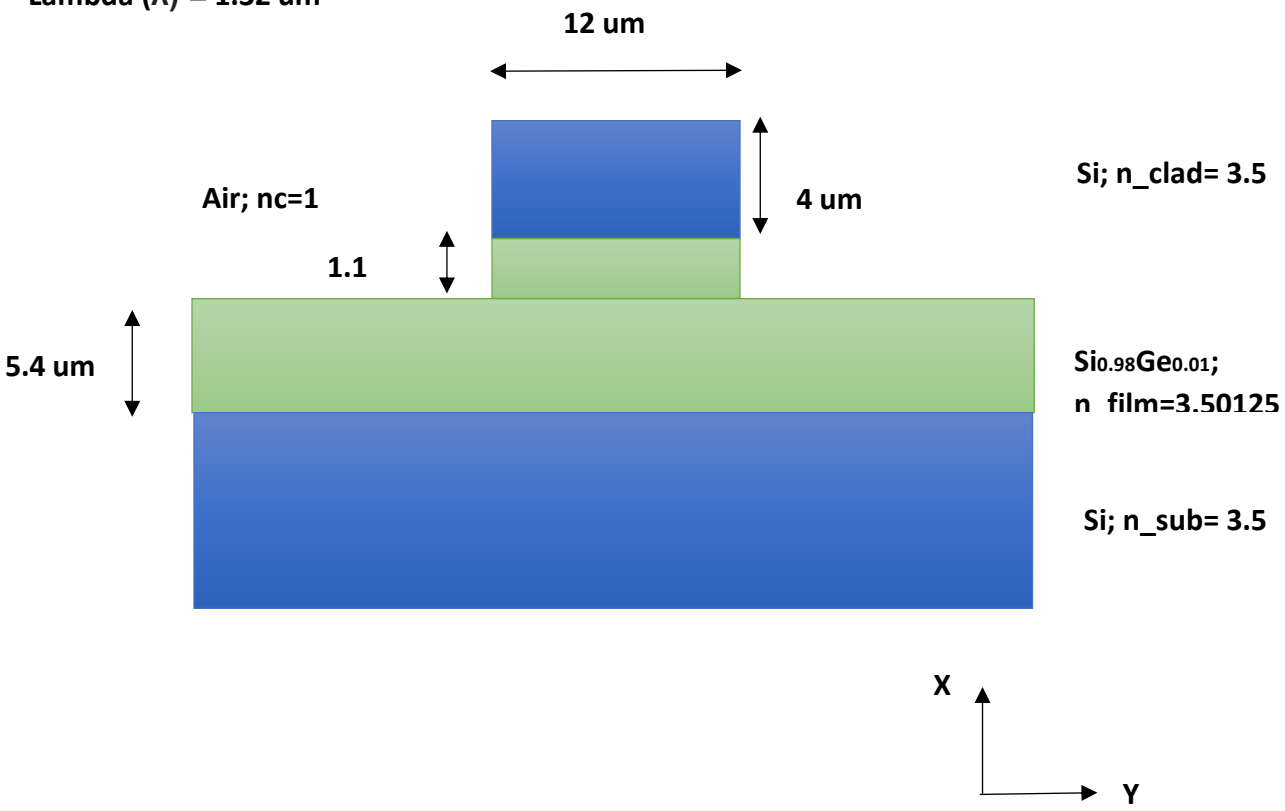
Project Report

Construction of waveguide

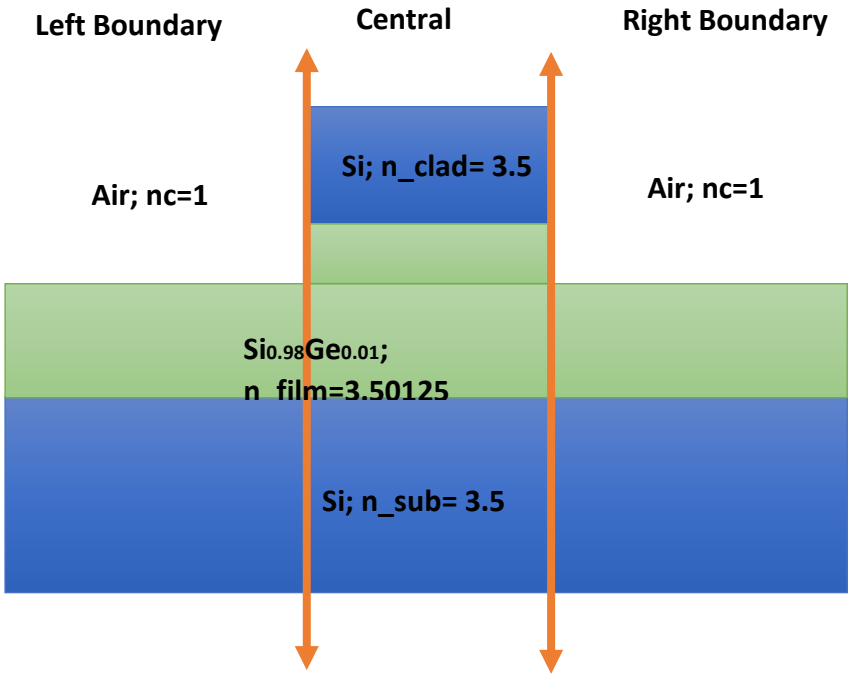
The first layer is of Air, second layer is Silicon cladding, Third layer is silicon germanium film in a ratio of 0.98:0.01 and last layer is of Silicon substrate. Their refractive index are mentioned alongside.

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

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

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

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

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

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

$$Neff = \frac{B}{ko}$$

The value of k has to be analytically calculated through the following expression

$$\tan(Wx * \gamma f) = \frac{\gamma c + \gamma s}{\gamma f * (1 - \gamma c \frac{\gamma s}{\gamma f^2})}$$

Wx is thickness of waveguide film in x-axis.

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

By using the following value, the Neff is calculated

$$n\_clad = 3.5;$$

$$n\_film = 3.50125$$

$$n\_sub = 3.5$$

$$Wx = 6.5$$

$$\boldsymbol{\lambda} = 1.32\ um$$

We have the effective index in the central part as

$$Neff\_Center = 3.5008$$

N-effective of Boundary

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

$$n\_clad = 1;$$

$$n\_film = 3.50125$$

$$n\_sub = 3.5$$

$$Wx = 5.4$$

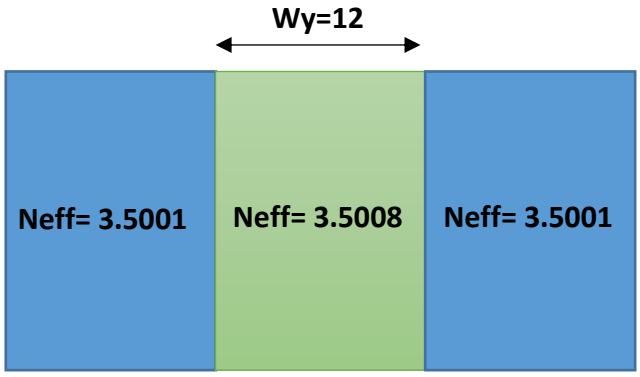
$$\lambda = 1.32\ um$$

We have the effective index in the both boundary parts as

$$Neff\_Boundary = 3.5001$$

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

$$n\_clad = 3.5001;$$

$$n\_film = 3.5008$$

$$n\_sub = 3.5001$$

$$Wy = 12$$

$$\boldsymbol{\lambda} = 1.32\ um$$

The effective index of the overall waveguide is

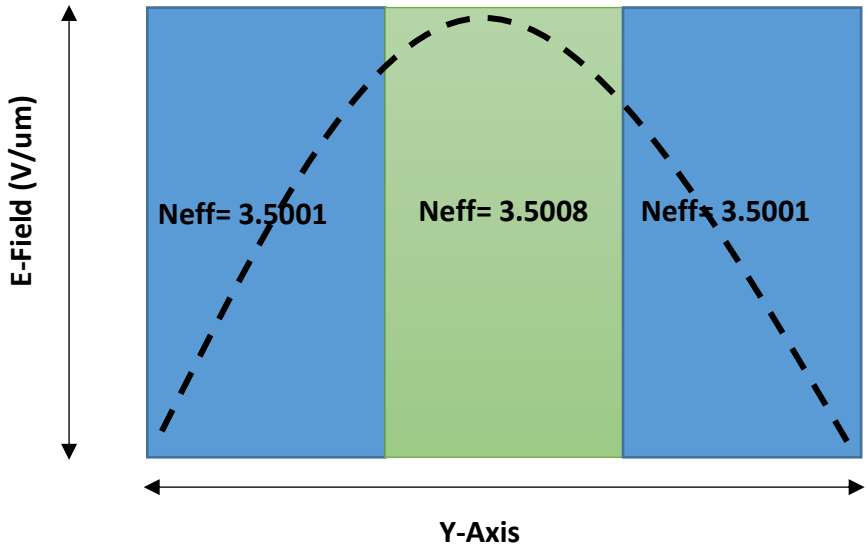
$$Neff\_Overall = 3.5006$$

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

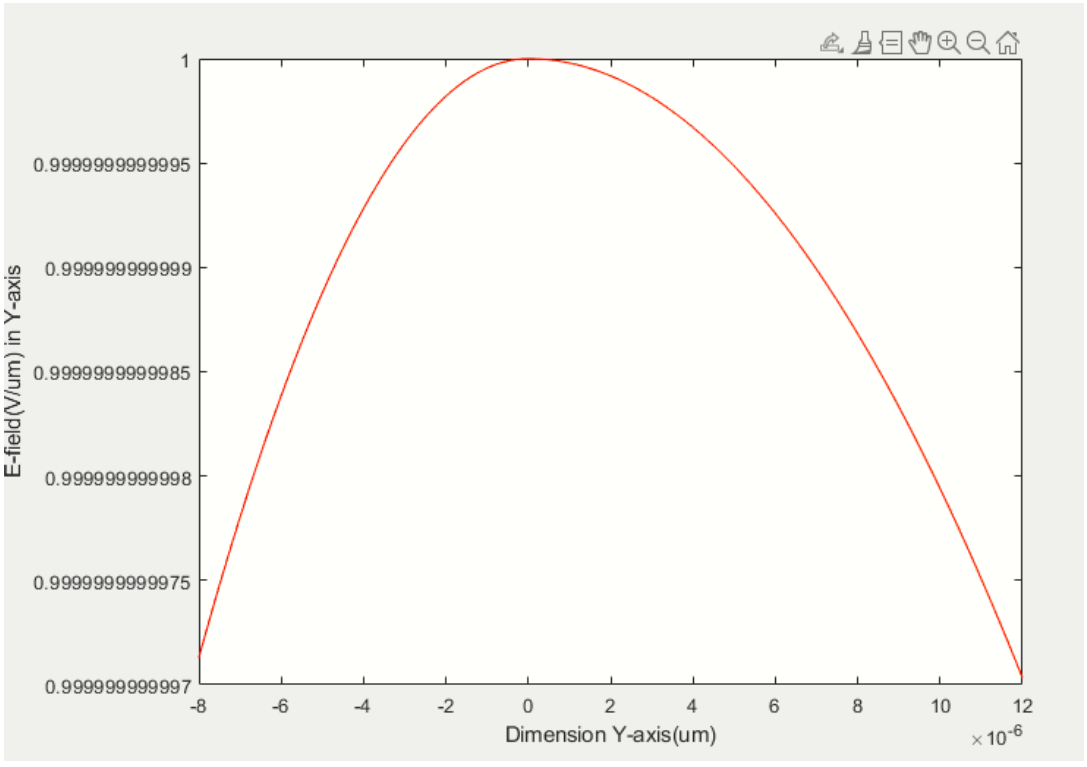
The E field distribution in the waveguide is plotted along X and Y Axis. The E field strength is strongest in the central region of the waveguide in both x-axis and y –axis indicating that the field is confined in the X-Y plane along the waveguide.

E-field in Y-Axis

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

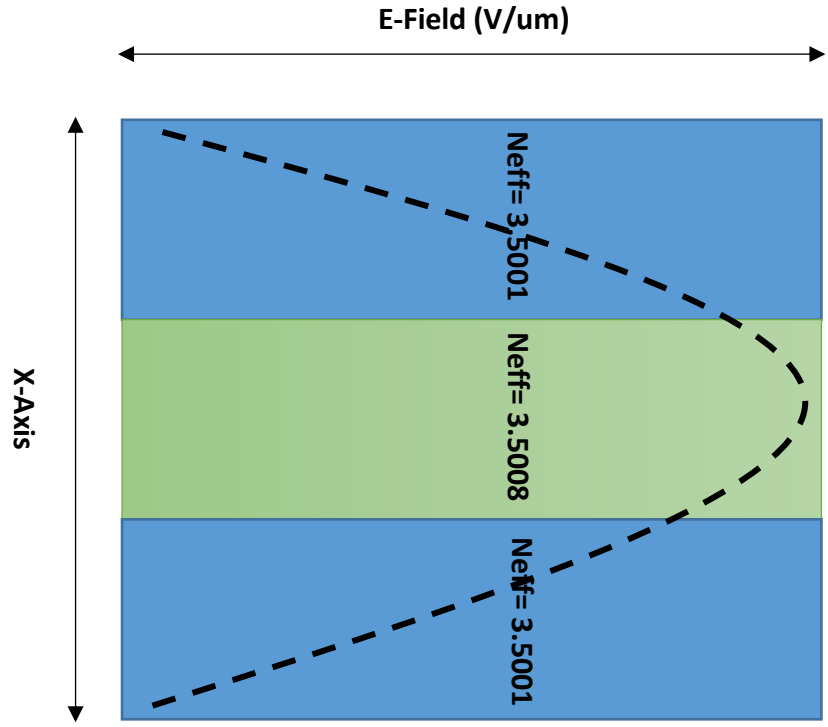


The Matlab Plot is presented in the figure below

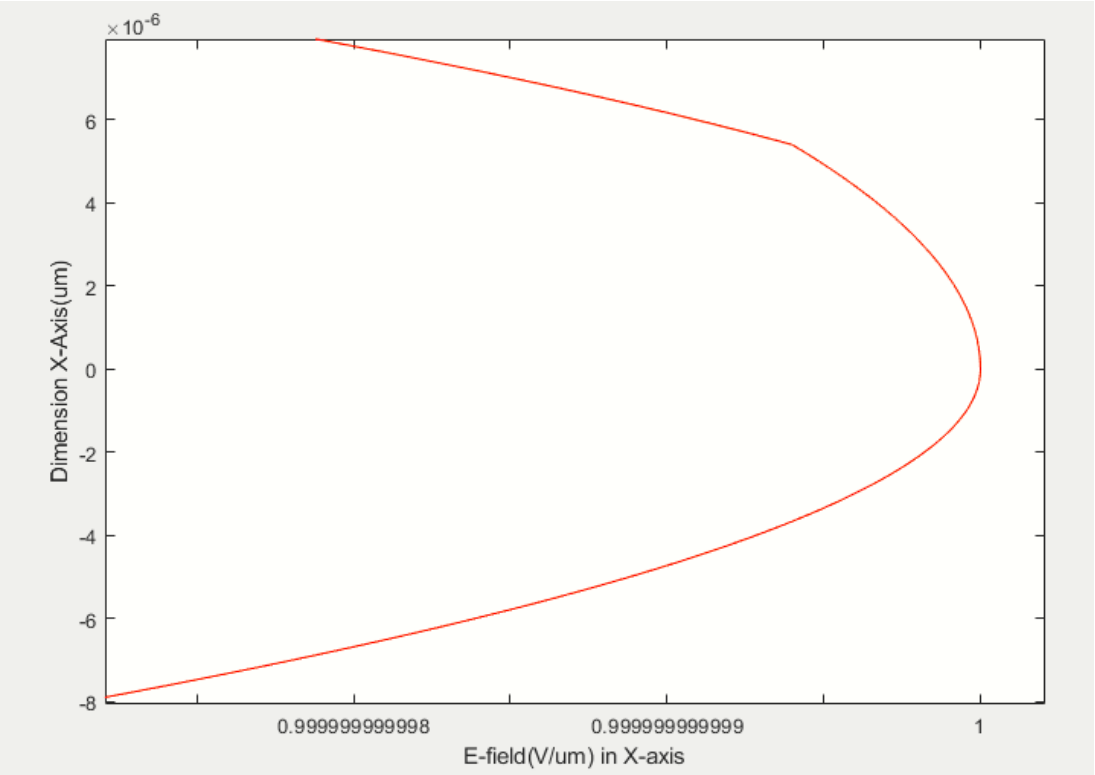


E-field in Y-Axis

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



Appendix

Neff Calculation

```
function [gc]=G_clad(ko,k,nc,nf)
gc= sqrt((ko^2)*(nf^2-nc^2)-k^2);
end


function [gc]=G_sub(ko,k,nc,nf)
gc= sqrt((ko^2)*(nf^2-nc^2)-k^2);
end


function [neff ko]=Neff(nfilm,nclad,nsub,wf,lambda)
ko=2*pi/lambda;
G_fm= sqrt((ko^2)*(nfilm^2-nsub^2));
G_f=linspace(0,G_fm,100)
LHS=tan(wf.*G_f);
for i=1:length(G_f)
    Gc(i)=G_clad(ko,G_f(i),nclad,nfilm);
    Gs(i)=G_sub(ko,G_f(i),nsub,nfilm);
    RHS(i)=(Gc(i)+Gs(i))/(G_f(i)*(1-(Gc(i)*Gs(i)/G_f(i)^2)));
    B(i)=sqrt(((nfilm*ko)^2)-G_f(i)^2);

end
[c,ia,ib]=intersect(round(LHS,3),round(RHS,3));
 B=B(ib);
 neff=B/ko;
 neff=mean(neff);
end


function [neff]=Neff_lateral(nfilm,nclad,nsub,wf,lambda)
ko=2*pi/lambda;
G_fm= sqrt((ko^2)*(nfilm^2-nsub^2));
G_f=linspace(0,G_fm,100)
for i=1:length(G_f)
    Gc(i)=G_clad(ko,G_f(i),nclad,nfilm);
    Gs(i)=G_sub(ko,G_f(i),nsub,nfilm);
    B(i)=sqrt(((nfilm*ko)^2)-G_f(i)^2);
    neff(i)= (B(i))/ko;
end
 neff=mean(neff);
end
```

```
%% Effective Index calculation

n_film=3.50125;              %% refractive index of SiGe
n_clad=3.5;               %% refractive index of Si cladding
n_clad_boundary=1;          %% refractive index of Air
n_sub=3.5;                %% refractive index of Si substrate
Wfc=6.5;                     %% central dimension of SiGe film in x axis
Wfb=5.4;                   %%  dimension of SiGe film at the bounadry
Wx=12;                       %%  dimension of SiGe film in y axis
Lambda=1.32;

[Neff_center,ko]=Neff(n_film,n_clad,n_sub,Wfc,Lambda);
Neff_boundary=Neff(n_film,n_clad_boundary,n_sub,Wfb,Lambda);
Neff_overall=Neff_lateral(Neff_center,Neff_boundary,Neff_boundary,Wx,Lambda);
```

E-field in X-Axis

```
[Neff_center,ko]=Neff(3.50125,3.5,3.5,6.5,1.32);
Neff_boundary=Neff(3.50125,1,3.5,5.4,1.32);
Neff_overall=Neff_lateral(3.5008,3.5001,3.5001,12,1.32);

Wfy=5.4e-6;
n_film=Neff_center;
B=ko*Neff_lat;
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=-8e-6:0.01e-6:0;
Esuby=D*exp(G_sub*y2);

y3=Wfy:0.01e-6:8e-6;
Eclady=Cc*exp(G_clad*(y3-Wfy));

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(V/um)  in X-axis');
```

E-field in Y-Axis

```
[Neff_center,ko]=Neff(3.50125,3.5,3.5,6.5,1.32);
```

```
Neff_boundary=Neff(3.50125,1,3.5,5.4,1.32);
Neff_overall=Neff_lateral(3.5008,3.5001,3.5001,12,1.32);

Wf=12e-6;               %% dimension of Si Film in x axis
n_film=Neff_center;     %% effective index of film
B=ko*Neff_lat;
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*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=-8e-6:0.01e-6:0;
Esub=D*exp(G_sub*x2);

x3=Wf:0.01e-6:8e-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(V/um) in Y-axis');
```