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Ultrafast Epsilon-Near-Zero Electroabsorption Modulators

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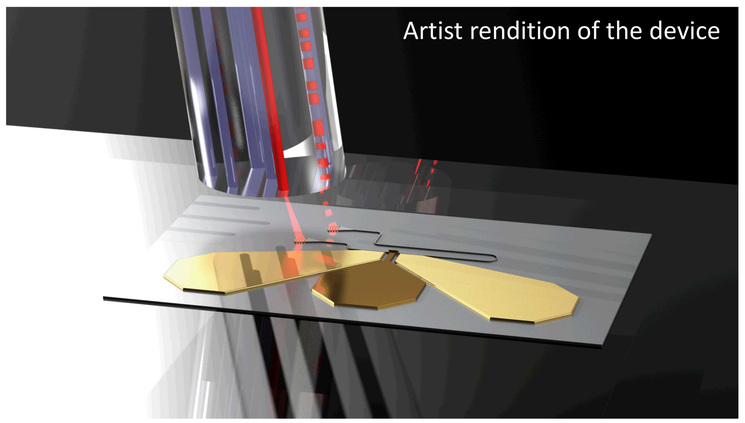
Introduction

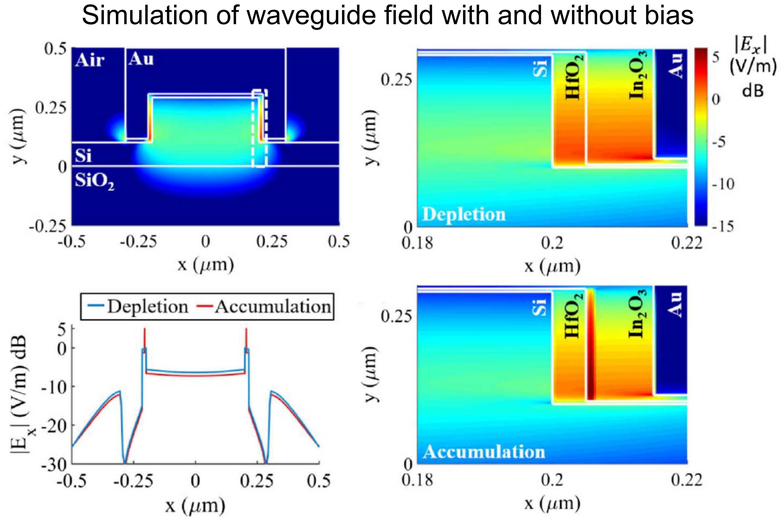
- Silicon photonics is here to stay.
- Compact and energy efficient optical modulator is important to promote wider application space for silicon photonics.
- Current method using thermo-optic effect is energy inefficient, narrow band operation.
- Instead of mm size, epsilon-near-zero (ENZ) modulator here is 4μm long.
- 6.5-dB extinction ratio across the 1530–1590 nm band at 2.5 Gb/s with 2 V_{pp} drive voltage.
- Not limited to size-bandwidth trade off.



Device Concept and Operation

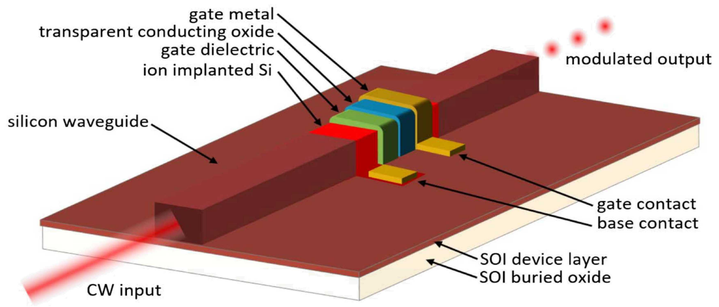
- Optical waveguide mode is coupled to an ENZ mode strongly.
- The frequency of the ENZ mode is controlled by the carrier density in the accumulation/depletion layer by voltage bias.
- When the plasma frequency of the accumulation layer is close to the waveguide frequency (also the optical frequency), modal field is concentrated at the ENZ layer, thus inducing large absorption.

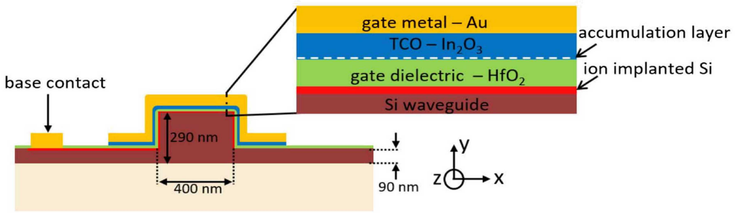
Simulation of waveguide field with and without bias

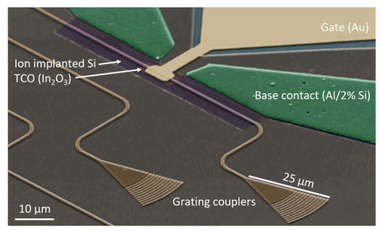


Implementation and results

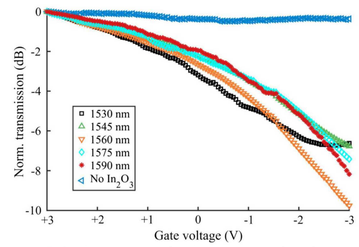
- Waveguide is Si.
- In_2O_3 is the ENZ layer.
- HfO_2 high-k gate dielectric.
- Au as one of the gate metal
- The part of the waveguide being modulated is heavy n-doped Si as the bias base contact
- Modulator length: 4um
- Gate oxide thickness: 10nm
- Modulation speed: 2.5Gb/s, can be substantially improved
- Modulation depth: 6.5dB for 1530-1590nm
- Insertion loss: 10 dB, can be substantially improved



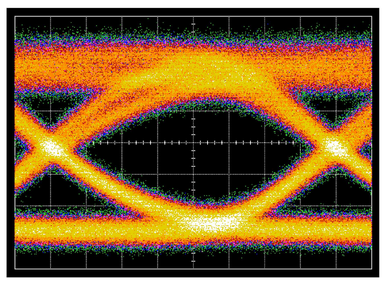




False-color SEM image

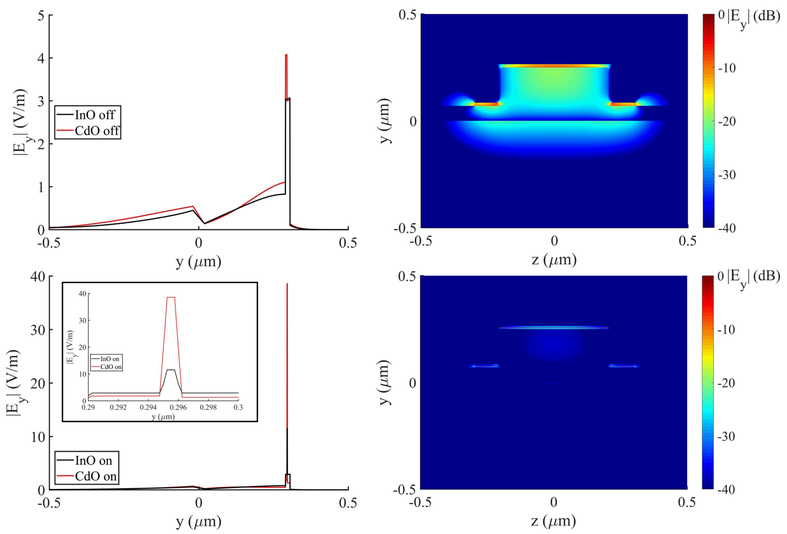


DC electro-optical characterization

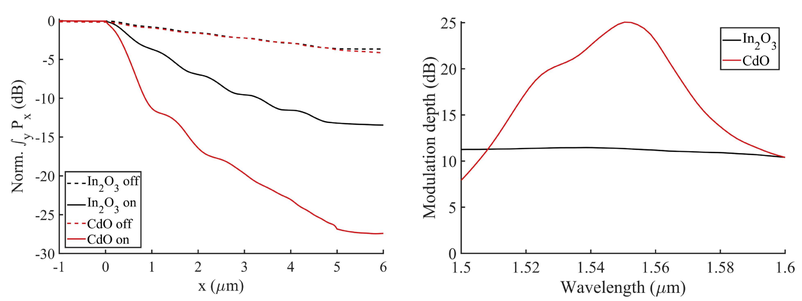


2.5 Gbps data transmission

Improvement roadmap: replace In2O3 with CdO



- CdO has 3-5x higher mobility than In_2O_3.
- An increased mobility leads to reduced losses in the off-state and increased confinement and absorption in the on-state.
- FDTD (Lumerical) model of 5 μm long device shows 2.5 times improvement in extinction ratio with CdO, with 5 dB/μm peak extinction ratio; 60 nm bandwidth for 3 dB/μm operation.
- Decreased bandwidth due to reduced on-state absorption in CdO away from ENZ point.



M. G. Wood, S. Campione, S. Parameswaran, T. S. Luk, J. R. Wendt, D. K. Serkland, and G. A. Keeler, "Gigahertz speed operation of epsilon-near-zero silicon photonic modulators," Optica **5**, 233-236 (2018).

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