A Lateral MOS-Capacitor Enabled ITO Mach-Zehnder Modulator for Beam Steering

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Motivation

Kramers–Kronig relations → Modulation → Change in $\tilde{n}$ → Refractive Index, n ⇓ Extinction Coefficient, κ ⇑ ← Interferometric Scheme for Phase Modulation

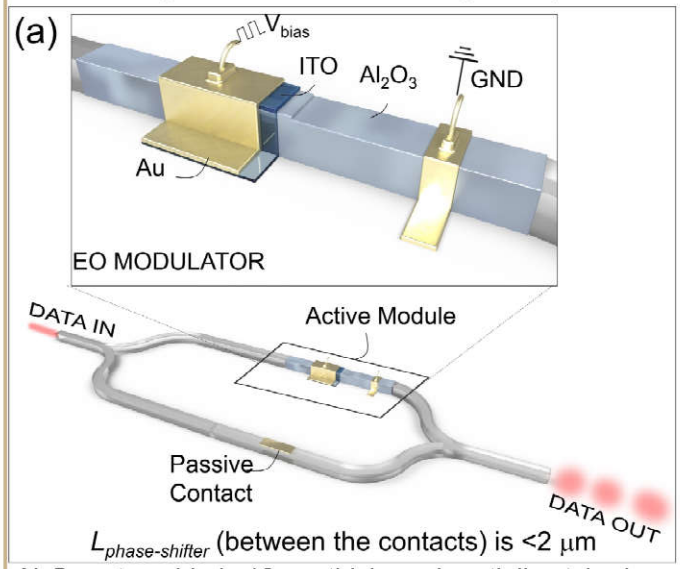
$FOM_{MZ} = V_\pi L$

- Physical Tradeoffs:
  - ✓ Index modulation ⇔ ✗ Loss
  - ⇔ (!) Optical Confinement Factors
  - ⇔ (!) Slow-Light Effects
- We find that there exist combinations of:
  - Bias + Material + Optical-Mode
  - ⇒ ✓ Efficient Phase/Amplitude Modulation
  - + ✓ Acceptable Insertion Loss

FIGURE OF MERIT (FOM) COMPARISON FOR MACH ZEHNDER DEVICES WITH DIFFERENT ACTIVE MODULATION MATERIALS AND WAVEGUIDE STRUCTURES IN RECENT YEARS

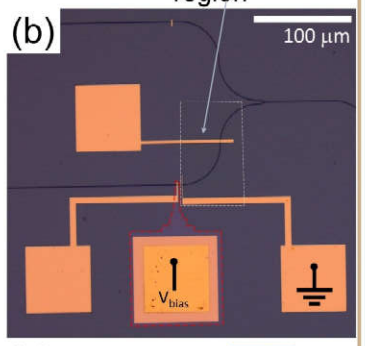
Structure/Material	$V_\pi L$ (V.μm)
Si Wrapped around-pn	140,000
Coplanar waveguide $LiNbO_3$	120,000
Si Wrapped around-pn	110,000
Domain inverted push-pull $LiNbO_3$	90,000
Dual driven coplanar waveguide $LiNbO_3$	80,000
Si Vertical-pn	40,000
Bulk $LiNbO_3$ physical limit	36,000
Si pipin	35,000
Si Lateral-pn	28,000
Si Lateral-pn	27,000
Si pn-depletion	24,000
Doping optimized Si	20,500
Si Self-aligned-pn	18,600
Integrated thin film $LiNbO_3$ on insulator	18,000
Si pin	13,000
Silicon-organic hybrid (SOH)	9,000
Si Lateral-pn	8,500
Si Projection MOS	5,000
III-V Multiple Quantum Wells (MQW)	4,600
SOH	3,800
GaAs/AlGaAs	2,100
Hybrid Si MQW	2,000
InGaAlAs/InAlAs MQW	600
ITO MOS	520
Si p^+-i-n^+	360
EO Polymer Plasmonic	70
ITO Lateral MOS	63
Liquid crystals with SOH slot/ all-plasmonic polymer	60

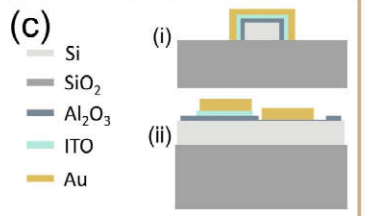
Device Design, Fabrication and Working Principles



$L_{phase\text{-}shifter}$ (between the contacts) is <2 μm

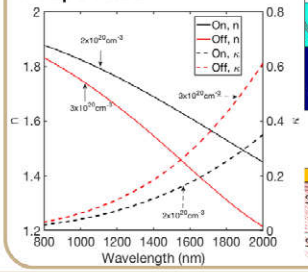
Al_2O_3 gate oxide is 10 nm thick, and partially etched down to 1-2 nm thickness in white dashed area

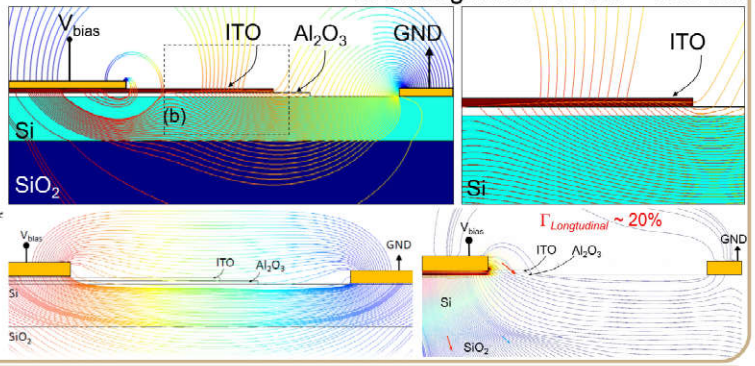




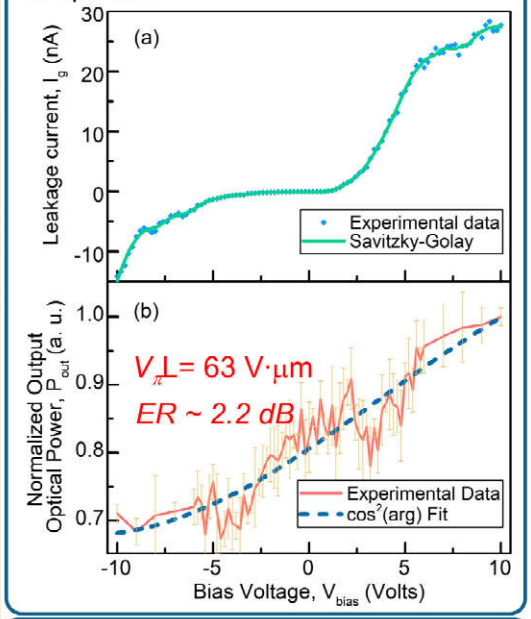
ITO layer is 10 nm thick
Au layers are 50 nm thick
Si waveguides 500 nm × 220 nm

ITO Material Properties





Material/Modal Properties



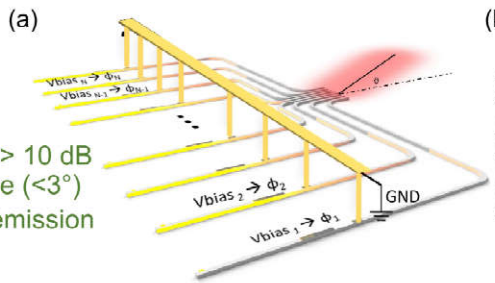
Conclusion

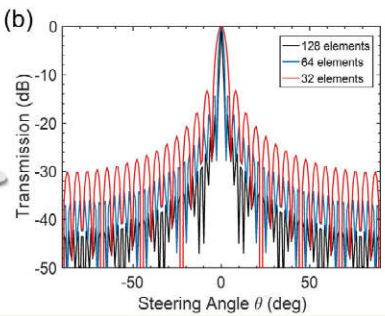
- ✓ ITO based EOM in a lateral capacitor configuration leads to favorable electrostatics and carrier tunability in ITO
- ✓ Competitive performance in FOM just 63 V·μm in a <2 μm compact phase shifter
- ✓ Building block for efficient beam steering availing GHz speeds for next generation LiDAR systems, holographic displays, etc.
- ✓ End-fire Si photonics optical phased array with ½λ pitch within the waveguides with narrow main beam lobe (<3°) and >10 dB suppression of the side lobes, while electrostatically steering the emission profile up to ±80°

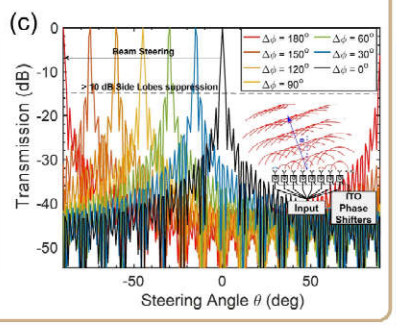
Optical Phased Array

½λ pitch within the waveguides

- ✓ Side lobe suppression > 10 dB
- ✓ Narrow main beam lobe (<3°)
- ✓ Electrostatic steering emission profile up to ±80°







Related Works & References

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