Part 1: 50 points, please describe your answers as complete as possible.

1. (15%) An EM wave with an electric amplitude Ei is passing through from medium 1 (refractive index n_1) to medium 2 (refractive index n_2), which reflection and transmission are satisfied with the following equations.

$$r_\parallel = \left(\frac{E_r}{E_i}\right)_\parallel = \frac{n_2\cos\theta_1 - n_1\cos\theta_2}{n_2\cos\theta_1 + n_1\cos\theta_2}$$
$$t_\parallel = \left(\frac{E_t}{E_i}\right)_\parallel = \frac{2n_1\cos\theta_1}{n_2\cos\theta_1 + n_1\cos\theta_2}.$$

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$$t_\perp = \left(\frac{E_t}{E_i}\right)_\perp = \frac{2n_1\cos\theta_1}{n_1\cos\theta_1 + n_2\cos\theta_2}.$$

where Er and Et are amplitudes for reflection and transmission; the symbols of ∥ and ⊥individually mean the electric field vectors parallel and perpendicular to the incident plane; θ_1 and θ_2 are incident and refractive angles, respectively. Please illustrate what is the Brewster angle and show the equation relative to the incident angle.

2. (15%) Consider a spherical mirror with a radius of curvature R whose reflectivity varies as

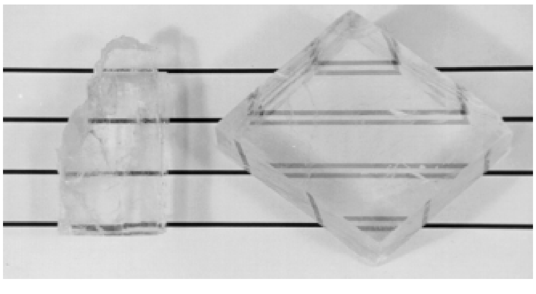
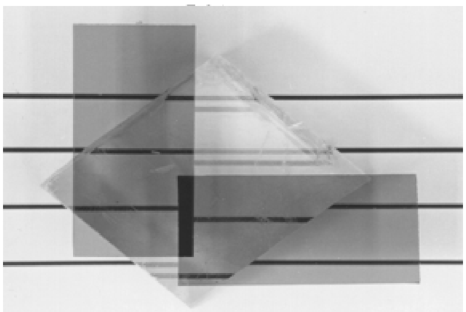
$$\rho(r) = \rho_0 \exp\left(-r^2/a^2\right)$$

where r is the radial distance from the center. Show that the (A, B, C, D) matrix of this mirror is given by

$$\begin{vmatrix} A & B \\ C & D \end{vmatrix} = \begin{vmatrix} 1 & 0 \\ -\dfrac{2}{2R} - i\dfrac{\lambda}{\pi a^2} & 1 \end{vmatrix}$$

3. (10%) Please mathematically describe what is the “Airy rings”, and simultaneously illustrate what is the “diffraction-limitation”?

4. (10%) According to the following two images, please make detailed illustration and comparisons to describe what optical phenomena exist in the images? (hint: optical characteristics of isotropic and anisotropic materials)

Part II . Laser Fundamentals and Applications

1. Explain the terminologies and phenomena below:
   (1) Second-Harmonic Generation (SHG) (4pts)
   (2) What is Franz-Keldysh effect? Please draw the influence of this effect on the band-gap and absorption spectrum (10pts)
   (3) Electroluminescence (4pts)
   (4) Stoke-shift (4pts)

2. (1) Please write down the rate equation for a two level laser system and explain why a two level system is not feasible. (6pts)
   (2) Lasers are commonly classified into “three-level” or “four-level” lasers. Please indicate the classification of a Ruby Laser and describe the working principles, such as the characteristics, the energy level diagram, and the pumping, of a Ruby Laser. (10 pts)

3. (1) What voltage shall be applied to accelerate an electron from zero velocity in order that it acquire the same energy as a photon of wavelength equal to 0.87 um. (4 pts)
   (2) Compare the total momentum of the photons in a 10-J laser pulse with that of a 1-g mass moving at a velocity of 1 cm/s and with an electron moving at a velocity of $C_0/10$. (8 pts) (where C_0 is the speed of light, $M_e = 9.1 \times 10^{-31}$ kg)

Part III. Optoelectronic Devices

1.Consider an AlGaInP/InGaP heterostructure laser diode which has an optical cavity of length 300 μm. the emission peak is 700nm and the refractive index of InGaP is around 3.5.

(a)What is the mode integer m of the emission peak and the separation between the modes of the cavity? (5 points) (b)If the optical gain vs. wavelength characteristics has a FWHM wavelength width of about 6 nm how many modes are there within this bandwidth? (5 points) (c)How many modes are there if the cavity length is 50 μm? (5 points)

2.(a)If a p-i-n photodiode has an constant external quantum efficiency of 60% at 200 nm and 400 nm. What are the theoretical responsivities? (5 points)(b) For a practical GaN p-i-n photodiode, the measured responsivity is far less than the theoretical value when the wavelength of incident light is at 200 nm or 400 nm. Please explain about it and depict the relation of responsivity (R) vs. wavelength (λ) for an ideal photodiode with 100 % quantum efficiency and for a practical GaN p-i-n photodiode.(15 points) (Note: The bandgap of GaN is around 3.4 eV at 300K)

3. If the width of the relative light intensity vs. photon energy spectrum of an LED is typically around **$\sim 3k_BT$**, what is the theoretical linewidth, $\triangle\lambda_{1/2}$, in the output spectrum in terms of wavelength?

(a) InGaN LED emits at a peak wavelength of 470 nm(5 points)

(b) AlInGaP LED emits at a peak wavelength of 630 nm. (5 points)

note: $\frac{\Delta\lambda}{\Delta E_{ph}} \approx \left|\frac{d\lambda}{dE_{ph}}\right|$

4.What is the photoconductive gain for a semiconductor photodetector(5%)