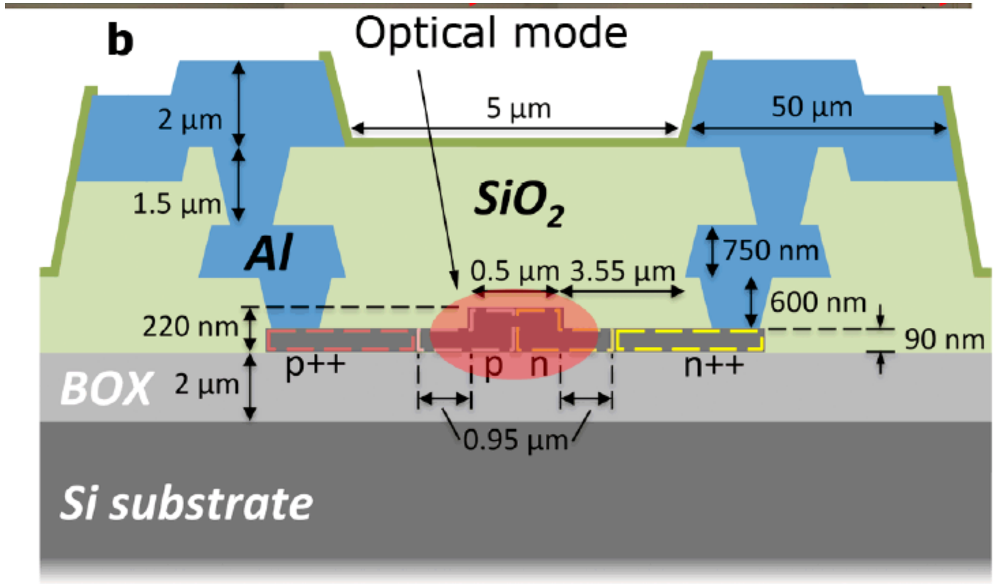
LAB 4: silicon TW MZI modulator

Silicon MZI modulator

- A silicon MZI modulator has been realized with a device structure as shown in the figure:



From:
T.B Jones at al. “Ultralow drive voltage silicon travelling wave modulator”,

#164128 - $15.00 USD Received 5 Mar 2012; revised 24 Apr 2012; accepted 24 Apr 2012; published 11 May 2012
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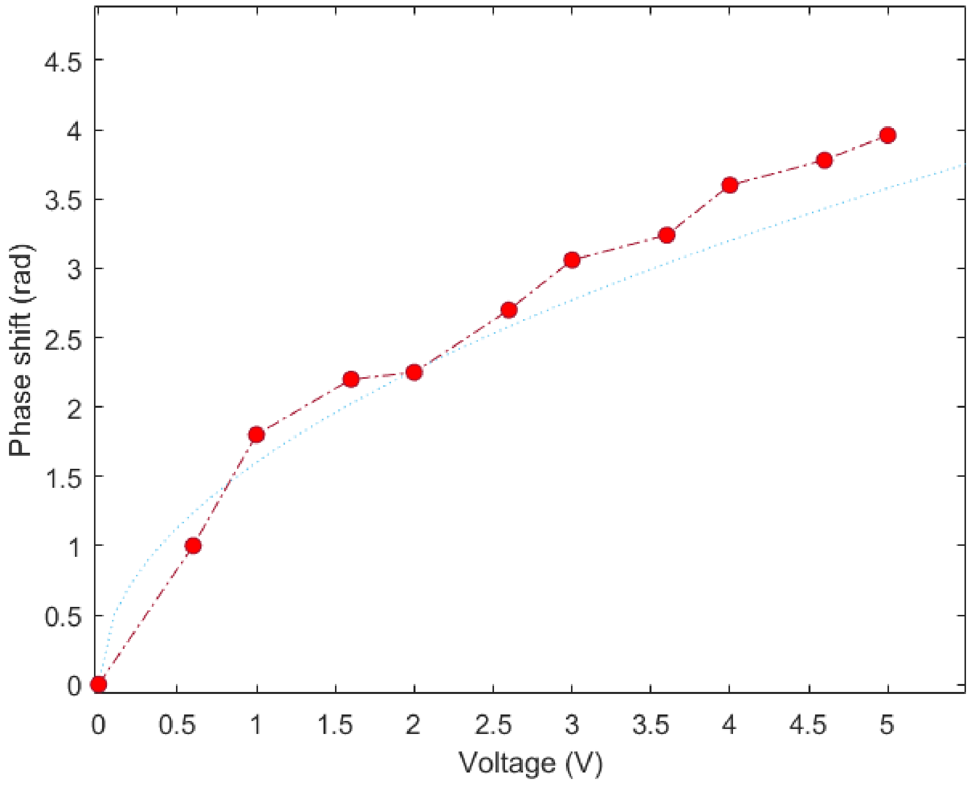
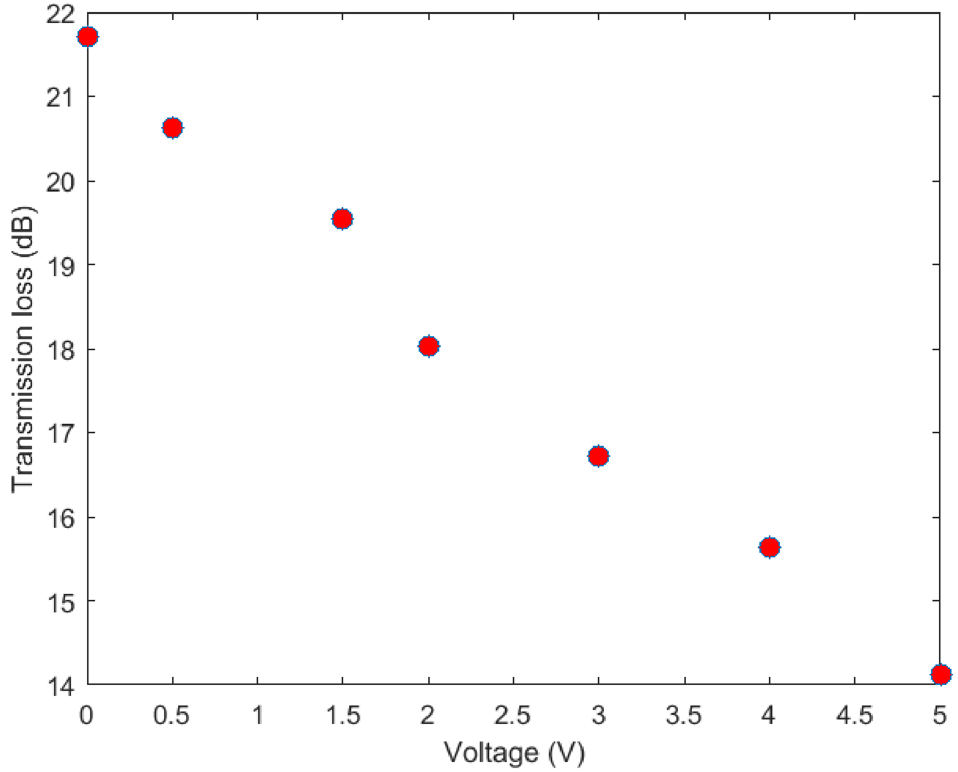
The figure shows the cross section of the ridge waveguide p-n junction of the MZI modulator.
The reverse bias of the p-n junction modulates the waveguide refractive index. This modulation is based on **plasma effect** (see lesson D1).

Measured phase shift and loss versus voltage:

- The phase shift versus voltage and the transmission loss for a straight waveguide (L=5mm) was measured at λ=1550 nm as function of the reverse bias voltage (V_{bias}) as shown in the figures (see also "meas_phase.fig" and 'Tdb_meas.fig').





Problem 1.1: Determination of refractive index change and loss

a) Find proper functions of the applied voltage that fit the measured phase shift and the measured transmission loss

b) Using the functions obtained in (a), calculate and plot the effective refractive index change and the loss versus applied reverse bias voltage. Loss must be reported in cm^{-1} or μm^{-1}.

c) Explain why the loss decreases increasing the voltage.

Problem 1.2: Calculation of the MZI modulator transmission spectrum

a) A MZI intensity modulator has been realized with the waveguide of previous slides.

b) The length of one arm is L=5mm and the length of the other arm is 5mm+100μm; the two arms have therefore an asymmetry length of 100μm.

c) Calculate and plot the transmission spectrum (in dB) in the wavelength range 1545-1565 nm . Plot the transmission spectra **(T(λ))** at different bias voltage in the range between 0-2V (voltage step 0.1V). Assume that reverse bias voltage is applied to only one arm.

d) Evaluate from the figure the FSR (free spectra range). FSR is here defined as the periodicity of the transmission spectrum.

e) Justify and explain the results obtained.

Problem 1.3 MZI modulator: transmission versus bias voltage

- Choose a wavelength λ_{in} corresponding to one maximum of **T(λ)** at V_{bias} =0 V; calculate and plot:

a) Transmission coefficient **T($\boldsymbol{\lambda_{in}}$)** versus bias voltage in the range 0-6V

b) Find V_π

c) Assuming the modulator is modulated with voltage Vpp=1V:

-calculate and plot the ER versus the bias voltage V_{bias}. Which is the bias voltage that maximizes the ER?

- calculate and plot the transmission loss at level “1” versus bias voltage.

d) Discuss the result obtained

Problem 1.4 Modulator bandwidth (I)

- The measurements of the TW MZI modulator reports:

- RF line impedance (Z_0) at 10 GHz equal to 37Ω, generator impedance 50 Ω.
- RF loss at 10GHz 10.8 dB/cm
- RF effective index equal to 3.75 and optical waveguide effective index equal to 3.86 for the rib waveguide
- Assume that loss changes with frequency as $\alpha_m(f)=a\cdot f^{1/2}$

The next slide gives an expression for calculating the modulator frequency response in the general case with non-zero R_G , any termination load RL and in the case the phase velocity mismatch and the RF loss are not negligible.

Frequency response*

$$m(\omega) = \left|\frac{\Delta\phi(\omega)}{\Delta\phi(0)}\right| = \left|\frac{H(\omega)}{H(0)}\right| =$$

$$= \frac{R_L + R_G}{R_L}\left|\frac{Z_{in}}{Z_{in} + Z_G}\right|\left|\frac{(Z_L + Z_0)F(u_+) + (Z_L - Z_0)F(u_-)}{(Z_L + Z_0)\mathrm{e}^{\gamma_m L} + (Z_L - Z_0)\mathrm{e}^{-\gamma_m L}}\right|$$

$$F(u) = \frac{1 - \exp(u)}{u}$$

(notice that $\beta_o \neq 2\pi/\lambda_o$!!)

$$u_{\pm}(\omega) = \mathrm{j}(\pm\beta_m - \beta_o)L \pm \alpha_m L = \pm\alpha_m L + \mathrm{j}\frac{\omega}{c_0}(\pm n_m - n_o)L.$$

$$Z_{in} = Z_0\frac{Z_L + Z_0 \tanh(\gamma_m L)}{Z_0 + Z_L \tanh(\gamma_m L)}.$$

$$\gamma_m = \alpha_m + \mathrm{j}\beta_m = \alpha_m + \mathrm{j}\omega/v_m;$$

*G. Ghione "Semiconductor devices for high speed optoelectronics", Cambridge Press. Chapter 6

P1.4 Modulation bandwidth (II)

- Plot the modulator response *m(f)* in the following cases:

a) Negligible microwave loss and matched termination of the line. Evidence the role of the phase velocity mismatch.

b) As in (a) but assuming that the microwave loss are not negligible; use for α_m the value given in slide 7.

c) As in (a) and (b), assuming now the termination is not matched:

c.1. assume the line terminates with open circuit

c.2 assume the line terminates with ZL=50 Ω

d) Compare and discuss the results obtained in the previous points