**Homework 2**

1. You shine near-infrared (600-1000nm) laser light into a subject’s abdominal tissue. Due to the effects of optical scattering, light will eventually emerge from the tissue in the form of diffuse reflectance. You want to collect the light in order to perform tissue spectroscopy (i.e. study the light after it has interacted with the tissue) and place a lens 20 mm from the surface of the tissue. Because the light is diffuse, you may assume the light uniformly fills the full aperture of your lens.

   a) You place an optical fiber at the focal point of the lens in order to guide the light to a detector. Based on the table below, which lens would capture the most light from the tissue?

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (mm)</td>
<td>50</td>
<td>44</td>
<td>44</td>
</tr>
<tr>
<td>Focal (mm)</td>
<td>130</td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td>ARC$^1$ (nm)</td>
<td>350-1050</td>
<td>350-700</td>
<td>650-1050</td>
</tr>
</tbody>
</table>

$^1$ARC stands for “anti-reflective coating”

b) The optical fiber at the focal point of the lens has a core index of 1.44 and cladding index of 1.41. Based on the information given so far, which lens would best maximize the throughput to your detector?
c) Lens B and C are similar in specification. However, when using 852 nm laser light, your own testing shows that lens C actually has ~8% better throughput than lens B when installed in your system. Your boss tells you that is because of the ARC coating on the lens. Briefly explain in one or two sentences how the correct ARC can improve light throughput.

d) Your experimental setup to perform diffuse reflectance spectroscopy is shown in the figure below. In this case, what potential advantage does lens A have over the other lens options?
e) You measure a modal dispersion of 1.42 ns. How long is the optical fiber that you used? For this application where relatively deep (~centimeter) tissue spectroscopy is desired, what kind of optical fiber (step-index, GRIN, or single-mode) should you use in order to reduce modal dispersion? Assume you are using a fast photodiode as your detector.

2. A PMT mounted in a confocal microscope has 10 dynodes. In the first four dynodes, each primary electron stimulates 4 secondary electrons. In other dynodes, each primary stimulates 5 secondary electrons.

a) Determine the gain of the PMT.

b) The pulses that hit the PMT are 3 ns in width. Load resistance of the PMT is 40Ω. Calculate the peak voltage you detect with the PMT for a single photon.
3. An InGaAs photodiode's responsivity curve is shown below. Its dark current is 6nA. We designed an experiment where you mount a 1200 nm LED and the photodiode in a contact probe. We then put the probe on a PhD student's wrist and detected the reflected light with the photodiode. The photodiode connected to a multi-meter gave a photocurrent 3 times the amount of dark current.

a) What is the incident optical power on the photodiode? Determine the QE of the photodiode at the LED wavelength.
4. You have recently been hired as an engineer for a popular outdoors company, RE-Eye. You are tasked with finishing development of a series of products marketed towards backpackers who might find themselves in the wilderness at night.

a) The first product is called Crumb. Crumb is made of natural materials which are non-harmful to the environment and do not harm or attract wildlife (let’s say it’s mostly dirt). Inside of crumb is a trace amount of a proprietary luminescent material. RE-Eye hopes Crumb will be used for marking trails at night. You have many materials at your disposal and must tune the color of Crumb to work optimally at night. Based on what you’ve learned about the human eye, which color do you choose? Explain your answer in terms of rod/cone cells from the eye.

b) The second product is called AdaptMap. AdaptMaps are lightweight, waterproof maps which contain solar-chargeable LEDs for illumination at night. You want these maps to preserve dark-adapted vision, but also be illuminated well enough to read if needed.

I. Which cells in the eye are most utilized when dark-adapted?

II. To which colors of light are the cells from part (i) insensitive?

III. You have two LED types at your disposal: (1) GaN and (2) AlGaAs. Which do you choose for AdaptMap?
5. In a fluorescence interaction, will the emitted light have a shorter or longer wavelength than the incoming excitation? Explain why.

6. Describe 3 advantages and disadvantages of using confocal microscopy/multiphoton microscopy instead of single fluorescence.

7. Select a modality (single photon fluorescence, confocal microscopy, or multiphoton microscopy) for each application and justify your selection with at least two reasons.
   a) Imaging basal cell layer in vivo, using a fluorophore with excitation at 400 nm.
b) Imaging 50 slides of whole blood smears stained with acridine orange to count white blood cells present in entire slide.

c) Imaging microtubules in a cell culture, stack of images along axial direction desired

d) Imaging fluorescently labeled cell nuclei, microscope cost must be under $1500