Modulator

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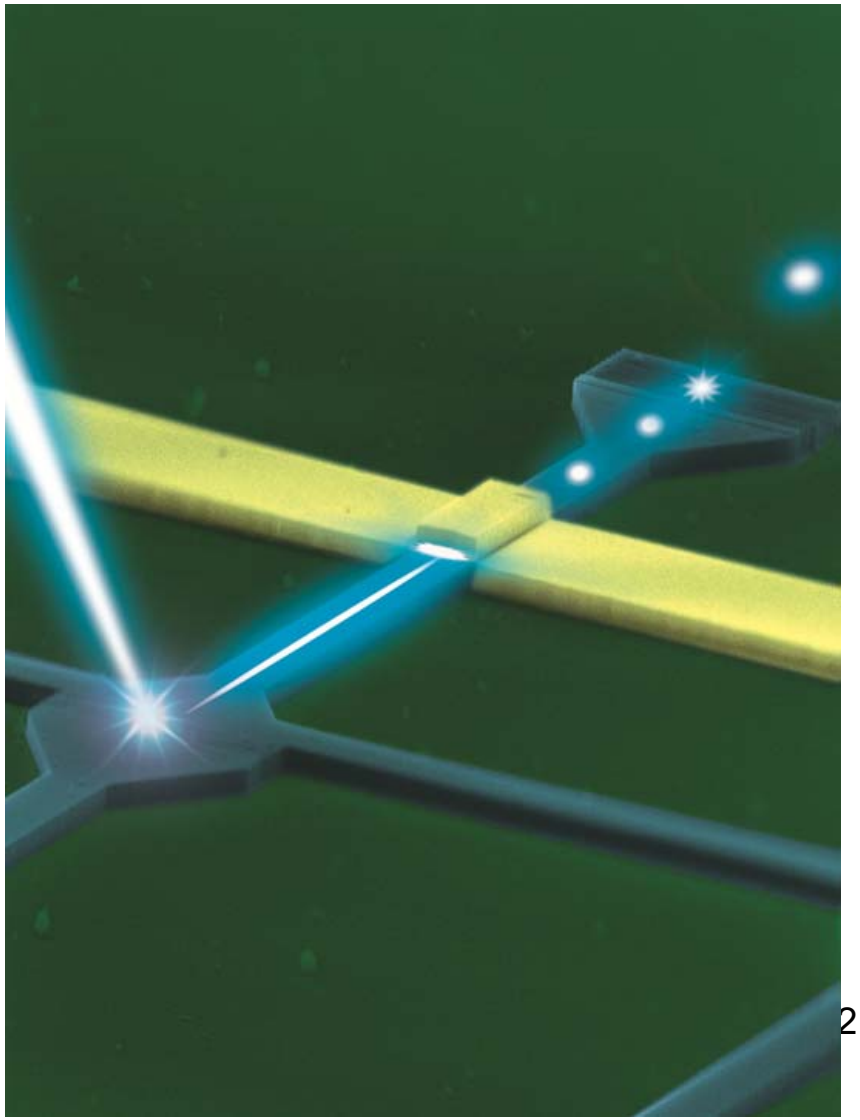
Ultra-compact silicon nanophotonic modulator with broadband response

Volker J. Sorger[1], Norberto D. Lanzillotti-Kimura[1], Ren-Min Ma[1] and Xiang Zhang[1,2,*]

Keywords: Modulator; silicon-on-insulator; ultra-compact.



SPIE Newsroom

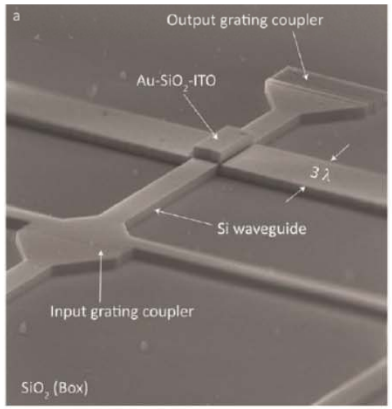
10.1117/2.1201305.004843

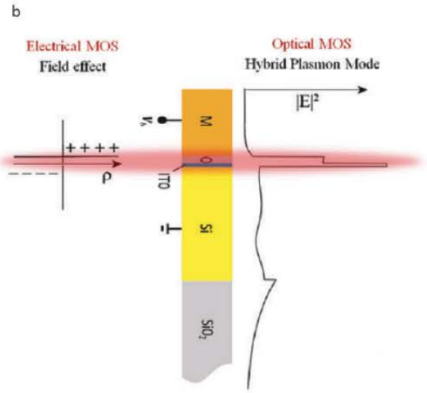
A high-performance silicon-based plasmonic modulator

Ren-Min Ma and Xiang Zhang

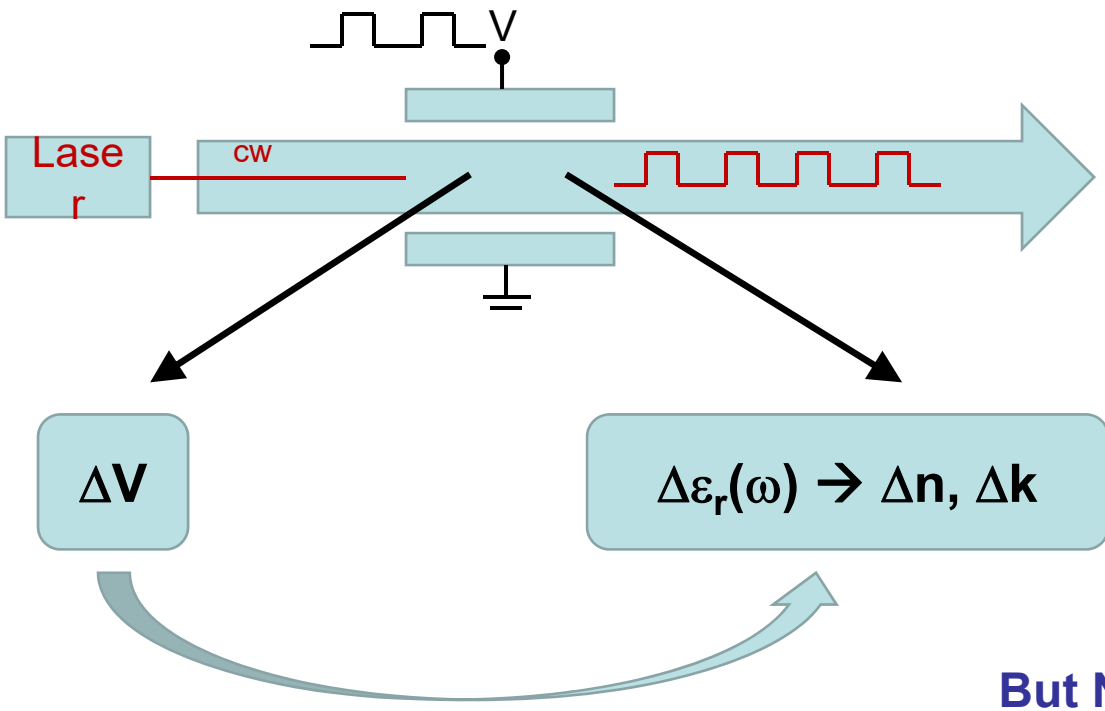
Photonic integrated circuits could be scaled down for future optical communication applications with the help of a new wavelength-scale modulator.

To meet the ever-increasing global demand for bandwidth, optical interconnects are now being used to cover shorter distances. They will eventually account for all the interconnects inside a chip, setting a roadmap for reducing the photonic com-





Electro-Optic Modulator (EOM)



Materials

- $LiNbO_3$
- Silicon
- Polymers
- ITO

Franz Keldysh effects
Pockels effects
Kerr effects
Free carrier effects

But Non-Plasmonic = Weak Effect

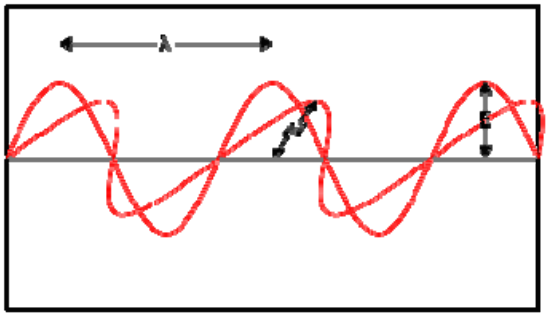
$$\frac{\Delta n}{\Delta U_{bias}} = 3 \times 10^{-6} V^{-1} *$$

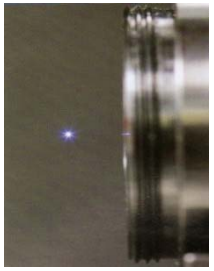
* Intel Si-Photonics, e.g. **Nature** (2004)

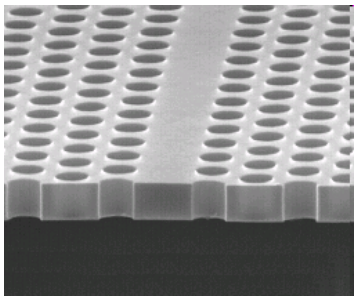
A Technological Opportunity: *Bridging the "Gap"*

Light

Visible / IR λ ~ 1 μm





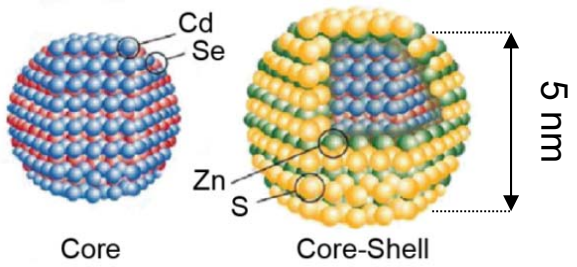


Weak Interaction

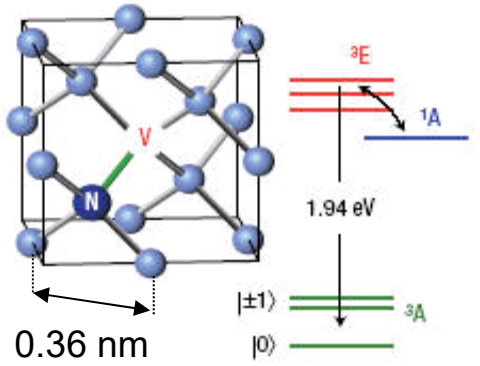
Electrons

λ_e ~ 1 nm

Quantum dot



NV-center

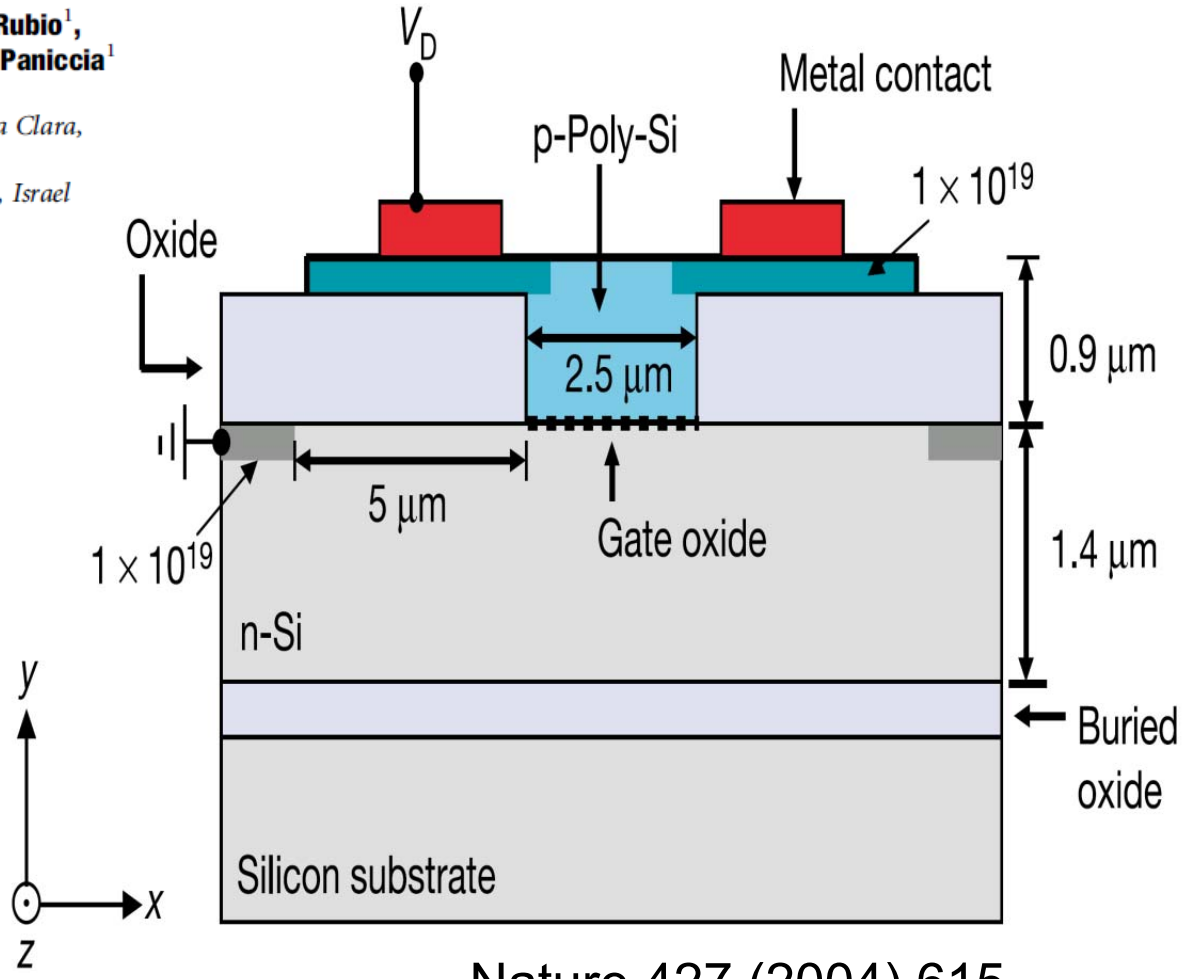


MOS Silicon Modulator

A high-speed silicon optical modulator based on a metal–oxide–semiconductor capacitor

Ansheng Liu[1], Richard Jones[1], Ling Liao[1], Dean Samara-Rubio[1], Doron Rubin[2], Oded Cohen[2], Remus Nicolaescu[1] & Mario Paniccia[1]

[1]*Intel Corporation, 2200 Mission College Blvd, CHP3-109, Santa Clara, California 95054, USA*
[2]*Intel Corporation, S. B. I. Park Har Hotzvim, Jerusalem, 91031, Israel*



Nature 427 (2004) 615

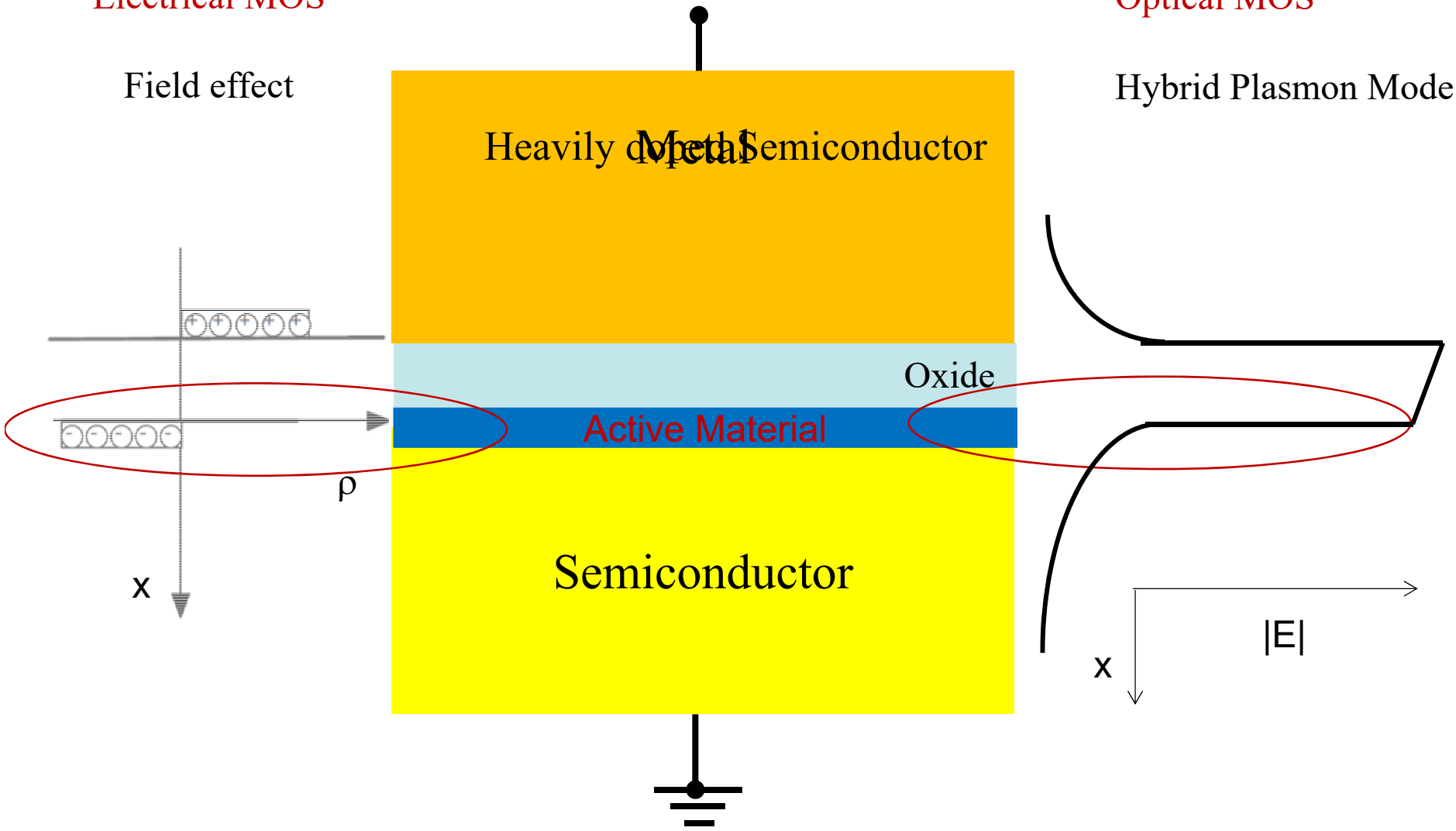
MOS Capacitor

Electrical MOS

Field effect

Optical MOS

Hybrid Plasmon Mode



Active Material : ITO

Indium **t**in **o**xide (ITO), is a heavily-doped n-type semiconductor with a large bandgap

Typically 90% In_2O_3, 10% SnO_2 by weight

NANO LETTERS

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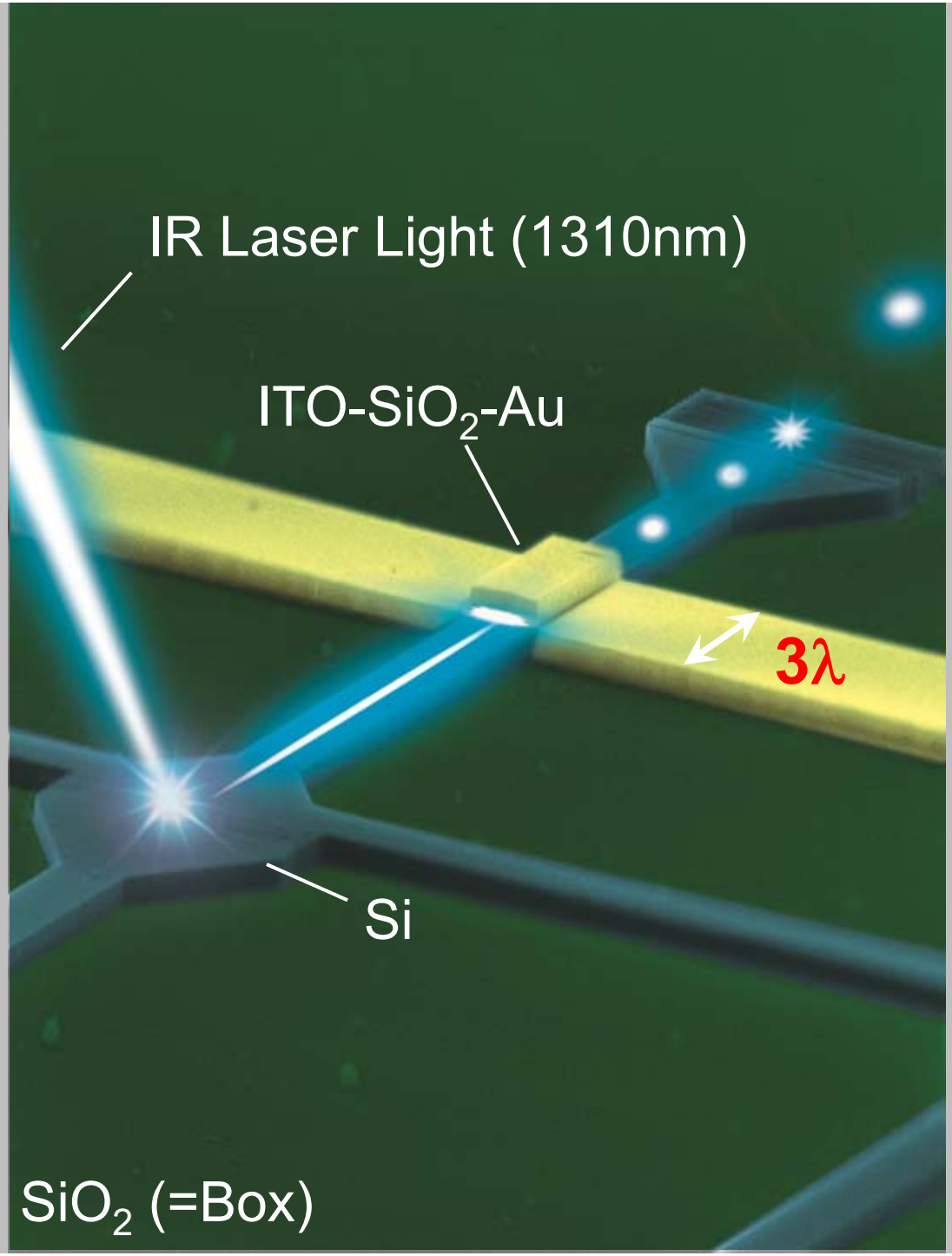
Unity-Order Index Change in Transparent Conducting Oxides at Visible Frequencies

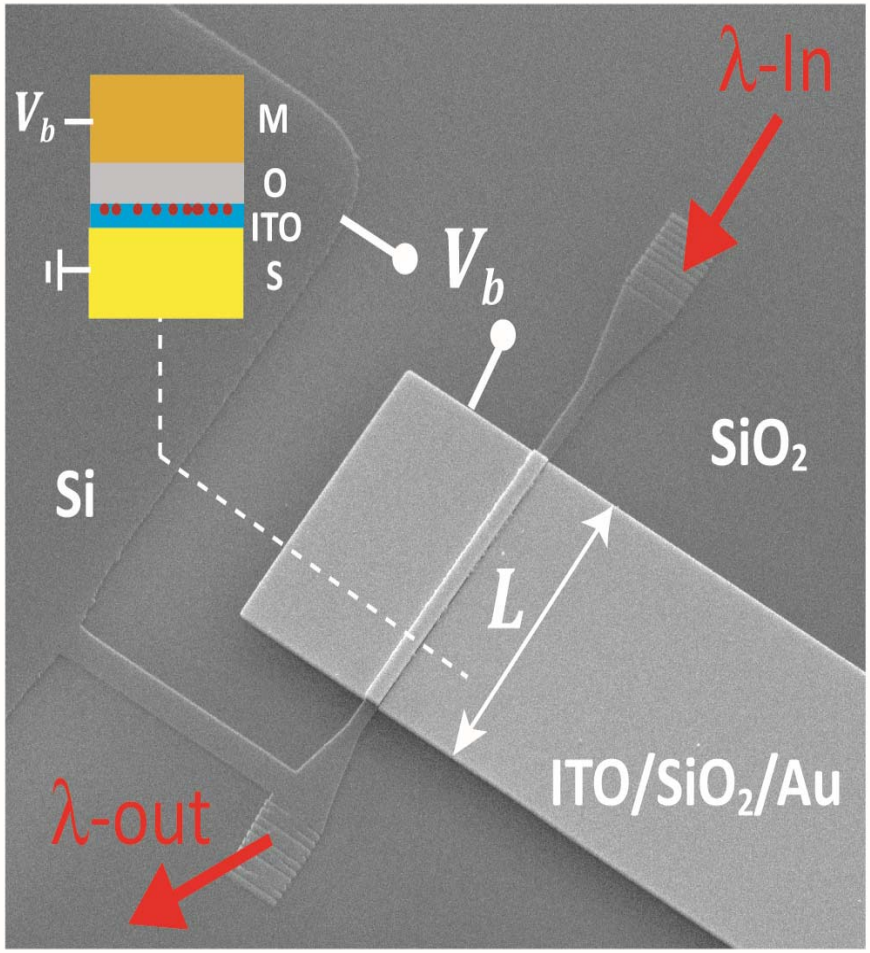
Eyal Feigenbaum,*,† Kenneth Diest,†,§ and Harry A. Atwater

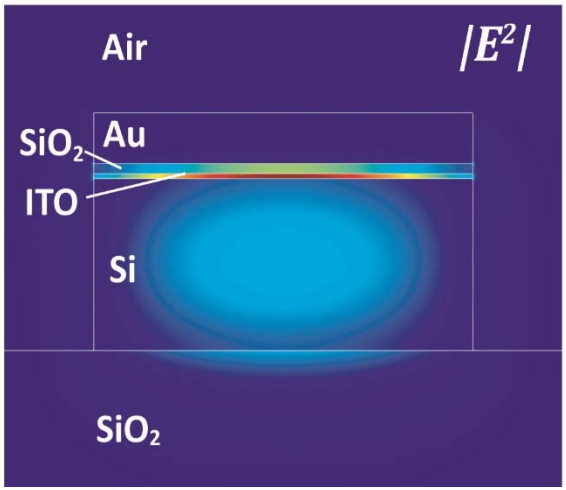
Thomas J. Watson Laboratory of Applied Physics, California Institute of Technology, Pasadena, California 91125

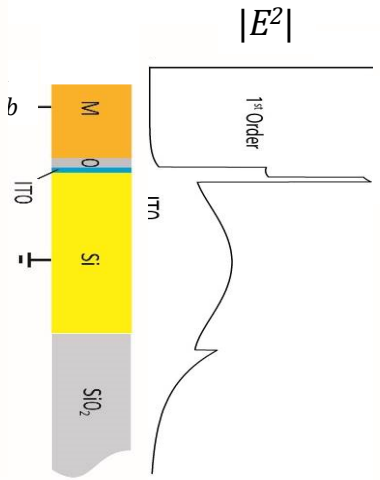
Nano Lett. **2010,** *10*, 2111–2116


IR Laser Light (1310nm)
ITO-SiO2-Au
3λ
Si
SiO2 (=Box)

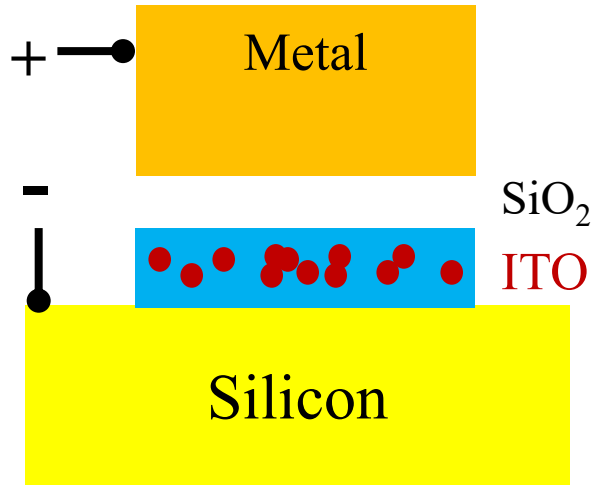
Ultra-compact Si-based Modulator







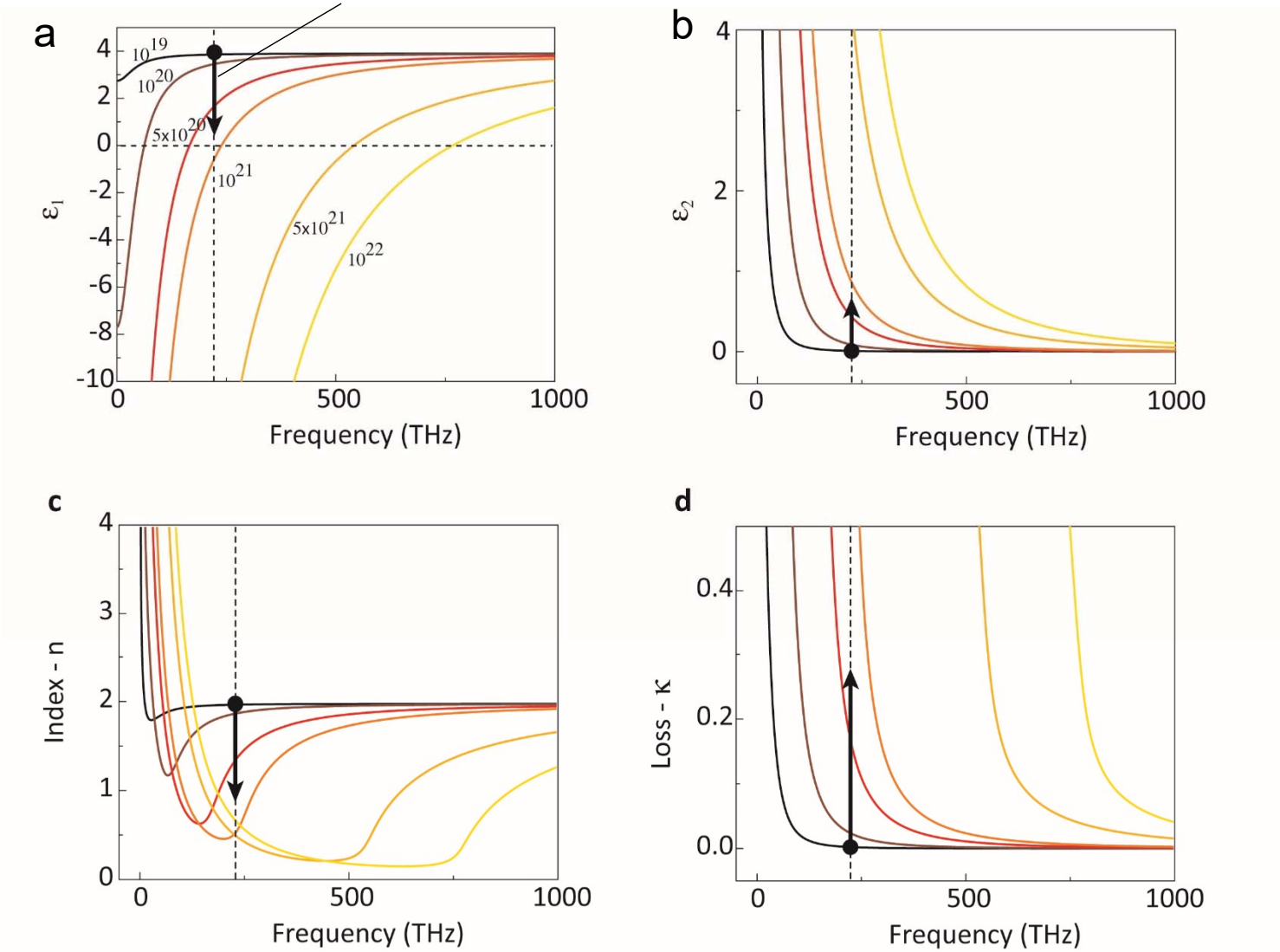
Optical MOS = Hybrid Plasmon Mode



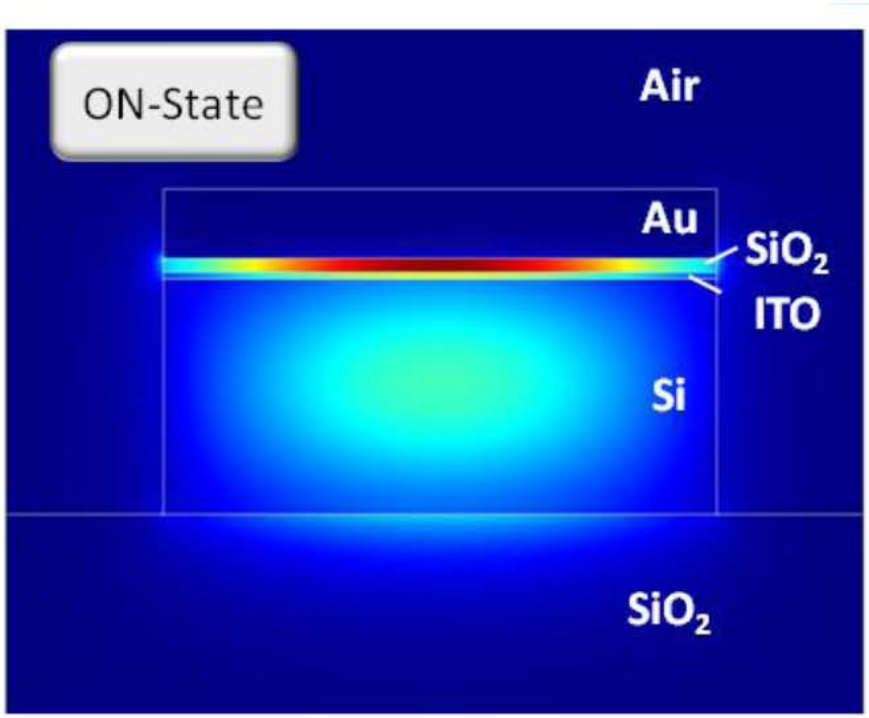
Electrical MOS = Field effect

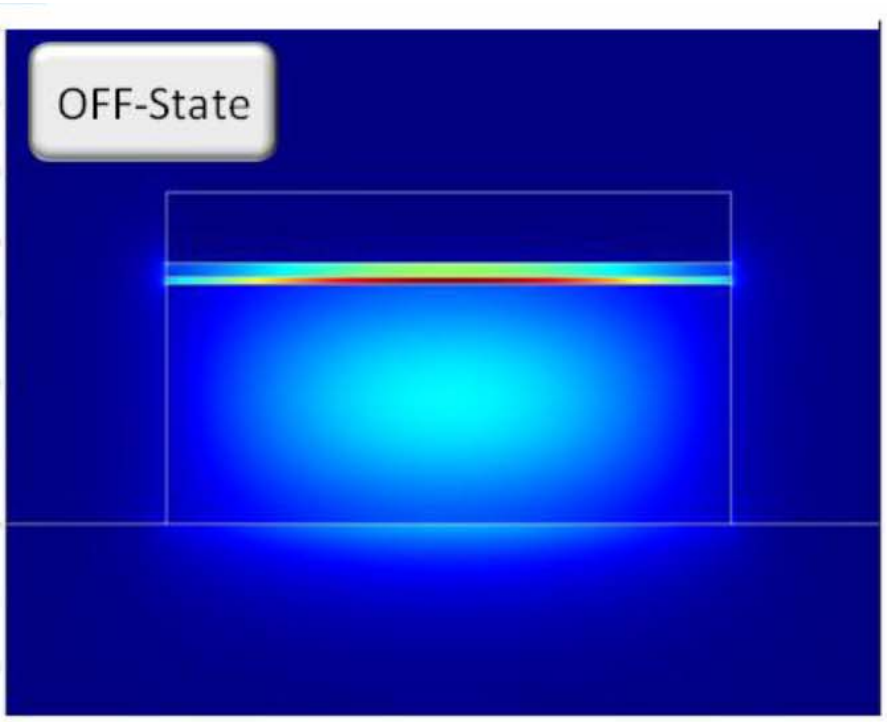
ITO Optical Properties at Biases

$n_0 \sim 10^{19}\,\mathrm{cm}^{-3}$ $\Delta n_e = 6 \times 10^{20}\,\mathrm{cm}^{-3}$



Electric field densities for the ON and OFF state

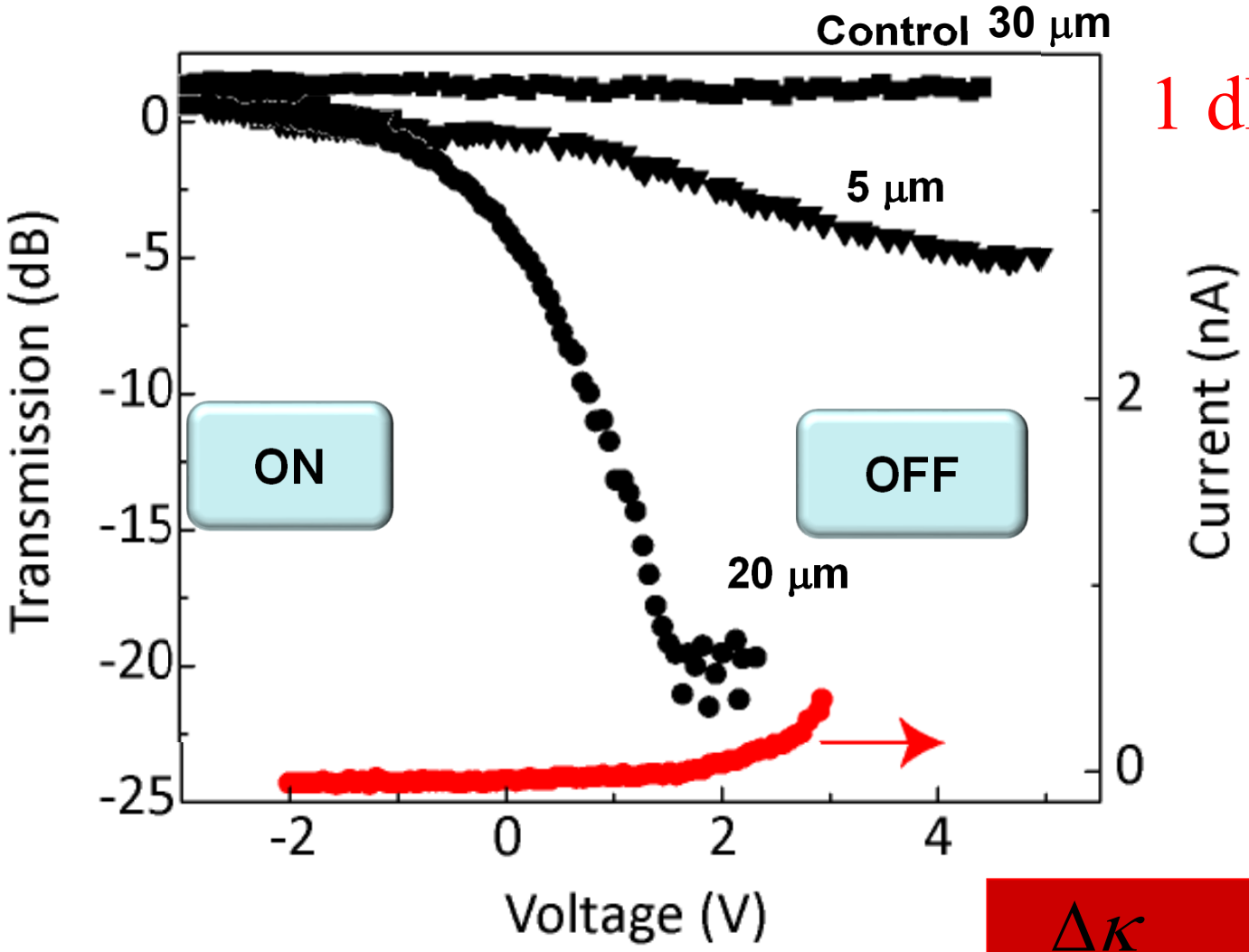




W/O bias
ITO → Semi. → larger n, smaller k
More field in SiO2 and Si
Low insertion loss

W/ bias
ITO → Metal → smaller n, larger k
More field in ITO
High modulation strength

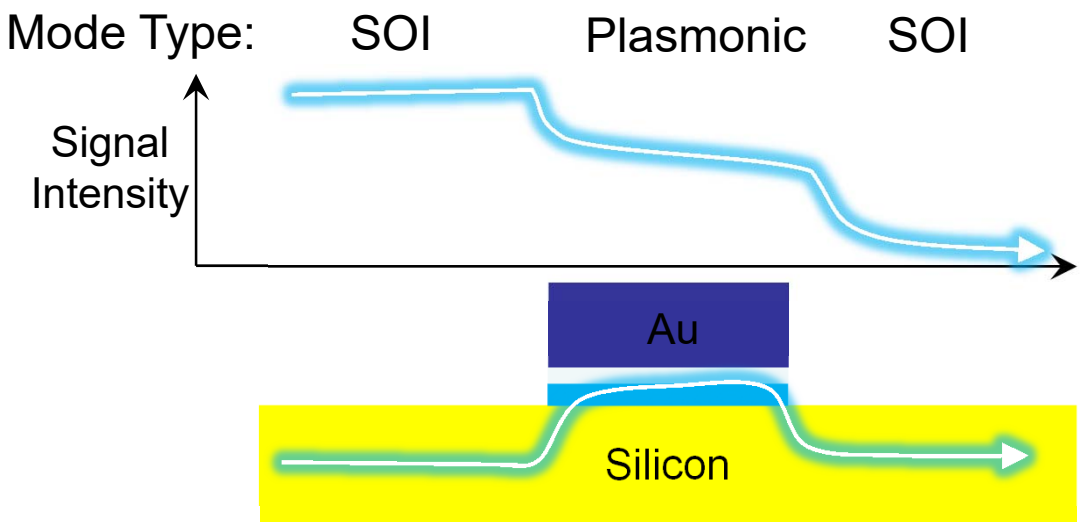
High Performance Modulation

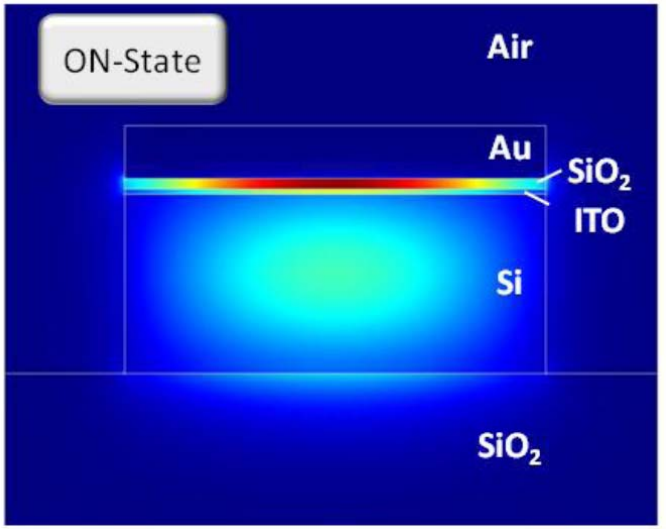


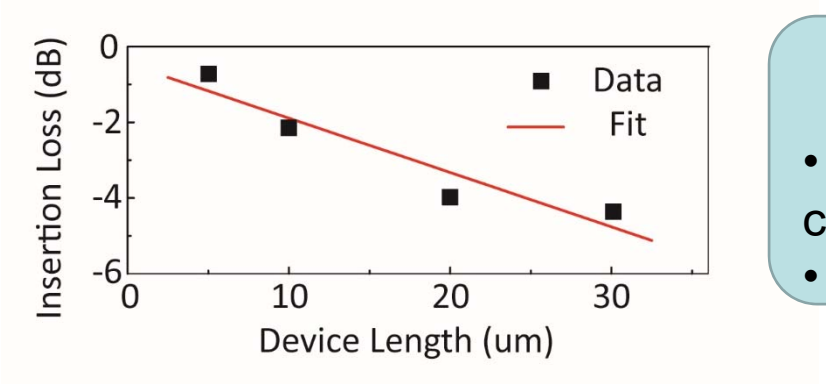
1 dB / μm

$$\frac{\Delta\kappa}{\Delta U_{bias}} \approx 1\% V^{-1}$$

Low Insertion Loss (on-chip)







Low Insertion loss

- -0.25dB / SOI-MOS coupler
- -0.14 dB / μm

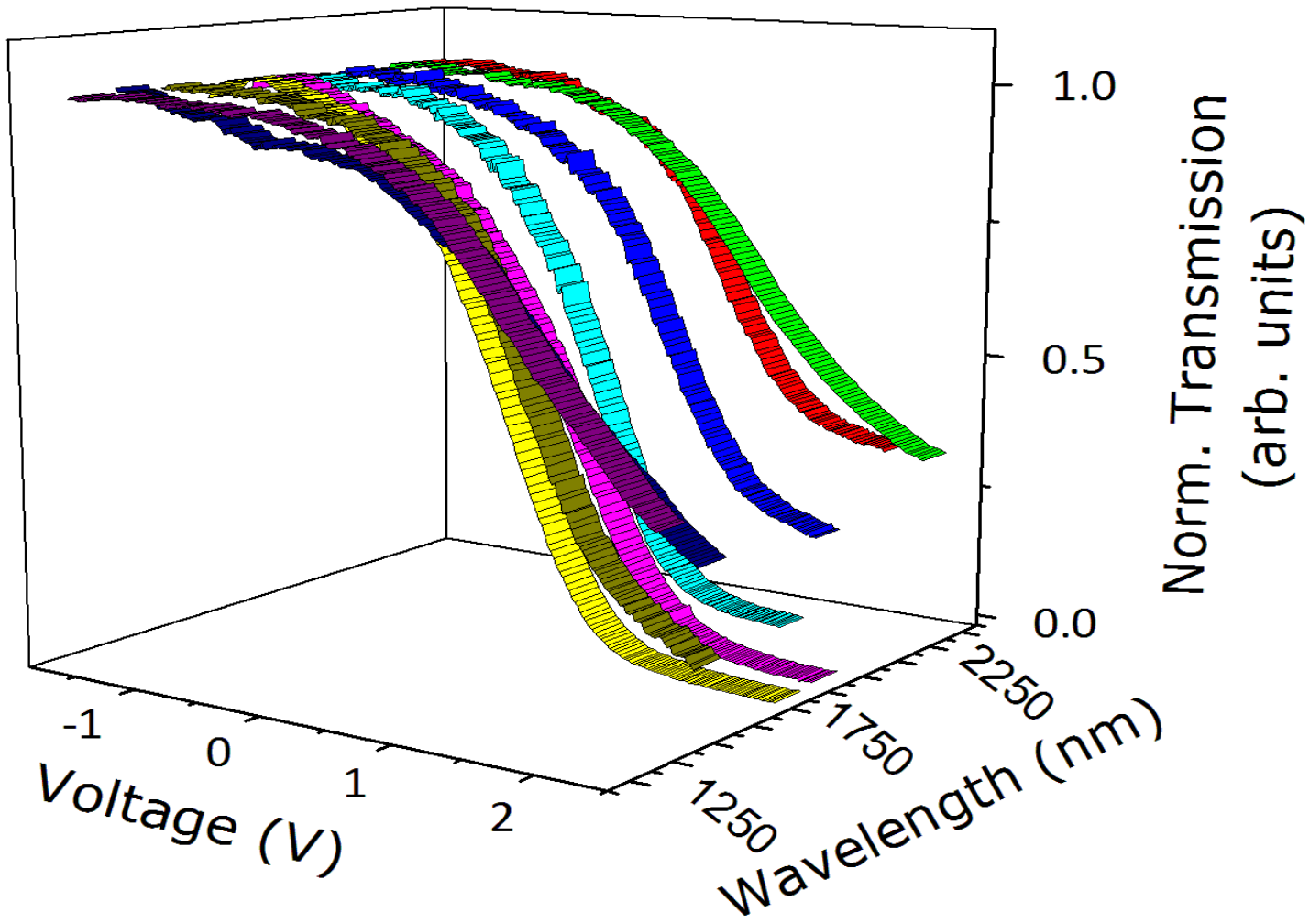
**Intel Group Nature (2004)

$$\Sigma \approx -6dB^{**}$$

$$\Sigma \approx -1dB^{*}$$

*5 μm long device

Modulation Bandwidth → WDM



Operation Bandwidth > 1000 nm

Summary

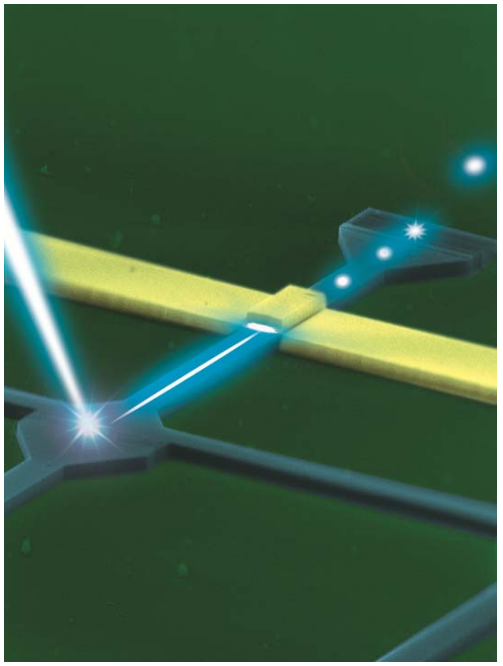
- An ultra-compact Si-based plasmonic modulator

  ---------High Modulation Strength

  ---------Ultra-Compact

  ---------Low Insertion Loss

  --------- Broadband



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