4th US-Korea Nano-Forum
Honolulu, Hawaii, USA
April 26-27, 2007

First Principles Nano-engineering of Organic-Electro Materials and Devices

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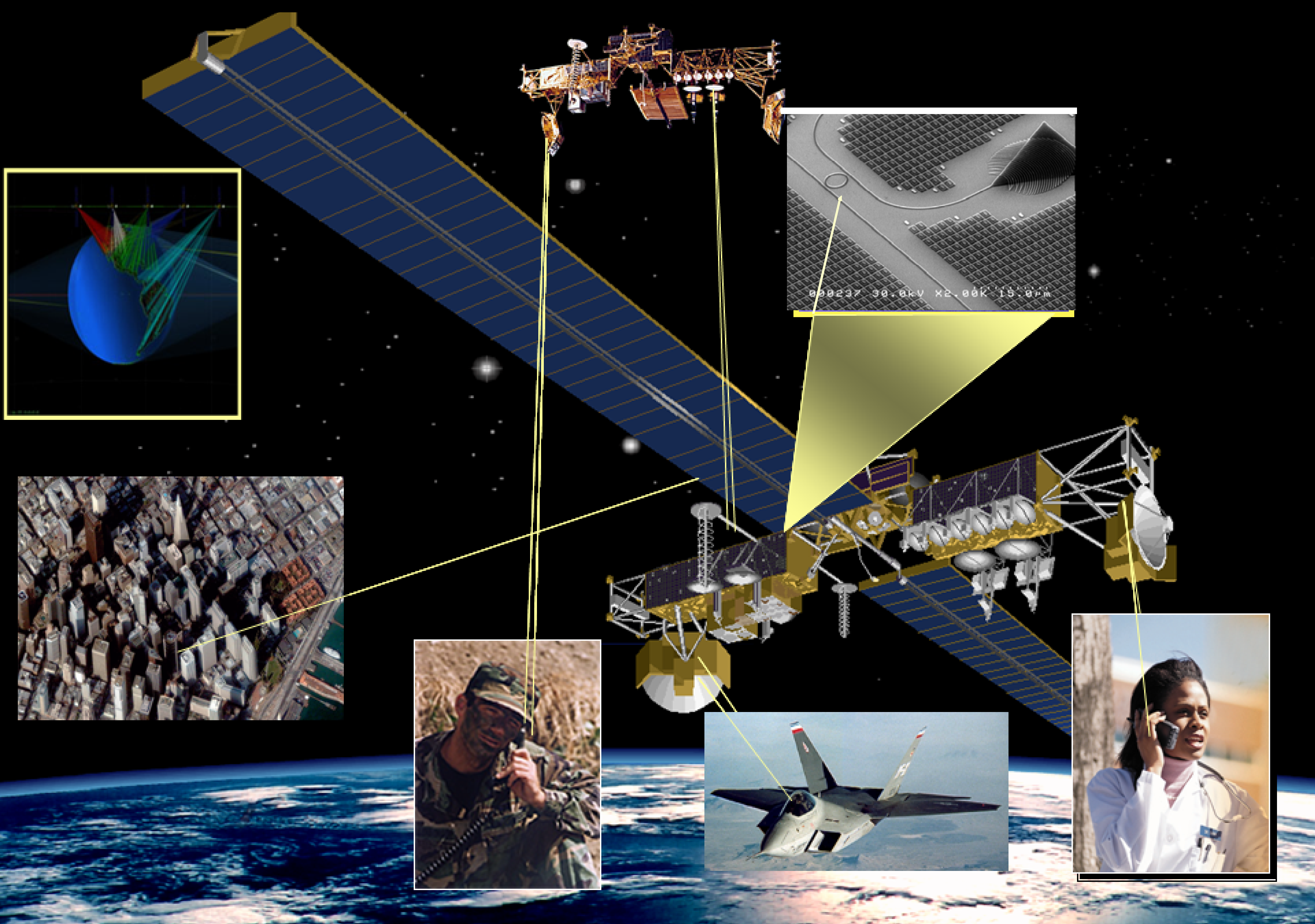
April 26, 2007

Goal: Tb/s Data Handing Capability With Milliwatt Power Requirements



APPROACH

Nano-engineering at all levels—Materials to Devices

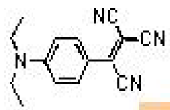
Nano-structured Electro-Optic Materials	$\Longrightarrow$	Hybrid Organic EO/Silicon Nano-Photonic Devices

$$r_{33} = \beta(\varepsilon,\omega)N<\cos^3\theta>$$

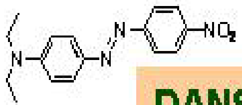
Quantum Mechanics:
TD-DFT calculations to calculate molecular linear & nonlinear optical properties and charge distributions

Statistical Mechanics:
Pseudo-atomistic Monte Carlo/Molecular Dynamic Calculations to compute chromophore order and reaction fields

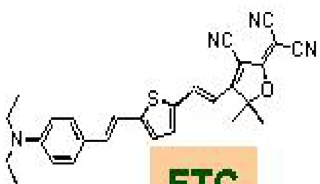
A Transformative Improvement



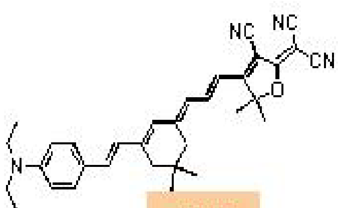
TCN



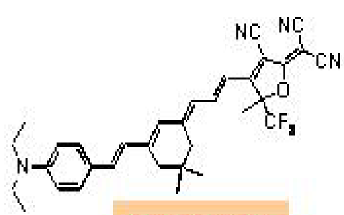
DANS



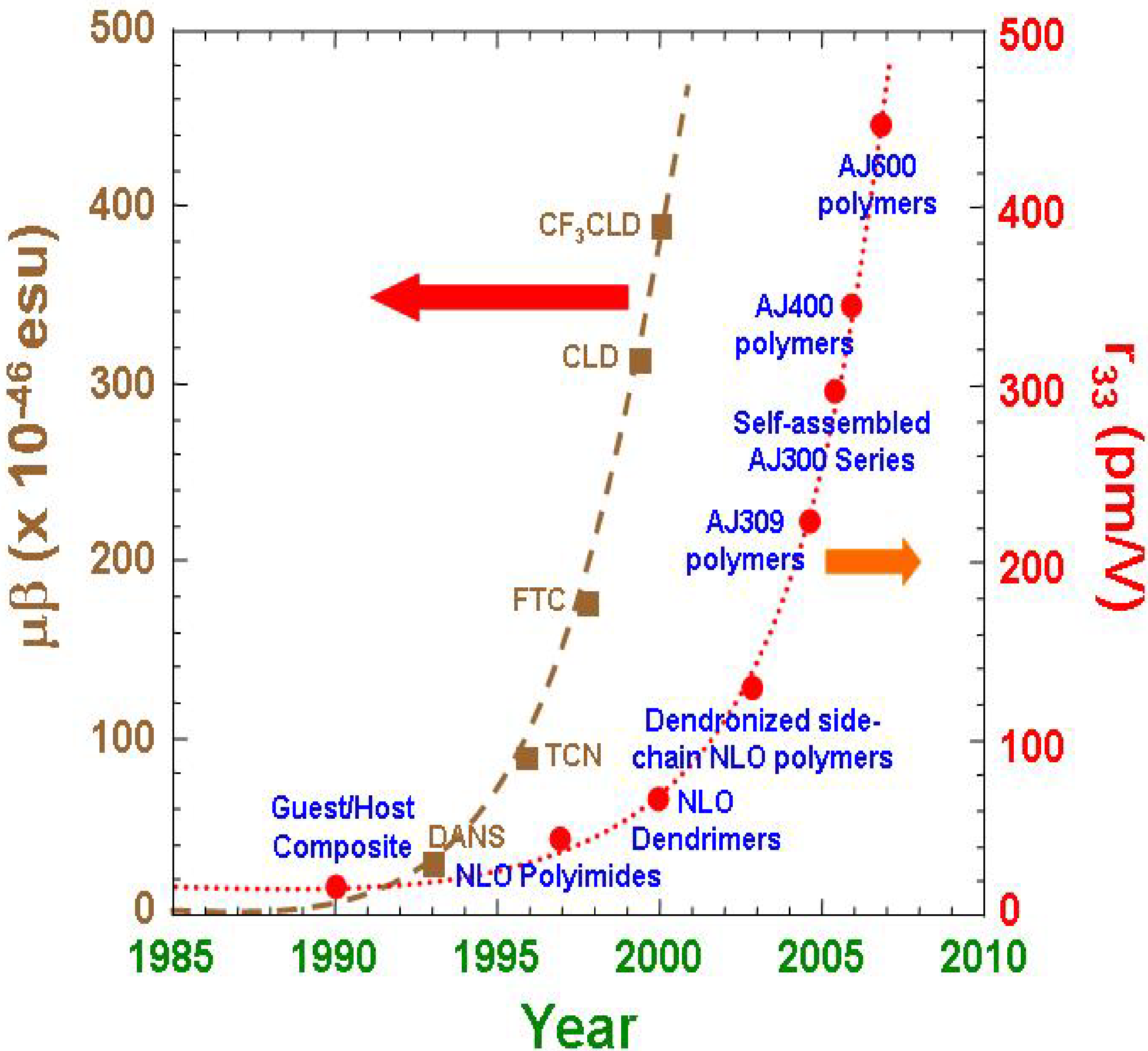
FTC



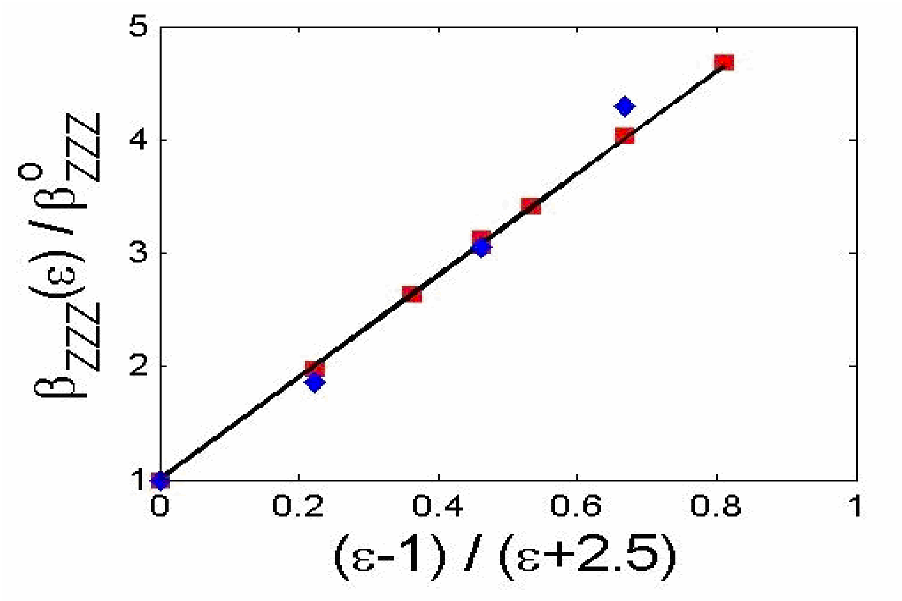
CLD

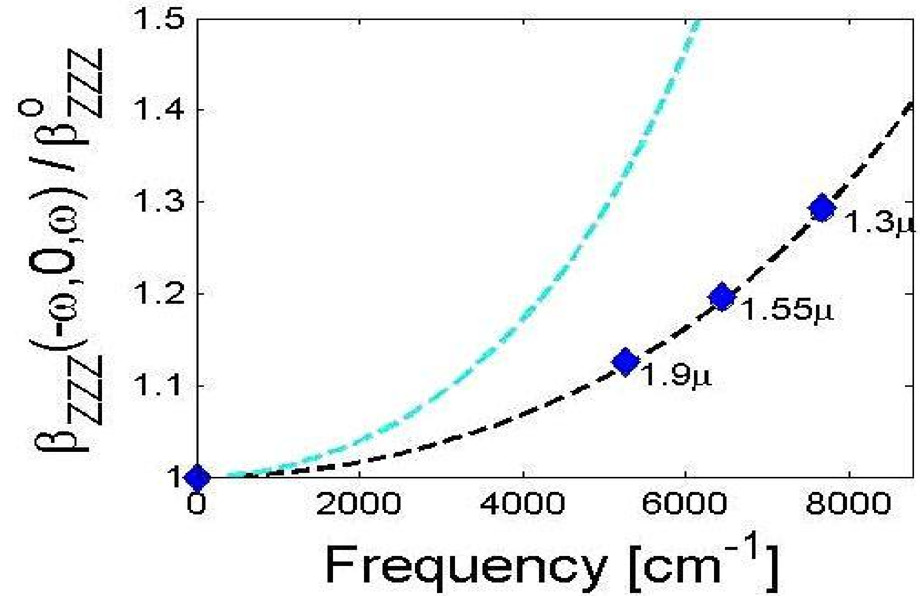


CF_3CLD

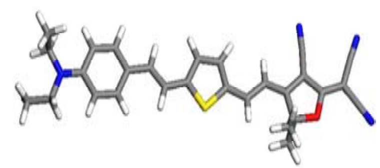


Getting Dielectric and Dispersion Effects Right



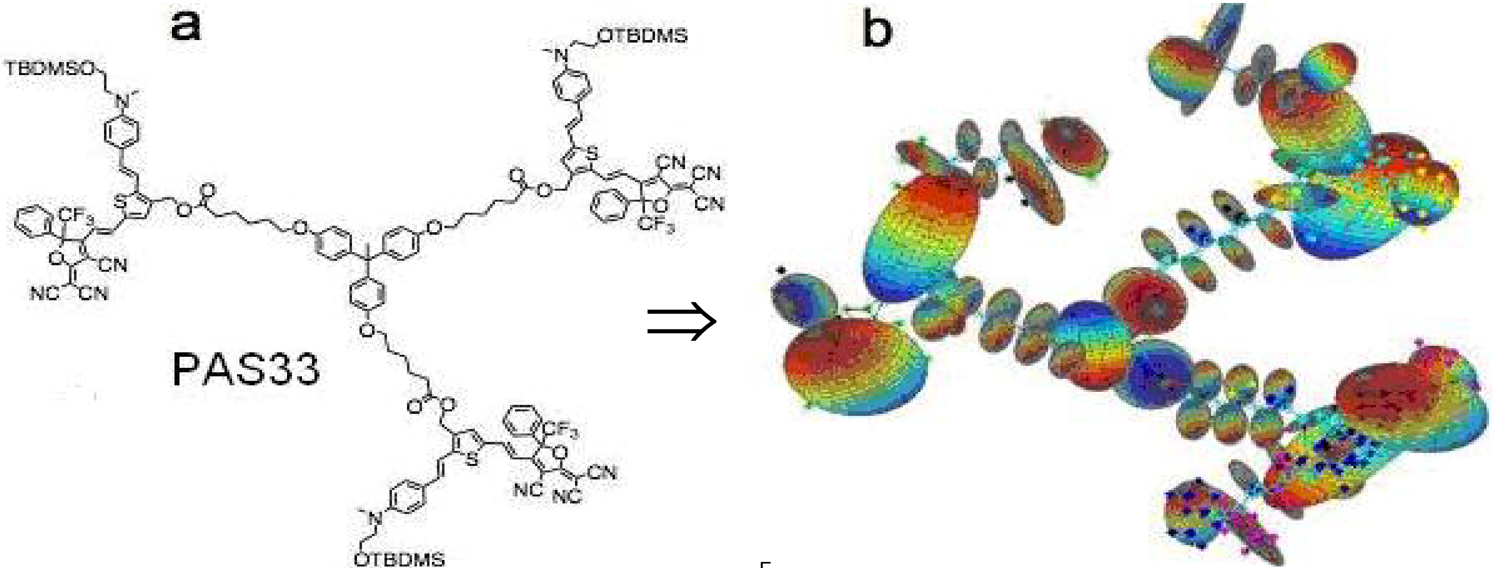


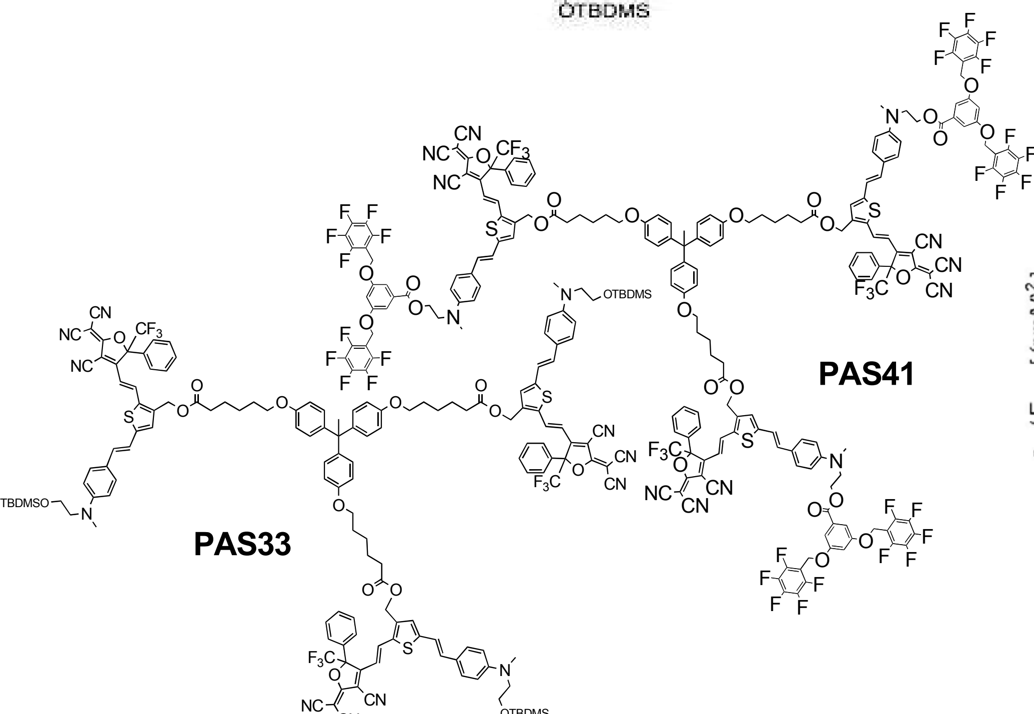
EFISH data for EZ-FTC

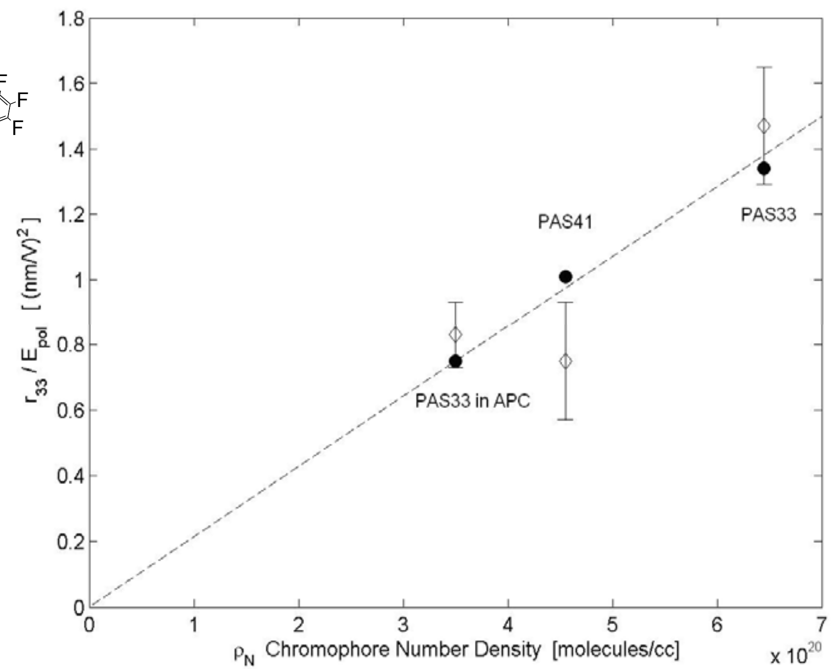


Solvent	ε	λ_{max}/nm	$\mu\beta_\omega/10^{-69}$ SI (exp.)	$\mu\beta_0/10^{-44}$ esu(exp.)	$\mu\beta_0/10^{-44}$ esu(theory)
Dioxane	2.21	622	9291	3.41	4.9
Chloroform	4.81	675	27280	8.52	8.9

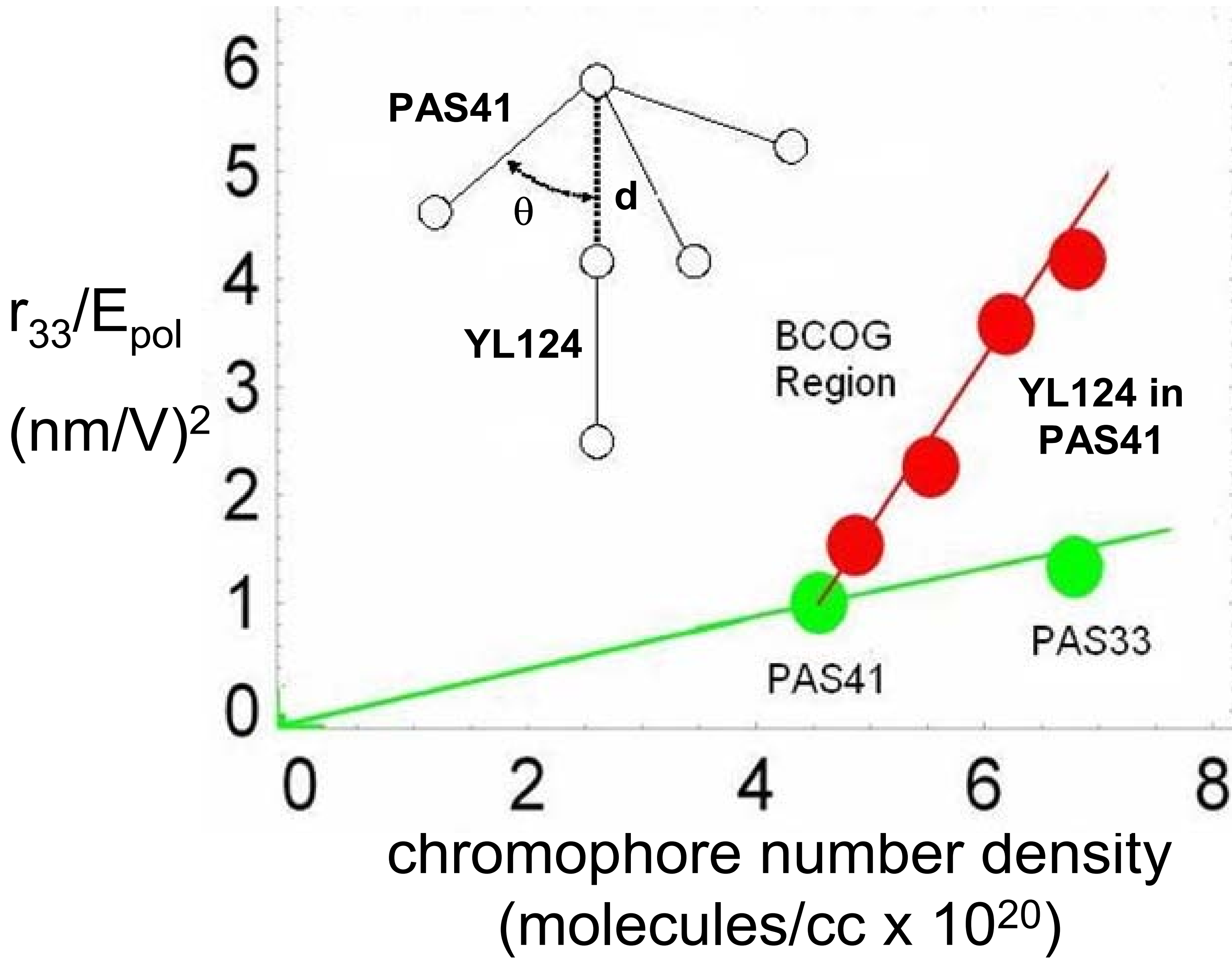
Pseudo-Atomistic Monte Carlo Calculations



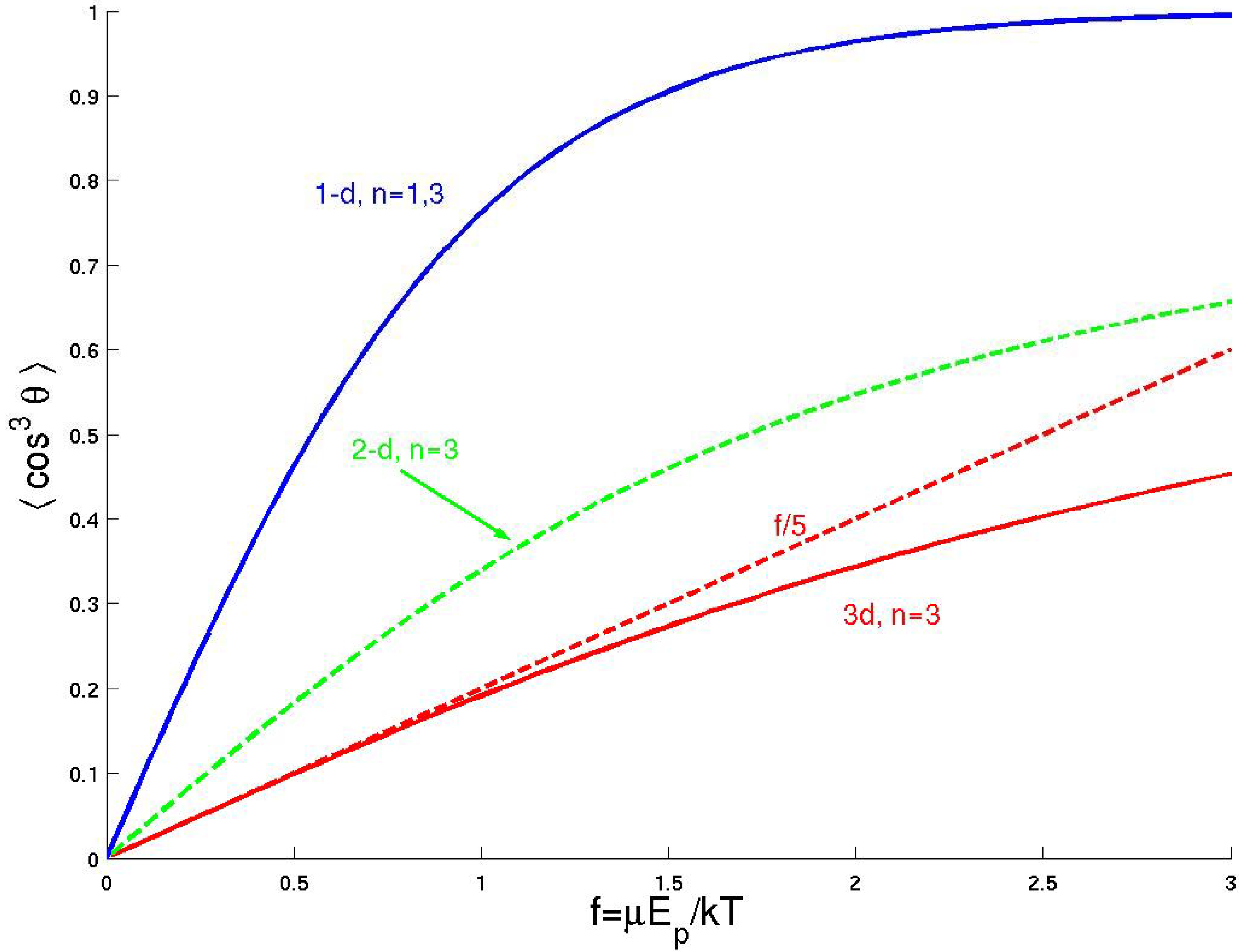




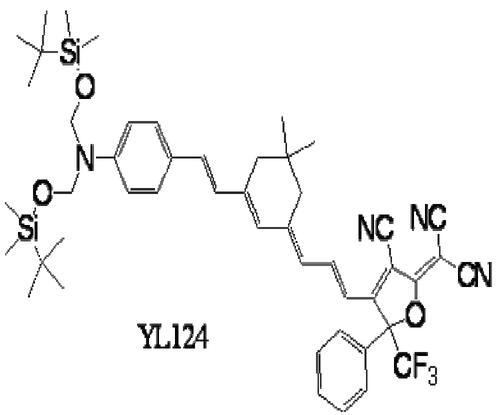
Binary Chromophore Organic Glasses



The Role of Lattice Symmetry



Laser-Assisted Poling: Proof of Guest-Host Influence on <$\cos^3\theta$>



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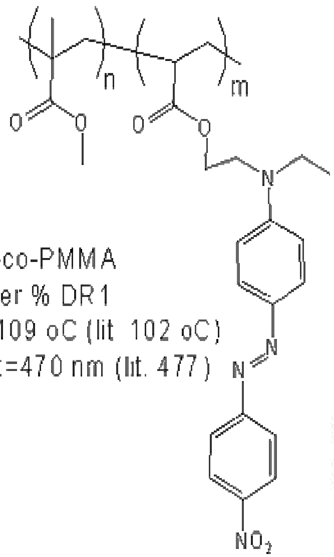
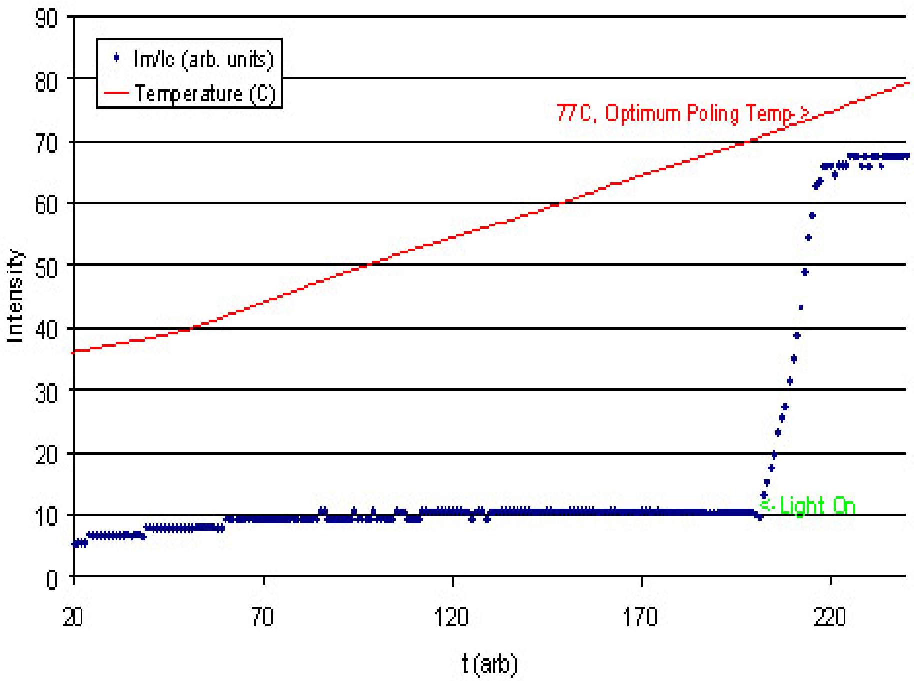
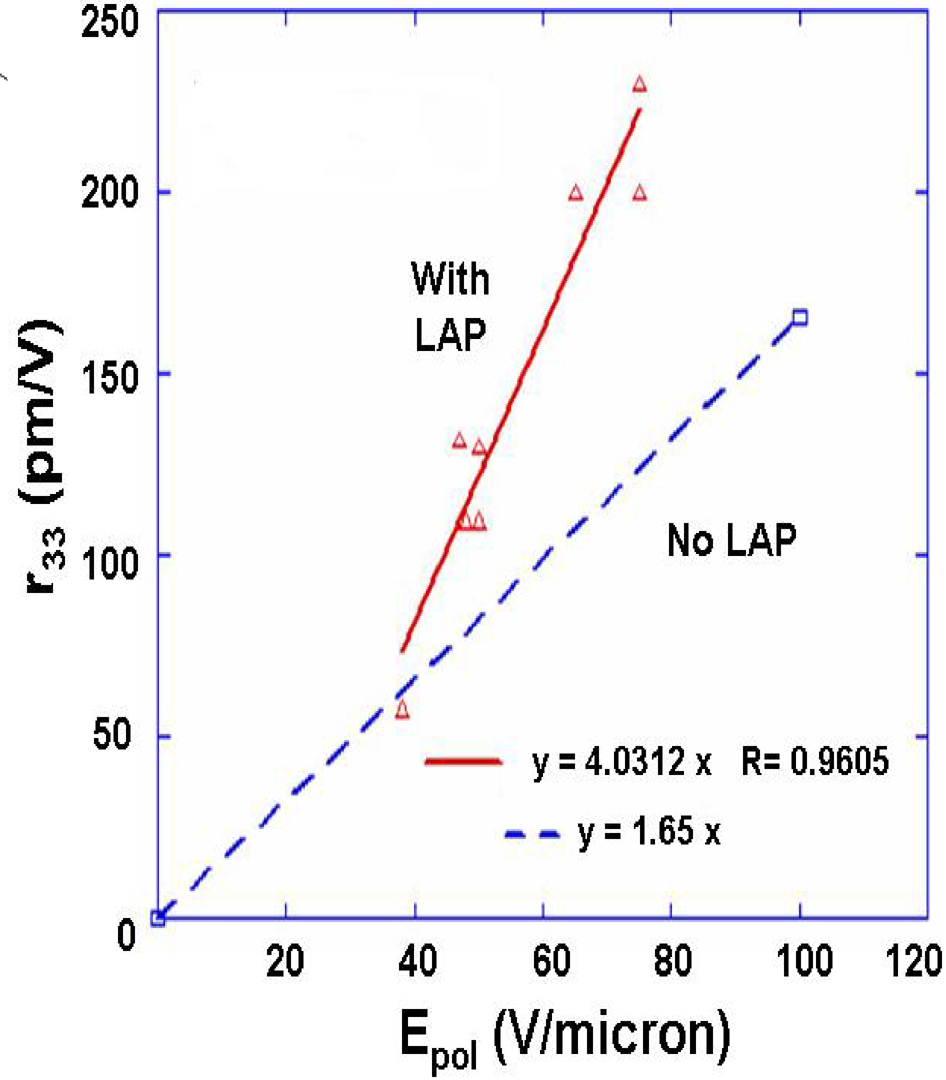


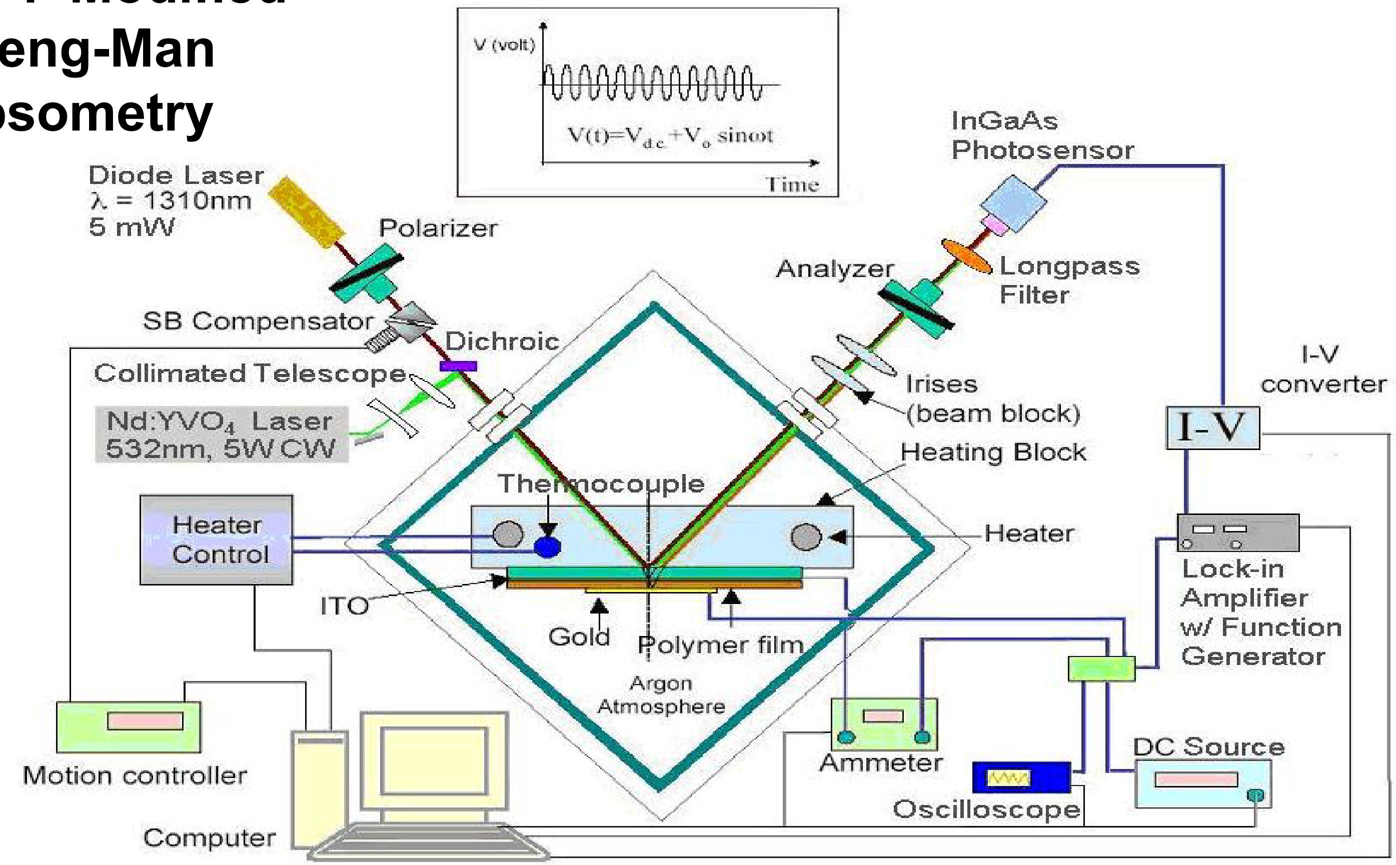
DR 1-co-PMMA
10 mer % DR 1
Tg =109 oC (lit 102 oC)
λmax=470 nm (lit. 477)



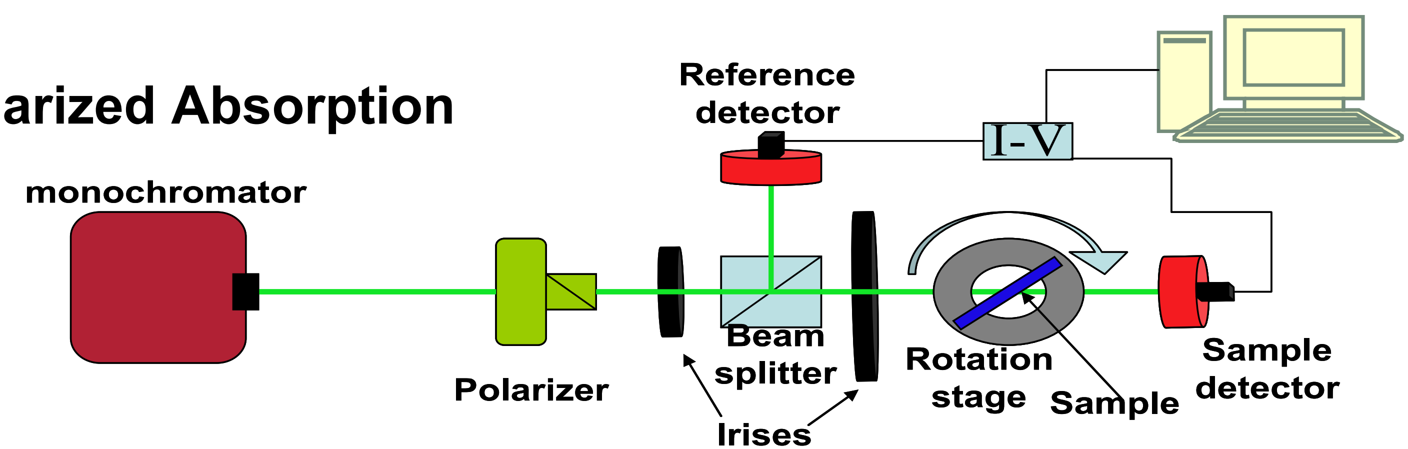


Measurement Techniques

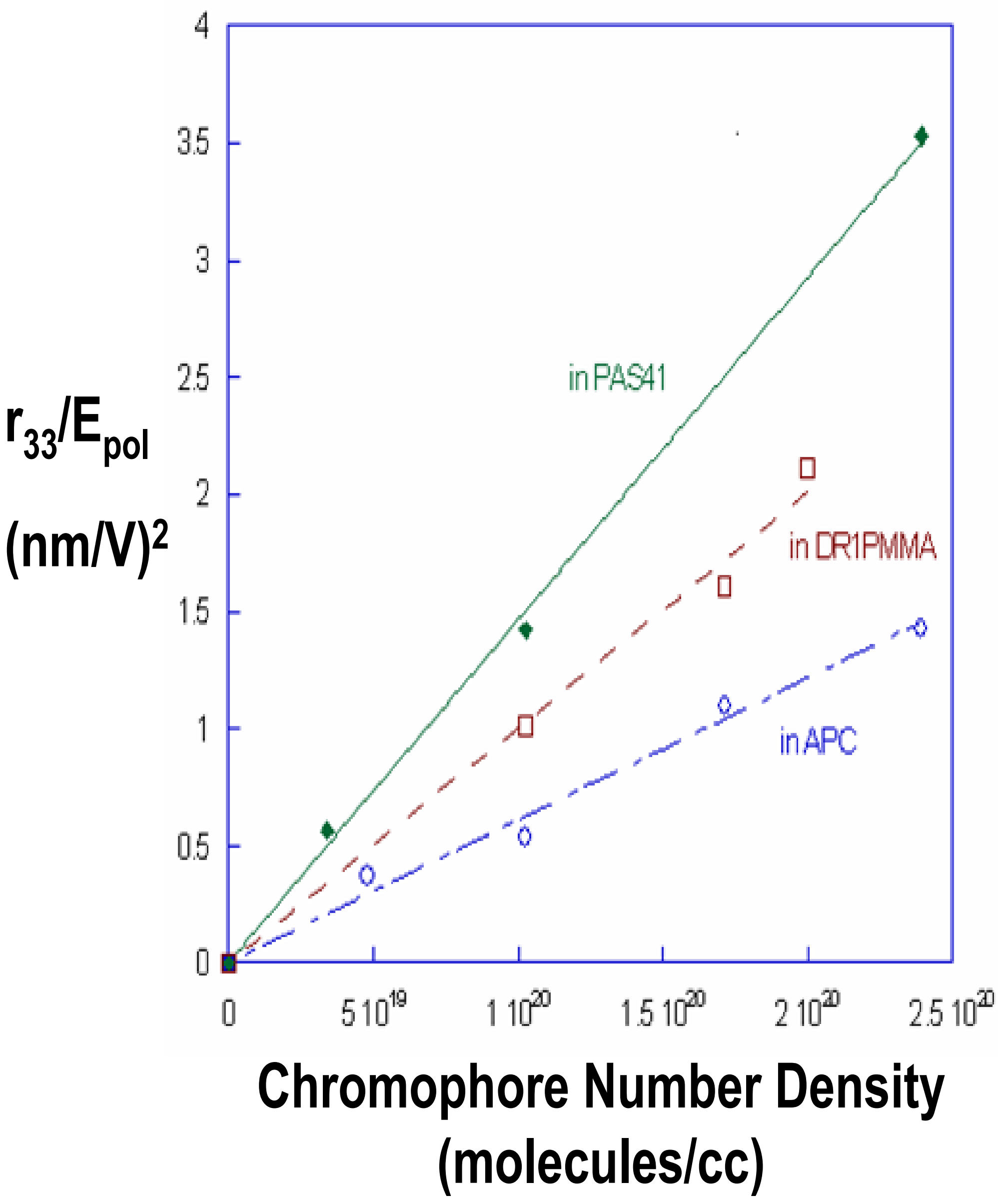
(a) LAP: Modified Teng-Man Ellipsometry

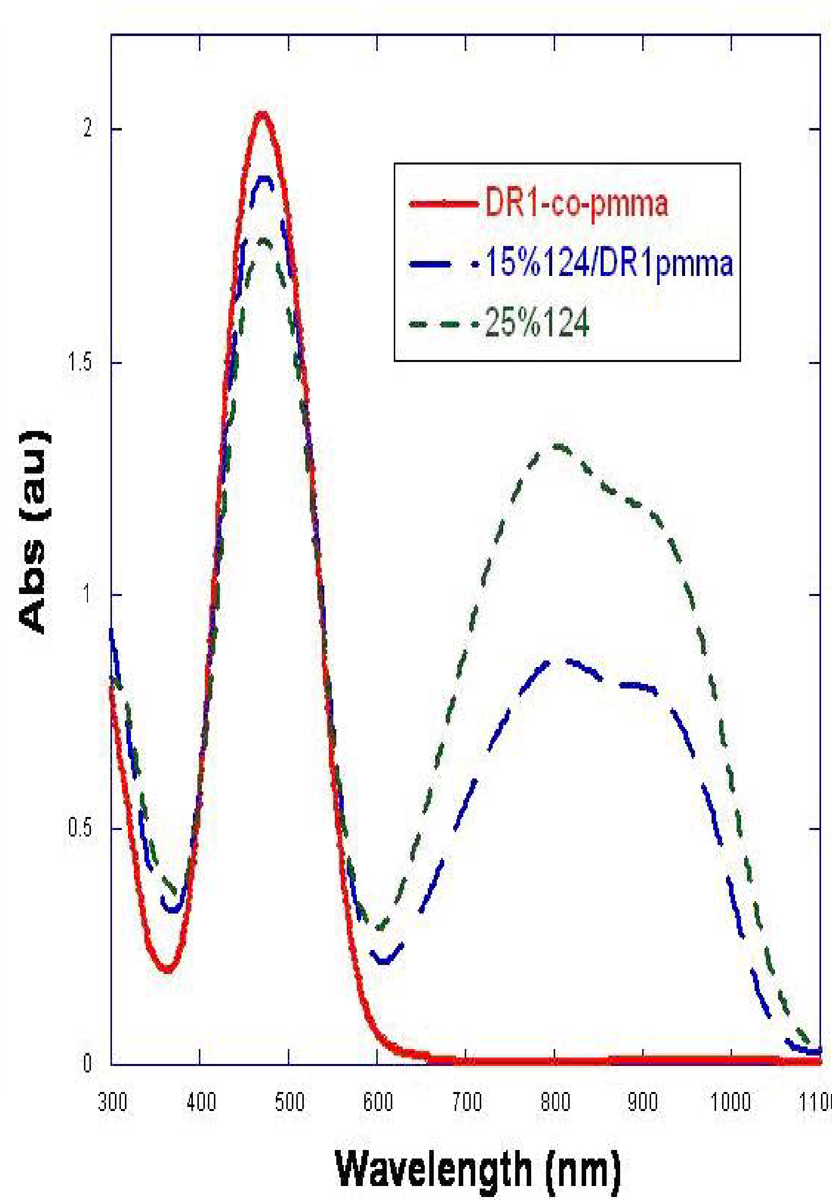


(b) Polarized Absorption



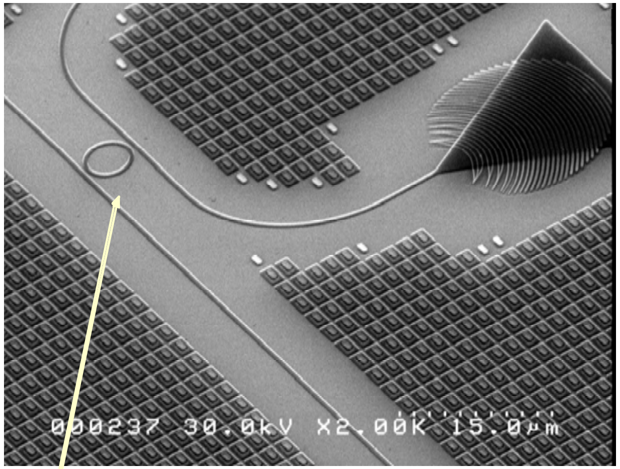
Simple Paradigm for Improved Linear & Nonlinear Optical Properties

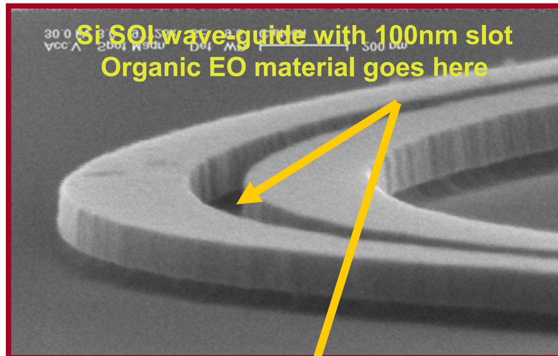


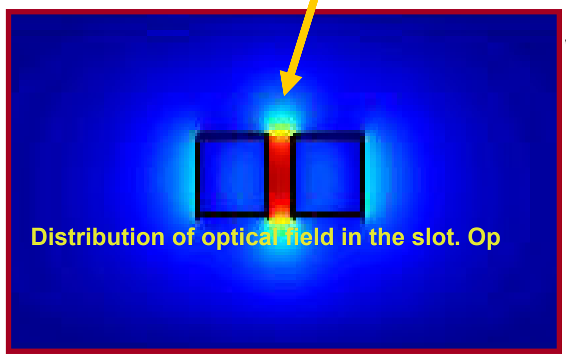


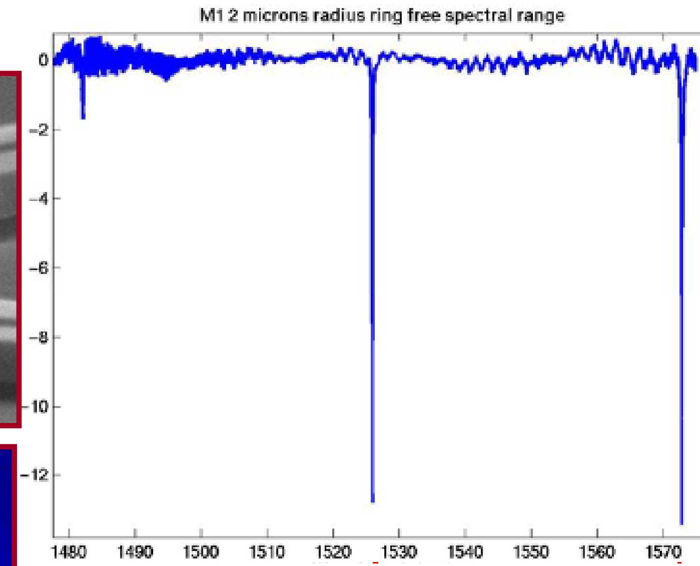
SILICON SLOTTED-MICRORING RESONATORS

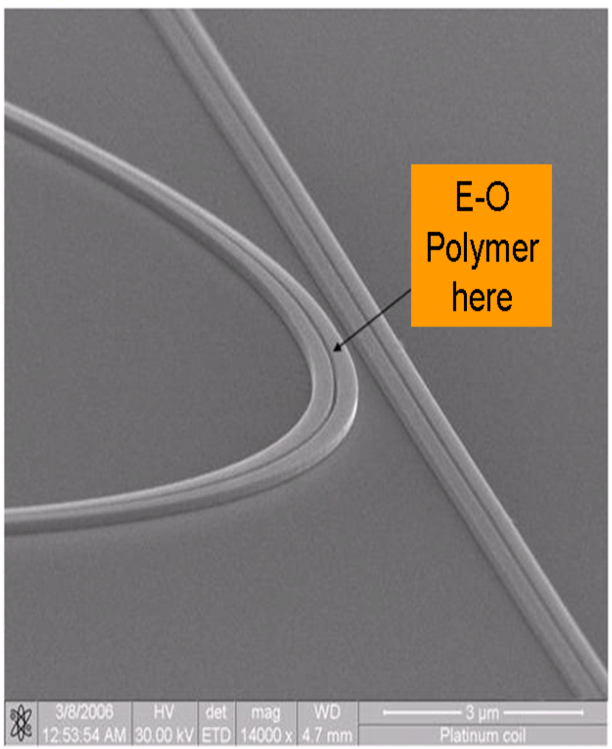
Sub 1-volt optical switching and modulation

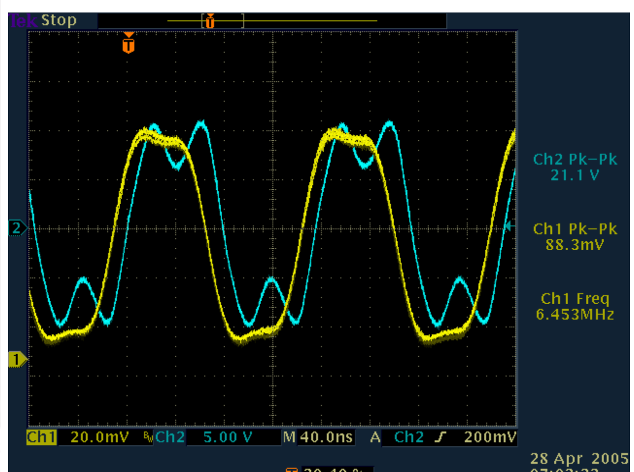


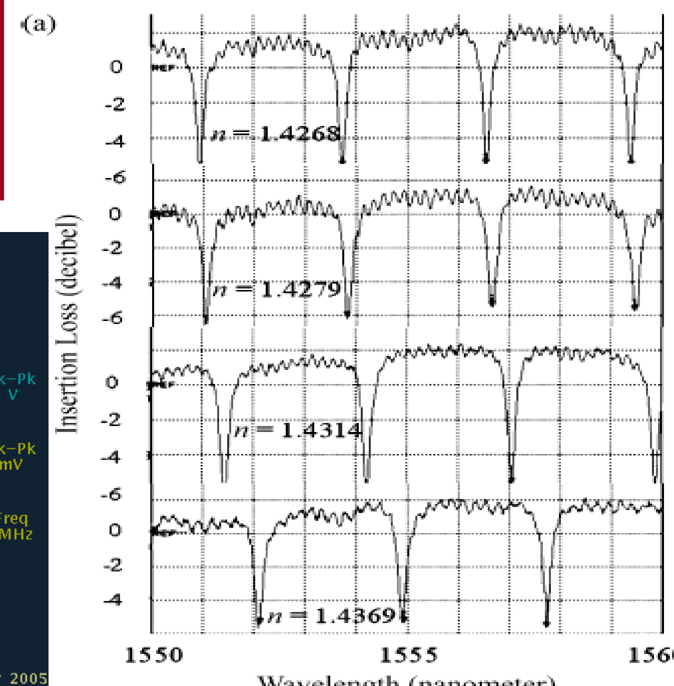












Drive Voltage-Bandwidth Parameters for Resonant Devices

Analog Signals

$$(V_{\pi\ \mathrm{equiv}}/\Delta f_{3dBe}) = 4\pi d\lambda/[(3\sqrt{3})(n_{eff})2r_{33}c]$$

$$\Delta f_{3dBe} = c/\lambda Q$$

if n = 1.6, r_{33} = 300 pm/V, d = 6 μm, and λ = 1.3 mm, then (V_π equiv/Δf_{3dBe}) = 0.08 V/GHz

$\Rightarrow$ Have achieved 0.05 V/GHz or 20 GHz/V (smaller electrode spacing)

Digital Signals

$$V_{10dB} = 3d\lambda B/((n_{eff})2r_{33}c)$$

if B = 10 Gb/s, n = 1.6, r_{33} = 300 pm/V, d = 6 μm, λ = 1.3 mm, Q = 5 x 10^3, then V_{10dB} = 1 V

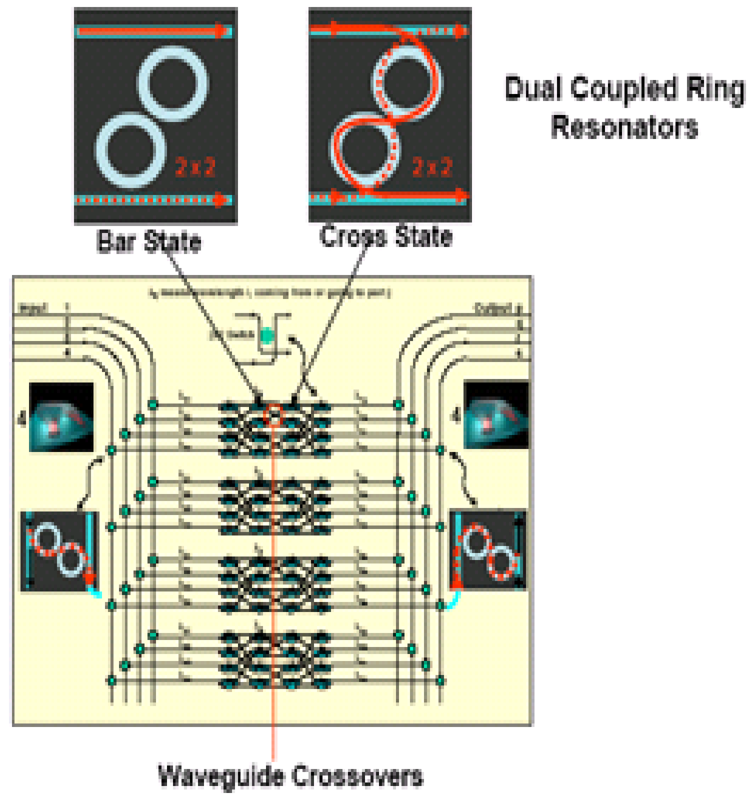
Electro-optic Polymer Tuned Si Modulators

Summary of Results

- **Demonstrated 20 *GHz/V* tuning in E-O polymer filled slotted ring resonators.**
- **These are the *lowest power E-O converters* operating at high frequencies, and are predicted to work at 100GHz/V tunability and well over 40Gb/sec.**
- **20 Gb/sec modulators with 0.2 V driving voltage and 50 micron diameters using E-O polymer filled slotted waveguide modulators**
- **We have used these waveguides to detect light by optical rectification – predicted to function at very high frequencies**

4x4x4 ROADM Constructed at Boeing

Wavelength Selective Cross-Connect Architectures



- **Silicon is used both for waveguide and as transparent electrical contact –enabling very high electrostatic fields across the 100nm waveguide slot without absorption losses.**
- **The slot geometry provides massive optical and electrostatic field enhancement. So far, Q values of 23k and modulation at 10 GHz have been measured in our slot resonators – limited by measurement electronics**

All-Optical Modulation > 5 THz

M. Hochberg et al., "All-Optical Modulator in Si with THz Bandwdith," *Nature Materials*, 5, 703-709 (2006). Two other papers in press.

- **Optical pump power < 1 mW (3×10^6 V/m)**
- **1/3 power in organic NLO cladding**
- **$\chi^{(3)} = 6\text{-}7 \times 10^{-21}\ (\mathrm{m/V})^2$**
- **Modulation to 10 THz**