Integrated Photonic Device

Homework 5
2007, Fall

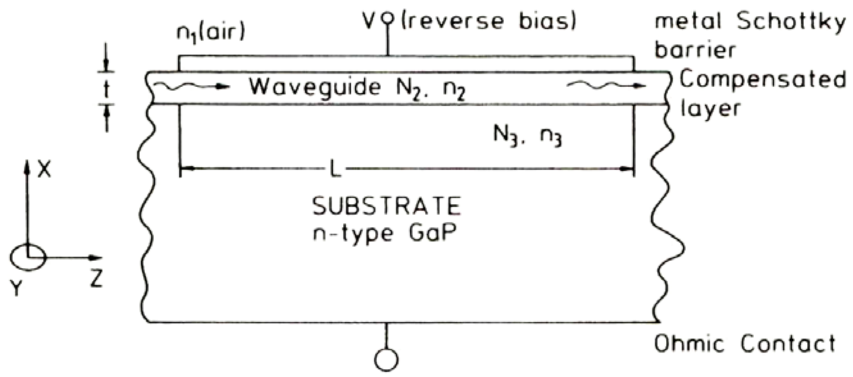
9.1 We wish to design a GaP electro-optic phase modulator as shown below for operation at 6300 Å wavelength.

a) What is the minimum thickness (t) required in the waveguiding layer if the carrier concentrations are $N_2 = 1 \times 10^{15}\,\mathrm{cm}^{-3}$ and $N_3 = 3 \times 10^{18}\,\mathrm{cm}^{-3}$?

b) How large a voltage (V) can be applied without producing electrical breakdown?

c) If this voltage is applied, how long (L) must the device be to produce a phase shift of π radians in the transmitted light wave? Assume the incident light is polarized in the Y direction. For GaP:

E_c (critical electric field for breakdown): 5×10^5 V/cm,
r_{41} (electro-optic coefficient for the above orientation): 5×10^{-11} cm/V,
m^* (effective mass): $0.013 m_0$,
$n = 3.2$.



9.7 In the waveguide modulator structure of Problem 9.1, with all parameters being as given in that problem:

a) What is the index of refraction difference at the interface between layers 2 and 3 due to the difference in carrier concentrations?

b) What applied voltage would be required to produce a Δn of the same magnitude due to the electro-optic effect? (Assume the minimum waveguide thickness as calculated in Problem 9.1a).

c) For the special case of $N_2 = N_3 = 1 \times 10^{15}\,\mathrm{cm}^{-3}$ (i.e. a Schottky barrier formed directly on a uniformly doped substrate), would the answer to part (b) be the same?

10.3 A Bragg modulator is formed in a $LiNbO_3$ planar waveguide which is capable of propagating only the lowest order mode for light of 6328 Å (vacuum) wavelength. This mode has $\beta = 2.085 \times 10^5\ \text{cm}^{-1}$. The bulk index of refraction for $LiNbO_3$ at this wavelength is 2.295. The acoustic wavelength in the waveguide is 2.5 μm, the optical beam width 4.0 mm, and the interaction length 2.0 mm. Obtain the following:

a) The angle (in degrees, with respect to the acoustic wave propagation direction) at which the optical beam must be introduced so as to obtain maximum diffraction efficiency.

b) If the input optical beam is a uniform plane wave, what is the angular divergence (in degrees) between the half-power points of the diffracted beam, and at what angle does it leave the modulator?

c) Make a sketch of the modulator, labeling the angles found in a) and b). (Do not attempt to draw the angles to scale.)

10.4 In a given hybrid OIC, a GaAs waveguide ($n = 3.59$) is butt-coupled to a $LiNbO_3$ Bragg modulator ($n_{\text{Bulk}} = 2.2$). (i) If an optical beam of vacuum wavelength $\lambda_0 = 1.15\ \mu\text{m}$ is traveling in the GaAs waveguide, incident on the modulator at an angle of 93° relative to the direction of propagation of the acoustic waves, for what acoustic wavelength Λ will the modulator produce the maximum output optical intensity? (ii) At what angle will the optical beam be traveling once it has left the modulator (in air)?

10.6 An acousto-optic, Bragg-type modulator/beam deflector is fabricated in a waveguide material which has refractive index $n = 2.2$ and an acoustic velocity $v_a = 2800\ \text{m/sec}$.

a) If the modulator is to be operated at an acoustic frequency of 100 MHz what should be the spacing between the interdigitated metal fingers of the acoustic transducer? Draw a sketch of the transducer fingers and label the spacing for clarity.

b) What is the angle through which the optical beam will be deflected if the light source is a He-Ne laser with wavelength $\lambda_0 = 6328$ Å?