ENEE 691 Problem Set #5 4/25/02

Due 5/2/02

(1) Keiser Problem 6-5
(2) Keiser Problem 6-6
(3) Keiser Problem 6-8
(4) Keiser Problem 7-8
(5) Keiser Problem 7-12
(6) Keiser Problem 7-23
(7) Do Problem (2) From ENEE 691 First examination 2001 40

(2) If the light in a single mode fiber crosses a perpendicular cleaved end face there is a back-reflection because of the index change. Calculate the reflectance in this case if n_1=1.455.

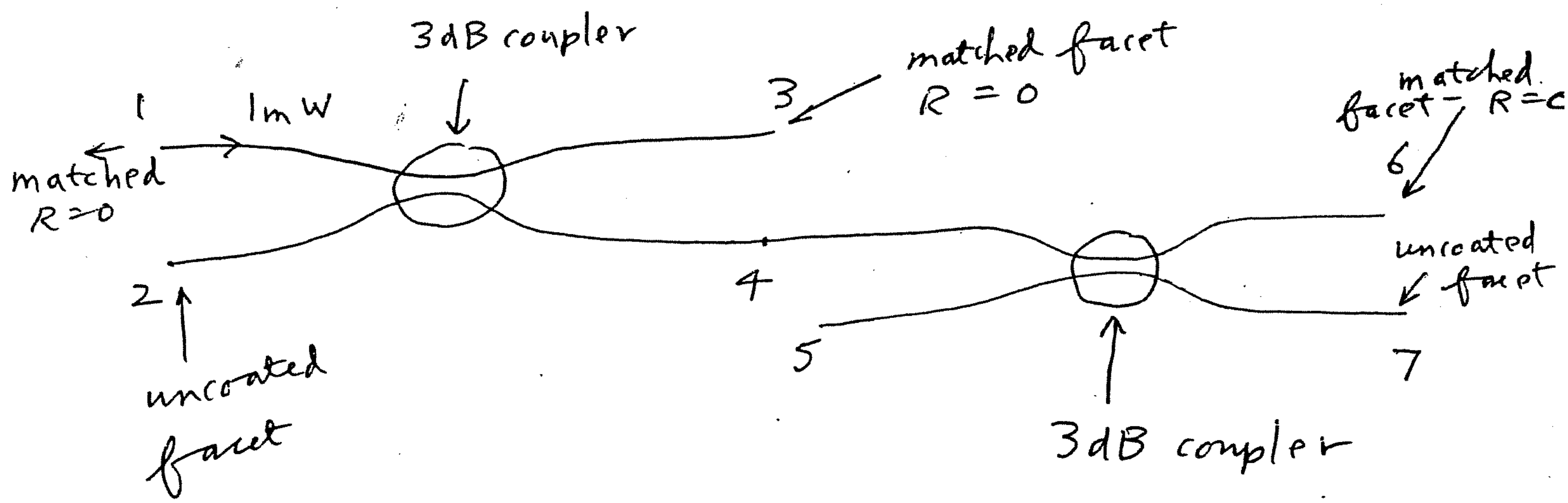
What coating (thickness and refractive index) could you place on the end face to reduce the reflectance to zero?

A common way to reduce back-reflection is to the cleave the fiber at an angle of 8° away from perpendicular. If a quarter wavelength thick layer is placed on this cleaved face what is the back-reflectance for a P-wave if the layer has $d = \lambda/4$, refractive index n=1.3?

Hint: the effective impedance for a P-wave is $Z \cos\theta$. The transformed impedance formula is:

$$Z_3'' = Z_2' \left(\frac{Z_3' \cos k_2 d' + jZ_2' \sin k_2 d'}{Z_2' \cos k_2 d' + jZ_3' \sin k_2 d'} \right).$$

In the following arrangement estimate how much power emerges at port 5.



6-5. $$\langle i_s^2(t)\rangle = \frac{1}{T}\int_0^T i_s^2(t)dt = \frac{\omega}{2\pi}\int_0^{2\pi/\omega} R_0^2 P^2(t)\, dt \qquad \text{(where } T = 2\pi/\omega\text{)},$$

$$= \frac{\omega}{2\pi} \mathcal{R}_0^2 P_0^2 \int_0^{2\pi/\omega} (1 + 2m\cos\omega t + m^2\cos^2\omega t)\, dt$$

Using

$$\int_0^{2\pi/\omega} \cos \omega t\, dt = \frac{1}{\omega} \sin \omega t \Big|_{t=0}^{t=2\pi/\omega} = 0$$

and $$\int_0^{2\pi/\omega} \cos^2 \omega t\, dt = \frac{1}{\omega}\int_0^{2\pi}\left(\frac{1}{2} + \frac{1}{2}\cos 2x\right) dx = \frac{\pi}{\omega}$$

we have $$\langle i_s^2(t)\rangle = \mathcal{R}_0^2 P_0^2\left(1 + \frac{m^2}{2}\right)$$

6-6. Same problem as Example 6-6: compare Eqs. (6-13), (6-14), and (6-17).

(a) First from Eq. (6-6), $I_p = \frac{\eta q \lambda}{hc} P_0 = 0.593\ \mu A$

Then $\sigma_Q^2 = 2qI_pB = 2(1.6 \times 10^{-19}\ C)(0.593\ \mu A)(150 \times 10^6\ Hz) = 2.84 \times 10^{-17}\ A^2$

(b) $\sigma_{DB}^2 = 2qI_DB = 2(1.6 \times 10^{-19}\ C)(1.0\ nA)(150 \times 10^6\ Hz) = 4.81 \times 10^{-20}\ A^2$

(c) $\sigma_T^2 = \frac{4k_BT}{R_L}B = \frac{4(1.38 \times 10^{-23}\ J/K)(293\ K)}{500\ \Omega}(150 \times 10^6\ Hz) = 4.85 \times 10^{-15}\ A^2$

6-8. Using Eq. (6-18) we have

$$\frac{S}{N} = \frac{\frac{1}{2}(R_0 P_0 m)^2 M^2}{2qB(R_0P_0 + I_D)M^{5/2} + 2qI_LB + 4k_BTB/R_L}$$

$$= \frac{1.215 \times 10^{-16} M^2}{2.176 \times 10^{-23} M^{5/2} + 1.656 \times 10^{-19}}$$

The value of M for maximum S/N is found from Eq. (6-19), with x = 0.5: $M_{optimum} = 62.1$.

7-8. From Eq. (7-1), the average number of electron-hole pairs generated in a time t is

$$N = \frac{\eta E}{h\nu} = \frac{\eta P t}{hc/\lambda} = \frac{0.65(25 \times 10^{-10} W)(1 \times 10^{-9} s)(1.3 \times 10^{-6} m)}{(6.6256 \times 10^{-34} Js)(3 \times 10^{8} m/s)} = 10.6$$

Then, from Eq. (7-2)

$$P(n) = N^n \frac{e^{-N}}{n!} = (10.6)^5 \frac{e^{-10.6}}{5!} = \frac{133822}{120} e^{-10.6} = 0.05 = 5\%$$

7-12. (a) Let $x = \frac{V}{2\sqrt{2}\,\sigma} = \frac{K}{2\sqrt{2}}$ For K = 10, x = 3.536. Thus

$$P_e = \frac{e^{-x^2}}{2\sqrt{\pi}\,x} = 2.97\times10^{-7} \text{ errors/bit}$$

(b) Given that $P_e = 10^{-5} = \frac{e^{-x^2}}{2\sqrt{\pi}\,x}$ then $e^{-x^2} = 2\sqrt{\pi}\ 10^{-5}\,x$.

This holds for $x \approx 3$, so that $K = 2\sqrt{2}\ x = 8.49$.

7-23. Consider using a Si JFET with $I_{gate} = 0.01$ nA. From Fig. 7-14 we have that $\alpha = 0.3$ for $\gamma = 0.9$. At $\alpha = 0.3$, Fig. 7-13 gives $I_2 = 0.543$ and $I_3 = 0.073$. Thus from Eq. (7-86)

$$W_{JFET} = \frac{1}{B}\left[\frac{2(.01\text{nA})}{1.6\times10^{-19}\text{C}} + \frac{4(1.38\times10^{-23}\text{J/K})(300\text{K})}{(1.6\times10^{-19}\text{C})^2 10^5\Omega}\right]0.543$$

$$+\frac{1}{B}\left[\frac{4(1.38\times10^{-23}\text{ J/K})(300\text{ K})(.7)}{(1.6\times10^{-19}\text{ C})^2(.005\text{ S})(10^5\ \Omega)^2}\right]0.543$$

$$+\left[\frac{2\pi(10\text{ pF})}{1.6\times10^{-19}\text{ C}}\right]^2\frac{4(1.38\times10^{-23}\text{ J/K})(300\text{ K})(.7)}{(.005\text{ S})}\,0.073\text{ B}$$

or

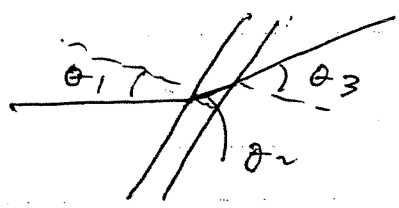
$$W_{JFET} \approx \frac{3.51\times10^{12}}{B} + 0.026B$$

and from Eq. (7-92) $$W_{BP} = \frac{3.39\times10^{13}}{B} + 0.0049B$$

(2)

$$\rho = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{\frac{1}{n_1} - 1}{\frac{1}{n_1} + 1} = \frac{1-n_1}{1+n_1}$$

$$R = |\rho|^2 = \left(\frac{1-n_1}{1+n_1}\right)^2 = 0.0343$$



$\theta_1 = 8°$

$1.955 \sin 8° = 1.3 \sin\theta_2$

$\theta_2 = 8.96°$

$1.3 \sin\theta_2 = \sin\theta_3 \qquad \theta_3 = 11.68°$

P wave impedances are of the form

$$Z = \frac{Z_0 \cos\theta}{n}$$

Ignore the Z_0, it cancels.

$Z_1' \propto 0.6806$

$Z_2' \propto 0.7598$

$Z_3' \propto 0.9793$

$$k_2 d' = k_2 d_2 \cos\theta_2 = \frac{2\pi}{\lambda_2}\frac{\lambda_2}{4}\cos\theta_2$$

$$= \frac{\pi}{2}\cos\theta_2 = 1.552$$

$$Z_3'' \propto 0.7598\left(\frac{0.9793\cos(1.552) + j\,0.7598\sin(1.552)}{0.7598\cos(1.552) + j\,0.9793\sin(1.552)}\right)$$

$$\propto \frac{0.01399 + j\,0.5772}{0.01428 + j\,0.9791} = 0.5894 - 0.00561$$

$$\rho = \frac{0.5894 - j\,0.00569 - 0.6806}{0.5894 - j\,0.00569 + 0.6806}$$

$$= \frac{-0.0912 - j\,0.00569}{1.27 - j\,0.00569}$$

$$R = |\rho|^2 = 0.00518$$

The power at port 5 is determined by R, the reflectance of a cleaved, uncoated facet

$R = 0.033$

$$P_2 = \underbrace{\frac{P}{2}\left(\frac{1}{2}\right)R\left(\frac{1}{2}\right)(1-R)}_{P_{51}} + \frac{P_{51}}{(1-R)}(R)\left(\frac{1}{2}\right)R\left(\frac{1}{2}\right)(1-R) + \cdots$$

$$= (1-R)\left[\frac{R}{8} + \frac{R^3}{32} + \frac{R^5}{128} + \cdots\right]P$$

additional contribution

$$P(1-R)\left[\frac{R^3}{128} + \frac{R^5}{512} + \cdots\right] + \text{smaller terms}$$

$= 0.00415$ mW