Assignment

Two Stage Tandem Solar Cell

Objective

- Choose two different energy bandgaps of a ternary semiconductor system for application in a two stage tandem solar cell.

- Minimize spectral losses.

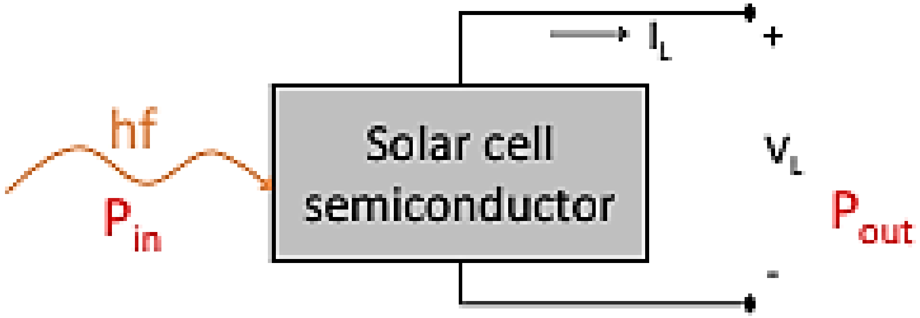
- Justify through necessary calculations and analysis.

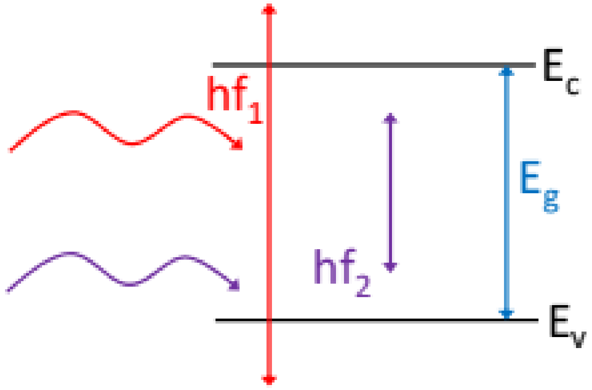
Outcomes

The assignment will address the following course outcomes (CO):

- **CO3: Compare different materials and select the most appropriate one for specific electrical engineering application**
- **CO4: Demonstrate the capacity to extend learning beyond classroom lectures and activities**
- **CO5: Describe environmental issues in processing and recycling of electronic materials**

Theory





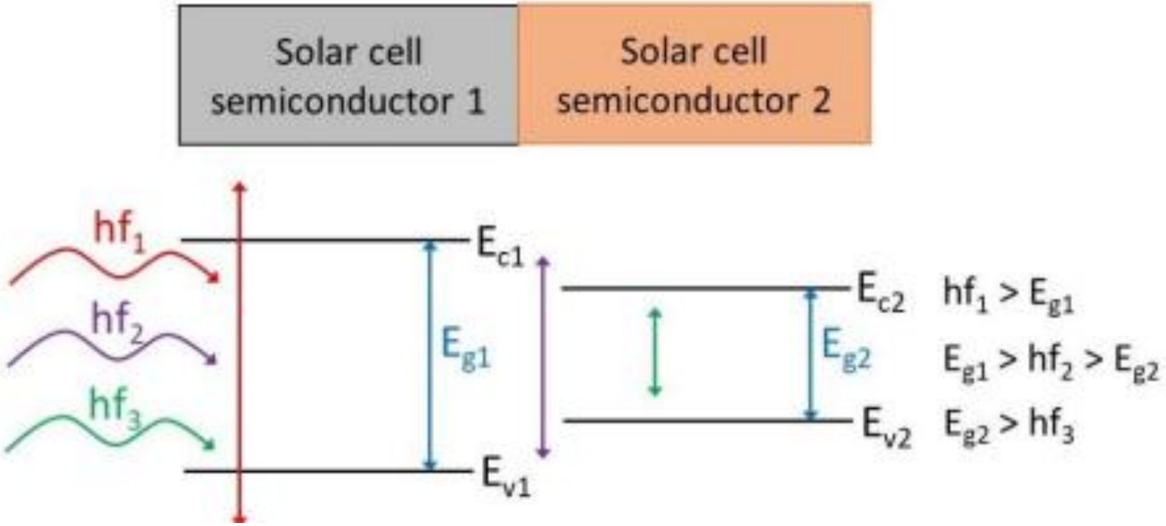
hf1 > Eg

Hf2 < Eg

Spectral losses:
i) hf1 – Eg

ii) hf2

Two Stage Tandem Solar Cell



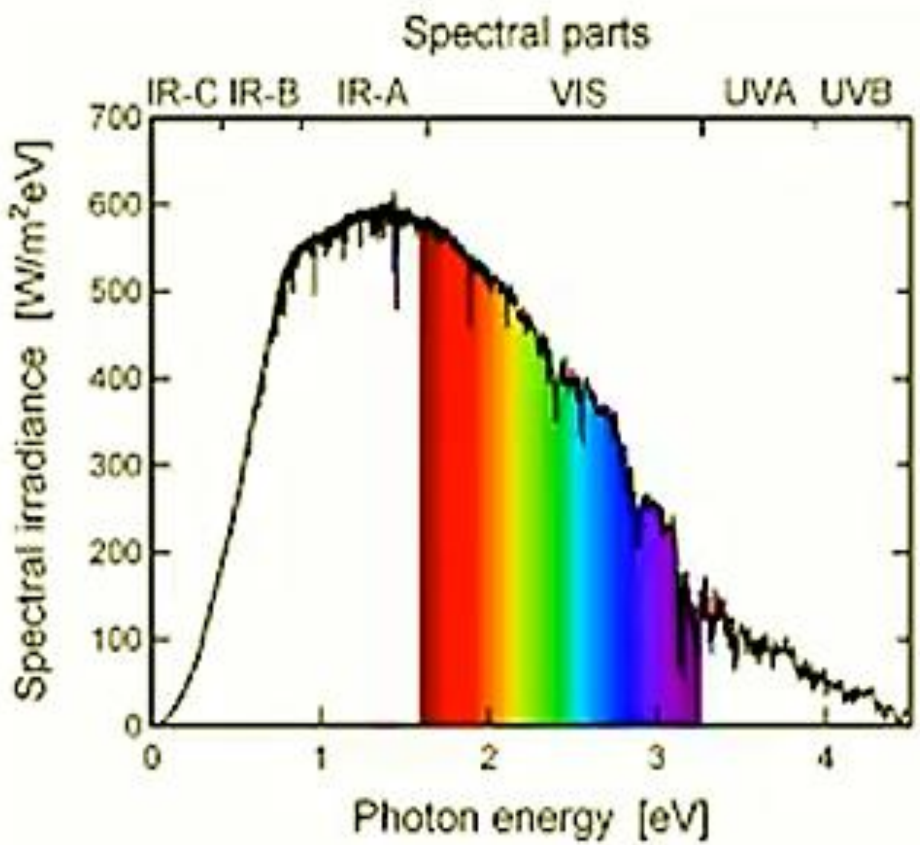
Spectral losses:

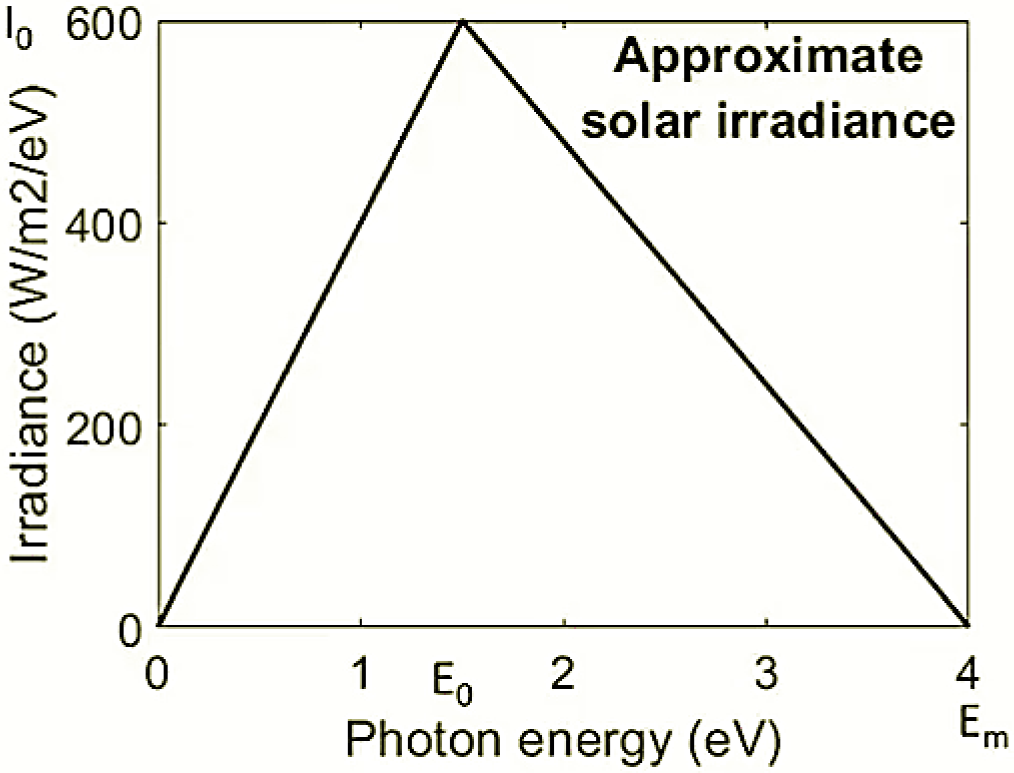
i) hf1 – Eg1

ii) hf2 – Eg2

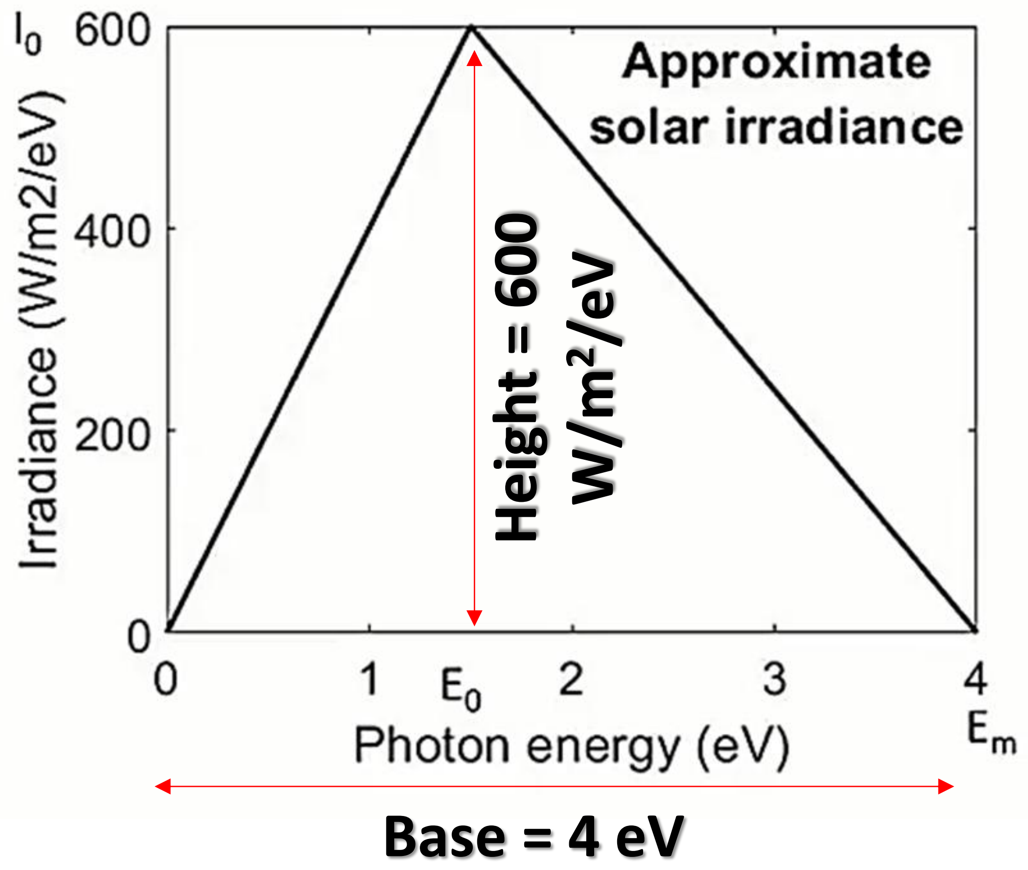
iii) hf3

Solar Irradiance Vs Photon Energy





Input Power Calculation



Input Power ,

P_{in} = Area of the Triangle (Representing Irradiance Vs Photon Energy)

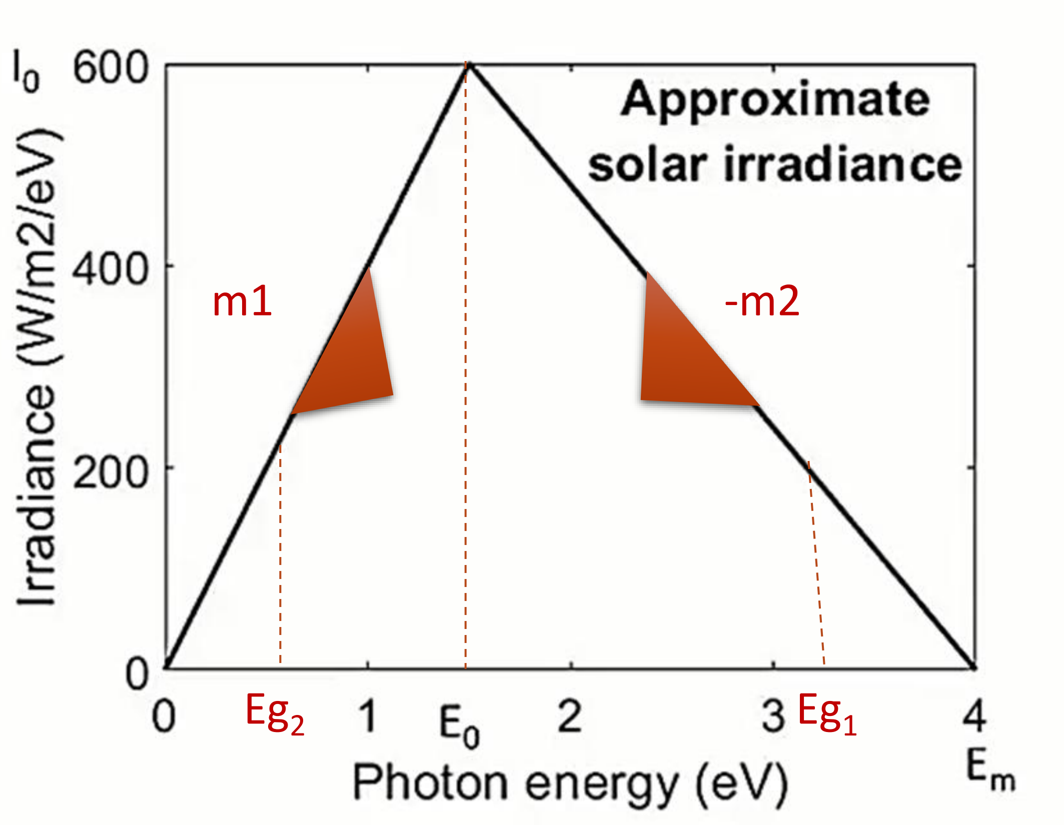
$$P_{in} = \frac{1}{2} \times Base \times Height$$

$$= \frac{1}{2} \times 4eV \times 600\mathrm{W/m^2/eV}$$

= 1200 W/m2

Output Power Equation

Case 1: $Eg_2 < E_0 < Eg_1$



$$\mathbf{I(absorbed)} = \begin{cases} \mathbf{I(\frac{Eg1}{E}); Eg1 < Em} \\ \mathbf{I(\frac{Eg2}{E}); Eg2 < E0 < Eg1} \end{cases}$$

$$I = \begin{cases} m1 \times E\,; 0 < E < E0 \\ I0 - m2(E - E0); E0 < E < Em \end{cases}$$

$$\mathbf{m1 = I0/E0}$$

$$\mathbf{m2 = I0/(Em\text{-}E0)}$$

Case 1

$$\mathrm{Pout} = \int_{\mathrm{Eg2}}^{\mathrm{Em}} \mathrm{I(absorbed)}\,\mathrm{dE} = \int_{\mathrm{Eg2}}^{\mathrm{E0}} \mathrm{I(absorbed)}\,\mathrm{dE} + \int_{\mathrm{E0}}^{\mathrm{Eg1}} \mathrm{I(absorbed)}\,\mathrm{dE} + \int_{\mathrm{Eg1}}^{\mathrm{Em}} \mathrm{I(absorbed)}\,\mathrm{dE}$$

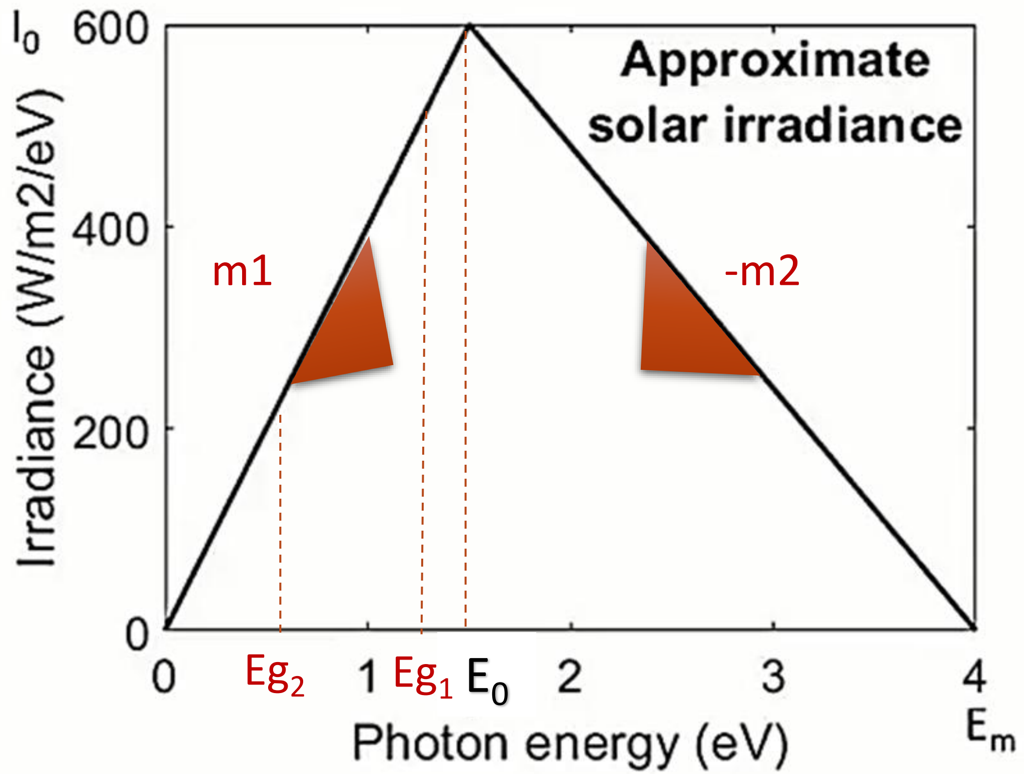
$$= \int_{\mathrm{Eg2}}^{\mathrm{E0}} \mathrm{m1E}\left(\frac{\mathrm{Eg2}}{\mathrm{E}}\right)\mathrm{dE} + \int_{\mathrm{E0}}^{\mathrm{Eg1}} \{\mathrm{I0} - \mathrm{m2}(\mathrm{E} - \mathrm{E0})\}\left(\frac{\mathrm{Eg2}}{\mathrm{E}}\right)\mathrm{dE} + \int_{\mathrm{Eg1}}^{\mathrm{Em}} \{\mathrm{I0} - \mathrm{m2}(\mathrm{E} - \mathrm{E0})\}\left(\frac{\mathrm{Eg1}}{\mathrm{E}}\right)\mathrm{dE}$$

$$= \mathrm{m1.Eg2(E0-Eg2) + I0.Eg2.ln(Eg1/E0) - m2.Eg2(Eg1-E0) + m2.E0.Eg2.ln(Eg1/E0)}$$
$$\mathrm{+ I0.Eg1.ln(Em/Eg1) - m2.Eg1(Em-Eg1) + m2.E0.Eg1.ln(Em/Eg1)}$$

$$= \mathrm{m1.Eg2(E0-Eg2) - m2.Eg2(Eg1-E0) + \{I0+(m2.E0)\}Eg2.ln(Eg1/E0)}$$
$$\mathrm{- m2.Eg1(Em-Eg1) + \{I0+(m2.E0)\}Eg1.ln(Em/Eg1)}$$

Output Power Equation

Case 2: $Eg_2 < Eg_1 < E_0$



$$\mathbf{I(absorbed)} = \begin{cases} I\left(\frac{Eg1}{E}\right); Eg1 < Em \\ I\left(\frac{Eg2}{E}\right); Eg2 < Eg1 \end{cases}$$

$$\mathbf{I} = \begin{cases} \mathbf{m1 \times E\,; 0 < E < E0} \\ \mathbf{I0 - m2(E - E0); E0 < E < Em} \end{cases}$$

$$\mathbf{m1 = I0/E0}$$

$$\mathbf{m2 = I0/(Em\text{-}E0)}$$

Case 2

$$\mathrm{Pout} = \int_{Eg2}^{Em} \mathrm{I(absorbed)}\,dE = \int_{Eg2}^{Eg1} \mathrm{I(absorbed)}\,dE + \int_{Eg1}^{E0} \mathrm{I(absorbed)}\,dE + \int_{E0}^{Em} \mathrm{I(absorbed)}\,dE$$

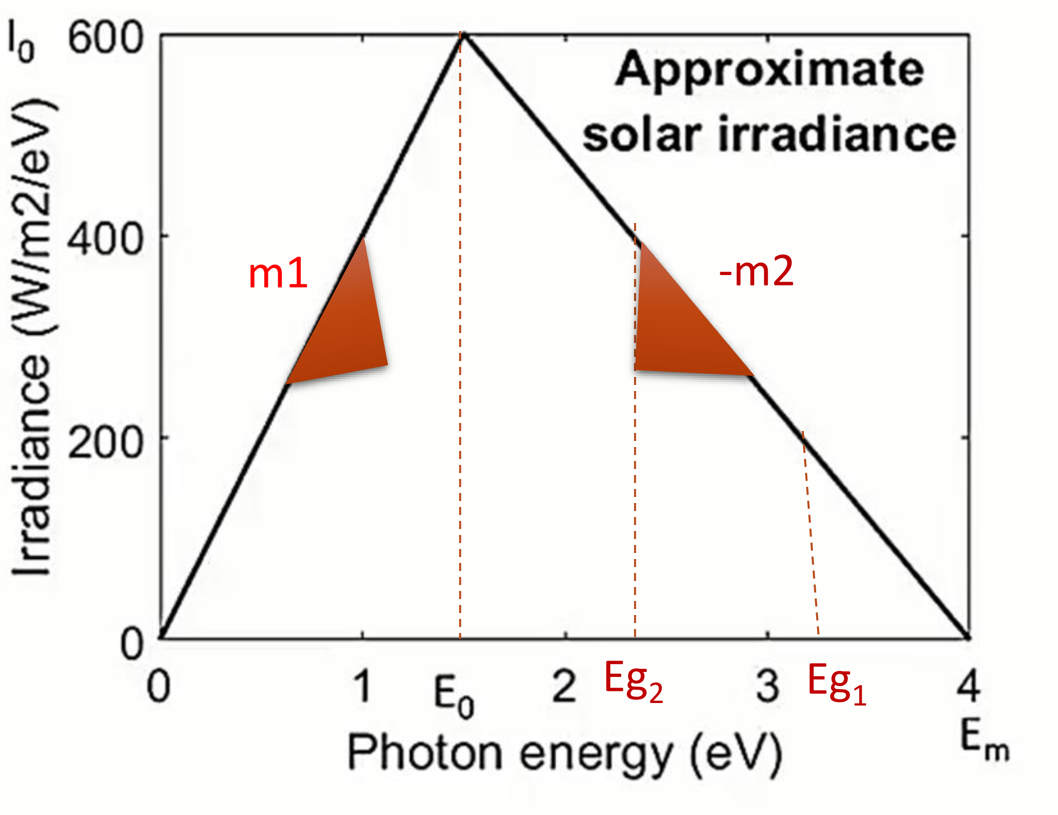
$$= \int_{Eg2}^{Eg1} m1E\left(\frac{Eg2}{E}\right) dE + \int_{Eg1}^{E0} m1E\left(\frac{Eg1}{E}\right) dE + \int_{E0}^{Em} \{I0 - m2(E - E0)\}\left(\frac{Eg1}{E}\right) dE$$

$$= m1.Eg2(Eg1\text{-}Eg2) + m1.Eg1(E0\text{-}Eg1) + I0.Eg1.\ln(Em/E0) - m2.Eg1(Em\text{-}E0) + m2.E0.Eg1.\ln(Em/E0)$$

$$= m1.Eg2(Eg1\text{-}Eg2) + m1.Eg1(E0\text{-}Eg1) - m2.Eg1(Em\text{-}E0) + \{I0+(m2.E0)\}Eg1.\ln(Em/E0)$$

Output Power Equation

Case 3: $E_0 < Eg_2 < Eg_1$



$$\mathbf{I(absorbed)} = \begin{cases} I\left(\frac{Eg1}{E}\right); Eg1 < Em \\ I\left(\frac{Eg2}{E}\right); Eg2 < E0 < Eg1 \end{cases}$$

$$\mathbf{I} = \begin{cases} m1 \times E\ ; 0 < E < E0 \\ I0 - m2(E - E0); E0 < E < Em \end{cases}$$

$$m1 = I0/E0$$

$$m2 = I0/(Em\text{-}E0)$$

Case 3

$$\mathrm{Pout} = \int_{Eg2}^{Em} I(\mathrm{absorbed})\,dE = \int_{Eg2}^{Eg1} I(\mathrm{absorbed})\,dE + \int_{Eg1}^{Em} I(\mathrm{absorbed})\,dE$$

$$= \int_{Eg2}^{Eg1} \{I0 - m2(E - E0)\}\left(\frac{Eg2}{E}\right) dE + \int_{Eg1}^{Em} \{I0 - m2(E - E0)\}\left(\frac{Eg1}{E}\right) dE$$

$$= I0.Eg2.\ln(Eg1/Eg2) - m2.Eg2(Eg1-Eg2) + m2.E0.Eg2.\ln(Eg1/Eg2)$$
$$+ I0.Eg1.\ln(Em/Eg1) - m2.Eg1(Em-Eg1) + m2.E0.Eg1.\ln(Em/Eg1)$$

$$= \{I0+(m2.E0)\}Eg2.\ln(Eg1/Eg2) - m2.Eg2(Eg1-Eg2) - m2.Eg1(Em-Eg1)$$
$$+ \{I0+(m2.E0)\}Eg1.\ln(Em/Eg1)$$

$GaAs_{1-x}Sb_x$

Gallium Arsenide Antimonide

Equation for Bandgap,

$Eg = 1.42-1.9x+1.2x^2$; $[0<x<0.3]$

@ $x=0$, $Eg = (1.42-1.9*0+1.2*0^2) = 1.42$ eV

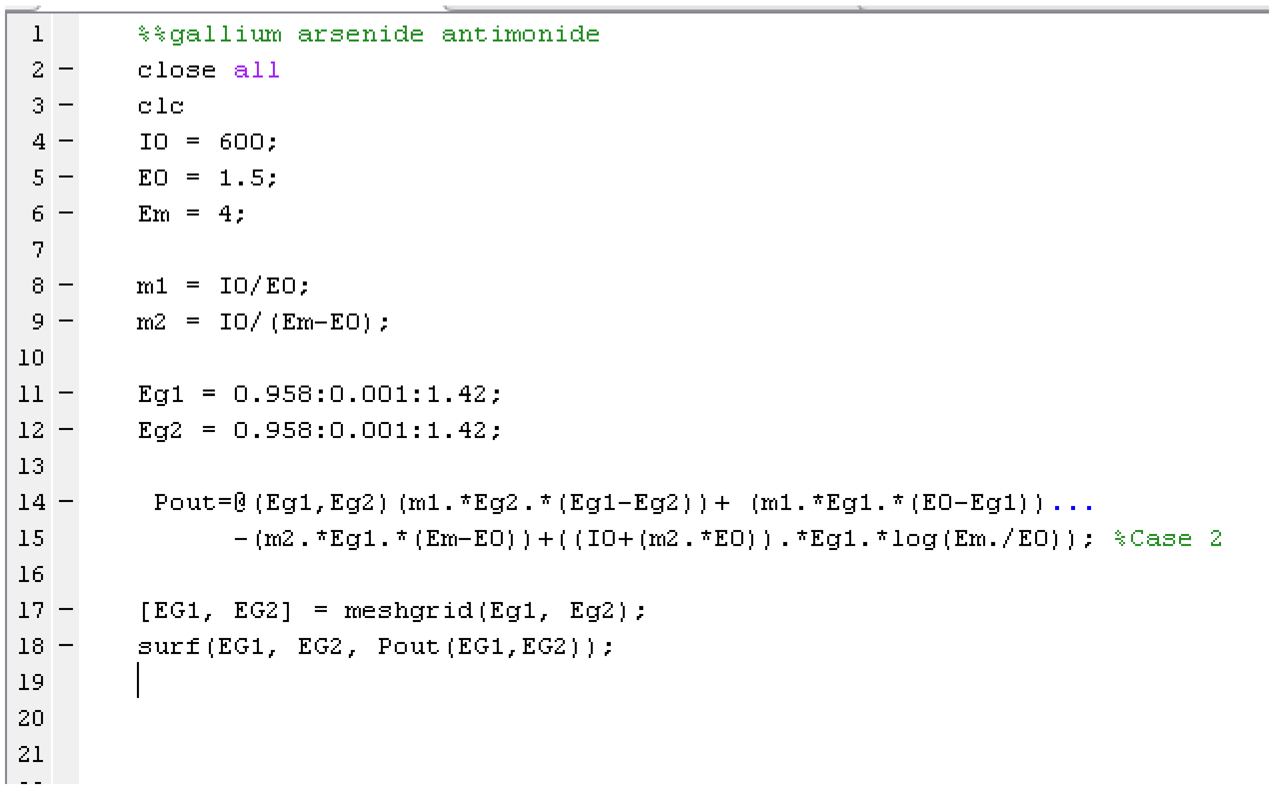
@ $x=0.3$, $Eg = (1.42-1.9*0.3+1.2*0.3^2) = 0.958$ eV

So, the bandgap for $GaAs_{1-x}Sb_x$ can be stated as,

$0.958<Eg<1.42$

GaAs$_{1-x}$Sb$_x$

Gallium Arsenide Antimonide



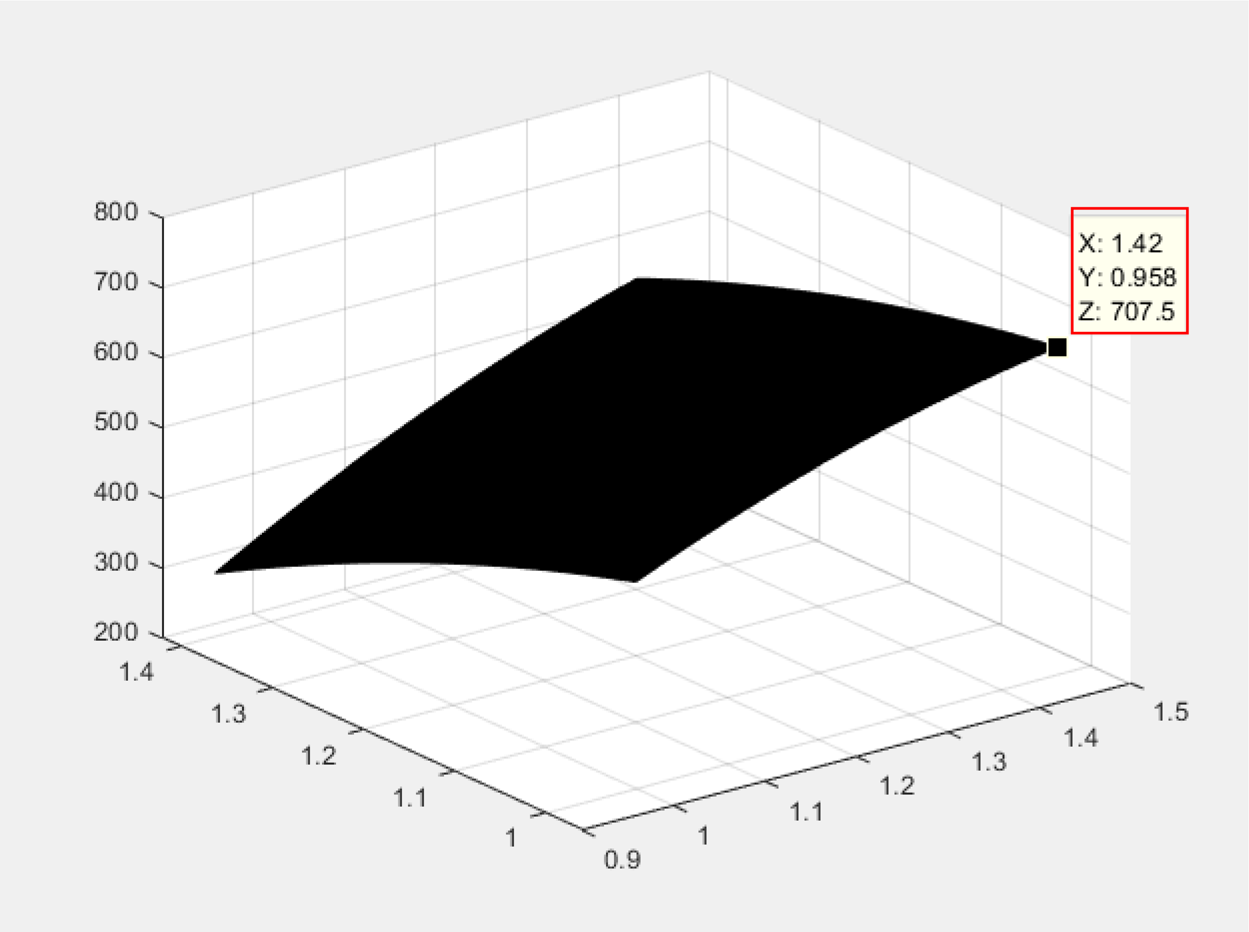
```matlab
%%gallium arsenide antimonide
close all
clc
IO = 600;
EO = 1.5;
Em = 4;

m1 = IO/EO;
m2 = IO/(Em-EO);

Eg1 = 0.958:0.001:1.42;
Eg2 = 0.958:0.001:1.42;

 Pout=@(Eg1,Eg2)(m1.*Eg2.*(Eg1-Eg2))+ (m1.*Eg1.*(EO-Eg1))...
      -(m2.*Eg1.*(Em-EO))+((IO+(m2.*EO)).*Eg1.*log(Em./EO)); %Case 2

[EG1, EG2] = meshgrid(Eg1, Eg2);
surf(EG1, EG2, Pout(EG1,EG2));
```

As the range of the bandgap is lower than E0, So we have used the Case 2 equation to calculate output power Pout.

In MATLAB we have used meshgrid and surf to plot a 3 dimensional figure.

$GaAs_{1-x}Sb_x$

Gallium Arsenide Antimonide



Here,

X axis represents Eg1,

Y axis represents Eg2,

Z axis represents Pout

Maximum Value of Pout = 707.5 W/m^2 for

corresponding Eg1 = 1.42eV and Eg2 = 0.958eV

$GaAs_{1-x}Sb_x$

Gallium Arsenide Antimonide

Maximum Value of Pout = 707.5 W/m^2
for
corresponding Eg1 = 1.42eV and Eg2 = 0.958eV

$Eg = 1.42 - 1.9x + 1.2x^2$; [0<x<0.3]

@ x=0, $Eg = (1.42 - 1.9*0 + 1.2*0^2) = 1.42$ eV
@x=0.3, $Eg = (1.42 - 1.9*0.3 + 1.2*0.3^2) = 0.958$ eV

Here, Eg1 = 1.42eV which is the maximum value of Eg we got from the bandgap equation for corresponding mol fraction x1 = 0.

@x1=0, Eg1(GaAs)= 1.42eV

Here, Eg2 = 0.958eV which is the minimum value of Eg we got from the bandgap equation for corresponding mol fraction x2 = 0.3.

@x2=0.3, Eg2($GaSb_{0.3}$)= 0.958eV

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide

Equation for Bandgap,

$$Eg = \begin{cases} 1\cdot 424 + 1.247x & ; x < 0.45 \\ 1.9 + 0.125x + 0.143x^2 & ; x > 0.45 \end{cases}$$

$Al_x\ Ga_{1-x}\ As$

Aluminium Gallium Arsenide

For $x<0.45$,

@ $x=0$,

$Eg=1.424+1.247x$

$= 1.424$ eV

@ $x=0.45$,

$Eg=1.424+1.247x$

$= 1.985$ eV

For $Eg<1.985$eV

For $x>0.45$,

@ $x=0.45$,

$Eg=1.9+0.125x+0.143x^2$

$= 1.985$ eV

@ $x=1$,

$Eg=1.9+0.125x+0.143x^2$

$= 2.168$ eV

For $Eg>1.985$eV

So, the bandgap for $Al_xGa_{1-x}As$ can be stated as,

$1.424<Eg<2.168$

$Al_x\, Ga_{1-x}\, As$

Aluminium Gallium Arsenide

As, the bandgap for Al_xGa_{1-x} is,

$1.424 < Eg < 2.168$

So, the output power should be calculated using all three equations.

Case 1 :

$Eg2 < E0 < Eg1$

$1.50 < Eg1 < 2.168$

$1.424 < Eg2 < 1.50$

Case 2 :

$Eg2 < Eg1 < E0$

$1.424 < Eg1 < 1.50$

$1.424 < Eg2 < 1.50$

Case 3 :

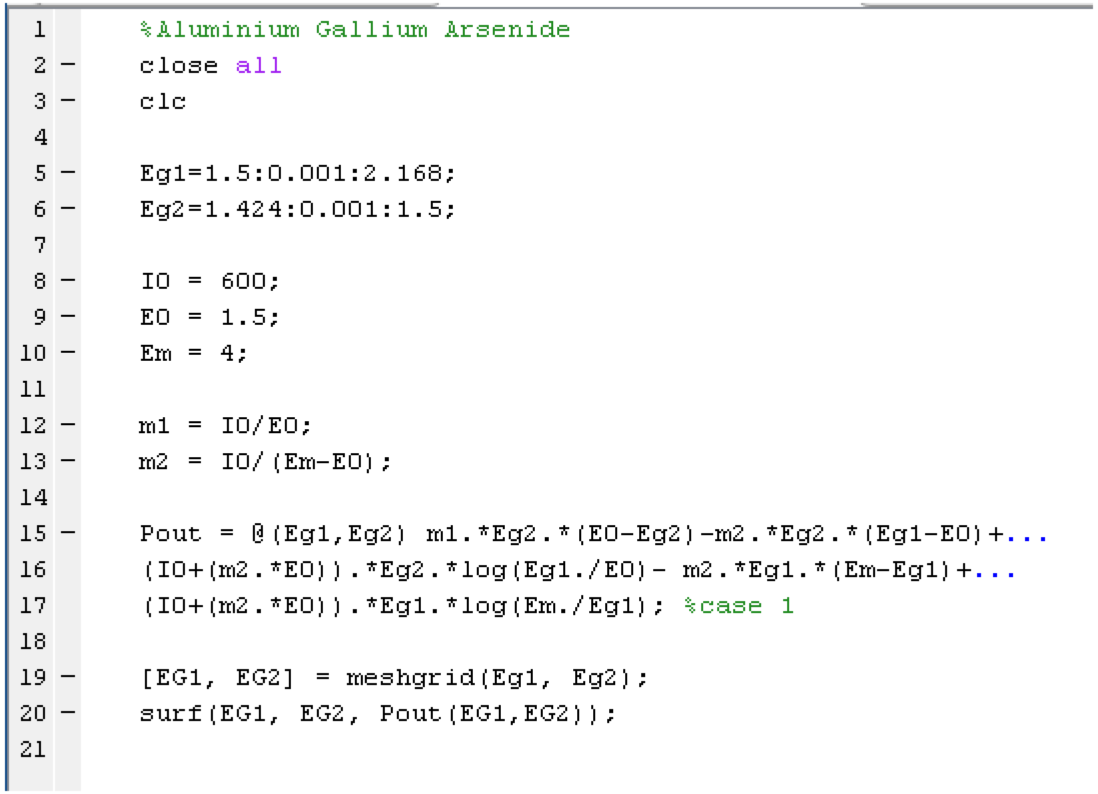
$E0 < Eg2 < Eg1$

$1.50 < Eg1 < 2.168$

$1.50 < Eg2 < 2.168$

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



```
%Aluminium Gallium Arsenide
close all
clc

Eg1=1.5:0.001:2.168;
Eg2=1.424:0.001:1.5;

I0 = 600;
E0 = 1.5;
Em = 4;

m1 = I0/E0;
m2 = I0/(Em-E0);

Pout = @(Eg1,Eg2) m1.*Eg2.*(E0-Eg2)-m2.*Eg2.*(Eg1-E0)+...
(I0+(m2.*E0)).*Eg2.*log(Eg1./E0)- m2.*Eg1.*(Em-Eg1)+...
(I0+(m2.*E0)).*Eg1.*log(Em./Eg1); %case 1

[EG1, EG2] = meshgrid(Eg1, Eg2);
surf(EG1, EG2, Pout(EG1,EG2));
```

Case 1 :

Eg2<E0<Eg1

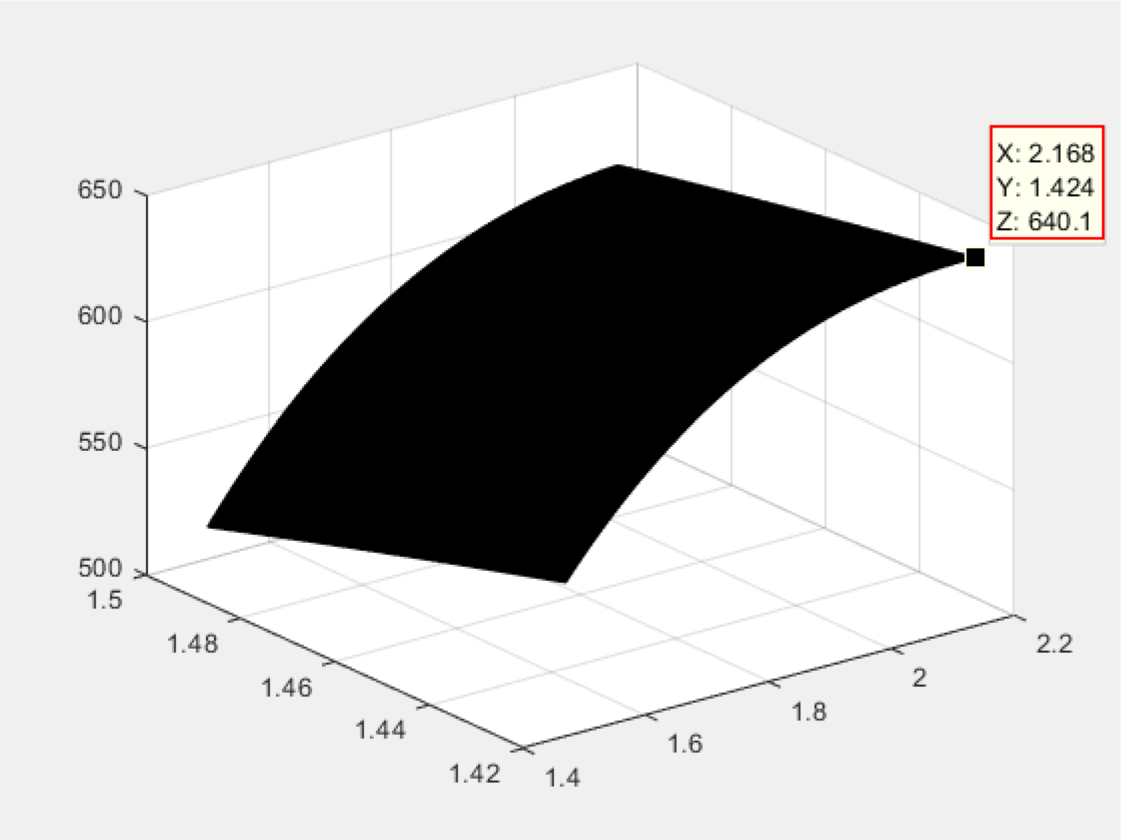
1.50<Eg1 <2.168

1.424<Eg2 <1.50

In MATLAB we have used meshgrid and surf to plot a 3 dimensional figure.

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



Here,

X axis represents Eg1,

Y axis represents Eg2,

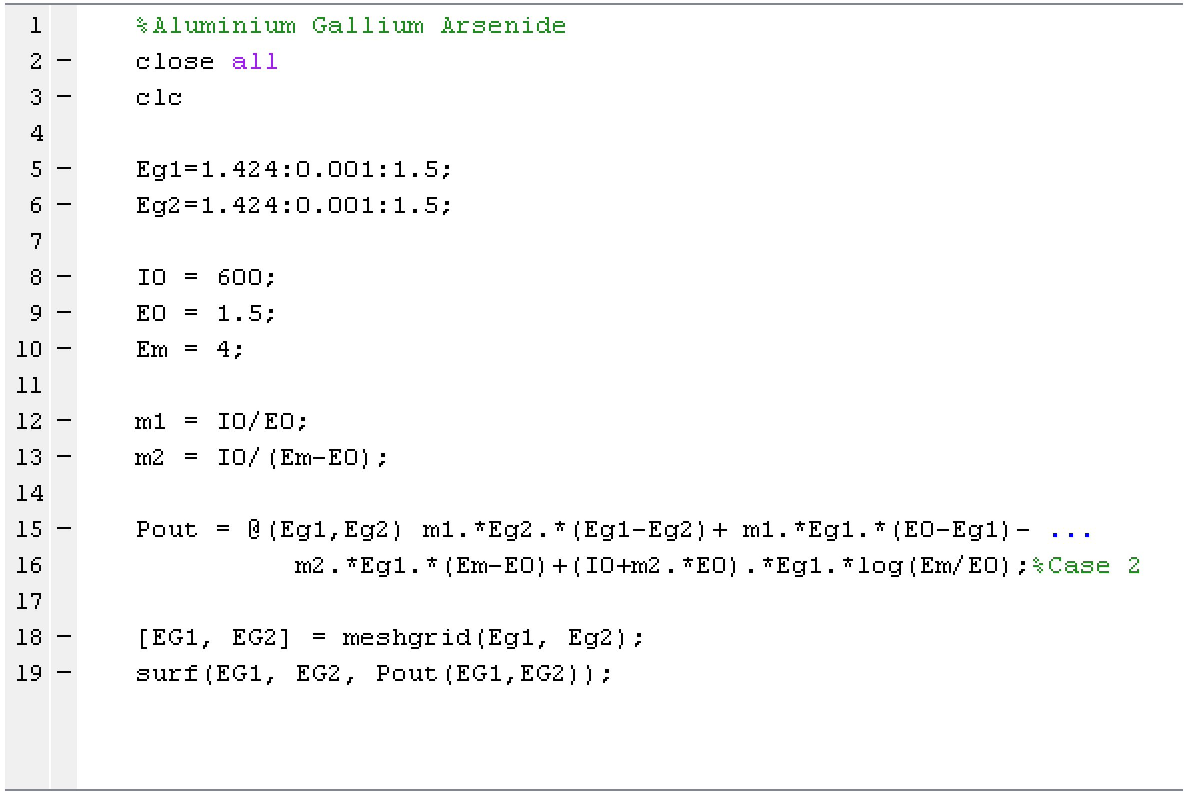
Z axis represents Pout

Maximum Value of Pout = 640.1 W/m^2 for

corresponding Eg1 = 2.168eV and Eg2 = 1.424eV

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



```matlab
%Aluminium Gallium Arsenide
close all
clc

Eg1=1.424:0.001:1.5;
Eg2=1.424:0.001:1.5;

I0 = 600;
E0 = 1.5;
Em = 4;

m1 = I0/E0;
m2 = I0/(Em-E0);

Pout = @(Eg1,Eg2) m1.*Eg2.*(Eg1-Eg2)+ m1.*Eg1.*(E0-Eg1)- ...
          m2.*Eg1.*(Em-E0)+(I0+m2.*E0).*Eg1.*log(Em/E0);%Case 2

[EG1, EG2] = meshgrid(Eg1, Eg2);
surf(EG1, EG2, Pout(EG1,EG2));
```

Case 2 :

Eg2<Eg1<E0

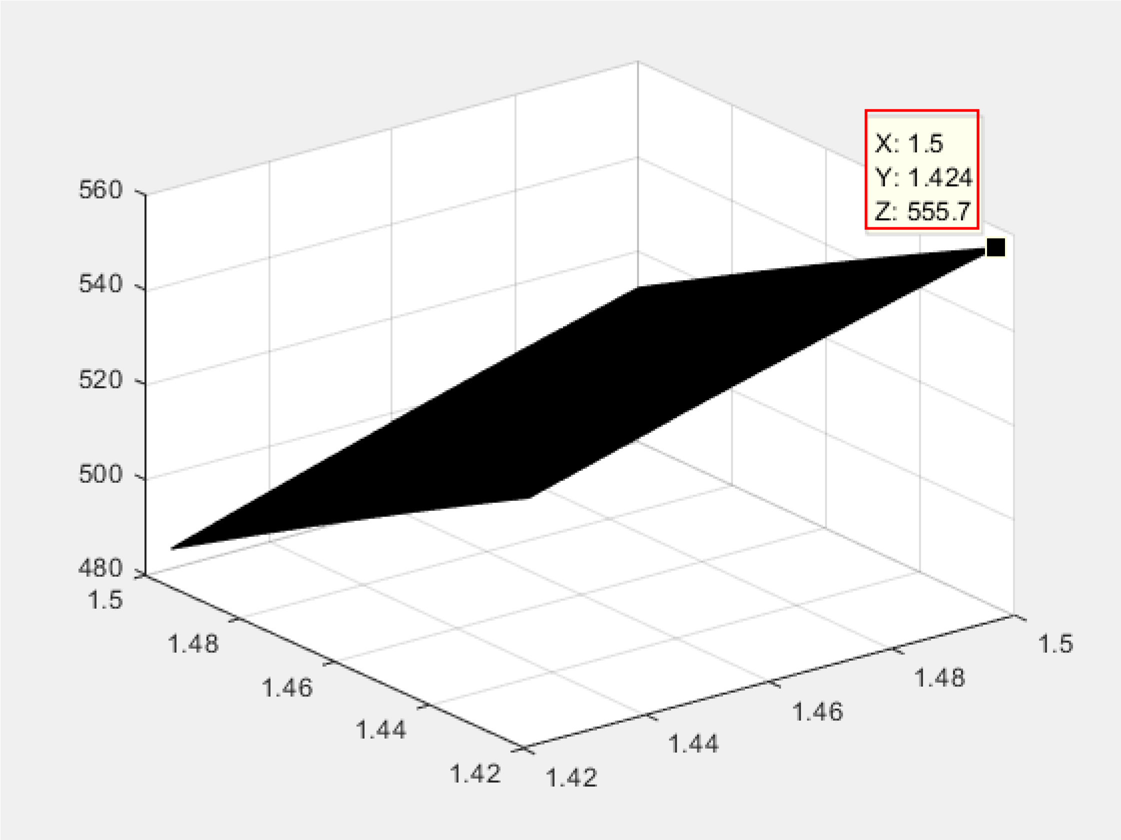
1.424<Eg1 <1.50

1.424<Eg2<1.50

In MATLAB we have used meshgrid and surf to plot a 3 dimensional figure.

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



Here,

X axis represents Eg1,

Y axis represents Eg2,

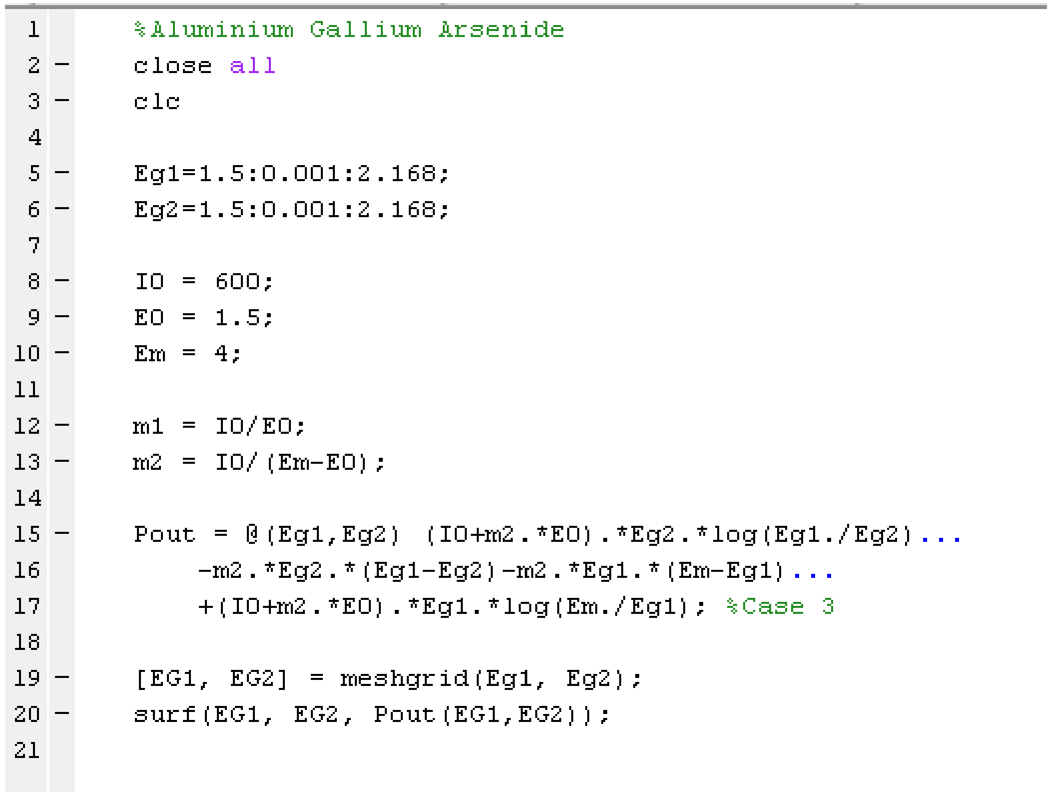
Z axis represents Pout

Maximum Value of Pout = 555.7 W/m^2 for

corresponding Eg1 = 1.5eV and Eg2 = 1.424eV

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



```
%Aluminium Gallium Arsenide
close all
clc

Eg1=1.5:0.001:2.168;
Eg2=1.5:0.001:2.168;

I0 = 600;
E0 = 1.5;
Em = 4;

m1 = I0/E0;
m2 = I0/(Em-E0);

Pout = @(Eg1,Eg2)  (I0+m2.*E0).*Eg2.*log(Eg1./Eg2)...
    -m2.*Eg2.*(Eg1-Eg2)-m2.*Eg1.*(Em-Eg1)...
    +(I0+m2.*E0).*Eg1.*log(Em./Eg1); %Case 3

[EG1, EG2] = meshgrid(Eg1, Eg2);
surf(EG1, EG2, Pout(EG1,EG2));

```

Case 3 :

E0<Eg2<Eg1

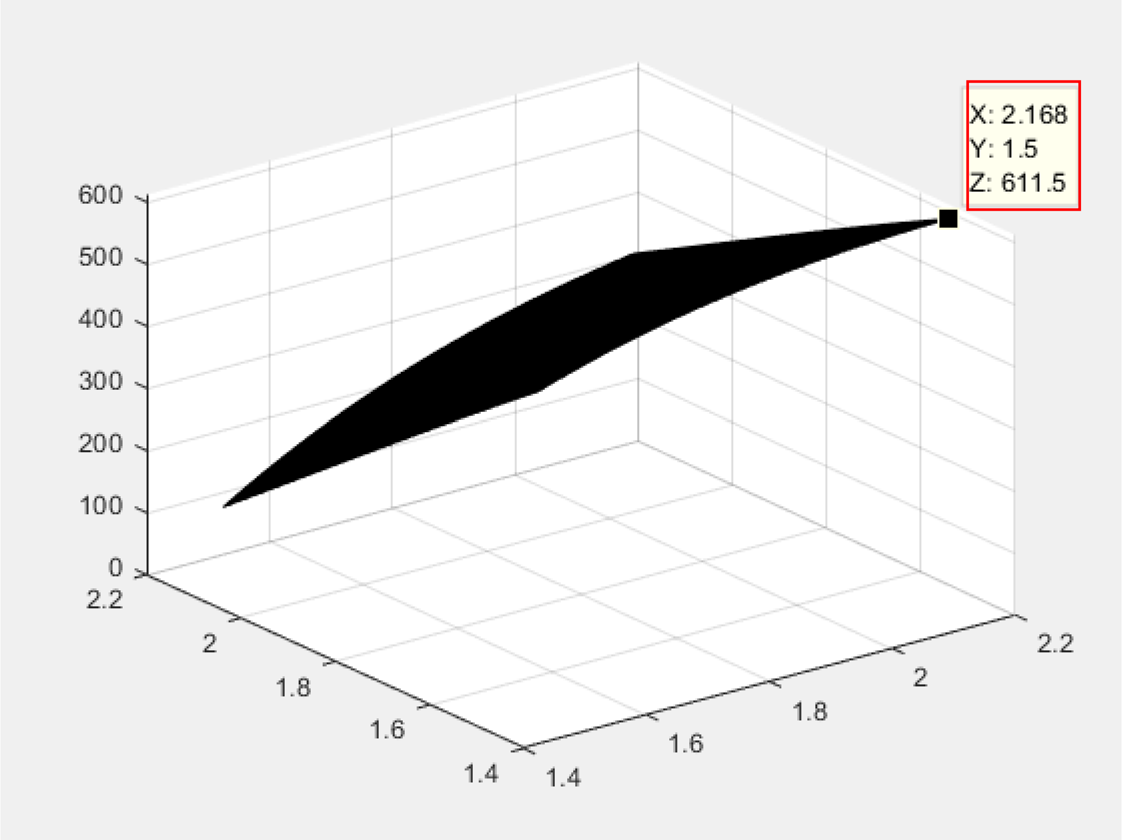
1.50<Eg1 <2.168

1.50<Eg2 <2.168

In MATLAB we have used meshgrid and surf to plot a 3 dimensional figure.

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide



Here,

X axis represents Eg1,

Y axis represents Eg2,

Z axis represents Pout

Maximum Value of Pout = 611.5 W/m² for

corresponding Eg1 = 2.168eV and Eg2 = 1.5eV

$Al_x Ga_{1-x} As$

Aluminium Gallium Arsenide

Maximum Value of Pout was found in Case 1.

$P_{out} = 640.1\ W/m^2$

for

corresponding $E_{g1} = 2.168eV$ and $E_{g2} = 1.424eV$

From Bandgap Equations,

If $Eg<1.985$, $Eg=1.424+1.247x$

If $Eg>1.985$, $Eg= 1.9+0.125x+0.143x^2$

Here, $Eg1 = 2.168eV$ which is greater than 1.985eV. It is the maximum value of Eg for the corresponding bandgap equation. Which can be obtained at mol fraction $x1 = 1$.

@x1=1, Eg1(AlAs)= 2.168eV

Here, $Eg2 = 1.424eV$ which is less than 1.985eV. It is the minimum value of Eg for the corresponding bandgap equation. Which can be obtained at mol fraction $x2 = 0$.

@x2=0, Eg2(GaAs)= 1.424eV

Comparison

$GaAs_{1-x}Sb_x$

Gallium Arsenide Antimonide

Maximum Output Power,
Pout = 707.5 W/m^2

Efficiency, η = Pout/Pin X 100%
= 707.5/1200 X 100%
= 58.9%

$Al_x Ga_{1-x} As$

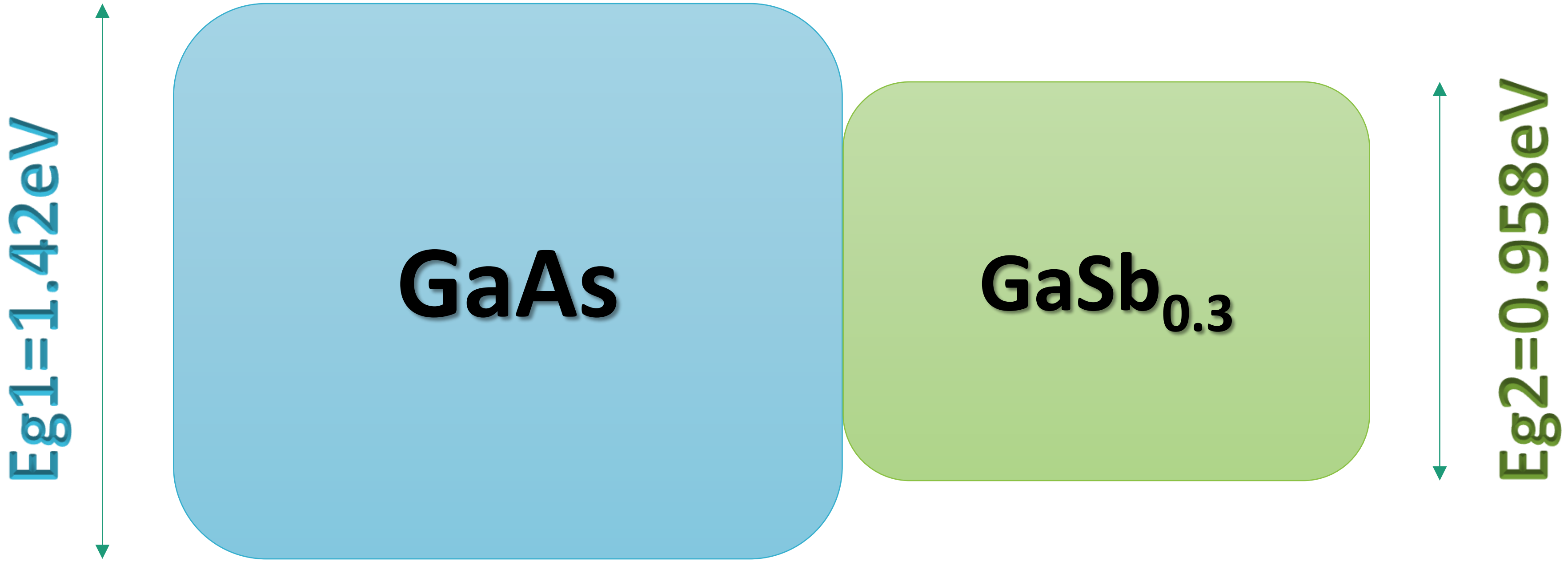
Aluminium Gallium Arsenide

Maximum Output Power,
Pout = 640.1 W/m^2

Efficiency, η = Pout/Pin X 100%
= 640.1/1200 X 100%
= 53.3%

Among the Ternary Semiconductors $GaAs_{1-x}Sb_x$ is more efficient. So we should select $GaAs_{1-x}Sb_x$

Two Stage Tandem Solar Cell



$E_{g1}=1.42\text{eV}$

GaAs

$GaSb_{0.3}$

$E_{g2}=0.958\text{eV}$

Solar Cell
Semiconductor 1

Solar Cell
Semiconductor 2

Environmental Impact

Disposal of the device made with $GaAs_{1-x}Sb_x$ can be harmful for the environment

- Disposed to water
- Disposed to earth
- Disposed by incineration

Environmental Impact

Solar cell systems do not produce any toxicity. The health and environmental impacts are also associated with the fabrication process of solar cells and solar panels.

Material	Toxicity Type	Critical effects
Arsenic	Poison	Cancer, lung
Arsine	Highly toxic gas	Blood, kidney
Antimony	Poison	Skin disease, respiratory and immune systems
Hydrochloric acid	Corrosive material	Destroys human cells and tissues
Methane	Flammable gas	Fire hazard
Trimethyl gallium	Pyrophoric liquid	Fire hazard

Thank You