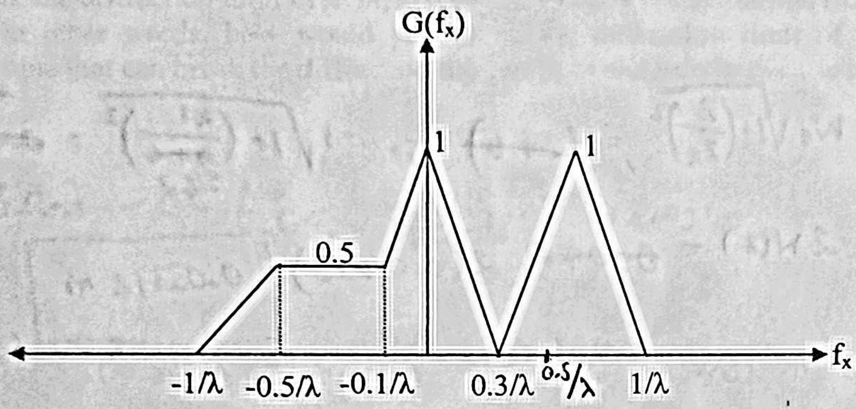
98

(OPEN BOOKS AND NOTES – NO INTERNET ACCESS)

+21 (1) (a) 10pts - For an object that has a spatial frequency spectrum given by $G(f_x)$ as shown below, plot the spatial frequency spectrum of the image, i.e., $U_i(f_x)$, that is formed under a coherent imaging system that has a numerical aperture of 0.5 = NA

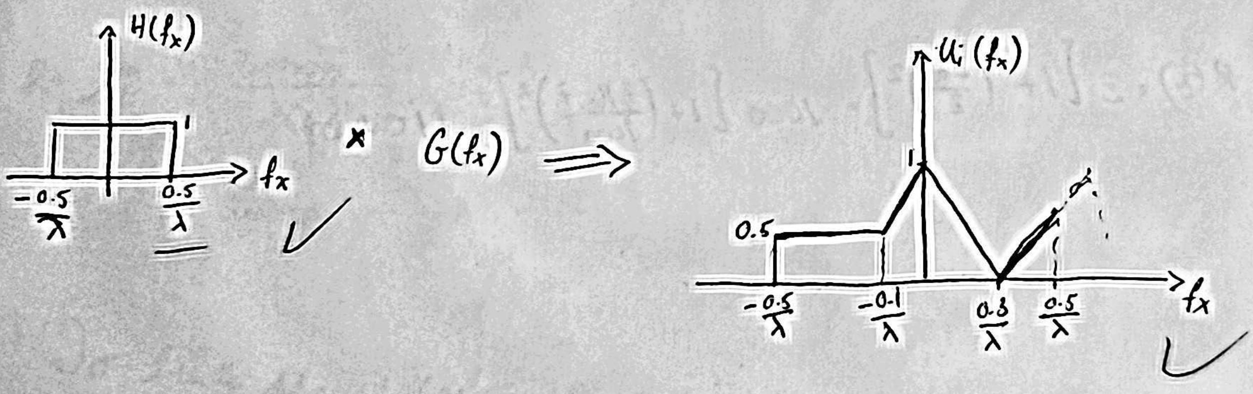
(b) 10 pts - How would your answer to (a) change if the imaging system was spatially incoherent with a numerical aperture of 0.5. **For part (b) only**, you can assume $G(f_x)$ refers to the spatial frequency spectrum of the object's intensity. This will simplify your analysis.

λ denotes the wavelength of light in each case, and f_x is the spatial frequency along x direction.



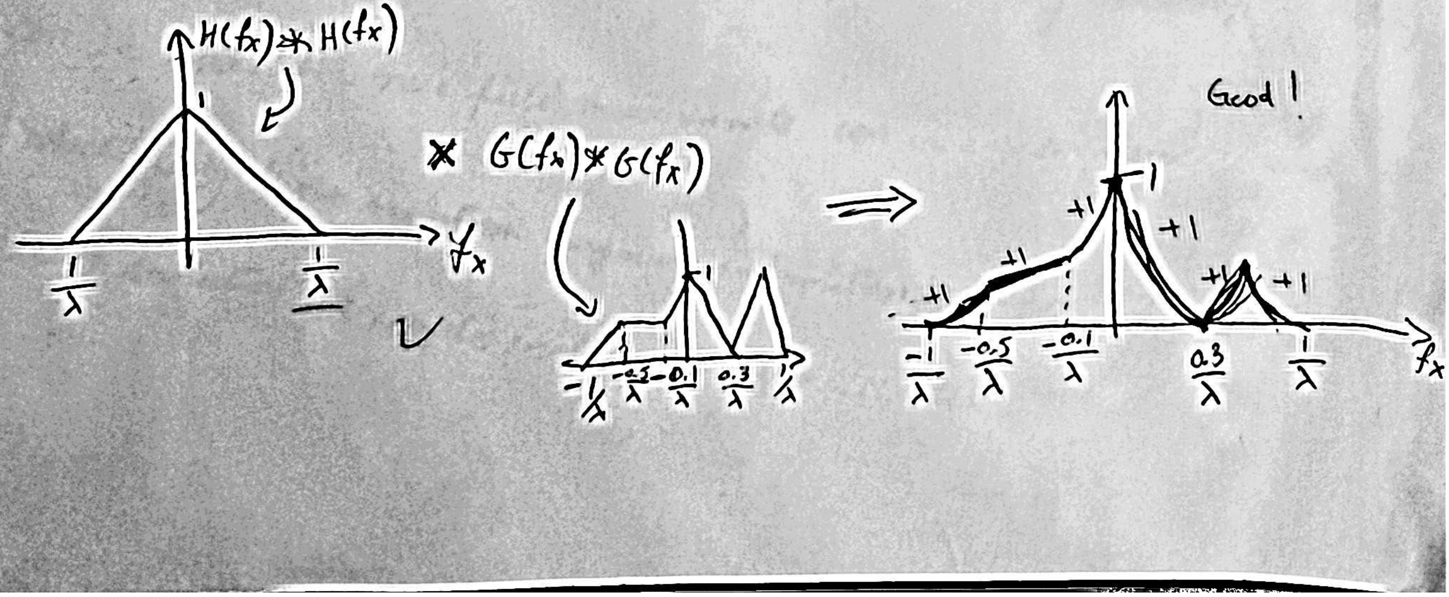
+10

a)



+11

b)



+14 (2) Suppose that you are operating an Excimer laser (with an active material of KrF) which lases at 248nm wavelength. The beam waist of this laser is measured as 5 mm. = W_o

(a) 7 pts - Calculate the beam diameter of the Excimer laser after 1 km of propagation in air from the location of the beam waist.

(b) 7 pts - Calculate the radius of curvature of the wavefront of the laser at the same distance (1 km) from the beam waist.

a) $Z_R = \frac{\frac{\pi}{2} W_o^2}{\lambda} = \frac{\pi (5 \times 10^{-3})^2}{248 \times 10^{-9}} = \sout{201.6}$ 316.7 m

beam radius = $W(z) = W_o \sqrt{1 + \left(\frac{z}{z_R}\right)^2} = \sout{(201.6)}\ 5 \times 10^{-3} \sqrt{1 + \left(\frac{10^3}{\sout{201.6}\ 316.7}\right)^2} = \sout{0.0253}$ $\sout{0.016}$ 0.01656 m

beam diameter = $2W(z) = \sout{0.0506}\ 2(0.01656) = \boxed{0.03312 \text{ m}}$ ✓

b) $R(z) = z\left[1 + \left(\frac{z_R}{z}\right)^2\right] = 1000\left[1 + \left(\frac{316.7}{1000}\right)^2\right] = 1100 \text{ m}$ ✓

(3) Suppose that you are working to find cure to cancer.
For this purpose, suppose also that you frequently label cells with fluorescent markers to make cancer cells glow among many other healthy cells such that you can tell them apart from the rest of the "good" cells. In one experiment, assume that to label these cells you have used a fluorophore that emits light (when pumped appropriately) at 600 nm wavelength (red color).

+18

(a) 7 pts - For this fluorescent cell imaging experiment, using an objective lens that has a numerical aperture (NA) of 0.75, what would be the expected spatial resolution in your images? Just for your information the typical size of a cancer cell would be ~20-50 μm.

(b) 7 pts - For the same cell imaging experiment, what would be the diffraction limited spatial resolution in air? This question assumes that now you have the best objective lens that operates in air, where the refractive index (n) is 1.0.

(c) 7 pts - To break the diffraction limit of light, and to achieve a better resolution than your answer to (b), what would you do? In other words, how would you break the diffraction limit of light? Name at least one microscopy technique that can break the diffraction limit of light and briefly discuss how it works.

+7 a)

resolution - R = ~~[illegible]~~

$$R = \frac{\lambda}{2NA} = \frac{600\,nm}{2(0.75)} = \frac{600\,nm}{1.5} = 400\,nm$$ ✓

+4

b) $R = \frac{\lambda}{2n} = \frac{600\,nm}{2(1.0)} = 300\,nm$

$NA = n\sin\theta \xrightarrow{\text{best obj.}} \rightarrow n$ -3

+7 c) To break the diffraction limit, a near field scanning microscopy (NSOM) can be used. The near field measurements can capture evanescent waves which carry higher ~~resolution~~ frequency information which results in better resolution. Examples include STED, PALM, etc.

+7 (4) 7 pts - Using pulsed lasers you can cut steel and rapidly manufacture prototypes. Similarly, using such lasers you can also remove tissue. In the same context, briefly discuss how the removal of tattoo and LASIK operation are different from each other. In other words, can you use the same pulsed laser that is designed for tattoo removal for LASIK operation? Why / Why not?

Pulsed lasers, usually called ~~Q lasers, etc~~ Q-switching lasers ✓ have high peak power to penetrate skin and shatter ink pigments into particles that are cleared by the body's lyphatic system. Different colors of tattoo ink are removed with different wavelengths, typically around 1000nm.

LASIK usually uses an eximer laser which operates around 200nm wavelength and vaporizes ✓ tissue in a finely controlled manner.

You **cannot** ✓ use the pulsed laser for LASIK because it is too powerful and not finely controlled, so it would damage the retina. Additionally the lasers operate at different depths.

+15

(5) 15 pts – For a plane wave, which one of the following spatial frequency pairs defines an evanescent wave in air:

(i) $(f_x, f_y) = (1.5/\lambda, 0)$ ---- Evanescent Wave? Yes or No? Why
(ii) $(f_x, f_y) = (0.2/\lambda, 0.1/\lambda)$ ---- Evanescent Wave? Yes or No? Why
(iii) $(f_x, f_y) = (1/\lambda, 0.01/\lambda)$ ---- Evanescent Wave? Yes or No? Why

f_x, f_y refer to spatial frequencies along x and y, respectively, and λ is the wavelength of the light source. Assume that the refractive index of air is 1.

$R^2 = f_x^2 + f_y^2 > \left(\frac{n}{\lambda}\right)^2 \Rightarrow R > \frac{n}{\lambda}$ for evanescent waves

(i) $n = 1.0$

$R = \frac{1.5}{\lambda} > \frac{n}{\lambda} \Rightarrow$ evanescent wave

✓

(ii) $R = \sqrt{\left(\frac{0.2}{\lambda}\right)^2 + \left(\frac{0.1}{\lambda}\right)^2} > \frac{n}{\lambda}$

$\sqrt{\frac{0.04+0.01}{\lambda^2}} \not> \frac{1}{\lambda} \Rightarrow$ not evanescent wave

✓

(iii) $R = \sqrt{\frac{1+0.01}{\lambda^2}} > \frac{1}{\lambda} \Rightarrow$ evanescent wave

✓

+10 (6) (a) 5pts - How would you physically detect an evanescent wave?

(b) 5pts - Why would you bother to detect such evanescent waves? What is useful and desired about them? Briefly explain your answers.

a) In order to detect an evanescent wave, you need near-field measurements so that you can observe the waves before they decay. ✓

b) High frequency components are evanescent and decay rapidly. ✓ By catching these rapidly ~~decaying~~ oscillating components, you can achieve better resolution than the diffraction limit of $\frac{\lambda}{2NA}$.