Silicon Depletion-Mode TW Modulator
Introduction (MZM)

- **Mach Zehnder Modulator (MZM)**
  - Phase shift is achieved from using Pockels Effect, Kerr, or carrier injection/depletion
  - Short and compact but requires higher voltage/power
  - Limited modulation speed (10-40 Gb/s)

- **Building blocks**
  - 1 Splitter
  - 1 Joiner
  - 2 Waveguides

- **OptiSPICE Model**
  - Explicit multilayer filter model is set up with a single layer
  - The change in the refractive index can be controlled by a voltage source
  - Can be configured as push-pull or asymmetric
Introduction (TW Modulator)

- **Traveling Wave MZM**
  - Modulation occurs the same way as MZM
  - Phase shift is achieved from using Pockels Effect, Kerr, or carrier injection/depletion
  - Longer device but uses lower voltage/power compared to regular MZM
  - Can achieve higher modulation speeds (~70 Gbit/s)

- **Building blocks**
  - 1 Splitter
  - 1 Joiner
  - 2 Transmission line electrodes
  - 2 Waveguides

- **OptiSPICE Model**
  - The waveguide consists of many layers with controllable refractive indexes
  - Each transmission line corresponds to a different metal contact connected to one of the waveguides
  - The waveguides and the transmission line models have the same length and the same number of sections
  - The refractive index of each layer is a function of the voltage in the corresponding section of the transmission line
Si-TWM Model Overview

- Modified transmission line model for PN Junction
- Sectionalized modulator arms (MLF + TL)
- $\Delta n \propto E$ in each section (can be nonlinear)

Transmission line model

Modified Transmission Line Model*

Single sections connected to a single layer of a multilayer filter

Parameters

- Transmission line (model parameters)
  - 100 Sections (*Number of sections*)
  - Rtl = 2kohm/m
  - Ctl = 120 pf/m
  - Ltl = 500 nH/m
  - RS = 13e-3 ohm*m
  - CJ = 186 pf/m @(-3V Reverse Bias)
  - d = 2 mm (*Modulator length*)

- Transmission line (calculated parameters)
  - R0 = re(Z0) = 43 ohm @ 40 Ghz
  - neff = 3.4@ 40 Ghz
  - v = 8.8174e+07 m/s @ 40 Ghz

- Multilayer filter (model parameters)
  - n = 3.4 (*Refractive index*)
  - d = 2 mm (*Modulator length*)
  - 100 ML filter layers (*Number of sections*)

- Multilayer filter (calculated parameters)
  - v = c/n = 8.8174e+07 m/s
  - Vpi =1.3 V
OptiSPICE TWM circuit

Load at the end of the metal contact

Sub-circuit combining all the elements

Optiwave
Transmission line characteristics

Optical eye results

Eye diagram results for traveling wave modulator simulation (Ref design: TWMZM_Silicon.osch)
Velocity mismatch simulation

- In this simulation the refractive index of the waveguide was increased to reduce the velocity of the electric field.
- As the velocity mismatch becomes more severe, the change in the refractive index and the electric field traveling in the waveguide do not overlap long enough.
- The reduced overlapping time decreases the total amount of phase shift accumulated by the traveling electric field, therefore the extinction ratio gets smaller.

OptiSPICE simulation showing velocity mismatch in the traveling wave modulator (Ref design: TWMZM_Silicon_VelocityMismatch.osch)