# Week #7&8 – Fiber Optics

Reminder, still practice good optics alignment and Laser Safety practices!   You can use photos instead of diagrams/or drawings in your lab report where ever it is appropriate and where they can be properly labeled/understood.

FYI, the fiber-optics are VERY expensive (treat them with care!). They are in the large cabinet.

You have TWO weeks to complete this lab, and the lab report is worth 50% more than regular lab reports.

Hint to limit room light entering the photodetector. Tape a piece of black electrical tape over the detector, punch a small fiber sized hole in the center of the tape, then gently insert the fiber.

Hint to ensure you have a good fiber cleave here is the approach, shown at right, that I think works best: (1) strip the polymer with a razor blade at a shallow angle and gentle pressure as to not break the fiber. When all the polymer is gone you should be able to pull the glass-only fiber through your fingers and feel that it is smooth and free of the polymer jacket. (2) cleave both ends as shown in the diagram at right using the fiber cleaver (looks like a mini axe). It will take a few attempts typically to get a good cleave. (3) couple laser into the fiber, with your eye at least 12" distance away, look at the output end and look for red sparkle at unexpected angles as shown in diagram at right. You can also look for an irregular output pattern onto a white card. If you see no irregular sparkle or output patterns, then you have a good cleave, otherwise repeat the cleaving process; (4) once you have a good cleave on the output end, reverse the fiber output/input ends and repeat the above procedure until you once again confirm you have a good cleave on the other end of the fiber. Be very careful to not damage the tiny/bare/exposed fiber once you have a good cleave! A good fiber cleave can 'make-or-break' the entire experiment!
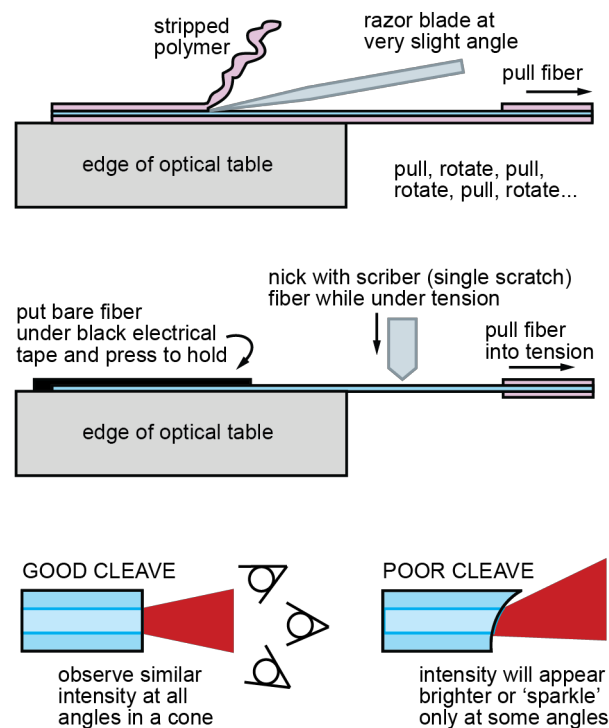

■ **1. Proximity Sensor** – Goal: there are numerous sensors based on optical fibers (chemical, pressure, etc.), and the goal today is to create a simple proximity sensor.

Procedure:

(1) Setup your experiment as shown at right. Use the fiber bundle splitter (labeled PROX SENSOR). You can insert one input-end directly into the laser (don't push in too far, you will damage the laser optics).

(2) Measure the optical power vs. distance of the fiber bundle from the white card for distances starting 0.5 cm away until the change in optical power is very small.   Measure at 0.5 cm intervals. Plot the data and compare to a theoretical plot or curve fit of a $1/d^2$ dependence (d= distance of fiber bundle from the card). The $1/d^2$ is because light reflects off the diffuse card into a hemisphere (but this assumes point source approximation, which is beyond the scope of this experiment).
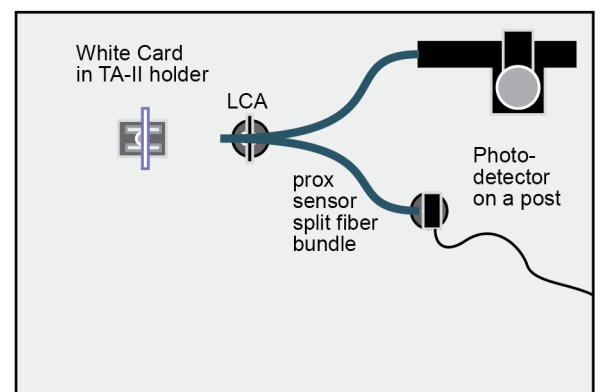

■ **2. Fiber Loss Measurement** *Now it gets a bit harder!* Goal: use the cutback method to measure the optical loss of a multi-mode fiber.

Procedure:

(1) Properly cleave both ends of the 500 m multimode (MLD) fiber (InfiniCor® 300). Look at the fiber spool to see the actual length that remains (previous groups have also used it and reduced the length a bit, and written the new length down on the spool). It has a 65 μm core diameter surrounded by cladding). Be careful not to damage the spool of fiber!


Please! Make sure when you are done with the fiber spool that you write down the NEW length so that future groups also know the correct length!

(2) Place one cleaved end down into the slotted brass rod and holding clip (FH fiber holder, see 'Week 0 – Assemblies' document). The fiber should just stick out the end of the rod by a few mm. Mount this into the fiber positioner (FP). Note, the FP has x, y, and z, controls for fine adjustment. Line up the FP with the photo detector (top of diagram at right) and gently push the fiber through a previously-punched hole in a black piece of electrical tape covering the face of the photodetector.
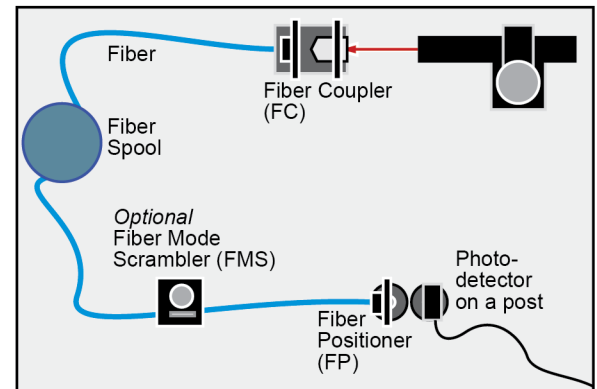
Note: Despite what the procedure steps 3 and 4 below say, you might not have to use the 20X objective to couple light into the fiber (just shine the laser straight onto it, this *might* give you enough power). You can see if this is adequate before you go to steps 3 and 4.

Note: You do not need to use the mode-scrambler (FMS) either (see setup diagram at right). It is optional. This puts some gentle bends in the fiber and simulates kilometer lengths of fiber (helps mix all the fiber modes).
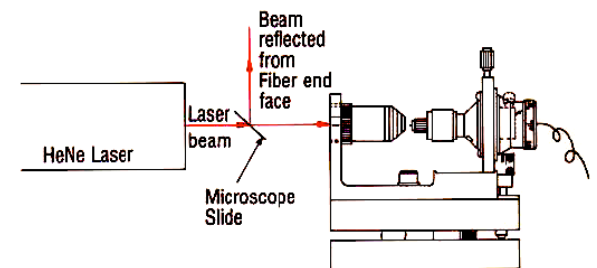
(3) Repeat step 2, but with the other end of the fiber and placing into the Fiber Coupler (FC, see diagram at right). The 20X microscope objective should be used in the FC. Use the adjustment features of the F-916 fiber coupler, and crude positioning before you bolt it down fully, to ensure the laser couples into the 20X objective in a way that is centered and able to focus down to the smallest possible point of light after the 20X objective.

(4) Now maximize coupling of laser light into the fiber. Remember, this is a microscope objective so in theory you should be able to see the coupling onto the fiber. To get maximum coupling, you will need to tune/adjust several times x,y, and z on the FP fiber positioner that is part of the FC fiber coupler. The best procedure is to optimize x, then y, then z, then repeat again, looking for maximum power each time with the photo-detector. Don't be fooled by coupling into the cladding, you need coupling into the core of the fiber! You can also 1st focus on the end of the fiber holder (FH) at first, to get a small spot, and then reposition the fiber end to that spot.
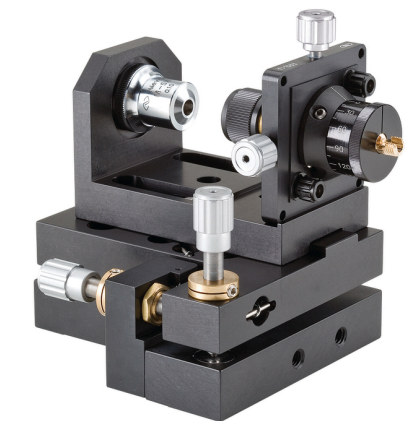
A microscope slide tilted at 45 degrees between the lens and the fiber might also be helpful because if the laser is directly on the fiber, some of the laser light will be Fresnel reflected back to the glass slide and then Fresnel reflected again of the glass eye to where you can observe it.

(5) Record your maximum optical power coupled into the fiber. Make sure you subtract out the background noise/power that the photo-detector reads out.

(6) Next, break ~1.5 meters off the fiber. Break it between the laser input end and the spool such that you have a total length of 1.5 m. Record the new optical power for the new 1.5 m length. *The reason why you break it between the laser input end and the spool (and not between the output end and the spool) is so you don't have to redo the laser coupling*

into the fiber (_otherwise the input power to the fiber will change_ for certain and you can't make an accurate loss calculation). Reminder, make sure you obtain a good cleave on the NEW output end, because you will need that for the next experiment.

(7) Calculate the optical loss using equations provided in lecture. Make sure you use the actual length of the fiber written on the spool in your calculation. SAVE THE FIBER SETUP FOR THE NEXT EXPERIMENT.

AGAIN, MAKE SURE YOU WRITE ON THE SPOOL THE DATE AND THE REMAINING FIBER LENGTH AFTER YOU CUT IT! FUTURE GROUPS WILL NEED TO KNOW THIS! Lastly, the fiber loss for the MLD fiber is specified to be approximately 4.0 dB/km at 850 nm and 1.5 dB/km at 1300 nm.

■ _**3. Numerical Aperture of an Optical Fiber**_ Goal: use two methods to measure the NA of an optical fiber.


Note, before you can use the fiber from the previous experiment for numerical aperture, ensure you also have a good fiber cleave on the fiber output.

Procedure:

1) Shine the fiber output onto a white card and use the observed spot size and distance between the card and the fiber to do a rough calculation of the numerical aperture. For this part you might need to use the mode scrambler (MS) to redistribute the light in the fiber to all the possible angles of propagation (and therefore full use of the numerical aperture). If you use the mode scrambler, do NOT clamp it too tightly else you will break the fiber. The MS is in the common bins.

2) Next, at the laser input side of the fiber, mount the FP onto a rotation stage (RSX-2) as pictured at right. You will now measure numerical aperture by rotating the fiber and determining at what angles the laser light can no-longer couple into the optical fiber. However:

The key challenge in this experiment is centering the fiber above the rotation stage. You don't want the fiber input to move out of the laser beam as you rotate it! You may find it easier to have the fiber just barely protrude from the fiber holder, so you can visualize on the surface of the fiber holder whether or not you are centered. Furthermore, you can confirm good centering by rotating the stage to + and - 90° and looking for shadowing and diffraction off the very end of the fiber.
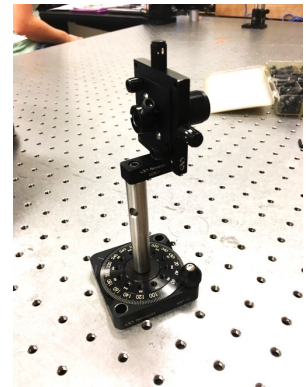
3) Use the photo-detector to measure the light coupled into the fiber, and using the rotation stage, rotate the fiber as a function on incident angle to determine the numerical aperture of the fiber. Plot the measurements (semi-log plot might help) and mark on the plot the angles at which the light irradiance drops to 5% of the maximum irradiance. Ideally you should see the two angles at 5% be similar but opposite in sign (numerical aperture is symmetric about the optical axis). Compare your results with the previous method for measuring numerical aperture.

4) For your results obtained in part 3, calculate the cladding refractive index assuming that the core is n=1.50.

■ _**4. Observation of Modes in a V~5 Fiber**_ – _This is challenging!_ Goal – observe actual fiber modes in action!

Procedure:

(1) use a setup similar to the fiber loss measurement, except, you will use ~1.5 M of the SMF-28 fiber ('single mode' fiber). Make sure you have good cleaves. Before observing fiber modes, first maximize the optical power coupled into the fiber (20X objective and FC fiber coupler) and irradiate the fiber output onto the photodetector assembly. You should be able to achieve > 0.1 µW. Record the optical power that you achieve. When you are done with the photo-detector, power it off (don't kill the batteries!).

Hints to maximize light coupling. (1) ENSURE you have an excellent fiber cleave! (2) ENSURE you laser is properly aligned with the 20X objective and fiber before you start fine tuning. (3) Maximize the power coupling by optimizing, x, then, y, then z, then repeat again and again (one axis at a time!).

(2) After maximizing coupled power, setup a white card or whiteboard at an imaging distance of ~6-12" from the output end of the fiber (move the photo-detector out of the way of course).

(3) identify as many modes as you can generate through slighting changing the x,y,z coupling of the fiber coupler. Using the fiber mode scrambler (MS) might also help generate some modes, but remember, for the MS only light pressure on the fiber is needed and too much pressure will break the fiber. There are only two mode scramblers available for use (are in the common bins). Take photos and add them to your lab report (even camera phone images might be okay).

■ *5. Setup Dismantle and Storage* – Proper care of optical components is just as important to achieving reliable results as is careful experimental setup. Improper handling, setup, dismantling, and storage will detract from your final grade in this course. Unsure about any component? Just ask. The next group should find all parts neatly stored in the optics kit. There is a card with each kit that shows where each component goes.

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■ *6. Theory/Calculation Problem#1 (Single Mode Fibers)* – Goal – theoretically explore simple single mode fiber.

We will not perform the actual experiment because it is extremely challenging for most students (I had to do it as a student, but I will spare you). However, we will calculate the modes supported by two types of single mode fibers.

Procedure:

(1) calculate V for single mode fiber F-SV with 4 μm diameter core and 0.13 NA and for single mode fiber SMF-28 with 8.5 μm diameter core and 0.13 NA; (Note, lecture notes had an error on one slide, a is RADIUS in the equations in lecture).

(2) using the mode chart from lecture, what modes might you expect to observe for each of these fibers using the HeNe laser (λ=0.633 μm)?

(3) question, for *telecommunications applications* the SMF-28 fiber is a called single mode fiber, how can that be? why?


■ *7. Theory/Calculation Problem#2 (Optical Modulators)* – Goal – theoretically explore how an optical modulator is made.

Recent press release on a new device used to modulate a continuous laser signal into 1's and 0's of optical pulses for high-speed fiber communications:

(a) explain how you believe that this device works. Hints, Silicon is transparent to 1.5 μm light, and the equation below explains how the refractive index of Si changes as the electron concentration in Si changes (by injection, accumulation, depletion, etc.).

$$\Delta n \cong 3 \times 10^{-21}(cc) \quad \times \quad \Delta N(\frac{1}{cc})$$

(b) assuming the device uses the standard telcom wavelength of 1.5 μm light (which is low enough energy that Si does not absorb it!), and the refractive index of the waveguide is nominally n=3.5, how much difference in refractive index is needed between the two arms of the waveguide to cause a logic zero (0) to be created at the output of this modulator?
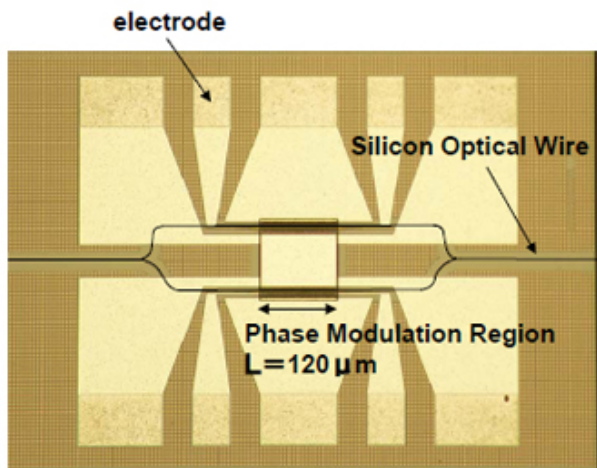
Tokyo, March 23, 2010 - NEC Corporation (NEC; TSE: 6701), announced today the successful development of a silicon MOS (metal-oxide-semiconductor) optical modulator that boasts a leading power-consumption efficiency of less than 1mW/Gbps, a compact size of 120 µm in length and high-speed operation of 25Gbps. The device has only one-tenth the power consumption when compared to conventional PN-type silicon optical modulators.

Hint _– I found this great journal paper for this exact device!_
http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=05465181

◼ **8. Theory/Calculation Problem#3 (Fiber Mode Plots)** - Add to your lab reports a theoretical plot of the modes you were able to generate in step 5. Remember, in some cases you might have seen mixing of two modes (in that case, plot them both). The naming for different modes can be found in the lecture slides for this week (LPxx). The code for the most likely modes you will find is provided below (courtesy Lucian Bojor and MATLAB Central File Exchange). The code is below and the polar3d.m file you will need can be found here: http://www.mathworks.com/matlabcentral/fileexchange/9126-fiber-modes

```
****** LP01 ******
a=8.335;lambda=0.6328;nc=1.462420;ng=1.457420;
v=(2*pi*a/lambda)*sqrt(nc^2-ng^2);
umax=v;umin=0;wmax=v;wmin=0;
u=[0:0.1:v];
Su=size(u);
for m=1:Su(2);
    J(m)=u(m)*besselj(1,u(m))/besselj(0,u(m));
end
for m=1:Su(2);
    w(m)=sqrt(v^2-u(m)*u(m));
    K(m)=w(m)*besselk(1,w(m))/besselk(0,w(m));
end
 %plot(u,J);hold on;plot(w,K);
u01=2.1845;neff01=sqrt(nc^2-
(u01/(2*pi*a/lambda))^2);
u02=4.9966;neff02=sqrt(nc^2-
(u02/(2*pi*a/lambda))^2);
u03=7.7642;neff03=sqrt(nc^2-
(u03/(2*pi*a/lambda))^2);
w01=sqrt(v^2-u01^2);
w02=sqrt(v^2-u02^2);
w03=sqrt(v^2-u03^2);
rc=[0:0.1:a];
Src=size(rc);
for m=1:Src(2);
    psic01(m)=besselj(0,u01*rc(m)/a)/besselj(0,u01);
end
rg=[a:0.1:2*a];
Srg=size(rg);
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for m=1:Srg(2);
    psig01(m)=besselk(0,w01*rg(m)/a)/besselk(0,w01);
end
psic01t=psic01';
psig01t=psig01';
psic01t = psic01t(end:-1:1);
psig01t=psig01t(end:-1:1);
    PSIC01=repmat(psic01t,1,500);
    PSIG01=repmat(psig01t,1,500);
[Xc,Yc,Zc]=polar3d(PSIC01.^2/max(max(PSIC01))^2,0,2*
pi,0,a,2,'off');
[Xg,Yg,Zg]=polar3d(PSIG01.^2/max(max(PSIC01))^2,0,2*
pi,a,2*a,2,'off');
subplot(2,1,1);
surf(Xc,Yc,Zc);  hold on;surf(Xg,Yg,Zg);axis([-20 20
-20 20]);shading interp;colorbar;
subplot(2,1,2);
pcolor(Xc,Yc,Zc);hold  on;pcolor(Xg,Yg,Zg);axis([-10
10 -10 10]);shading interp
colorbar

****** LP02 ******
a=8.335;lambda=0.6328;nc=1.462420;ng=1.457420;
v=(2*pi*a/lambda)*sqrt(nc^2-ng^2);
umax=v;umin=0;wmax=v;wmin=0;
u=[0:0.1:v];
Su=size(u);
for m=1:Su(2);
    J(m)=u(m)*besselj(1,u(m))/besselj(0,u(m));
end
for m=1:Su(2);
    w(m)=sqrt(v^2-u(m)*u(m));
    K(m)=w(m)*besselk(1,w(m))/besselk(0,w(m));
```

```
end
 %plot(u,J);hold on;plot(w,K);
u01=2.1845;neff01=sqrt(nc^2-
(u01/(2*pi*a/lambda))^2);
u02=4.9966;neff02=sqrt(nc^2-
(u02/(2*pi*a/lambda))^2);
u03=7.7642;neff03=sqrt(nc^2-
(u03/(2*pi*a/lambda))^2);
w01=sqrt(v^2-u01^2);
w02=sqrt(v^2-u02^2);
w03=sqrt(v^2-u03^2);
rc=[0:0.1:a];
Src=size(rc);
for m=1:Src(2);
    psic02(m)=besselj(0,u02*rc(m)/a)/besselj(0,u02);
end
rg=[a:0.1:2*a];
Srg=size(rg);
for m=1:Srg(2);
    psig02(m)=besselk(0,w02*rg(m)/a)/besselk(0,w02);
end
psic02t=psic02';
psig02t=psig02';
psic02t=psic02t(end:-1:1);
psig02t=psig02t(end:-1:1);
    PSIC02=repmat(psic02t,1,500);
    PSIG02=repmat(psig02t,1,500);
[Xc,Yc,Zc]=polar3d(PSIC02.^2/min(min(PSIC02))^2,0,2*
pi,0,a,2,'off');
[Xg,Yg,Zg]=polar3d(PSIG02.^2/min(min(PSIC02))^2,0,2*
pi,a,2*a,2,'off');
subplot(2,1,1);
surf(Xc,Yc,Zc); hold on;surf(Xg,Yg,Zg);axis([-20 20
-20 20]);shading interp;colorbar;
subplot(2,1,2);
pcolor(Xc,Yc,Zc);hold on;pcolor(Xg,Yg,Zg);axis([-10
10 -10 10]);shading interp
colorbar


****** LP11 ******
a=8.335;lambda=0.6328;nc=1.462420;ng=1.457420;
v=(2*pi*a/lambda)*sqrt(nc^2-ng^2);
umax=v;umin=0;wmax=v;wmin=0;
u=[0:0.1:v];
Su=size(u);
for m=1:Su(2);
    J(m)=u(m)*besselj(2,u(m))/besselj(1,u(m));
end
for m=1:Su(2);
    w(m)=sqrt(v^2-u(m)*u(m));
    K(m)=w(m)*besselk(2,w(m))/besselk(1,w(m));
end
 %plot(u,J);hold on;plot(w,K);
u11=3.4770;neff11=sqrt(nc^2-
(u11/(2*pi*a/lambda))^2);
u12=6.3310;neff12=sqrt(nc^2-
(u12/(2*pi*a/lambda))^2);
u13=9.0463;neff13=sqrt(nc^2-
(u13/(2*pi*a/lambda))^2);
w11=sqrt(v^2-u11^2);
w12=sqrt(v^2-u12^2);
w13=sqrt(v^2-u13^2);
rc=[0:0.1:a];
Src=size(rc);
for m=1:Src(2);
    psic11(m)=besselj(1,u11*rc(m)/a)/besselj(1,u11);
end
rg=[a:0.1:2*a];
Srg=size(rg);
for m=1:Srg(2);
    psig11(m)=besselk(1,w11*rg(m)/a)/besselk(1,w11);
end
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psic11t=psic11';
psig11t=psig11';
psic11t = psic11t(end:-1:1);
psig11t=psig11t(end:-1:1);
    PSIC11=repmat(psic11t,1,500);
    PSIG11=repmat(psig11t,1,500);
    SPSIC11=size(PSIC11);
    SPSIG11=size(PSIG11);
    angl = 0:2*pi/(SPSIC11(2)-1):2*pi;
    anglg= 0:2*pi/(SPSIG11(2)-1):2*pi;
    COS=cos(angl);
    COSg=cos(anglg);
    COSMAT=repmat(COS,SPSIC11(1),1);
    COSMATg=repmat(COSg,SPSIG11(1),1);
[Xc,Yc,Zc]=polar3d(PSIC11.*PSIC11.*COSMAT.*COSMAT/ma
x(max(PSIC11))^2,0,2*pi,0,a,2,'off');
[Xg,Yg,Zg]=polar3d(PSIG11.*PSIG11.*COSMATg.*COSMATg/
max(max(PSIC11))^2,0,2*pi,a,2*a,2,'off');
subplot(2,1,1);
surf(Xc,Yc,Zc); hold on;surf(Xg,Yg,Zg);axis([-20 20
-20 20]);shading interp;colorbar;
subplot(2,1,2);
pcolor(Xc,Yc,Zc);hold on;pcolor(Xg,Yg,Zg);axis([-10
10 -10 10]);shading interp
colorbar


****** LP 21 ******
a=8.335;lambda=0.6328;nc=1.462420;ng=1.457420;
v=(2*pi*a/lambda)*sqrt(nc^2-ng^2);
u21=4.6544;neff22=sqrt(nc^2-
(u21/(2*pi*a/lambda))^2);
w21=sqrt(v^2-u21^2);
rc=[0:0.1:a];
Src=size(rc);
for m=1:Src(2);
    psic21(m)=besselj(2,u21*rc(m)/a)/besselj(2,u21);
end
rg=[a:0.1:3*a];
Srg=size(rg);
for m=1:Srg(2);
    psig21(m)=besselk(2,w21*rg(m)/a)/besselk(2,w21);
end
psic21t=psic21';
psig21t=psig21';
psic21t = psic21t(end:-1:1);
psig21t=psig21t(end:-1:1);
    PSIC21=repmat(psic21t,1,500);
    PSIG21=repmat(psig21t,1,500);
    SPSIC21=size(PSIC21);
    SPSIG21=size(PSIG21);
    angl = 0:2*pi/(SPSIC21(2)-1):2*pi;
    anglg= 0:2*pi/(SPSIG21(2)-1):2*pi;
    COS=cos(2*angl);
    COSg=cos(2*anglg);
    COSMAT=repmat(COS,SPSIC21(1),1);
    COSMATg=repmat(COSg,SPSIG21(1),1);
[Xc,Yc,Zc]=polar3d(PSIC21.*PSIC21.*COSMAT.*COSMAT/ma
x(max(PSIC21))^2,0,2*pi,0,a,2,'off');
[Xg,Yg,Zg]=polar3d(PSIG21.*PSIG21.*COSMATg.*COSMATg/
max(max(PSIC21))^2,0,2*pi,a,2*a,2,'off');
subplot(2,1,1);
surf(Xc,Yc,Zc); hold on;surf(Xg,Yg,Zg);axis([-20 20
-20 20]);shading interp;colorbar;
subplot(2,1,2);
pcolor(Xc,Yc,Zc);hold on;pcolor(Xg,Yg,Zg);axis([-10
10 -10 10]);shading interp
colorbar
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