- Technologically important biological photochrome. Applications in photonics and optoelectronics.
- Shares structure with G-protein coupled receptors.






## *Trans-cis* isomerization and orientation of the retinal



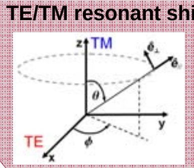

- Photoinduced *all-trans* to *13-cis isomerization* of the chromophore retinal monitored off-resonance with a 1,310nm probe.
- Novel pump-probe spectroscopy tool.
- Direct measurements of polarizabilities of molecules in complex proteo-lipid environments.

**Average retinal polarizability change:**

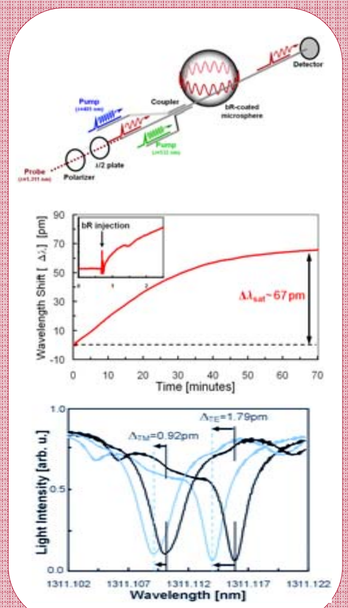
$$\langle\Delta\alpha_{iso}\rangle = \frac{1}{3}\left(\langle\Delta\alpha\rangle_{TM} + 2\langle\Delta\alpha\rangle_{TE}\right) \cong -384\,au$$

- Direct orientation measurements of molecular self assemblies

**TE/TM resonant shift (** $\beta = \left|\frac{\delta\alpha_{//}}{\delta\alpha_{\perp}}\right| \sim 10, \langle\theta\rangle = 61^\circ$ **):**




$$\frac{\Delta\lambda_{TE}}{\Delta\lambda_{TM}} \approx \frac{1}{2}\left(\frac{1+\cos^2\langle\theta\rangle+\beta\sin^2\langle\theta\rangle}{\sin^2\langle\theta\rangle+\beta\cos^2\langle\theta\rangle}\right) \approx 2$$




## All-optical switching in the near-infrared

- All-optical resonant coupler.
- Optical functionality provided by ultra-thin molecular layer.
- Operation at frequencies far from *bR* molecular transitions.
- Full-linewidth shift achieved by multiple *bR* layering (*bR*/PDAC).
- Switching speed limited by the speed of the photochromic transitions (~50$\mu$s).
- Faster all-optical switching at arbitrary optical frequencies with molecular monolayers is possible.