EE 587 Introduction to Photonics Project Report

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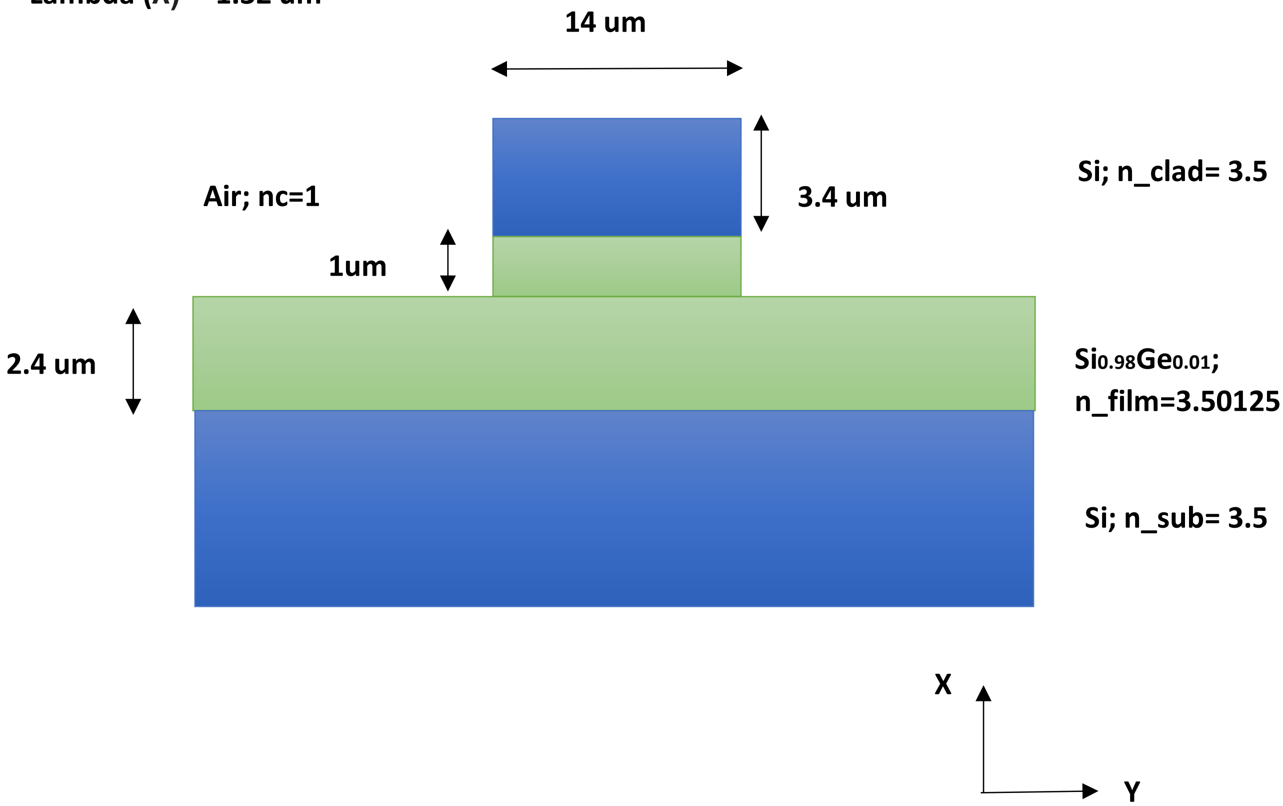
Construction of waveguide

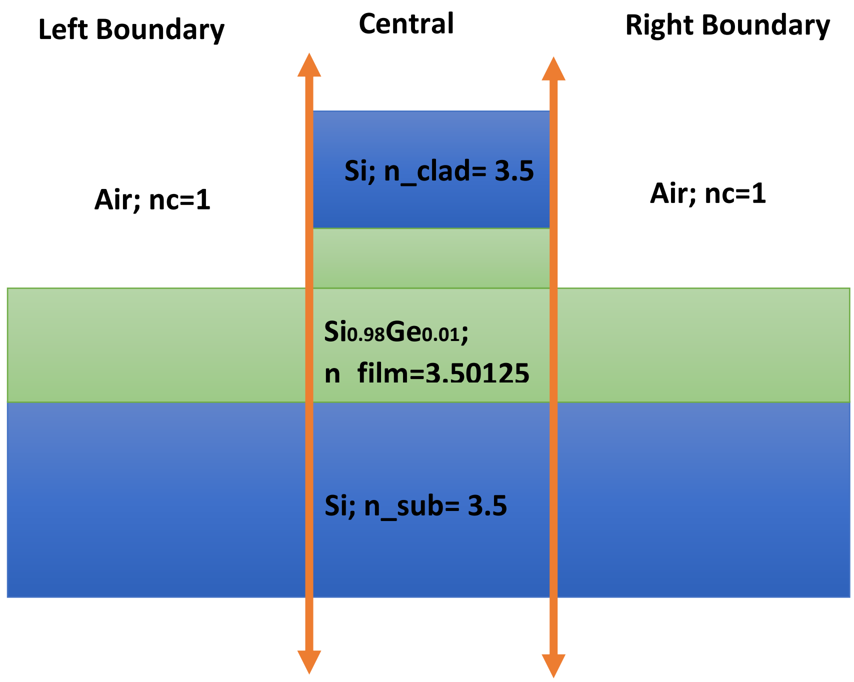
The first layer is of Air, second layer is Silicon cladding, Third layer is silicon germanium film in a ratio of 0.98:0.01 and last layer is of Silicon substrate. Their refractive index are mentioned alongside.

Lambda (λ) = 1.32 um



Division of waveguide

The waveguide is divided into three part for the determination of overall effective index.



We will calculate the effective index of each part separately

N-effective of Central Part

In the central part we have three layer namely Si cladding, $Si_{0.98}Ge_{0.01}$ film and Si substrate

$$ko = \frac{2\pi}{\lambda}$$

$$\gamma c = \sqrt{ko^2\left(n_{film}^2 - n_{clad}^2\right) - k^2}$$

$$\gamma s = \sqrt{ko^2\left(n_{film}^2 - n_{sub}^2\right) - k^2}$$

$$\gamma f = \sqrt{ko^2\left(n_{film}^2 - n_{sub}^2\right)}$$

Dispersion equation can be represented as

$$V\sqrt{1-b} = m \times \pi + \tan^{-1}(\sqrt{(}\frac{b}{1+b}) + \tan^{-1}(\sqrt{(}\frac{b+a}{1-b})$$

Where

$$b = \frac{Neff^2 - nsub^2}{nfilm^2 - nsub^2}$$

$$a = \frac{nclad^2 - nsub^2}{nfilm^2 - nsub^2}$$

Wx is thickness of waveguide film in x-axis.

The Matlab code is presented in the appendix for the calculation of Neff using dispersion equation

By using the following value, the Neff is calculated

$$n\_clad = 3.5;$$

$$n\_film = 3.50125$$

$$n\_sub = 3.5$$

$$Wx = 3.4$$

$$\lambda = 1.32\ um$$

We have the effective index in the central part as

$$Neff\_Center = 3.5008$$

Field confinement is also calculated as

$$\Gamma_x = 0.6749$$

N-effective of Boundary

Dispersion equation reduces to following expression in the boundary since b=0;

$$V = m \times \pi + \tan^{-1}(\sqrt{a})$$

In this case cladding is of air and therefore following values are used to calculated the Neff of boundary

$$n\_clad = 1;$$

$$n\_film = 3.50125$$

$$n\_sub = 3.5$$

$$Wx = 3.4$$

$$\lambda = 1.32\ um$$

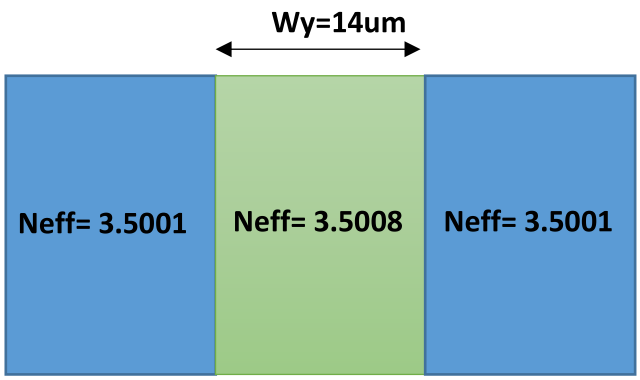
We have the effective index in the both boundary parts with the help of data from the graph as

$$Neff\_Boundary = 3.5001$$

The MATLAB code is presented in the appendix

N-effective of Overall Waveguide

Now that we have calculated the effective index of each part, we will calculate the effective index of overall waveguide. Below figure shows the effective index of waveguide.Wy is the thickness of SiGe film in Y-axis.



The Matlab code for the calculation of Neff of overall waveguide is present in the appendix. By using the following values we can calculate the Neff of overall waveguide

$$n\_clad = 3.5001;$$

$$n\_film = 3.5008$$

$$n\_sub = 3.5001$$

$$Wy = 12$$

$$\lambda = 1.32\ um$$

The effective index of the overall waveguide is

$$Neff\_Overall = 3.5005$$

Field confinement is also calculated as

$$\Gamma_y = 0.866$$

Total Field confinement in X and Y axis is given by

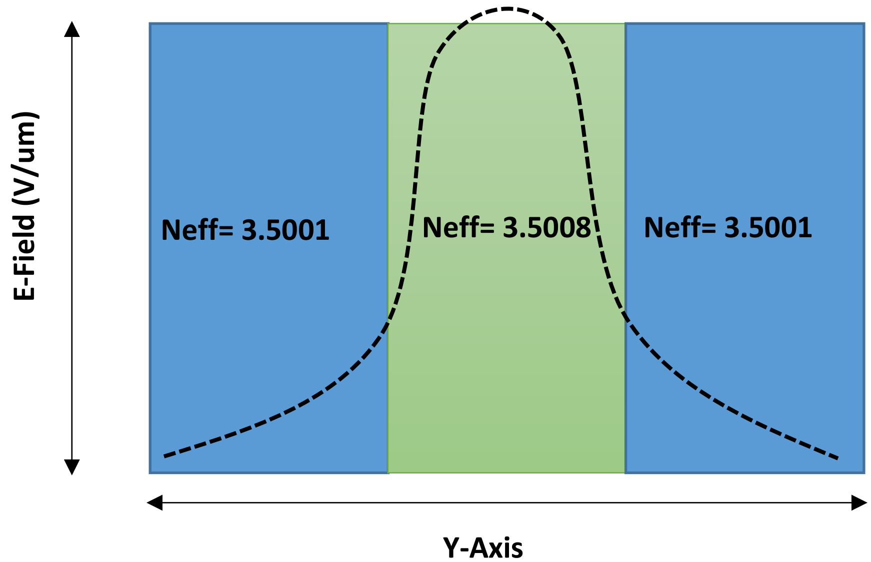
$$\Gamma_y \Gamma_y = 0.5849$$

E-field Distribution in X-Axis and Y-Axis

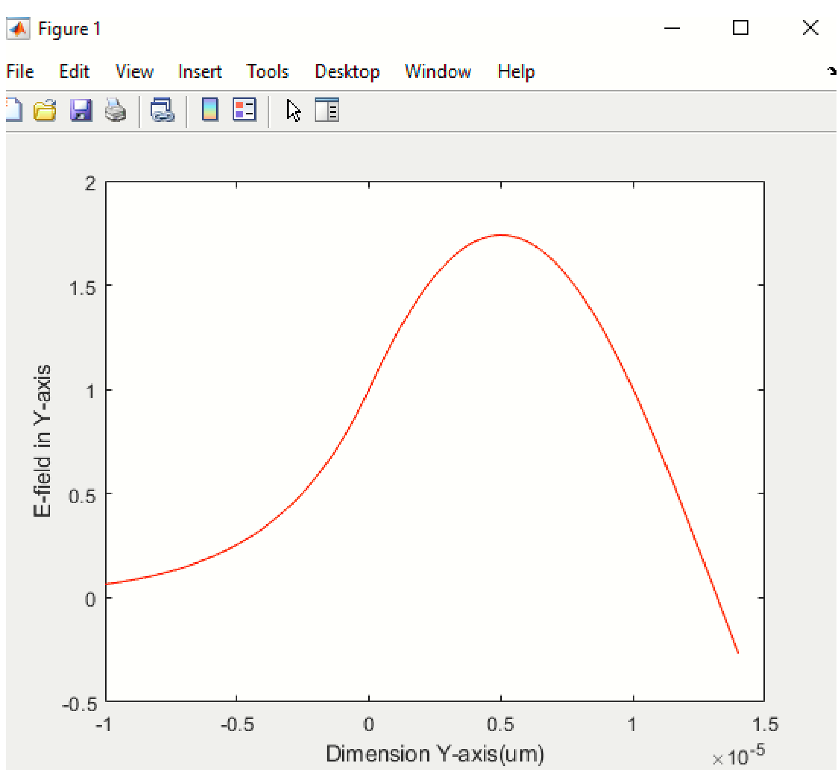
The E field distribution in the waveguide is plotted along X and Y Axis. The E field strength is strongest in the central region of the waveguide in both x-axis and y –axis indicating that the field is confined in the X-Y plane along the waveguide.

E-field in Y-Axis

The Matlab code for the plot of E-field in Y Axis is presented in the appendix.



The Matlab Plot is presented in the figure below



E-field in Y-Axis

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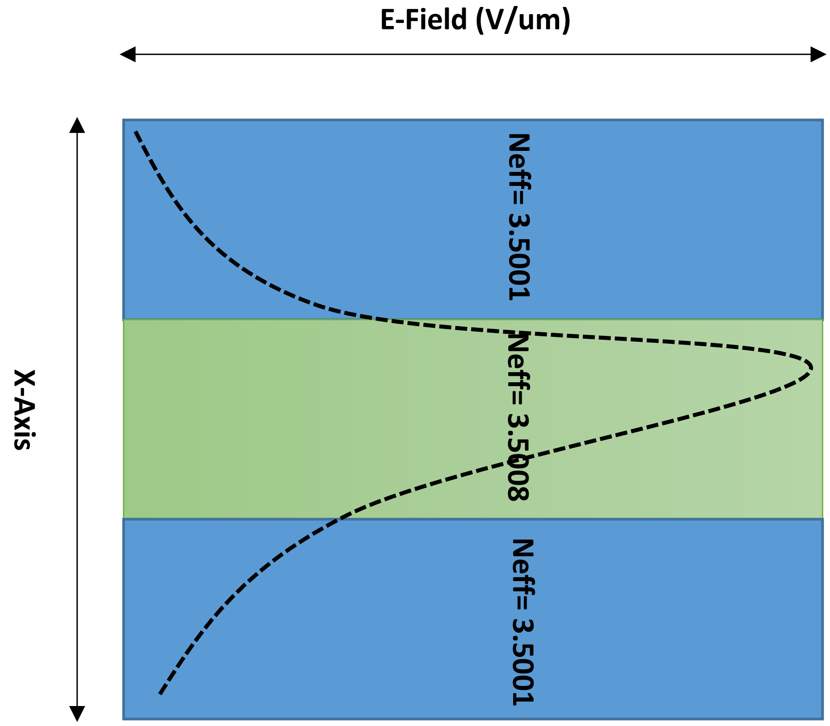

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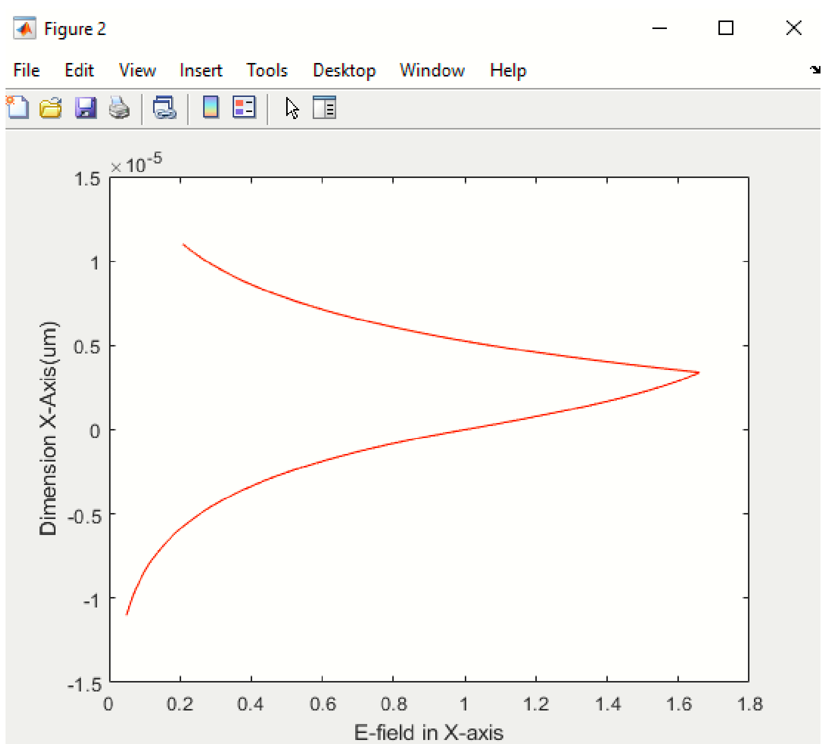

```
%% Neffective in central X-axis

m=0;
lambda=1.32e-6;
h1=3.4e-6;                %% Film dimension in central x-axis
k=(2.*pi)/lambda;
nc=1;
ns=3.50;
nf=3.50125;
%%% implementation of Dispersion equation
N=linspace(ns,nf,100000);
b=(N.^2-ns.^2)./(nf.^2-ns.^2);
LHS_c=sqrt(nf.^2-ns.^2).*k.*h1;
RHS_c=m.*pi+atan(sqrt(b./(1+b)))+ atan(sqrt((b)./(1-b)));

[c,ia,iy]=intersect(round(LHS_c,1),round((RHS_c),1));

%%% Neff in the central X-axis
Neff_c=N(iy);

%%% confinement in X-Axis
Tx= (LHS_c+ 2*(b(iy))^1/2)/(LHS_c+ 2*(b(iy))^-1/2);

%% Neffective in boundary X-axis
nc=1;
ns=3.50;
nf=3.50125;
V=sqrt(nf.^2-ns.^2).*k.*h1;
a=(ns.^2-nc.^2)./(nf.^2-ns.^2);
%%% from graph of V vs b, the value of V=1.51 and a=10.5 line ; the value of
b=0.05
b_s=0.05;


%%% Neff in the boundary X-axis
Neff_b= sqrt(ns^2+b_s *(nf^2-ns^2));
```

Appendix

Neff Calculation

```
%% Neffective in Y axis
m=1;
lambda=1.32e-6;
h2=14e-6;                    %% Film dimension in central y-axis
k=(2.*pi)/lambda;
nc=Neff_b;
ns=Neff_b;
nf=Neff_c;

%%% implementation of Dispersion equation

N_y=linspace(ns,nf,10000);
b=(N_y.^2-ns.^2)./(nf.^2-ns.^2);
LHS_y=sqrt(nf.^2-ns.^2).*k.*h2;
RHS_y=m.*pi+atan(sqrt(b./(1+b)))+ atan(sqrt((b)./(1-b)));

[c,ia,iy]=intersect(round(LHS_y,2),round((RHS_y),2));

%%% Neff in the central y-axis
Neff_y=N_y(iy);

%%% confinement in Y-Axis
Ty= (LHS_y+ 2*(b(iy))^1/2)/(LHS_y+ 2*(b(iy))^-1/2);

%% confinement factor

TxTy=Tx*Ty;
```

E-field in X-Axis

```
%% E-field in Y-axis

Wf=14e-6;               %% dimension of Si Film in x axis
lambda=1.32e-6;
k=2*pi/lambda;
n_clad=Neff_b;
n_sub=Neff_b;
n_film=Neff_c;            %% refractive index of substrate
B=k*Neff_y;
G_film=sqrt((k*n_film)^2-B^2);
G_clad=sqrt(-(k*n_clad)^2+B^2);
G_sub=sqrt(-(k*n_sub)^2+B^2);

C1=cos(G_film*Wf);
C2=sin(G_film*Wf);
A=1;
D=1;
B=G_sub/G_film;
Cc=B*C2+C1;
```

```
x1=0:0.01e-6:Wf;
Efilm=A*cos(G_film*x1)+B*sin(G_film*x1);

x2=-10e-6:0.01e-6:0;
Esub=D*exp(G_sub*x2);

x3=Wf:0.01e-6:10e-6;
Eclad=Cc*exp(-G_clad*(x3-Wf));

figure(1)
plot(x1,(Efilm),'r')
hold on
plot(x2,(Esub),'r')
hold on
plot(x3,Eclad,'r')
xlabel('Dimension Y-axis(um)');
ylabel('E-field in Y-axis');
```

E-field in Y-Axis

```
%% E-field in X-axis
lambda=1.32e-6;
ko=2*pi/lambda;
Wfy=3.4e-6;
n_clad=Neff_b;
n_sub=Neff_b;
n_film=Neff_c;
B=k*Neff_y;
G_film=sqrt((ko*n_film)^2-B^2);
G_clad=sqrt(-(ko*n_clad)^2+B^2);
G_sub=sqrt(-(ko*n_sub)^2+B^2);
%
C1=cos(G_film*Wfy);
C2=sin(G_film*Wfy);
A=1;
D=1;
B=G_sub/G_film;
Cc=B*C2+C1;
y1=0:0.01e-6:Wfy;
Efilmy=A*cos(G_film*y1)+B*sin(G_film*y1);

y2=-11e-6:0.01e-6:0;
Esuby=D*exp(G_sub*y2);

y3=Wfy:0.01e-6:11e-6;
Eclady=Cc*exp(G_clad*(Wfy-y3));

figure(2)
plot((Efilmy),y1,'r')
hold on
plot((Esuby),y2,'r')
hold on
plot(Eclady,y3,'r')
ylabel('Dimension X-Axis(um)');
xlabel('E-field in X-axis');
```