

---

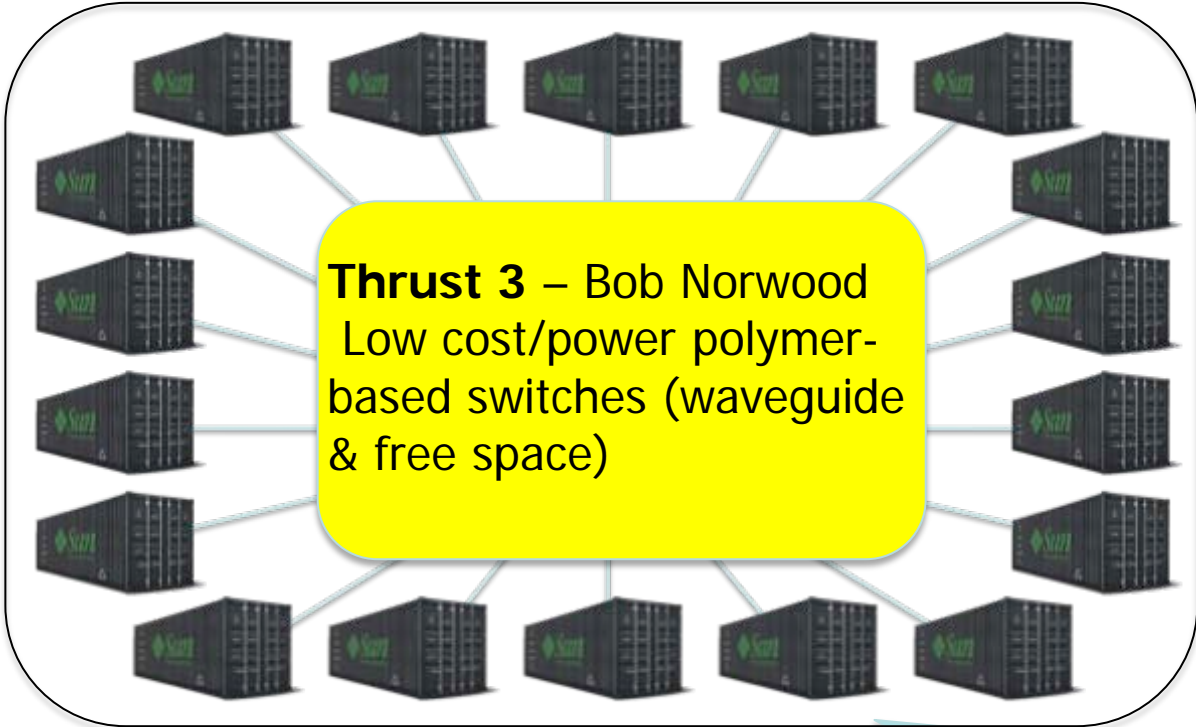
# Hybrid EO Polymer Devices for Data Center Networking

R. A. Norwood and N. Peyghambarian

November 2, 2010



# CIAN Projects Supporting Data Centers



**Thrust 3 – Bob Norwood**  
Low cost/power polymer-based switches (waveguide & free space)

**Thrust 1 – George Porter**

Data center topologies & architectures

System balance  
(software/hardware)

• **Thrust 2 – Connie Chang-Hasnain**  
Fast tunable VCSELs for wavelength-based architectures

# WG1: The Need for lower cost, more energy efficient data centers

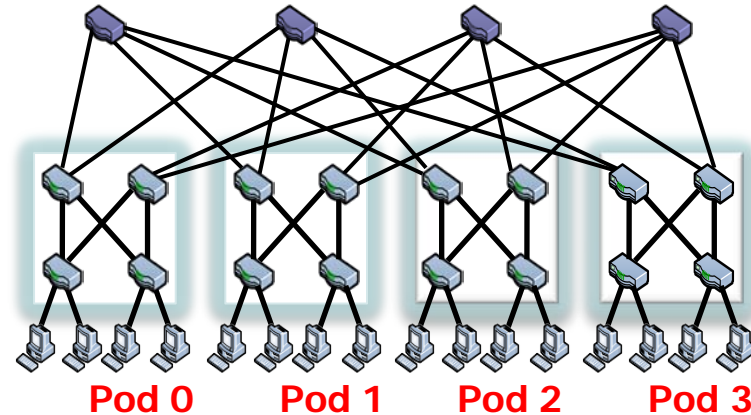
## Google's 36 Worldwide Data Centers



Walmart's Data Center

## "Cloud" Computing

- Massive migration of computing and storage into relatively small number of dense data centers



## Hybrid device goals:

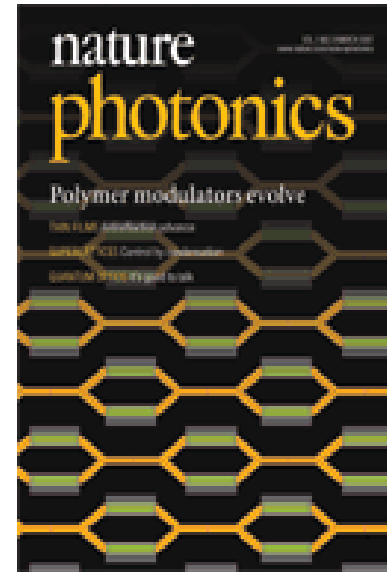
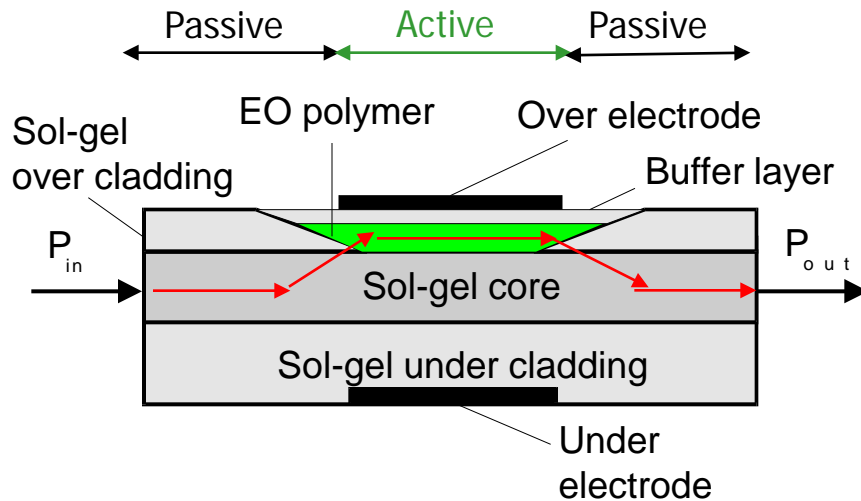
- Compact EO polymer modulators for reconfigurable optical interconnects
- Hybrid solid state EO switches for data centers
  - Waveguide-based - - high speed
  - Free space - - high connectivity

## Goals:

- Develop novel scalable architectures for cost effective and energy efficient operation of data centers
- Develop photonic technology in support of optical communication



# Hybrid polymer/sol-gel technology



Enami, et. al. *Nat. Phot.* **1**, 180 (2007)

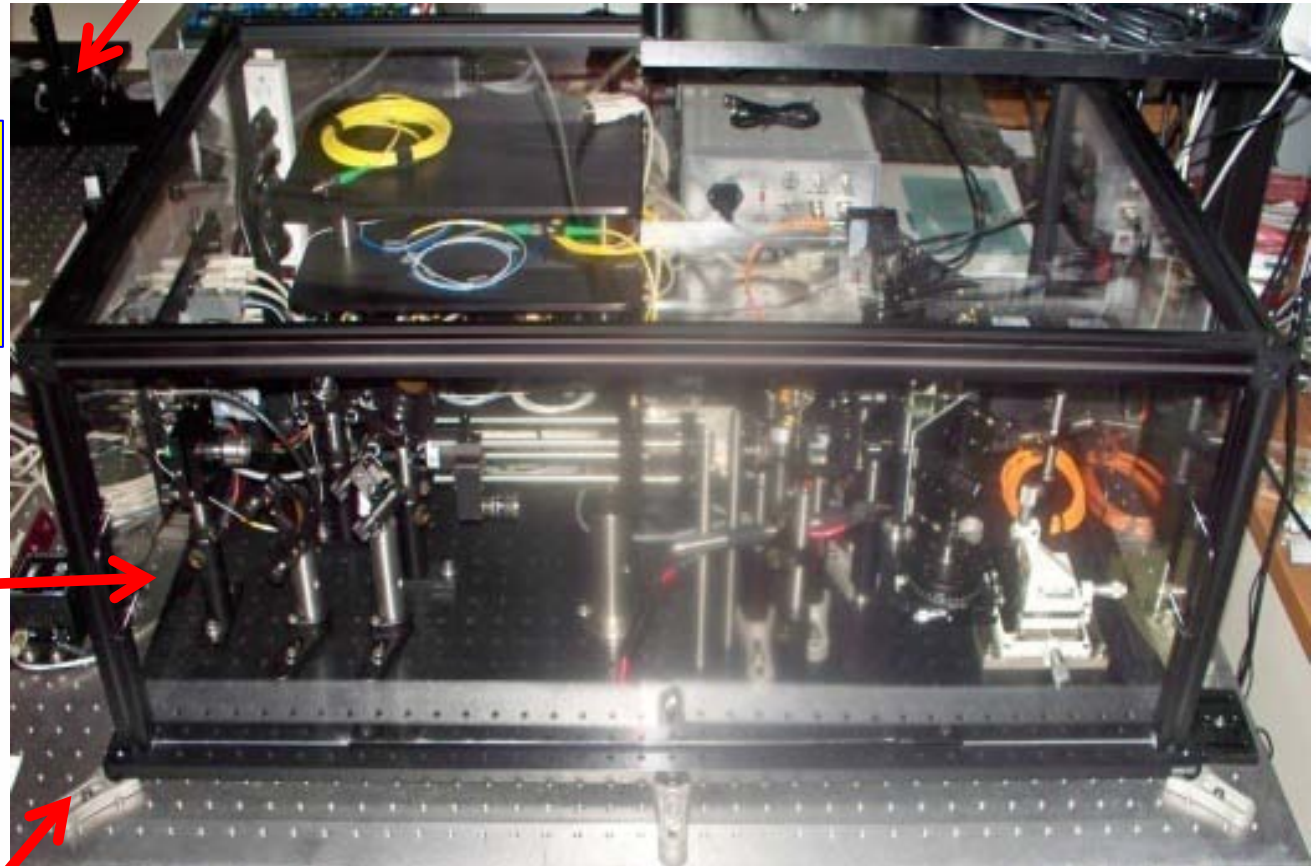
- Using advanced EO polymers
- Unique device design allows > 100% poling efficiency
- Record high EO coefficient  $r_{33}$  of 170pm/V demonstrated
- $V_{\pi}$  MZ Modulator 0.65 V: Enami, et. al. *APL* 91, 093505 (2007)

# MZI EO characterization system

3'x2'x1' enclosure

Provides for independent measurement of both  $r_{33}$  and  $r_{13}$  as well as the piezoelectric coefficient

Sliding door



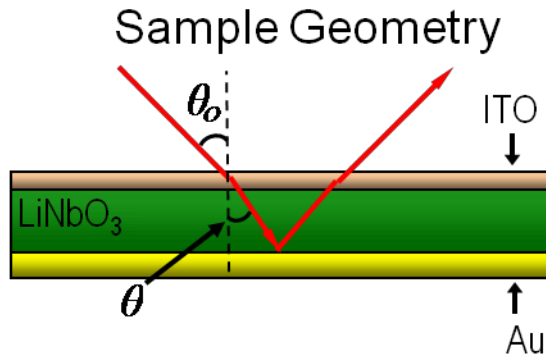
Isolation Table

C. Greenlee, et. al. *APL* **97**, 041109 (2010)



# Exceptional EO effects in EO polymers

## Lithium niobate standard

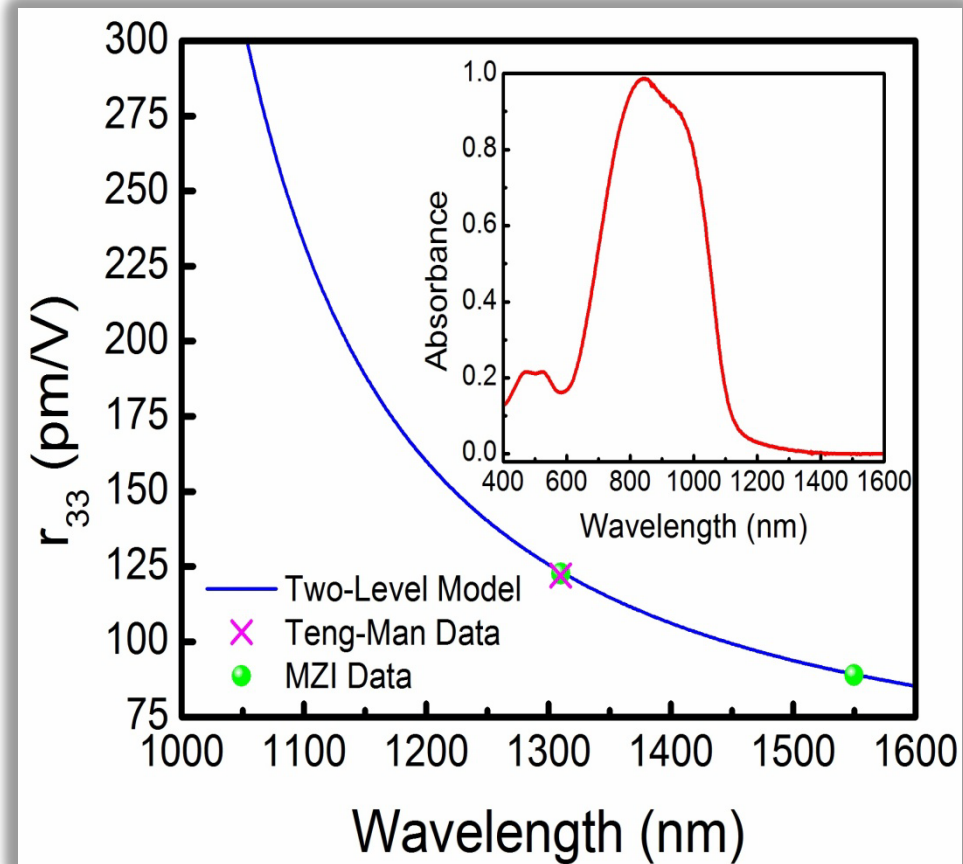


$\lambda$ ( $\mu\text{m}$ )	$r_{13}$ ( $\text{pm/V}$ )	$r_{33}$ ( $\text{pm/V}$ )	$r_{33}/r_{13}$
633*	10.1	32.0	3.2
980	10.3	32.0	3.1
1310	9.3	30.8	3.3
1550	10.2	26.6	2.6

\* obtained from literature

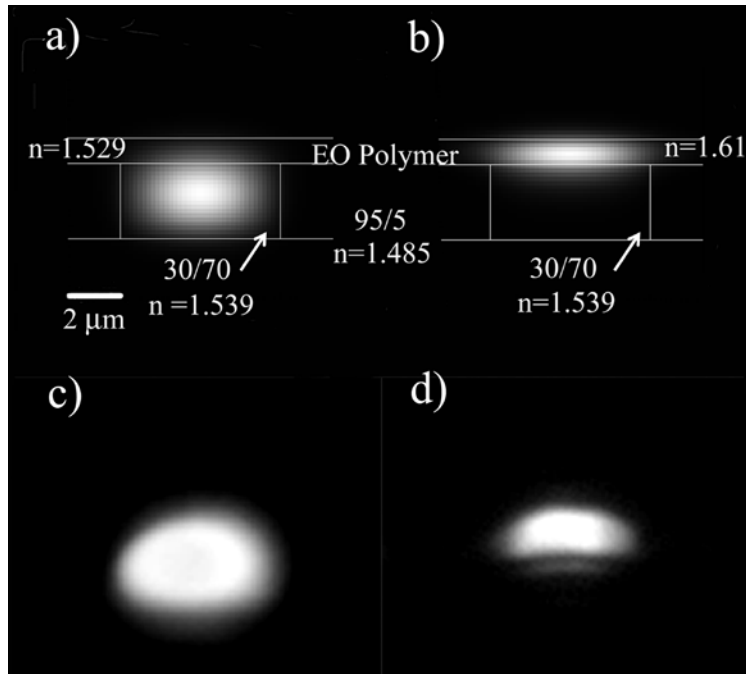
\*\* piezoelectric coefficient,  $d_{33} \sim 7 \text{ pm/V}$

## EO polymer



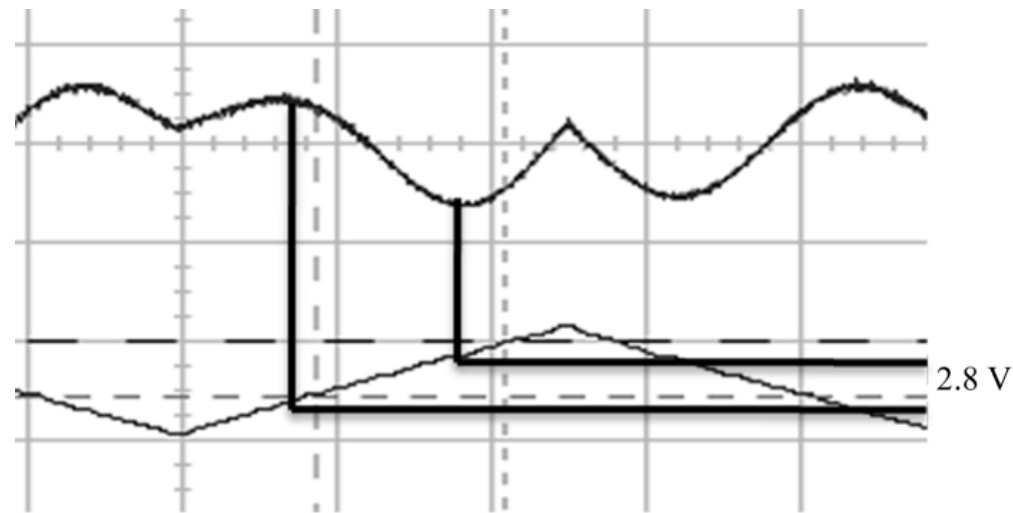
# Hybrid sol-gel/EO polymer MZ with 5.7 dB IL, $V_{\pi}$ of 2.8V: AJLS 102

*Low loss internal taper with  
high confinement factor*



FOM = 0.1 V<sup>-1</sup>

$$r_{33} = 70\text{pm/V}$$

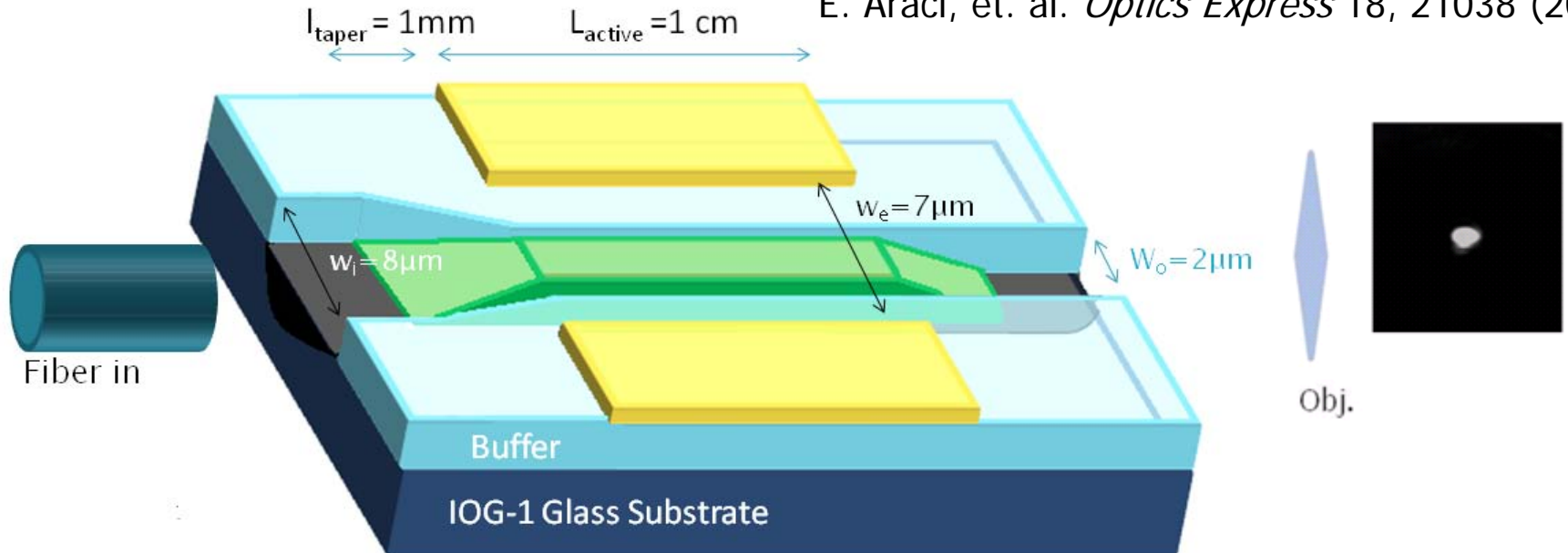


Insertion Loss: 5.7dB

C. DeRose, et al, *Optics Express* 17, 3316 (2009)

# Hybrid ion-exchange/EO polymer phase modulator

E. Araci, et. al. *Optics Express* 18, 21038 (2010)



- 4.5 dB insertion loss – used AJLY EO polymer ( $r_{33} = 20\text{pm/V}$ ) optimized for low-loss reactive ion etching
- $7.5\ \mu\text{m}$  electrode spacing
- $75\ \text{V}/\mu\text{m}$  poling field at  $135\ \text{°C}$
- $V_{\pi} = 16\text{V} \rightarrow 2.5\text{V}$  for dual drive MZ with AJLS102 ( $r_{33} = 60\text{pm/V}$ )

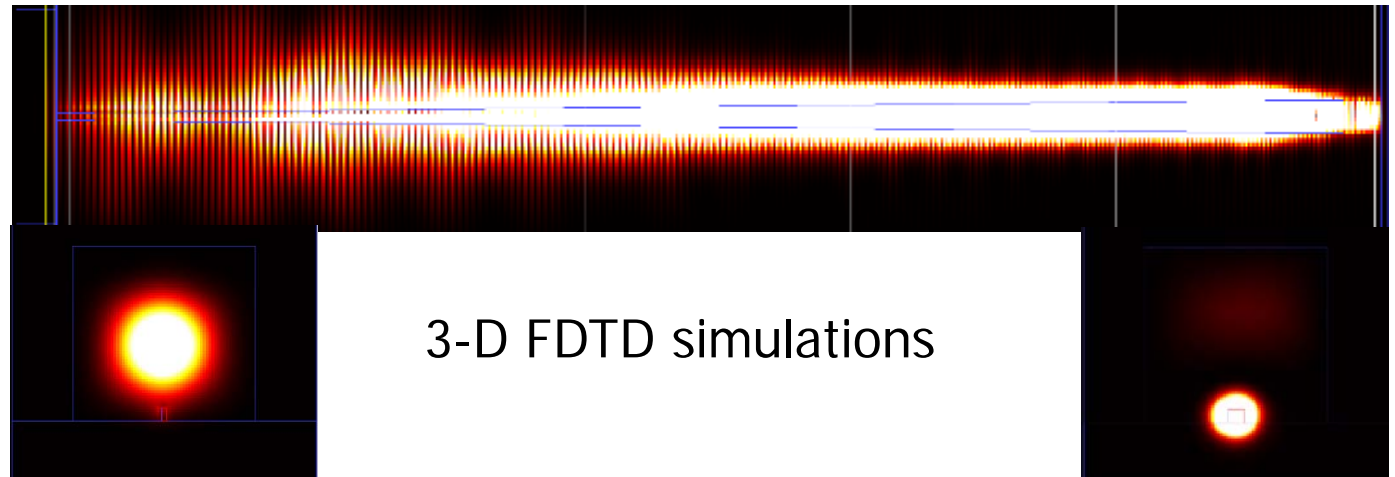
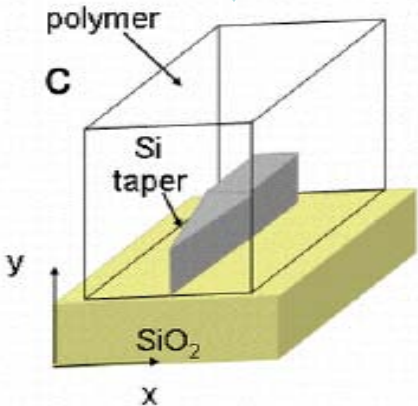
FOM projected =  $0.16\ \text{V}^{-1}$

# Highly efficient horizontal inverse taper for mode size conversion



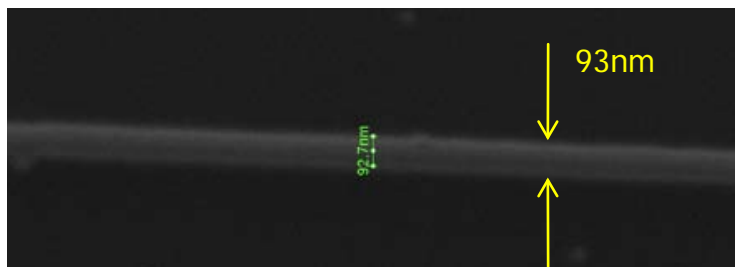
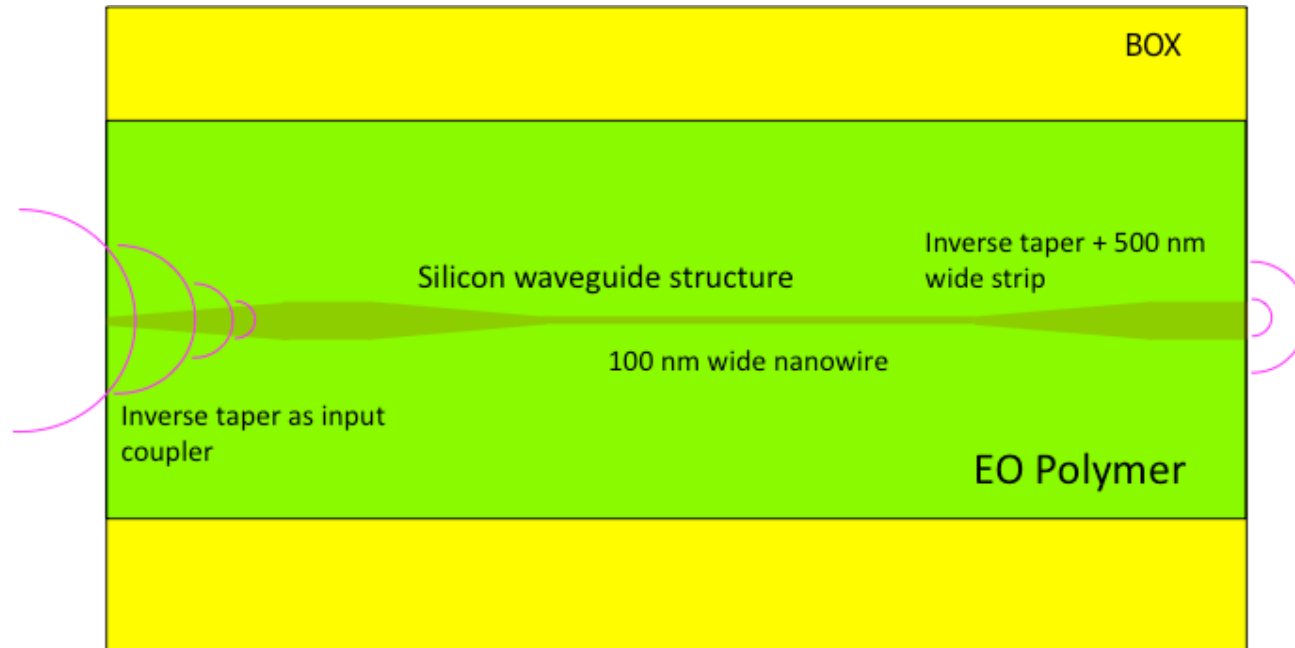
Si SM waveguide dimensions: 400 by 220 nm

- Si tip width: < 100 nm; taper length: < 200  $\mu\text{m}$
- Outer polymer cladding size: 3 x 3  $\mu\text{m}$



3-D FDTD simulations

# EO polymer clad Si nanowire waveguide modulator

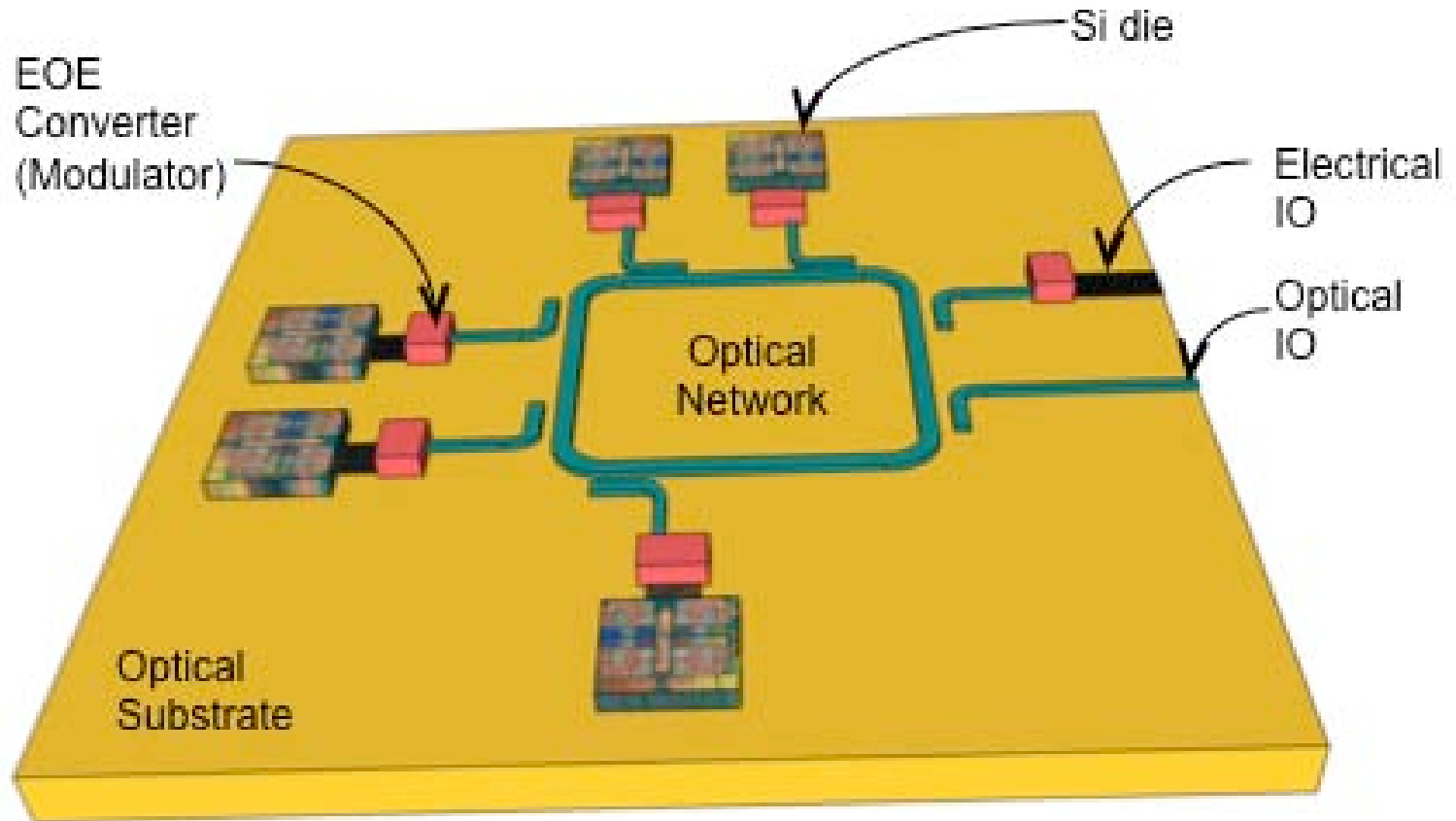


SEM photo: 100 nm wide Si nanowire waveguide



1550 nm light transmitted through the nanowire waveguide with tapered coupler

# Compact modulators for optical circuit boards



# Low loss waveguide optical switching

## Project Summary

- Microsecond pod level circuit switching required to allow the data center to act as a uniform computer.
- Optical switching in waveguides based on the electro-optic effect in organic nonlinear optical materials has been demonstrated at speeds in excess of 150 GHz. Switching voltages as low as 0.65V lead to low power consumption.
- Nanosecond response enables optical packet switching to address core-edge bottleneck

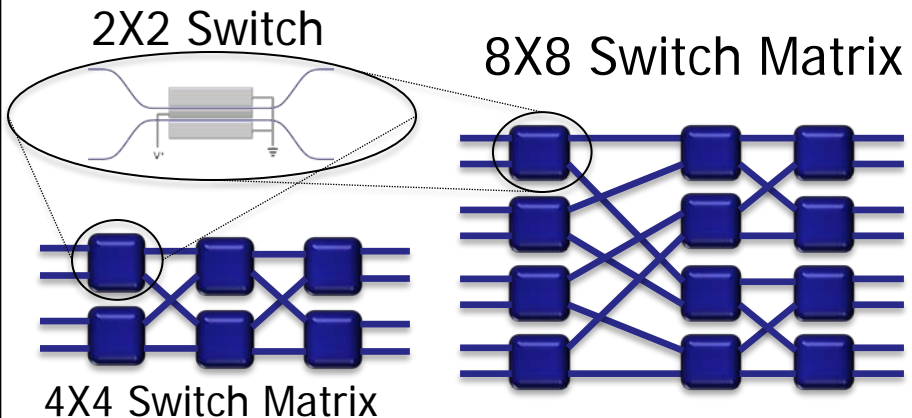
## Deliverables/Impact

- Switching speed >1000 times faster than commercially available technology, which is limited to switching times on the order of tens of milliseconds.
- Competitive insertion loss
- Initially, port count limited to 2. Expansion to 8 port switches expected by 2012.
- Hybrid electrical & optical switching expected to lead to 3X cost reduction, 6X cabling reduction, and 9X power reduction in next generation modular data centers.

## Schedule

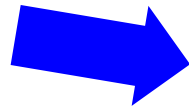
- 2X2 switch with < 3 dB insertion loss, <5V switching voltage and sub-millisecond switching speed – 2 months
- 4X4 switch with < 4 dB insertion loss, <5V switching voltage and sub-millisecond switching speed - 6-9 months
- Determine desired specs and fabricate 8X8 switch – 2 years

## Graphic



# Optical switch fabrication

400 nanometer pitch lines on a five inch photomask



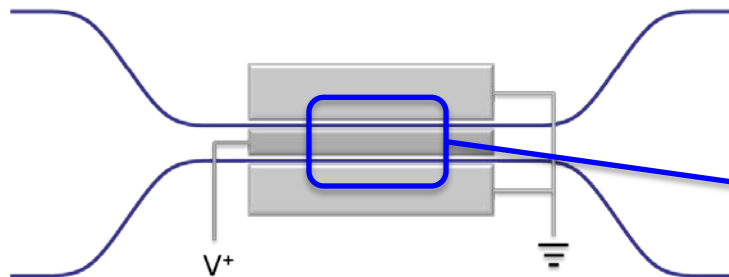
Pattern Transferred to PMMA via Deep UV exposure



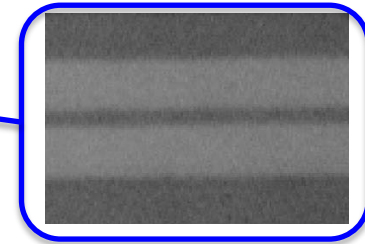
Transfer to chrome via wet etch



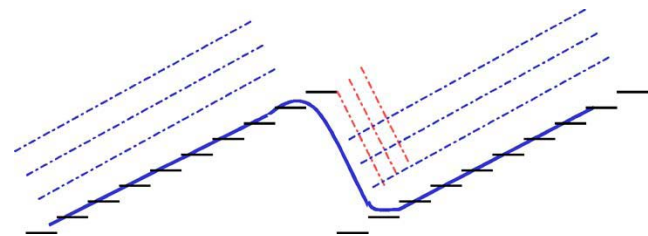
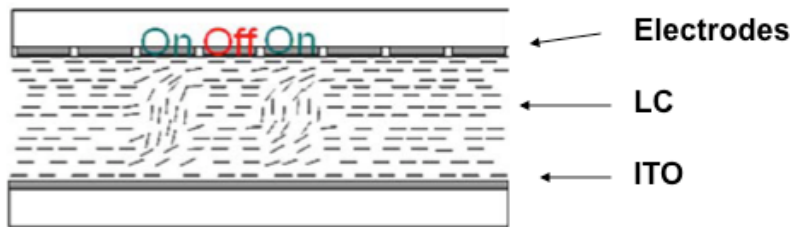
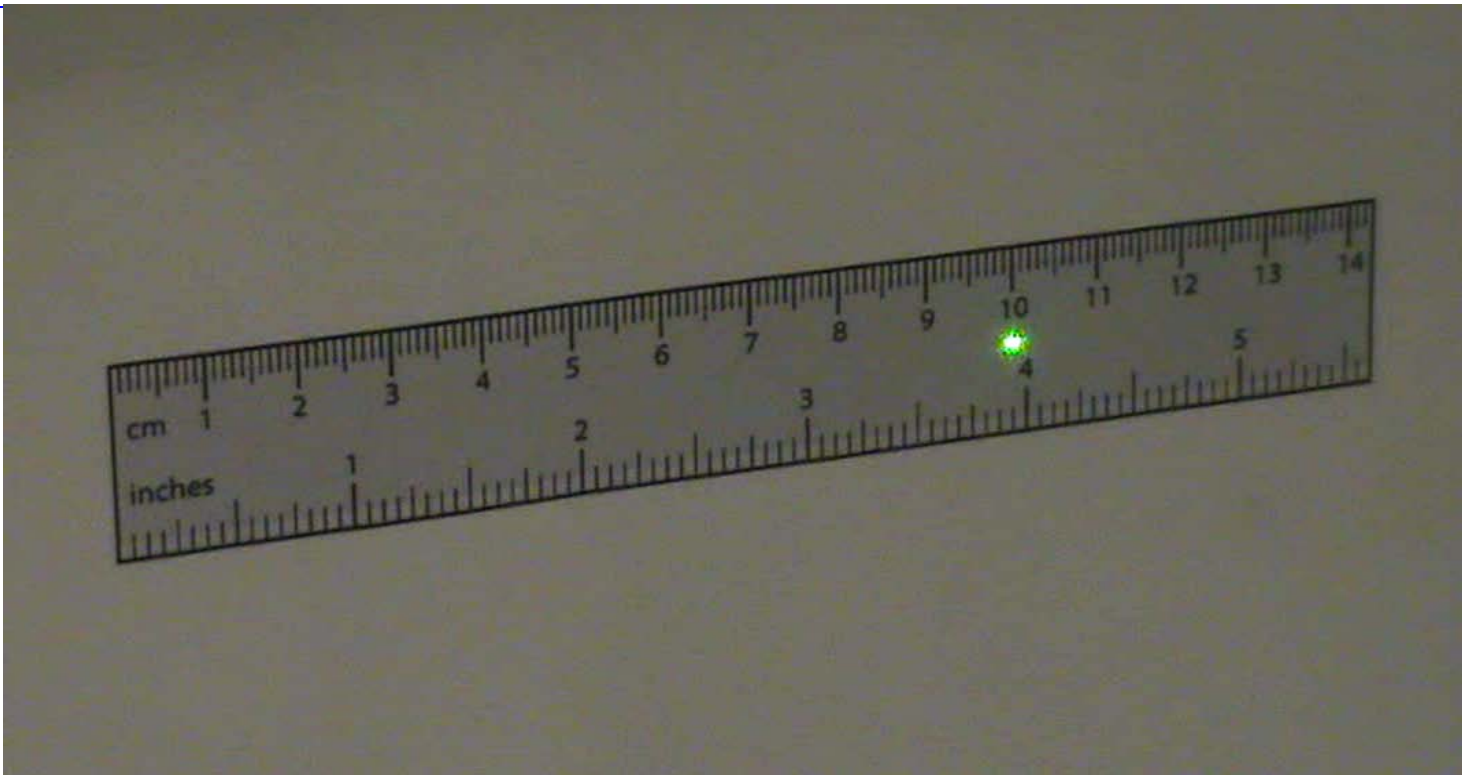
## 2X2 Directional Coupler Based Switch Schematic



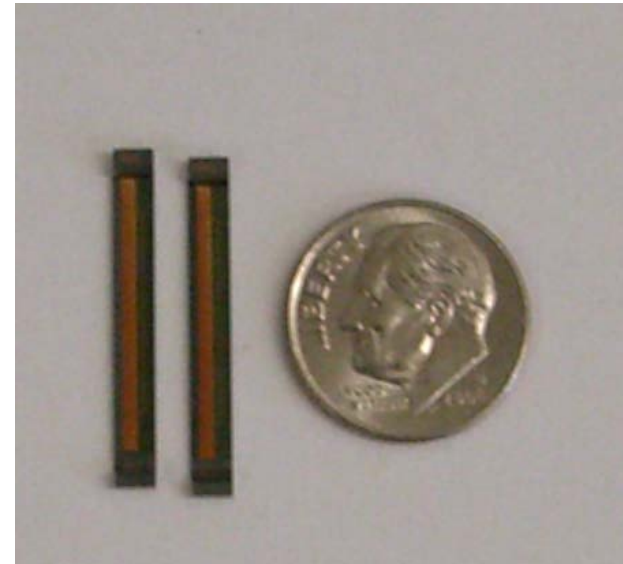
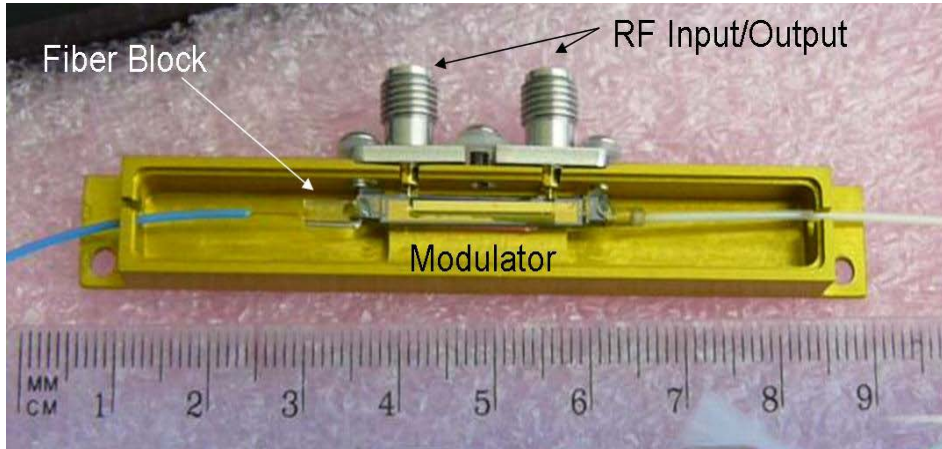
SEM Image of Directional Coupler with 500 nm Waveguide Separation in PMMA



# Free-space electro-optic switches



# Packaged devices



- Diced modulator chip fiber attached
- Low-shrinkage, index matching UV Epoxy
- Robust fiber attach

- Diced RF modulator chips
- Electrode length 15 mm for high speed operation
- High yield dicing process

# Acknowledgements

---

## College of Optical Sciences

- E. Araci (now Stanford)
- C. DeRose (now Sandia)
- O. Herrera
- R. Himmelhuber
- A. Jones

## EO Materials

- C. Zhang at NSU
- A. Jen at UW
- Soluxra