# ECE447 - Homework 4

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## A. Thought Experiment

Three orthogonal and degenerate energy valleys in bulk silicon have one electron each. The electric field is applied along the $y$-direction to which all three electrons respond giving rise to a current $I_1$. Now, some amount of tensile strain is applied in the material causing all three electrons located in the transverse valleys and producing a current flow of $I_2$. Given that $I \propto 1/m^*$ and $m_l^* \propto 4m_t^*$ what will be the ratio of $I_2/I_1$?

**Solution**
For the first current $I_1$, in the presence of the electric field $\vec{E} = \hat{y}E$, we will get the $k_y$ electron along the semimajor axis of its energy valley, and the $k_x$ and $k_z$ electrons will move along the semiminor axis of their respective energy valleys. This tells us to use $m_l^*$ for $k_y$, and $m_t^*$ for $k_x$ and $k_z$.
We can then find the average effective mass $m_1^*$:

$$\begin{aligned} m_1^* &= \frac{1}{3}(m_l^* + 2m_t^*) \\ &= \frac{1}{3}(4m_t^* + 2m_t^*) \\ &= 2m_t^* \end{aligned}$$

Then we can do the same, finding the average effective mass, for when all of the electrons are located in transverse valleys.

$$\begin{aligned} m_2^* &= \frac{1}{3}(3m_t^*) \\ &= m_t^* \end{aligned}$$

Using the inverse relationship between current and effective mass:

$$\boxed{\frac{I_2}{I_1} \propto \frac{1/m_t^*}{1/2m_t^*} = 2}$$

So, from adding tensile strain and forcing our electrons into their transverse valleys, we can effectively **double** the current.

## Problem 3.12

Plot $E_g = E_g(0) - \frac{\alpha T^2}{(\beta+T)}$

**Solution**
I implemented the following plot for $E_g(T)$ using python's library *matplotlib.pyplot*.

```
import matplotlib.pyplot as plt
import numpy as np
import math

# IMPORTANT CONSTANTS
Eg0 = 1.17            # Si bandgap at T=0K [eV]
alpha = 4.73e-4       # [eV/K]
beta = 636            # [K]

# define Eg(T) function
def bandgapTemp(T):
    """
    Calculate Si bandgap energy for a given temperature in K.
    Parameters:
    T = temp in K.
    """
    Eg = Eg0 - ( ( alpha * T**2 ) / (beta + T) )
    return Eg


##  Plotting ##

# Set up x-vals and input into Eg(T)
x = np.linspace(0, 600, 6000)
y = bandgapTemp(x)

markers_on = [3000]

# Create plot of Eg(T)
plt.plot(x, y, '-go', markevery=markers_on, label = "Eg(T)")

EgROOM = bandgapTemp(300)
plt.text((300 + 20), EgROOM, "(300, %.4f)" % EgROOM, fontsize = 12)

# Labels and Titles
plt.xlabel('Temperature (K)')
plt.ylabel('Bandgap Energy (eV)')
plt.title('Si Bandgap Energy v. Temperature')

# Axis Formatting
```

```
plt.xlim(0,600)

# Show plot
plt.legend()
plt.show()
```

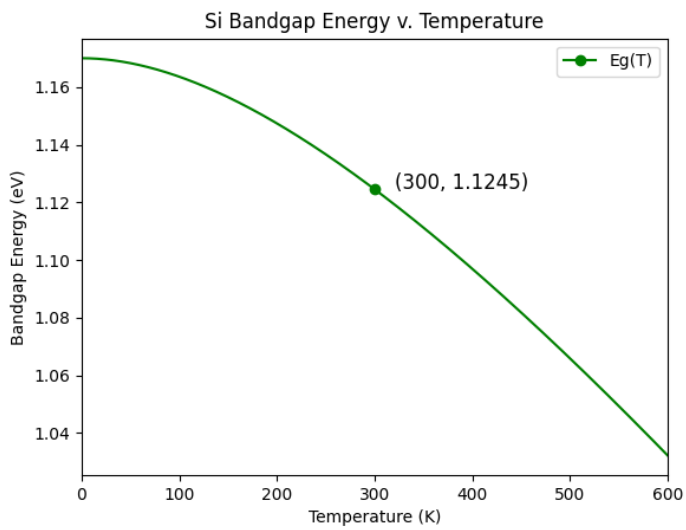


Figure 1: $E_G$ versus $T$

For $T = 300K$, we see that the bangap energy of Silicon is 1.1245 eV, which is the textbook bandgap for Silicon at room temperature.