# Surface Plasmon Resonance Demo

**Items:**

a) Polarization stabilized He-Ne laser at 633nm
b) Equilateral Prism of known refractive index
c) Linear Polarizer
d) Half wave-plate @ 633nm
e) Precision Rotation stage (0.5 degree or better)
f) Photo-detector

**Procedure Gold Deposition:**

Wipe Prism Clean with Tissue

HCL immersion for 2 minutes

Rinse with water

10 minutes immersion in acetone, followed by 10 minutes in Isopropanol then dry

Clean sputtering system with acetone. Since prism height is large and there is not enough headroom in the chamber, to accommodate the prism remove rod below the round sample holder by rotating it off (! be careful not to bend or strain the wire connected to the holder). Replace with the shorter screw/rod in the target drawer. Using the two copper supports place the prism with the deposition surface horizontal and facing the target. Deposit gold for 360seconds at 22mA current under argon gas (Denton system is open loop and measured current under stable conditions is always 2mA less than inputted current hence actual current should be 20mA).

Using acetone wipe clean the other two surfaces to remove unintended gold deposition.

The estimated gold film thickness is 50nm for given time/current.

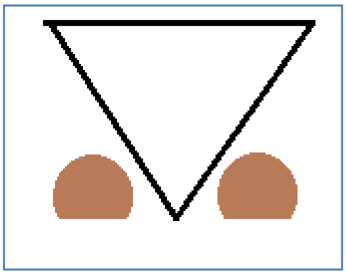

Fig 1. Prism arrangement in sputtering chamber

**Experimental Setup:**

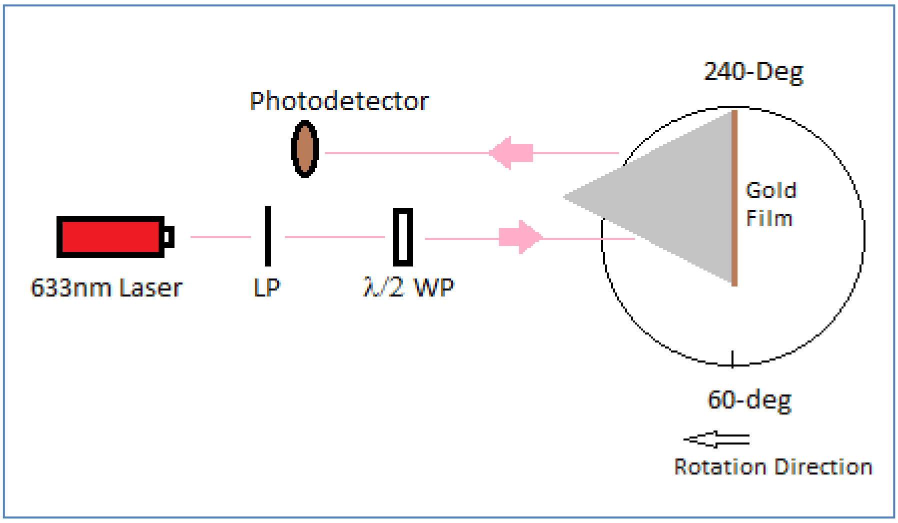


Fig 2. Setup for SPR Observation

Setup the prism onto the rotation stage such that the back face with the gold film is on the 240-60deg line and the line marker on the stage points to 60 degrees in the orientation shown in figure 2. This ensures that the angle indicated by the line marker is $\emptyset ext$ the external angle onto the prism face. As the stage is rotated in clockwise direction the photodetector needs to be moved manually to detect the light reflected from the back face. To check if alignment is accurate rotate the prism to zero degree position and see if the light reflected from the front surface goes directly back towards the incident beam.

Ensure that the photodetector is not saturated at the maximum reflection intensity; reduce power using the linear polarizer if needed. The SPR dip is maximized for p polarized light; use the waveplate to ensure that the beam is p or s polarized as needed.

**Results:**

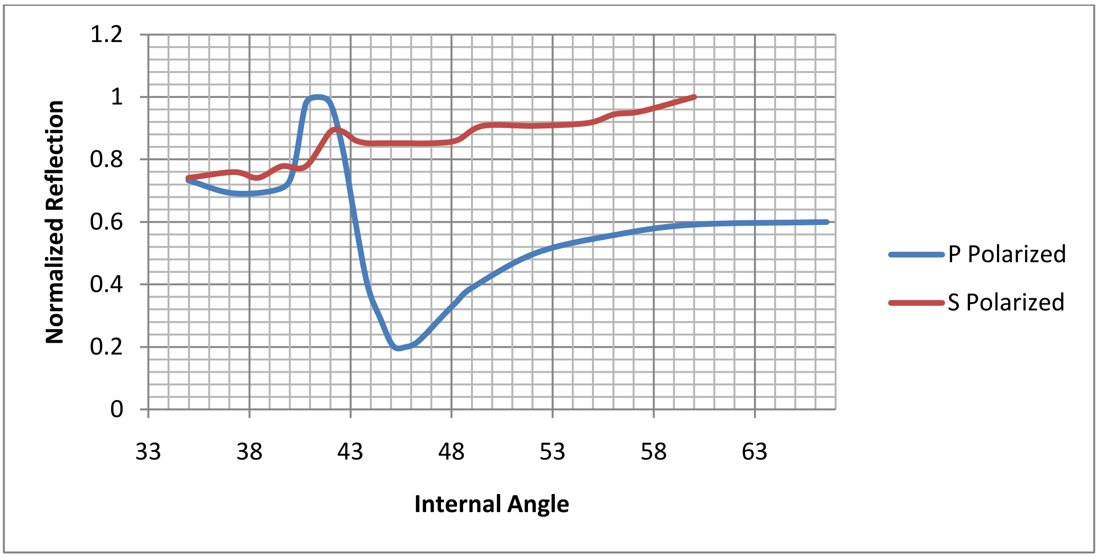


Fig 3. Reflection vs internal angle for 6minute Deposition ( Prism B)

The total internal reflection angle for glass with n=1.49 is 42 degrees which corresponds to external angle of 28 degrees. This is where the reflection maximizes as shown in figure 3. Beyond that SPR dip is observed for P Polarized light only at 45 degrees.

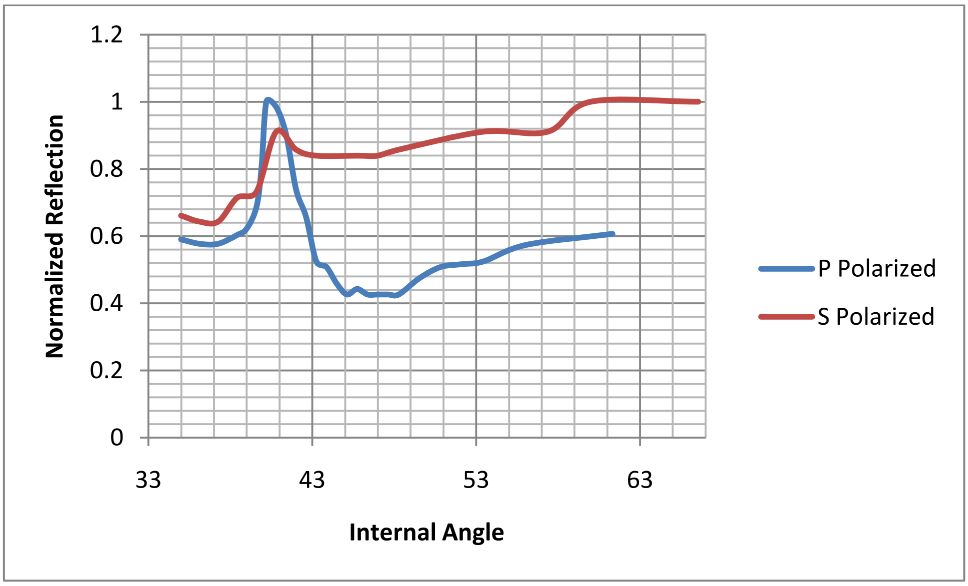


Fig 4. Reflection vs internal angle for 5minute deposition (Prism A)

Reduced dip observed for 5 minute deposition suggesting that optical film thickness was not reached at 5minutes.

**NOTE: Prism A** – 5 minutes Deposition, **Prism B** – 6 minutes deposition and **Prism C** – 9 minutes deposition

The SPR technique can be used for high sensitivity detection of molecules adsorbing onto the metallic film. To see this effect the prism was dipped in water for 5 minutes then dried in air. We deposited gold for 6 minutes on a second prism for this experiment. The SPR dip before water is slightly shifted from the results in figure 3 and 4 possibly due to different refractive index of the prism.

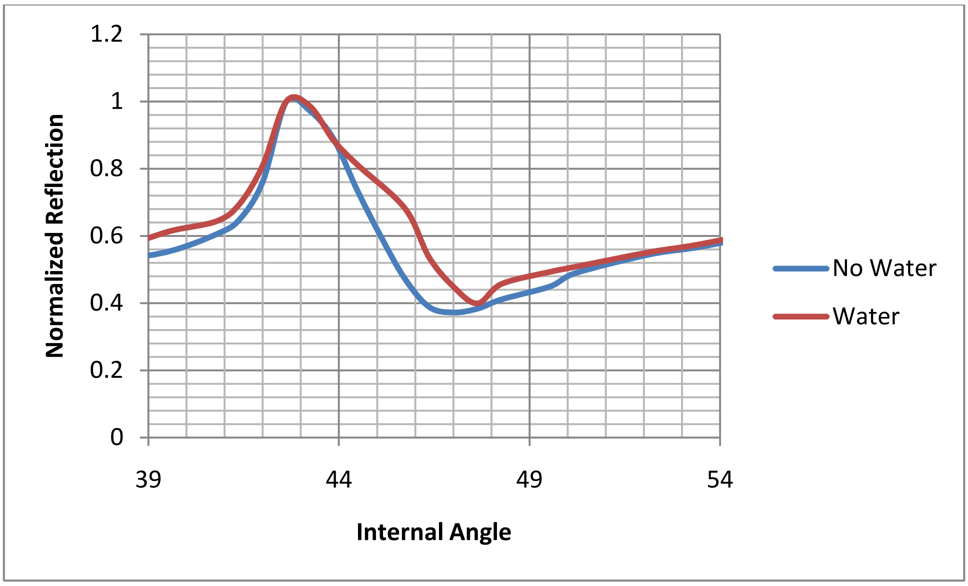


Fig 5. Effect of immersing prism in water for 5 minutes

We observe a 1 degree shift after exposure to water. From simulation results shown in figure 6 a 1 degree shift corresponds to a 10nm layer of water molecules.

More data is in appendix 3.

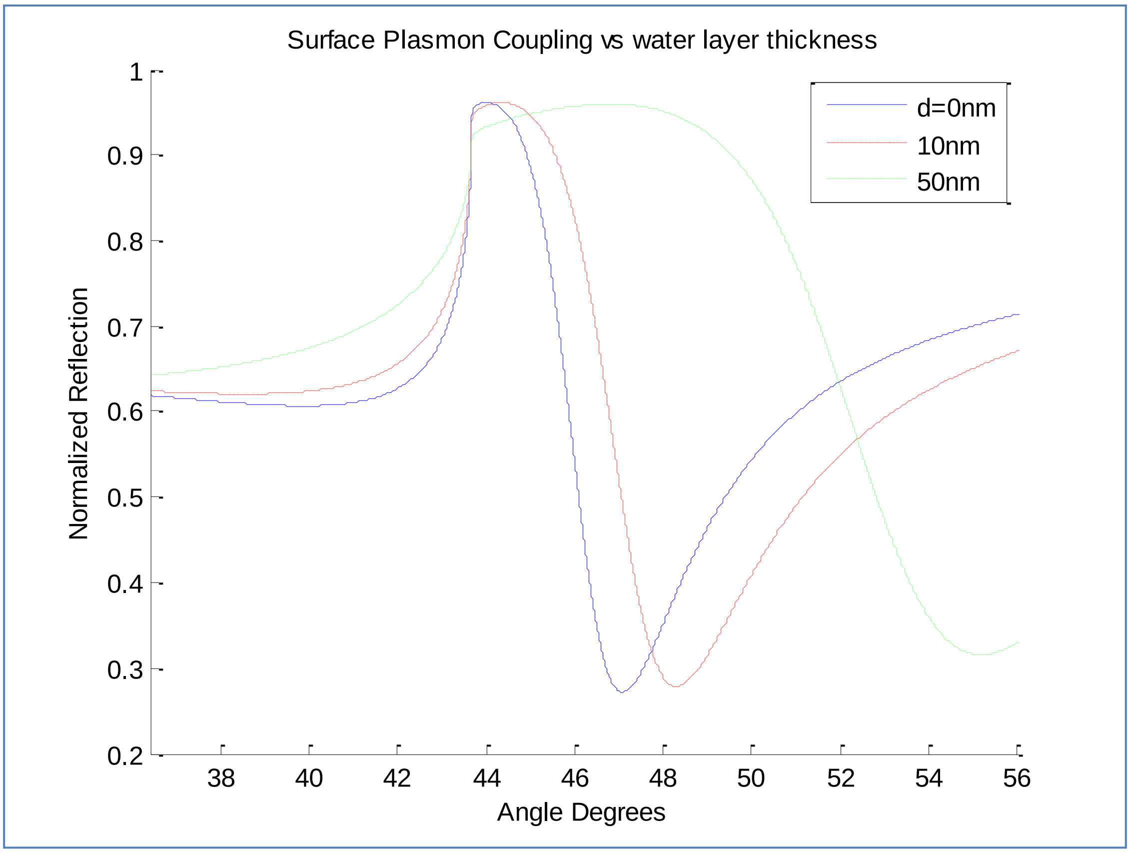


Fig 6. Simulation for different water thicknesses on gold (nprism taken to be 1.45)

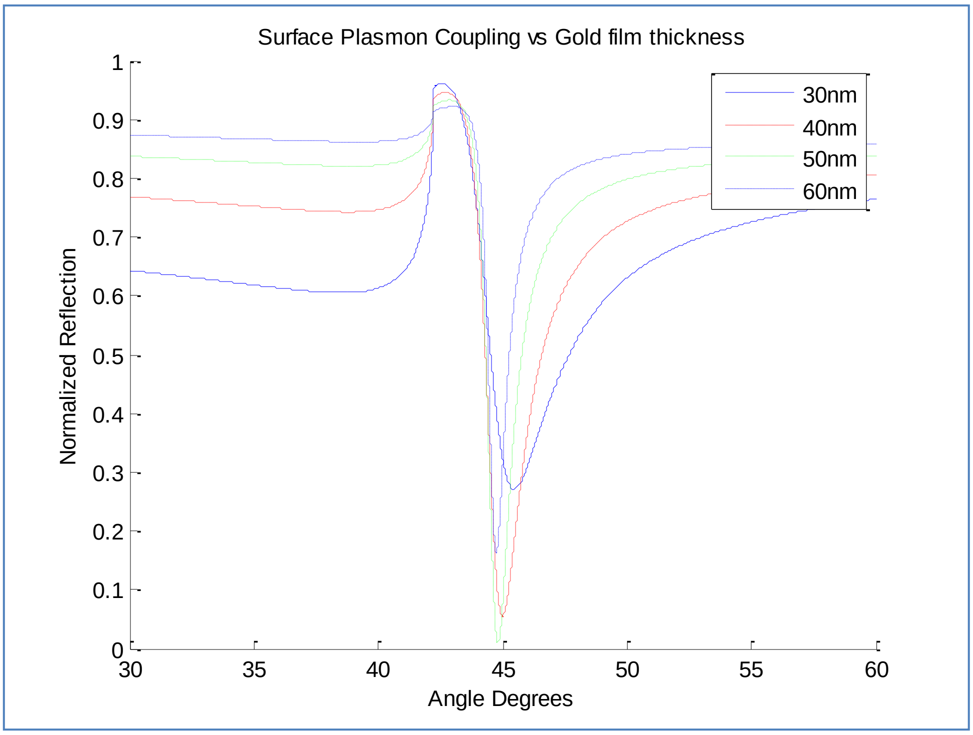


Fig 7. Effect of different gold thicknesses on SPR dip

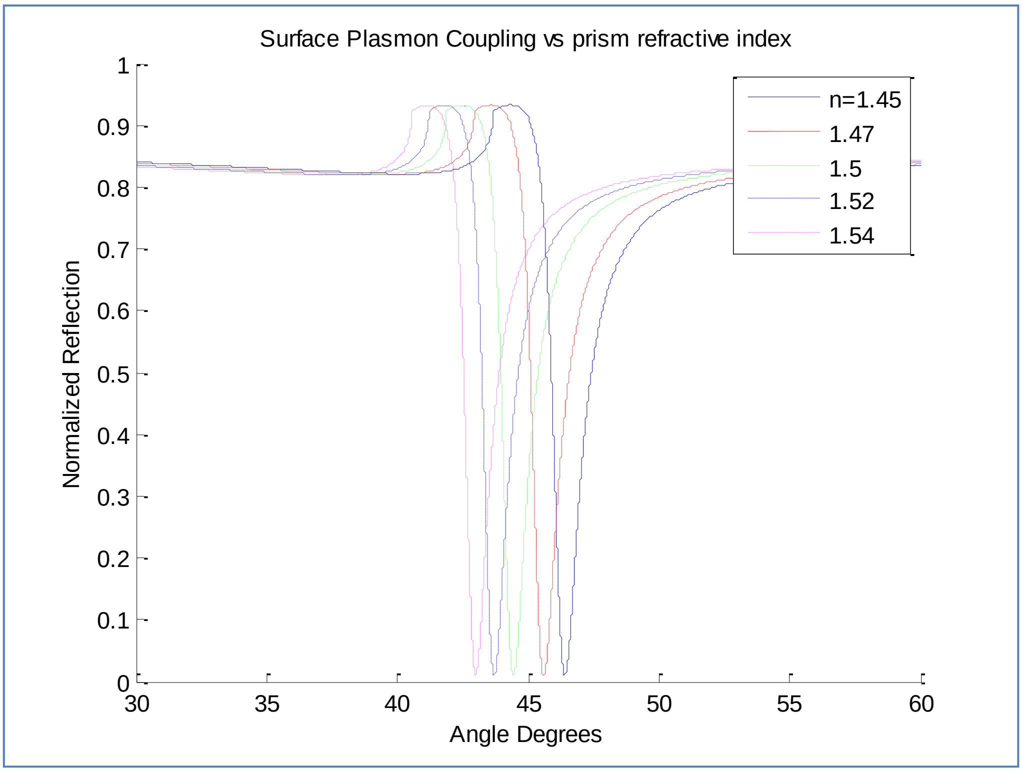


Fig 8. Effect of prism refractive index on gold.

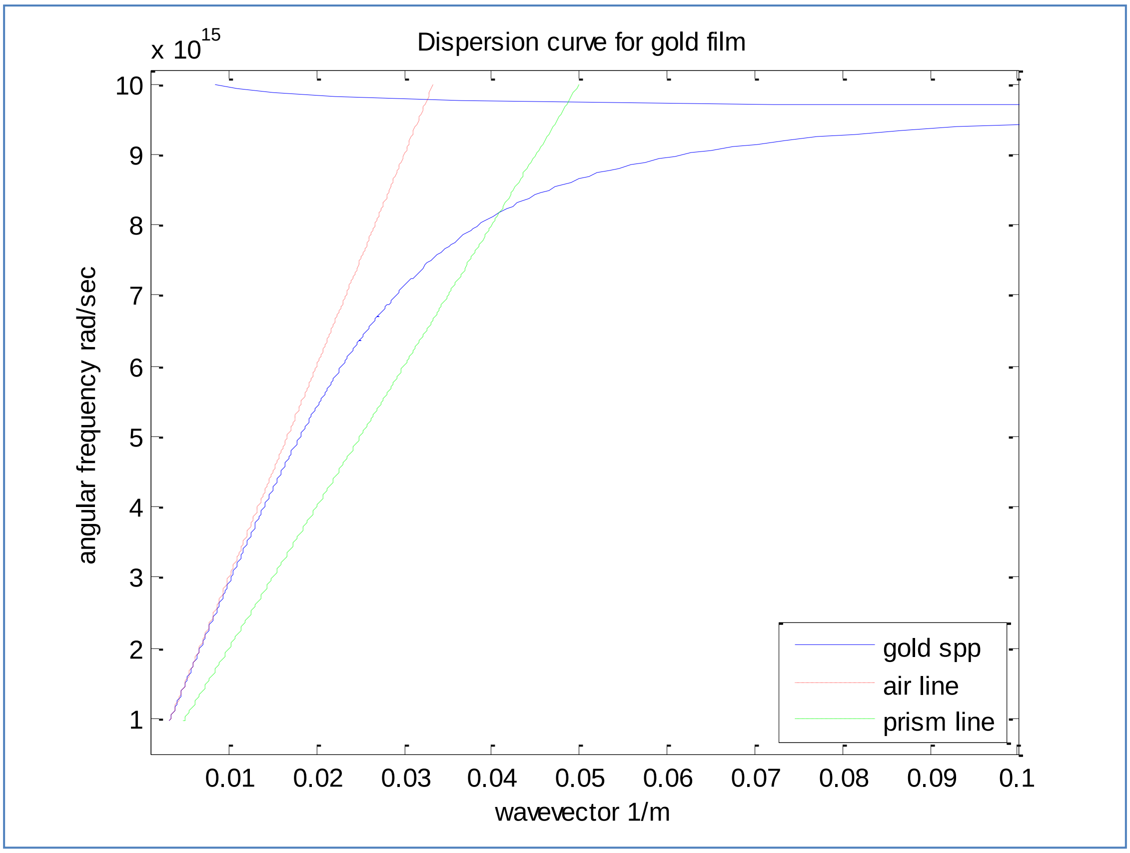


Fig 9. Dispersion curve for gold thin film

## Useful relations/theory:

1- **Fresnel reflection coefficient for 2 thin film system (e.g. gold/water) [Quail et al, Optics Letters 1983]:**

$$R_{1234} = \frac{r_{12} + R_{234}\exp(i2k_{2z}d_2)}{1 + r_{12}R_{234}\exp(i2k_{2z}d_2)},$$

where

$$R_{234} = \frac{r_{23} + r_{34}\exp(i2k_{3z}d_3)}{1 + r_{23}r_{34}\exp(i2k_{3z}d_3)}.$$

$$r_{ij} = \frac{\sqrt{\epsilon_j}\cos\theta_i - \sqrt{\epsilon_i}\cos\theta_j}{\sqrt{\epsilon_j}\cos\theta_i + \sqrt{\epsilon_i}\cos\theta_j}$$

and

$$k_{iz} = \frac{\omega}{c}(\epsilon_i - \epsilon_1\sin^2\theta_1)^{1/2}.$$

i,j go from 1 to 4 corresponding to prism, gold, water (or other dielectric) and air respectively.

2- **Dispersion relation for SPR between a dielectric and a metal [Maier, Plasmonics: Fundamentals and Applications]:**

$$\beta = k_0\sqrt{\frac{\varepsilon_1\varepsilon_2}{\varepsilon_1 + \varepsilon_2}}.$$

3- **Relationship between internal and external angle of a equilateral prism for the used geometry**

$$\emptyset int = 60 - \arcsin\left(\frac{\sin(\emptyset ext)}{n}\right)$$

$\emptyset int$ is the internal angle on the prism/gold interface

$\emptyset ext$ is the external angle onto the prism wrt. the surface normal

## References:


Laboratory experiments for exploring the surface Plasmon resonance, Pluchery et al, European Journal of Physics, 2011

Quantitative Interpretation of the Response of Surface Plasmon Resonance Sensors to the Adsorbed Films, S. Jung, Langmuir 1998

Long-range surface-plasmon modes in silver and aluminum films, J.C. Quail Optics Letters 1983

Magnetoplasmonic Nanostructures: systems supporting both plasmonic and magnetic properties , F Armelles, Journal of Optics A: Pure and Applied Optics, 2009

Plasmonics: Applications and Fundamentals, Maier, 2007

## Appendix - 1

```
%%% SPP dispersion curve for gold thin film and light lines for air and
%%% glass
close all,
clear;
nprism=1.5;
gma=1/(9e-15);
wp=2*pi*2.175e15;
lambda=189:1:1940;
eps=gold_eps(lambda);

c1=3e17;
w2=2*pi*c1./lambda;


eps2=1-((wp^2)./(w2.^2+1i*gma*w2));

beta=w2/c1.*((eps2)./(eps2+1)).^0.5;
k1=w2./c1;
plot(real(beta),w2);
hold on
plot(k1,w2,':r');
plot(k1*nprism,w2,'--g');
legend ('gold spp','air line','prism line','Location','Southeast')
xlabel ('wavevector 1/m');
ylabel ('angular frequency rad/sec');
axis([0.001 0.1 0.5*10^15 1.02e16]);
title ('Dispersion curve for gold film')
lmda=2*pi*c1/8.15e15 %intersection of gold spp with prism ie max possible
wavelength
%figure
%plot(lambda,real(eps));
%figure
%plot(lambda,imag(eps));
```

## Appendix - 2

```
% Fresnel Reflection Calculations for gold thin film on glass prism%
clc
clear
close all
dgold=50e-9;
dwater=0e-9;
nprism=1.49;
lmda=633e-9; %% laser wavelength

epsi(4)= 1; %air
epsi(3)= 1.33^2; % liquid (water)
epsi(2)=gold_eps(lmda*10^9); %%gold_eps is a function that gives the
dielectric constant for gold for a given lmda (download from mathwork
website)
epsi(1)=nprism^2; %prism/substrate

div=1000; %% no. of points
d(1)=dgold; %gold layer
d(2)=dwater; % water layer thickness
```

```
rnge1=35; %angle start range
rnge2=60; %angle end range


thetain=rnge1:(rnge2-rnge1)/div:rnge2; %internal angle

    theta(1,:)=thetain;


for i=1:3

theta(i+1,:)=(asin(sqrt(epsi(i)).*sin(theta(i,:)*3.14/180)./sqrt(epsi(i+1))
))*180/pi; %% rest of the angles in each layer
end


for i=1:3
    r(i,:)=(sqrt(epsi(i+1))*cos(theta(i,:)*3.14/180)-
sqrt(epsi(i))*cos(theta(i+1,:)*3.14/180))./(sqrt(epsi(i+1))*cos(theta(i,:)*
3.14/180)+sqrt(epsi(i))*cos(theta(i+1,:)*3.14/180));
end

for i=1:3
        k(i,:)=(2*pi/lmda)*(epsi(i)-
epsi(1)*(sin(theta(1,:)*3.14/180).^2)).^0.5; %wavevectors for each layer
end


R2=(r(2,:)+r(3,:).*exp(1i*2.*k(3,:)*d(2)))./(1+r(2,:).*r(3,:).*exp(1i*2*k(3
,:)*d(2))); %% reflection coeffecient for layer 2 to 4

R1=(r(1,:)+R2.*exp(1i*2.*k(2,:).*d(1)))./(1+r(1,:).*R2.*exp(1i*2.*k(2,:).*d
(1)));%% reflection for total stack

ref=sgolayfilt(abs(R1),1,15);
plot(theta(1,:),(abs(R1)).^2);
grid on
xlabel('Internal angle deg')
ylabel('Normalized Reflection')
```

## Appendix - 3 - READINGS

**P Polarized on glass slide with 6 minute deposition**

| theta | thetain | theta | pdiode mV | Normalized |
|---|---|---|---|---|
| 20 | 40 | 34.98304 | 236 | 0.813793103 |
| 23 | 37 | 36.67595 | 244 | 0.84137931 |
| 24 | 36 | 37.25063 | 248 | 0.855172414 |
| 26 | 34 | 38.41445 | 256 | 0.882758621 |
| 28 | 32 | 39.59639 | 264 | 0.910344828 |
| 30 | 30 | 40.7951 | 288 | 0.993103448 |
| 31 | 29 | 41.40034 | 288 | 0.993103448 |
| 32 | 28 | 42.00928 | 280 | 0.965517241 |
| 33 | 27 | 42.62178 | 272 | 0.937931034 |
| 34 | 26 | 43.23769 | 260 | 0.896551724 |
| 35 | 25 | 43.85684 | 252 | 0.868965517 |
| 36 | 24 | 44.4791 | 240 | 0.827586207 |
| 37 | 23 | 45.10432 | 232 | 0.8 |
| 38 | 22 | 45.73236 | 236 | 0.813793103 |
| 40 | 20 | 46.99634 | 244 | 0.84137931 |
| 42 | 18 | 48.26996 | 248 | 0.855172414 |
| 44 | 16 | 49.55216 | 252 | 0.868965517 |
| 46 | 14 | 50.84191 | 256 | 0.882758621 |
| 48 | 12 | 52.13821 | 260 | 0.896551724 |
| 50 | 10 | 53.44008 | 268 | 0.924137931 |
| 52 | 8 | 54.74657 | 272 | 0.937931034 |
| 54 | 6 | 56.05673 | 276 | 0.951724138 |

**6.5 minutes P Polorized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 30 | 40.7951 | 18.8 | 0.810344828 |
| 26 | 43.23769 | 23.2 | 1 |
| 25 | 43.85684 | 21.6 | 0.931034483 |
| 24 | 44.4791 | 16 | 0.689655172 |
| 23 | 45.10432 | 10 | 0.431034483 |
| 22 | 45.73236 | 6 | 0.25862069 |
| 21 | 46.36308 | 4 | 0.172413793 |
| 20 | 46.99634 | 2.4 | 0.103448276 |
| 19 | 47.63201 | 2 | 0.086206897 |
| 18 | 48.26996 | 2.4 | 0.103448276 |
| 17 | 48.91005 | 3.2 | 0.137931034 |
| 16 | 49.55216 | 4.4 | 0.189655172 |
| 14 | 50.84191 | 4.4 | 0.189655172 |
| 12 | 52.13821 | 6.4 | 0.275862069 |
| 10 | 53.44008 | 7.6 | 0.327586207 |
| 8 | 54.74657 | 8.8 | 0.379310345 |
| 6 | 56.05673 | 10 | 0.431034483 |
| 4 | 57.36963 | 11 | 0.474137931 |
| 2 | 58.68436 | 12.6 | 0.543103448 |
| 0 | 60 | 13.2 | 0.568965517 |

**S Polarized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 80 | 0.689655 |
| 36 | 37.25063 | 82 | 0.706897 |
| 34 | 38.41445 | 80 | 0.689655 |
| 32 | 39.59639 | 84 | 0.724138 |
| 30 | 40.7951 | 84 | 0.724138 |
| 28 | 42.00928 | 90 | 0.775862 |
| 27 | 42.62178 | 94 | 0.810345 |
| 26 | 43.23769 | 96 | 0.827586 |
| 25 | 43.85684 | 94 | 0.810345 |
| 24 | 44.4791 | 94 | 0.810345 |
| 22 | 45.73236 | 94 | 0.810345 |
| 20 | 46.99634 | 102 | 0.87931 |
| 18 | 48.26996 | 102 | 0.87931 |
| 16 | 49.55216 | 102 | 0.87931 |
| 12 | 52.13821 | 108 | 0.931034 |
| 8 | 54.74657 | 112 | 0.965517 |
| 6 | 56.05673 | 116 | 1 |
| 4 | 57.36963 | 112 | 0.965517 |
| 0 | 60 | 112 | 0.965517 |

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**4 minutes 50 seconds P Polarized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 72 | 0.590163934 |
| 38 | 36.10634 | 70.4 | 0.57704918 |
| 36 | 37.25063 | 70.4 | 0.57704918 |
| 34 | 38.41445 | 73.6 | 0.603278689 |
| 33 | 39.00324 | 76 | 0.62295082 |
| 32 | 39.59639 | 84 | 0.68852459 |
| 31.5 | 39.89455 | 98 | 0.803278689 |
| 31 | 40.19373 | 122 | 1 |
| 30 | 40.7951 | 120 | 0.983606557 |
| 29 | 41.40034 | 110 | 0.901639344 |
| 28 | 42.00928 | 90 | 0.737704918 |
| 27 | 42.62178 | 80 | 0.655737705 |
| 26 | 43.23769 | 64 | 0.524590164 |
| 25 | 43.85684 | 62 | 0.508196721 |
| 24 | 44.4791 | 56 | 0.459016393 |
| 23 | 45.10432 | 52 | 0.426229508 |
| 22 | 45.73236 | 54 | 0.442622951 |
| 21 | 46.36308 | 52 | 0.426229508 |
| 20 | 46.99634 | 52 | 0.426229508 |
| 19 | 47.63201 | 52 | 0.426229508 |
| 18 | 48.26996 | 52 | 0.426229508 |
| 16 | 49.55216 | 58 | 0.475409836 |
| 14 | 50.84191 | 62 | 0.508196721 |
| 12 | 52.13821 | 63 | 0.516393443 |
| 10 | 53.44008 | 64 | 0.524590164 |
| 6 | 56.05673 | 70 | 0.573770492 |
| -2 | 61.31564 | 74 | 0.606557377 |

**S Polarized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 74 | 0.660714 |
| 38 | 36.10634 | 72 | 0.642857 |
| 36 | 37.25063 | 72 | 0.642857 |
| 34 | 38.41445 | 80 | 0.714286 |
| 32 | 39.59639 | 82 | 0.732143 |
| 30 | 40.7951 | 102 | 0.910714 |
| 28 | 42.00928 | 96 | 0.857143 |
| 26 | 43.23769 | 94 | 0.839286 |
| 22 | 45.73236 | 94 | 0.839286 |
| 20 | 46.99634 | 94 | 0.839286 |
| 18 | 48.26996 | 96 | 0.857143 |
| 10 | 53.44008 | 102 | 0.910714 |
| 4 | 57.36963 | 102 | 0.910714 |
| 0 | 60 | 112 | 1 |
| -10 | 66.55992 | 112 | 1 |

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**P Polarized 9 minutes deposition**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 76 | 0.678571429 |
| 38 | 36.10634 | 72 | 0.642857143 |
| 32 | 39.59639 | 80 | 0.714285714 |
| 31 | 40.19373 | 92 | 0.821428571 |
| 30 | 40.7951 | 108 | 0.964285714 |
| 29 | 41.40034 | 112 | 1 |
| 28 | 42.00928 | 108 | 0.964285714 |
| 27 | 42.62178 | 102 | 0.910714286 |
| 26 | 43.23769 | 90 | 0.803571429 |
| 25 | 43.85684 | 72 | 0.642857143 |
| 24 | 44.4791 | 62 | 0.553571429 |
| 23 | 45.10432 | 52 | 0.464285714 |
| 22 | 45.73236 | 44 | 0.392857143 |
| 21 | 46.36308 | 38 | 0.339285714 |
| 20 | 46.99634 | 34 | 0.303571429 |
| 19 | 47.63201 | 32 | 0.285714286 |
| 18 | 48.26996 | 30 | 0.267857143 |
| 17 | 48.91005 | 30 | 0.267857143 |
| 16 | 49.55216 | 30 | 0.267857143 |
| 14 | 50.84191 | 30 | 0.267857143 |
| 10 | 53.44008 | 30 | 0.267857143 |
| 4 | 57.36963 | 38 | 0.339285714 |
| -2 | 61.31564 | 48 | 0.428571429 |
| -10 | 66.55992 | 58 | 0.517857143 |
| -14 | 69.15809 | 64 | 0.571428571 |
| -20 | 73.00366 | 80 | 0.714285714 |

**S Polarized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 84 | 0.777778 |
| 30 | 40.7951 | 94 | 0.87037 |
| 26 | 43.23769 | 94 | 0.87037 |
| 22 | 45.73236 | 90 | 0.833333 |
| 18 | 48.26996 | 92 | 0.851852 |
| 10 | 53.44008 | 102 | 0.944444 |
| 6 | 56.05673 | 104 | 0.962963 |
| 0 | 60 | 106 | 0.981481 |
| -4 | 62.63037 | 108 | 1 |
| -10 | 66.55992 | 106 | 0.981481 |
| -18 | 71.73004 | 98 | 0.907407 |

**P Polarized 6 minutes deposition**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 70.4 | 0.733333333 |
| 36 | 37.25063 | 66.4 | 0.691666667 |
| 32 | 39.59639 | 68 | 0.708333333 |
| 31 | 40.19373 | 74 | 0.770833333 |
| 30 | 40.7951 | 94 | 0.979166667 |
| 29 | 41.40034 | 96 | 1 |
| 28 | 42.00928 | 94 | 0.979166667 |
| 27 | 42.62178 | 80 | 0.833333333 |
| 26 | 43.23769 | 58 | 0.604166667 |
| 25 | 43.85684 | 38 | 0.395833333 |
| 24 | 44.4791 | 28 | 0.291666667 |
| 23 | 45.10432 | 19.6 | 0.204166667 |
| 22 | 45.73236 | 19.2 | 0.2 |
| 21 | 46.36308 | 21 | 0.21875 |
| 19 | 47.63201 | 29.2 | 0.304166667 |
| 18 | 48.26996 | 33.2 | 0.345833333 |
| 17 | 48.91005 | 37 | 0.385416667 |
| 12 | 52.13821 | 48 | 0.5 |
| 6 | 56.05673 | 53.6 | 0.558333333 |
| 0 | 60 | 56.8 | 0.591666667 |
| -10 | 66.55992 | 57.6 | 0.6 |

**S Polarized**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 80 | 0.740741 |
| 36 | 37.25063 | 82 | 0.759259 |
| 34 | 38.41445 | 80 | 0.740741 |
| 32 | 39.59639 | 84 | 0.777778 |
| 30 | 40.7951 | 84 | 0.777778 |
| 28 | 42.00928 | 96 | 0.888889 |
| 27 | 42.62178 | 96 | 0.888889 |
| 26 | 43.23769 | 93 | 0.861111 |
| 25 | 43.85684 | 92 | 0.851852 |
| 24 | 44.4791 | 92 | 0.851852 |
| 22 | 45.73236 | 92 | 0.851852 |
| 20 | 46.99634 | 92 | 0.851852 |
| 18 | 48.26996 | 93 | 0.861111 |
| 16 | 49.55216 | 98 | 0.907407 |
| 12 | 52.13821 | 98 | 0.907407 |
| 8 | 54.74657 | 99 | 0.916667 |
| 6 | 56.05673 | 102 | 0.944444 |
| 4 | 57.36963 | 103 | 0.953704 |
| 0 | 60 | 108 | 1 |

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**6 min prism 2-- no water**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 100 | 0.471698113 |
| 38 | 36.10634 | 96 | 0.452830189 |
| 36 | 37.25063 | 96 | 0.452830189 |
| 34 | 38.41445 | 96 | 0.452830189 |
| 32 | 39.59639 | 108 | 0.509433962 |
| 31 | 40.19373 | 116 | 0.547169811 |
| 30 | 40.7951 | 124 | 0.58490566 |
| 29 | 41.40034 | 160 | 0.754716981 |
| 28 | 42.00928 | 212 | 1 |
| 27 | 42.62178 | 212 | 1 |
| 26 | 43.23769 | 188 | 0.886792453 |
| 24 | 44.4791 | 128 | 0.603773585 |
| 23 | 45.10432 | 96 | 0.452830189 |
| 22 | 45.73236 | 80 | 0.377358491 |
| 21 | 46.36308 | 64 | 0.301886792 |
| 20 | 46.99634 | 60 | 0.283018868 |
| 18 | 48.26996 | 60 | 0.283018868 |
| 17 | 48.91005 | 62 | 0.29245283 |
| 16 | 49.55216 | 64.8 | 0.305660377 |
| 14 | 50.84191 | 74 | 0.349056604 |
| 12 | 52.13821 | 82.4 | 0.388679245 |
| 10 | 53.44008 | 92 | 0.433962264 |
| 8 | 54.74657 | 108 | 0.509433962 |
| 6 | 56.05673 | 112 | 0.528301887 |
| 4 | 57.36963 | 118 | 0.556603774 |
| 2 | 58.68436 | 126 | 0.594339623 |
| 0 | 60 | 134 | 0.632075472 |

**6 min prism 2-- with water**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 90 | 0.416667 |
| 38 | 36.10634 | 92 | 0.425926 |
| 36 | 37.25063 | 94 | 0.435185 |
| 34 | 38.41445 | 98 | 0.453704 |
| 30 | 40.7951 | 132 | 0.611111 |
| 29 | 41.40034 | 182 | 0.842593 |
| 28 | 42.00928 | 216 | 1 |
| 27 | 42.62178 | 196 | 0.907407 |
| 26 | 43.23769 | 176 | 0.814815 |
| 25 | 43.85684 | 140 | 0.648148 |
| 24 | 44.4791 | 104 | 0.481481 |
| 23 | 45.10432 | 86 | 0.398148 |
| 22 | 45.73236 | 76 | 0.351852 |
| 21 | 46.36308 | 66 | 0.305556 |
| 20 | 46.99634 | 66 | 0.305556 |
| 19 | 47.63201 | 70 | 0.324074 |
| 18 | 48.26996 | 70 | 0.324074 |
| 16 | 49.55216 | 84 | 0.388889 |
| 15 | 50.19615 | 84 | 0.388889 |
| 14 | 50.84191 | 96 | 0.444444 |
| 12 | 52.13821 | 112 | 0.518519 |
| 10 | 53.44008 | 122 | 0.564815 |
| 8 | 54.74657 | 126 | 0.583333 |
| 4 | 57.36963 | 144 | 0.666667 |
| 0 | 60 | 162 | 0.75 |
| -2 | 61.31564 | 168 | 0.777778 |
| -10 | 66.55992 | 168 | 0.777778 |

| | | | |
|---|---|---|---|
| -4 | 62.63037 | 140 | 0.660377358 |
| -10 | 66.55992 | 166 | 0.783018868 |

**6 min prism 2-- no water**

| thetain | theta | pdiode mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 76 | 0.527777778 |
| 36 | 37.25063 | 76 | 0.527777778 |
| 34 | 38.41445 | 76.8 | 0.533333333 |
| 32 | 39.59639 | 80 | 0.555555556 |
| 30 | 40.7951 | 87.2 | 0.605555556 |
| 29 | 41.40034 | 93.6 | 0.65 |
| 28 | 42.00928 | 110 | 0.763888889 |
| 27 | 42.62178 | 144 | 1 |
| 26 | 43.23769 | 140 | 0.972222222 |
| 25 | 43.85684 | 128 | 0.888888889 |
| 24 | 44.4791 | 106 | 0.736111111 |
| 23 | 45.10432 | 86 | 0.597222222 |
| 22 | 45.73236 | 68 | 0.472222222 |
| 21 | 46.36308 | 56 | 0.388888889 |
| 20 | 46.99634 | 53.6 | 0.372222222 |
| 19 | 47.63201 | 55.2 | 0.383333333 |
| 18 | 48.26996 | 59.2 | 0.411111111 |
| 16 | 49.55216 | 64.8 | 0.45 |
| 15 | 50.19615 | 70.4 | 0.488888889 |
| 12 | 52.13821 | 78.4 | 0.544444444 |
| 10 | 53.44008 | 81.6 | 0.566666667 |
| 8 | 54.74657 | 86 | 0.597222222 |
| 6 | 56.05673 | 92 | 0.638888889 |
| 0 | 60 | 92.8 | 0.644444444 |

**6 min prism 2-- immersed in water for 5 minutes then air dried**

| thetain | theta | mV | Normalized |
|---|---|---|---|
| 40 | 34.98304 | 76 | 0.550725 |
| 36 | 37.25063 | 77.8 | 0.563768 |
| 34 | 38.41445 | 79.2 | 0.573913 |
| 32 | 39.59639 | 84.8 | 0.614493 |
| 30 | 40.7951 | 88.8 | 0.643478 |
| 29 | 41.40034 | 96 | 0.695652 |
| 28 | 42.00928 | 112 | 0.811594 |
| 27 | 42.62178 | 138 | 1 |
| 26 | 43.23769 | 136 | 0.985507 |
| 25 | 43.85684 | 122 | 0.884058 |
| 24 | 44.4791 | 112 | 0.811594 |
| 22 | 45.73236 | 94 | 0.681159 |
| 21 | 46.36308 | 74 | 0.536232 |
| 20 | 46.99634 | 62 | 0.449275 |
| 19 | 47.63201 | 55 | 0.398551 |
| 18 | 48.26996 | 63 | 0.456522 |
| 16 | 49.55216 | 68 | 0.492754 |
| 15 | 50.19615 | 70 | 0.507246 |
| 12 | 52.13821 | 76 | 0.550725 |
| 10 | 53.44008 | 79.2 | 0.573913 |
| 6 | 56.05673 | 87.2 | 0.631884 |
| 4 | 57.36963 | 90.4 | 0.655072 |
| 0 | 60 | 95.2 | 0.689855 |