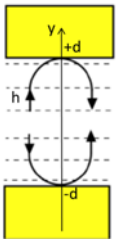
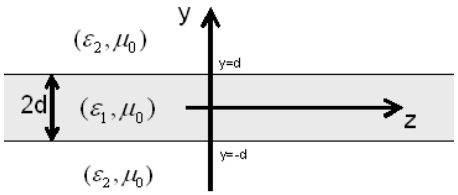
**NTHU Electrical Engineering Department**
**EE3360 Optoelectronic Devices Spring 2019**
**HW #7**




1. Consider a symmetric planar dielectric waveguide. Upward and downward traveling waves insides the core of the planar waveguide set up a standing wave along y. The standing wave can only exist if the wave can be replicated after it has traveled along the y-direction over one round trip. Given the wave vector long y is h, please derive the waveguide condition (the condition to build up standing wave).

2. In class, we have discussed TE modes in a dielectric waveguide where the longitudinal magnetic component Hz in the core layer is a sine function. Please follow similar procedures and derive TM modes with a cosine distribution in the core layer. Use the same notations in the hand out ($\varepsilon_1 > \varepsilon_2$).




   (a) Please write down proper solution form for Ez in $-d \le y \le d$ and $y \ge d$ , representing a mode guided in the middle layer.
   (b) Using Ez in (b), please use equations in the handout to derive the remaining components Ex, Ey, Hx, Hy.
   (c) Please use proper boundary conditions and derive relationships between h and $\alpha$ (two equations expected).
   (d) Assume the waveguide is 160μm wide and has $n_1$=1.51 and $n_2$= 1.49. The free space source wavelength is 1.5μm. Please estimate the number of TM modes that can be supported in this slab waveguide. Use graphical method to solve this problem and compare your result with the formula M=Int(2V/π)+1.
   (e) Find the maximum value of $d/\lambda_0$ for which the waveguide supports only one TE mode.

3. Consider a dielectric slab waveguide that has a thin GaAs layer of thickness 0.275μm between two AlGaAs layers. The refractive index of GaAs is 3.6 and that of the AlGaAs layers is 3.4.
   (a) What is the cutoff wavelength beyond which only a single mode can propagate in the waveguide?
   (b) If a radiation of wavelength 880 nm is propagating in the GaAs layer, what is the mode field width of this radiation?
   (c) Please point out the effect of change of operation wavelength on the mode field width.

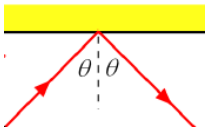
4. Consider a multimode fiber with a core diameter of 60μm, core refractive index of 1.47, and a cladding refractive index of 1.45, both at 870nm. (a) Calculate the numerical aperture. (b) Find out the normalized

core-cladding index difference. (c) Calculate he V number for the fiber and estimate the number of guided modes. (d) Calculate the wavelength beyond which the fiber becomes single mode. (e) Calculate the modal dispersion $\Delta\tau$. You may assume the max and min mode velocities are determined by the core and cladding refractive index.

5. Average power launched into a 10 km length of optical fiber is 100μW and the average optical power at the fiber output is 2μW. (a) Please find the signal attenuation in dB. (b) Find the signal attenuation per km for this fiber. (c) Find the overall signal attenuation for a 10km optical link using the same fiber with splices at 1km intervals, with splice loss of 1dB.

6. Please plot carefully the transverse mode field distributions of a dielectric slab waveguide for (a) $TE_0$ and $TM_0$, (b) $TM_1$ and $TM_2$. Discuss the differences on the field distributions.

7. Consider a slab dielectric waveguide that has a core thickness of 20μm, $n_1$=3 and $n_2$= 1.5. Solutions of $TE_0$ and $TE_1$ modes for selected wavelengths are shown in the table. Note that the angle defined in the table is shown below.




For each wavelength, please calculate w and β and then plot the dispersion diagram. Use the dispersion diagram, plot group velocity v.s. w for each mode. (Please use a software to make the plot.)

| $\lambda$, μm | 15 | 20 | 25 | 30 | 40 | 45 | 50 | 70 | 100 | 150 | 200 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\theta_0$° | 77.8 | 74.52 | 71.5 | 68.7 | 63.9 | 61.7 | 59.74 | 53.2 | 46.4 | 39.9 | 36.45 |
| $\theta_1$° | 65.2 | 58.15 | 51.6 | 45.5 | 35.5 | 32.02 | 30.17 | - | - | - | - |

8. Consider a step-index fiber with a core of diameter of 8μm and refractive index of 1.45 at 1.55μm and a normalized refractive index difference (defined by $(n_1-n_2)/n_1$) of 0.25% where the fiber is to be operated using a laser source with a spectral width of 3 nm. At 1.55μm, the material and waveguide dispersion coefficients of this fiber are approximately given by $D_m$=12psnm$^{-1}$km$^{-1}$ and $D_w$=−6psnm$^{-1}$km$^{-1}$.
   (a) Please calculate the V number of the fiber. Is it a single-mode fiber?
   (b) Please calculate the wavelength below which the fiber becomes multimode.
   (c) Please calculate the numerical aperture.
   (d) Calculate the maximum total acceptance angle.
   (e) Calculate the material and waveguide dispersion per kilometer of the fiber.