Benchmarking of Plasmonic MIM and MSM Waveguide Couplers for an Integrated Computing System

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Georgia Tech | Center for Research into Novel Computing Hierarchies

SPP and Plasmonic Computing

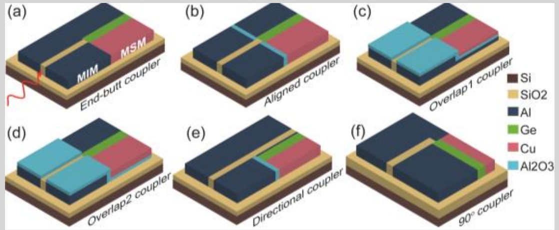
- Surface plasmon polariton (SPP): Electromagnetic wave propagating at metal-dielectric interface
- Plasmonic computing
- ✓ Miniaturization, dense integration (Electronic computing)
- ✓ High Speed (Photonic computing)
- Research goal: System-level performance optimization:

  Footprint Throughput Energy

Plasmonic MIM and MSM WG Couplers

Plasmonic Device (MIM WG-based) → Plasmonic Detector (MSM WG-based) → CMOS Circuit

MIM WG | WG Coupler | MSM WG



Coupling Efficiency

$$CL = -10\log(\eta)$$

- $CL < 1dB$ for most couplers
- Directional coupling: weakest due to large mode effective index difference

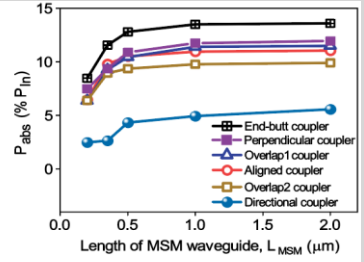
Coupling Scheme	CL dB
End-Butt Coupler	0.38
Aligned Coupler	1.03
Overlap1 Coupler	0.76
Overlap2 Coupler	0.86
Directional Coupler	3.5
Perpendicular Coupler	0.65

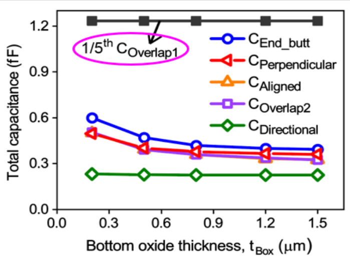
Static and Dynamic Performance of the Coupled Structures

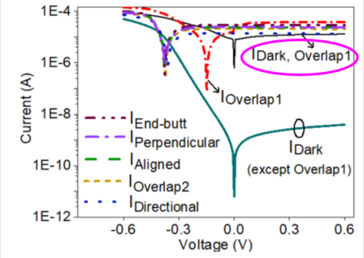
- Static and dynamic as well as noise analysis performed
- Directional coupler: lowest Power absorption, lowest photocurrent

$$P_{abs} = -0.5\omega|E|^2\mathrm{Im}(\epsilon)$$

- End-butt coupler: Highest power absorption and photocurrent
- Bandwidth mostly transit time limited
- Overlap1 coupler:
- ✓ High I_{dark}, higher noise
- ✓ High Capacitance, RC-limited bandwidth







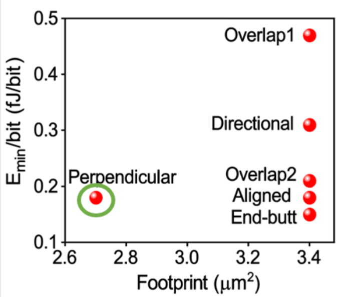
Benchmarking of couplers

- Holistic metric: min energy to detect single bit sent from MIM WG, E_{min}/bit

$$\frac{E_{min}}{bit} = \frac{NEP}{System\ Bandwidth}$$

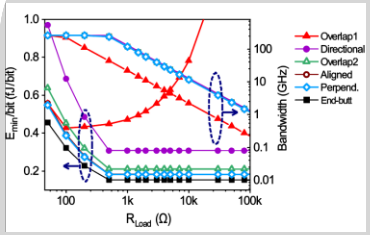
- E_{min}/bit encompasses,
- ✓ Coupling loss
- ✓ Power transmission in MSM WG
- ✓ Responsivity of detector
- ✓ Noise in the detector
- ✓ System bandwidth

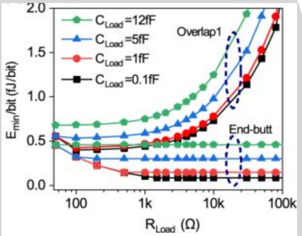
- trade-off between E_{min}/bit and footprint:



Perpendicular coupler best choice

Effect of Receiver Circuit





- R_{Load}, C_{Load} = input impedance of receiver circuit
- If R_{Load} increases, E_{min}/bit beyond transit time-limit :
- ➢ Except Overlap1: constant
- ➢ Overlap1: increases
- If C_{Load} increases, E_{min}/bit increases

Simulation Method

FDTD Solver Lumerical
Maxwell's Eqn
Result: E, H field

$G = \frac{P_{abs}}{\hbar\omega}$ →

Charge Transport Solver
Poisson & Drift-Diffusion Eqn
Result: potential, carrier density

RC3 Solver Raphael, Synopsys
Poisson's Eqn
Result: Capacitance

Summary

- Plasmonic MIM and MSM WG couplers designed
- Coupler performance evaluated
- Holistic performance metric introduced
- Couplers are benchmarked
- Effect of receiver circuit quantified

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