Resolution of Scanning Electron Microscope (SCM)

ELEC 4704 A

Lab 1

Author:

Harshpreet Kaur Kathuria

Student ID: 101102114

1.0 INTRODUCTION

This lab shows result of various simulations depicting different scenarios for a Scanning Electron Microscope (SEM). These simulations help better understand the behavior of SEM and what to expect in differ situation. In this lab report section 2.0 depicts the results and the code for the simulations and section 3.0 discusses the conclusion.

2.0 EXPERIMENT

2.1 Current Density as a function of Temperature

Figure 1 depicts the current density for a SEM for which the tungsten filament is coated with Cerium hexaboride (CeB_6). The effective work function of the cathode is 2.65eV. It can be observed in figure 1 that with the increase in temperature the current density increases exponentially.

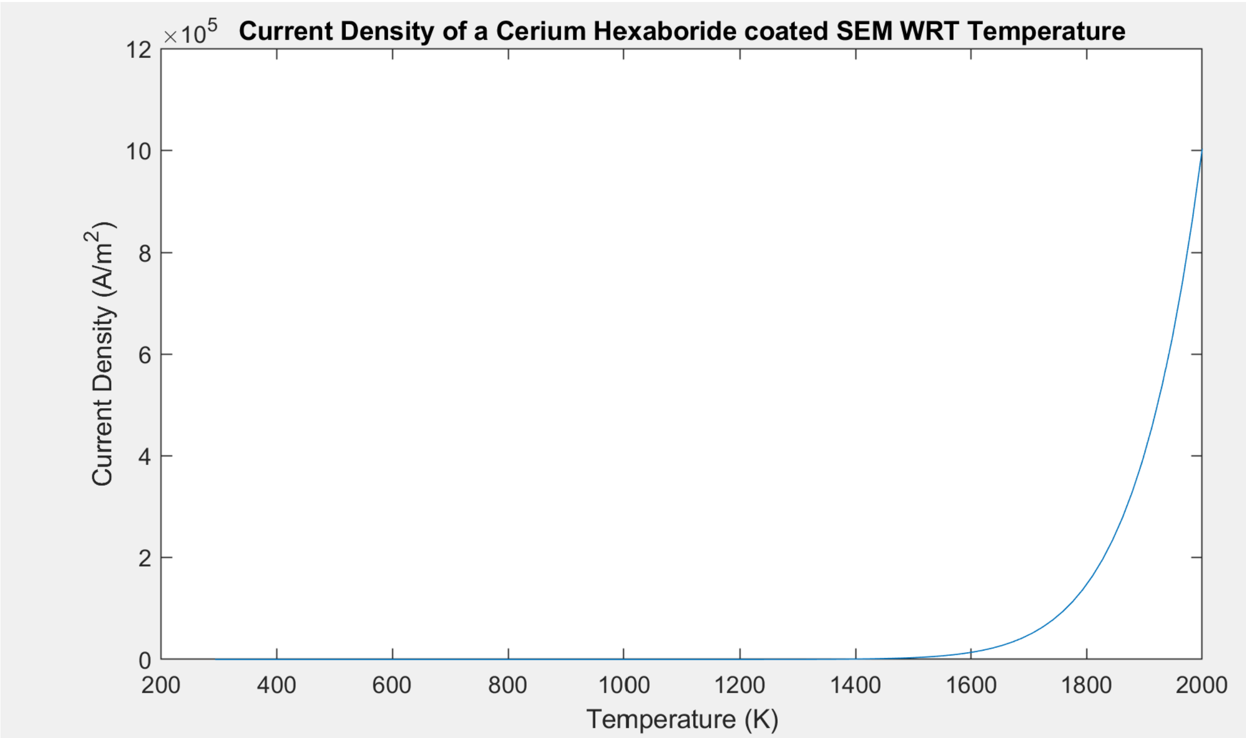

Figure 1: Current Density of CeB_6 Coated SEM

The MATLAB code associated with plotting the above figure in given below:

```
% This File is to plot the current density of a cerium hexaboride coated
electron gun vs temperature

me = 9.109*power(10,-31);
q  = 1.602*power(10,-19);
h  =  6.62607*power(10,-34);
k  = 1.380*power(10,-23);
```

```
wf = 2.65*q;
e  = 2.718281828459045;
T  = linspace(293,2000, 100);
wk = linspace(1,100,1);
J  = linspace(1,100,1);
pp = linspace(1,100,1);

J = (4*pi*me*q/(h^3)).*((k*T).^2).*exp(-wf./(k.*T));
plot(T,J)
title('Current Density of a Cerium Hexaboride coated SEM WRT Temperature')
xlabel('Temperature (K)')
ylabel('Current Density (A/m^2)')
```

2.2 Representation of Relative Number of Electrons at constant Potential

Figure 2 shows a 3D plot depicting a relationship between relative number of electrons, electron energy found in a range of temperature at the constant potential of 10kV. In the figure below it can be observed that at any given temperature the relative number of electrons is the highest at minimum energy and with increase in temperature this relationship becomes nonexistent such that the relative number of electrons across electron energy becomes constant.

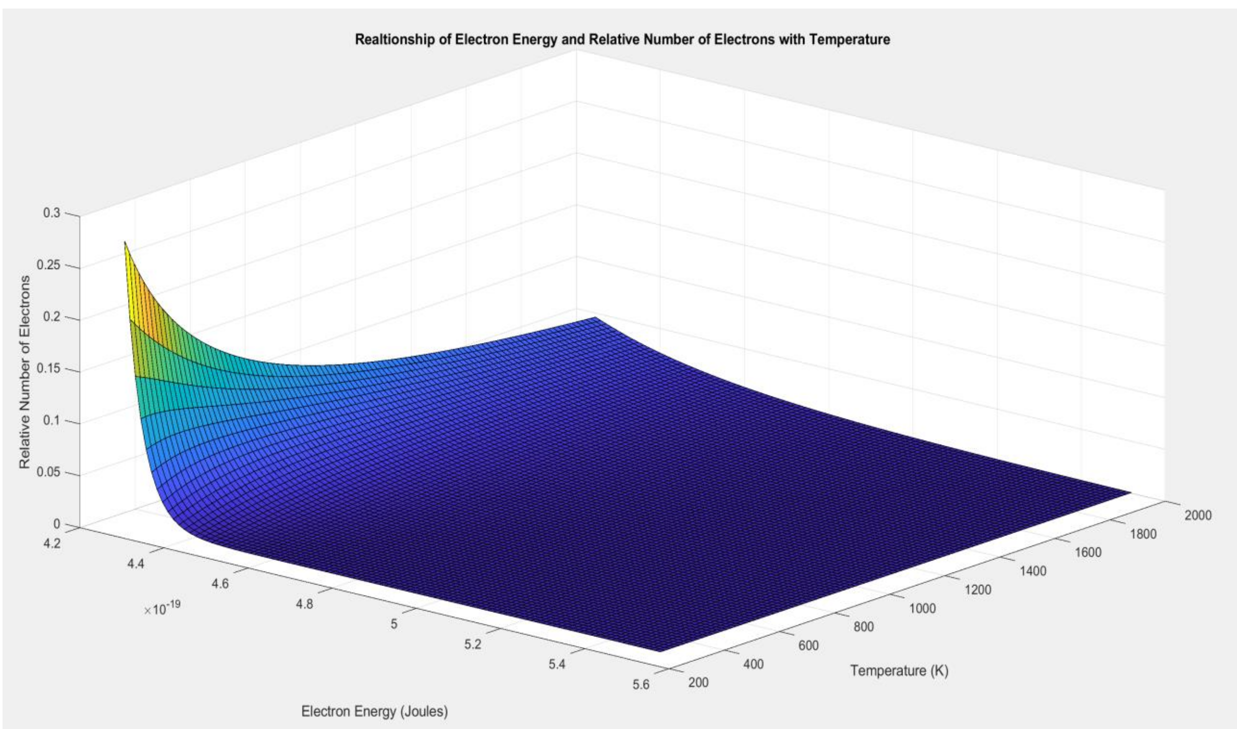

Figure 2: Surface plot for relation between relative number of electrons with relative energy at a range of temperature

The MATLAB code associated with plotting the above figure in given below:

```
% Plot a 3-D representation of the relative number of electrons vs electron
energy vs temperature for the conditions given in (a) above and an acceleration
potential of Va = 10kV
```

```
q  = 1.602*power(10,-19);
k  = 1.380*power(10,-23);
wf = 2.65*q;
T  = linspace(293,2000, 100);

dE = linspace(wf,1.3*wf, 100);
[dde, tt] = meshgrid(dE,T);

f = linspace(1,100,1);
f = 1./(1+exp(dde./(k.*tt)));
% Normalizing fermi destribution
fnorm= f./sum(f,2);
surf(dde,tt,fnorm)
title('Realtionship of Electron Energy and Relative Number of Electrons with Temperature')
xlabel('Electron Energy (Joules)')
ylabel('Temperature (K)')
zlabel('Relative Number of Electrons')
```

2.3 Electron Beam Spot Size based on Full Width Half Max (FWHM)

This section was meant to depict the variation in the electron bean spot size based on the variation in electron energy such that the applied potential is 10kV and the chromatic aberration coefficient is 2.0mm. The exact results could not be plotted appropriately.

Following is the code that was implemented:

```
% If other factors are neglected, the full-width half-maximum (FWHM) diameter of the focused electron spot on the sample may be limited due to chromatic aberration. Calculate and plot the electron beam spot size, dchrom, for parameters given in (a) and (b) if the SEM has a chromatic aberration coefficient of C chrom=2.0mm.

q  = 1.602*power(10,-19);
k  = 1.380*power(10,-23);
wf = 2.65*q;
T  = linspace(293,2000, 100);

dE = linspace(wf,1.3*wf, 100);
[dde, tt] = meshgrid(dE,T);

f = linspace(1,100,1);
f = 1./(1+exp(dde./(k.*tt)));
fnorm= f./sum(f,2);

[ee,ff] = meshgrid(dE,fnorm);
Fmax = max([ee,ff]);
Fmaxhalf = Fmax/2;

Em = dE.*ff;
Emean = sum(Em);
```

2.4 Current Density as a Function of Potential

Figure 3 depicts the Current density for a CeB_6 coated field emission electron gun with a tip radius of 50nm at room temperature (293 K) and the potential within the range of zero to 2kV.

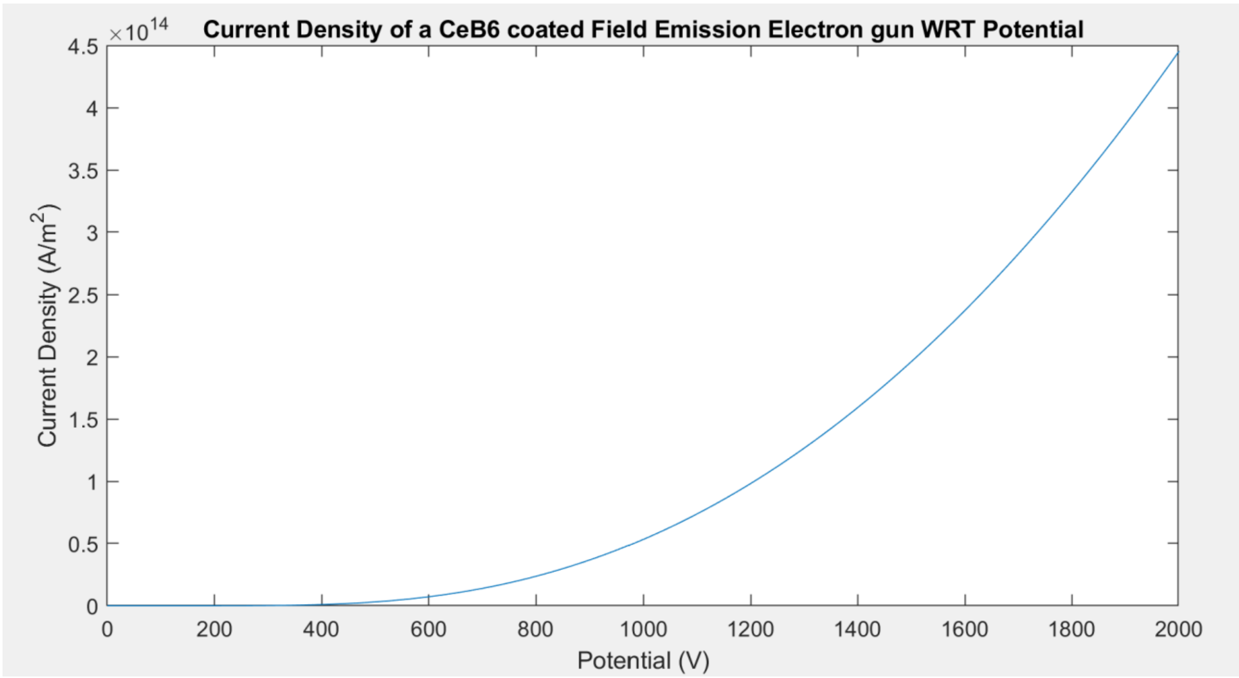

Figure 3: Current Density of CeB_6 Coated field emission Electron Gun

The MATLAB code associated with plotting the above figure in given below:

```
% Calculate and plot the current density, Jfe, for a CeB 6 coated field emission
electron gun having a tip radius of 50nm as a function of extraction voltage V
(0 to 2.0kV). Assume RT operation and that the work function is as given in (a).

me = 9.109*power(10,-31);
h  =  6.62607*power(10,-34);
k  = 1.380*power(10,-23);
T  = 293;
q  = 1.602*power(10,-19);
wf = 2.65*q;
r  = 50*power(10,-9);
V  = linspace(0, 2000, 100);
E  = V./r;
a  = ((q^3)*me)/(8*pi*h*me);
pp = ((4*2*pi)/(3*h*q))*power(2*me,0.5)*power(wf,1.5)./E;
J  = (a/wf).*(E.^2).*exp(-pp);
plot(V,J)
title('Current Density of a CeB6 coated Field Emission Electron gun WRT
Potential')
xlabel('Potential (V)')
ylabel('Current Density (A/m^2)')
```

2.5 Emission Current wrt Tip Radius for Field Emission Electron Gun

Figure 4 depicts, the emission current gradient with respect to the change in tip radius at 2kV potential. For a field Emission electron gun.

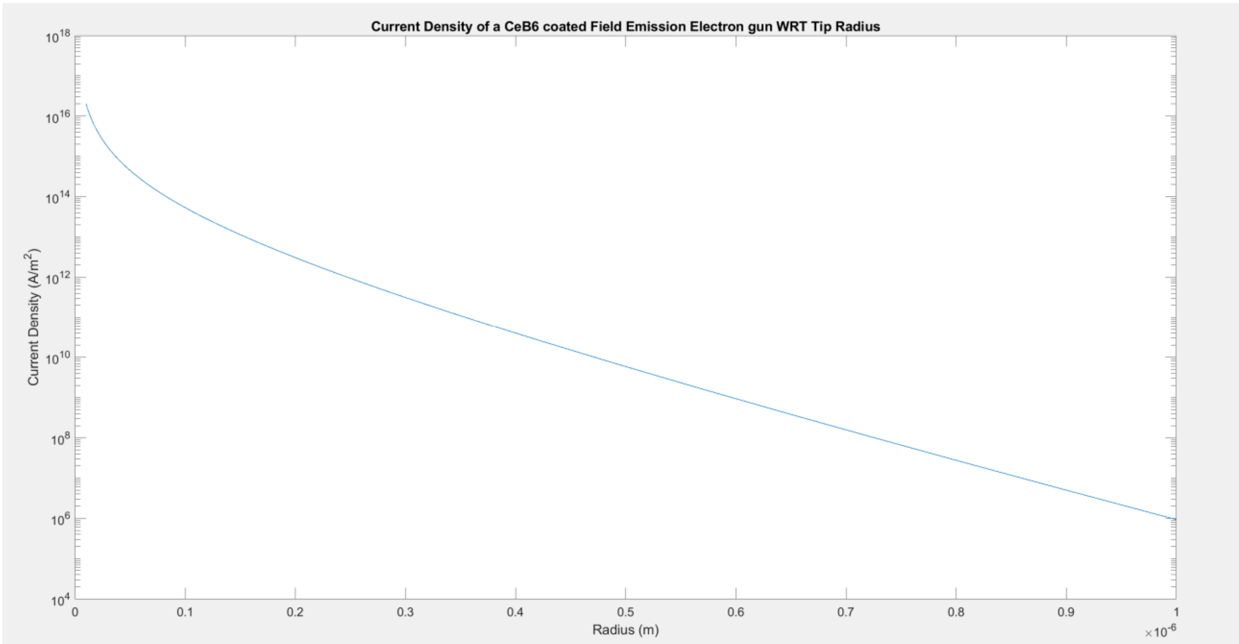

Figure 4: Variation of Current Density on Log scale based on Tip Radius

The MATLAB code associated with plotting the above figure in given below:

```
% Plot how the emission current changes with tip radius from 10nm to 1µm for a
fixed extraction voltage of 2.0kV

me = 9.109*power(10,-31);
h  =  6.62607*power(10,-34);
k  = 1.380*power(10,-23);
T  = 293;
q  = 1.602*power(10,-19);
wf = 2.65*q;
mm = 10^(-6);
r = linspace(1e-8,1e-6,1000);
% r  = rr.*mm;
V  = 2000;
E  = V./r;
a  = ((q^3)*me)/(8*pi*h*me);
pp = ((4*2*pi)/(3*h*q))*power(2*me,0.5)*power(wf,1.5)./E;
J  = (a/wf).*(E.^2).*exp(-pp);
semilogy (r,J)
title('Current Density of a CeB6 coated Field Emission Electron gun WRT Tip
Radius')
xlabel('Radius (m)')
ylabel('Current Density (A/m^2)')
```

2.6 Resolution of SEM based on Potential

Figure 5 shows a plot depicting a relationship between Resolution of an SEM with respect to Potential applied. In the figure below it can be observed the Rayleigh Criterion decreases dramatically with respect to the acceleration potential.

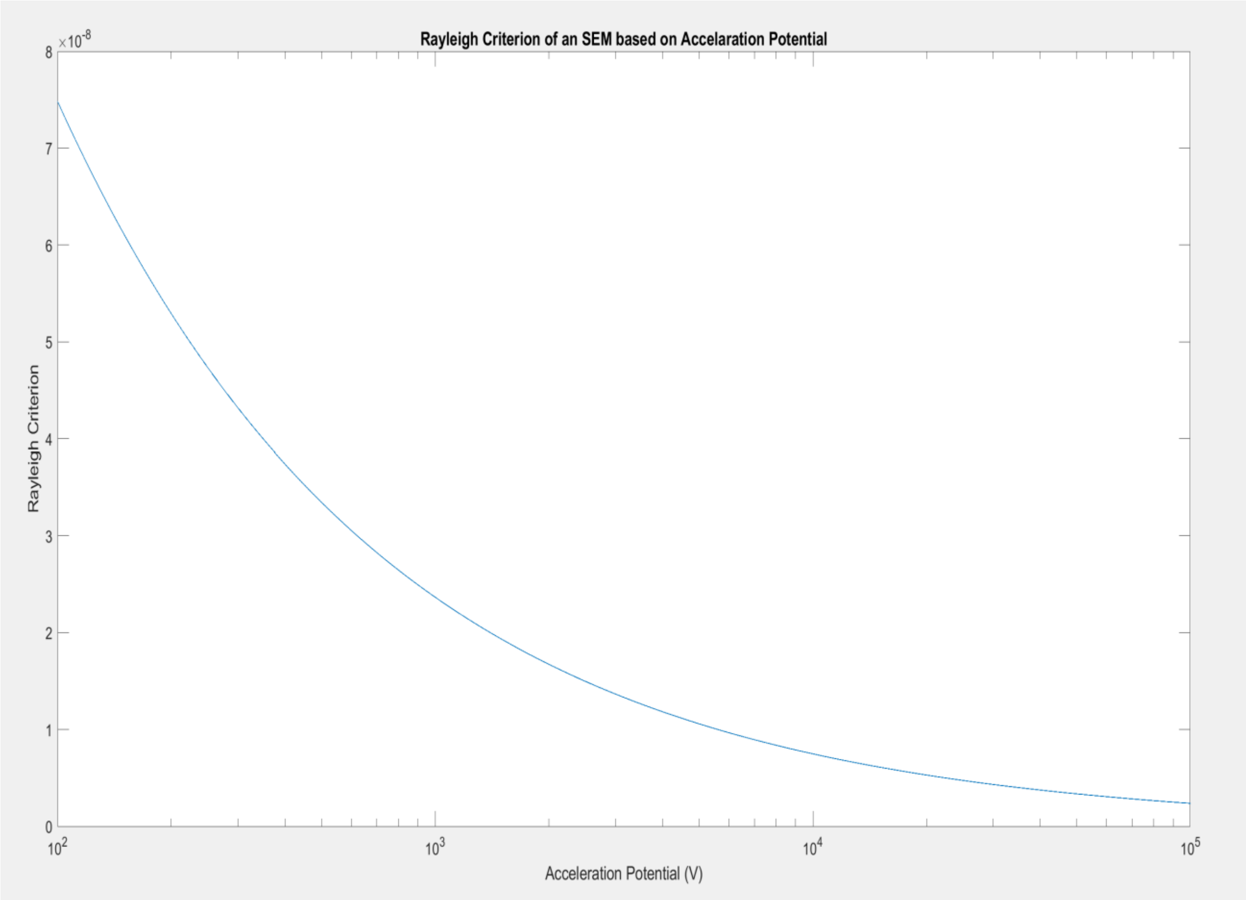

Figure 5: Variation in Rayleigh Criterion wrt Acceleration Potential (V)

The MATLAB code associated with plotting the above figure in given below:

```
% Assuming the electrons are "monochromatic" and the system is "diffraction-
limited" calculate and plot the resolution (using the Rayleigh criteria) of the
microscope on a semilog plot as function of acceleration voltage from 100V to
100kV.

V  = linspace(100,100000, 100000);
me = 9.109*power(10,-31);
h  = 6.62607*power(10,-34);
q  = 1.602*power(10,-19);
Wlength = h./power(2*me*q.*V,0.5);
R  = 0.61.*Wlength./0.001;
plot(V,R)
title('Rayleigh Criterion of an SEM based on Accelaration Potential')
xlabel('Acceleration Potential (V)')
ylabel('Rayleigh Criterion')
```

2.7 Resolution of SEM based on Potential (Replace electrons with H^+ Ions)

Figure 6 shows a plot depicting a relationship between Resolution of an SEM (Using Hydrogen ions in place of electrons) with respect to Potential applied. In the figure below it can be observed the Rayleigh Criterion decreases dramatically with respect to the acceleration potential.

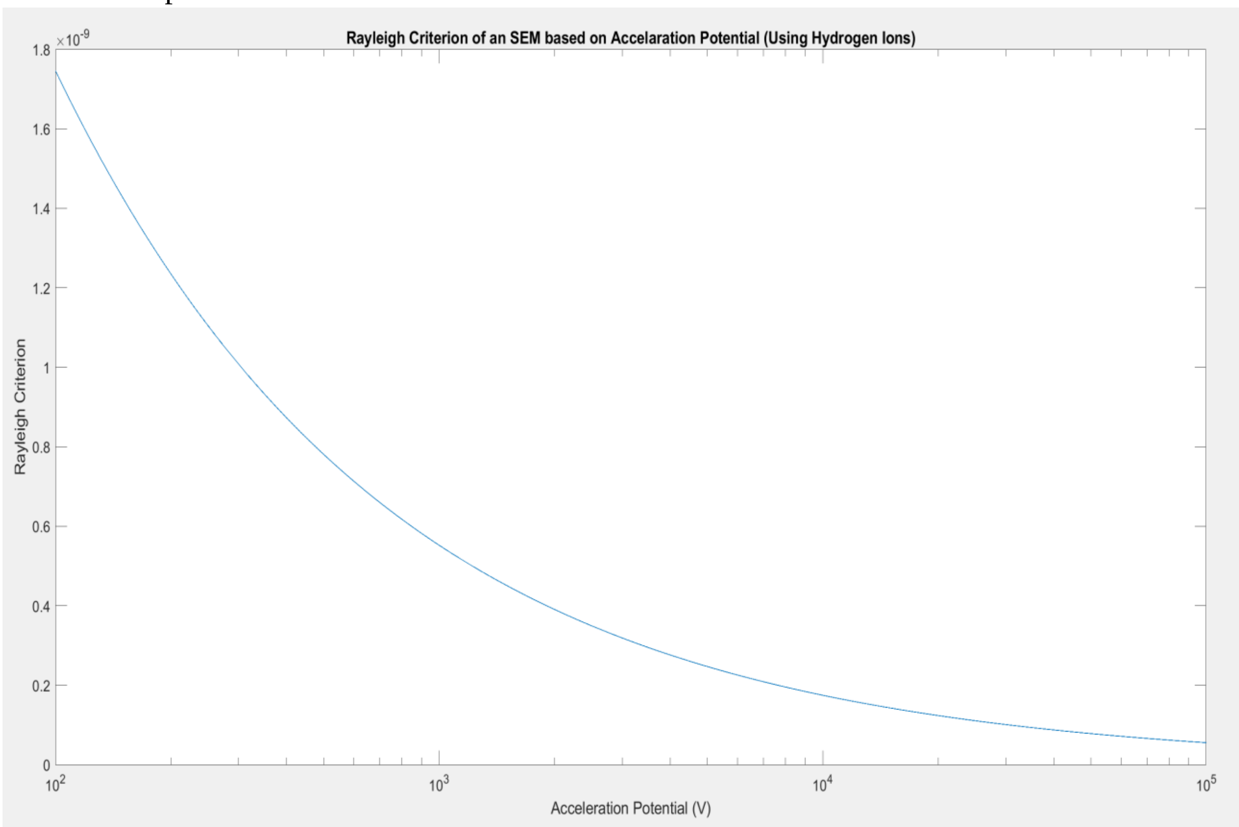

Figure 6: Variation in Rayleigh Criterion (H^+ ion in place of electrons) wrt Acceleration Potential (V)

The MATLAB code associated with plotting the above figure in given below:

```
% How would the results in (f) change if we were using a focused ion beam
microscope with protons (H+ ions) instead of electrons? Recalculate and plot
the resolution for the same energies as in (f).

V  =linspace(100,100000, 100000);
mp = 1.67262192*power(10,-27);
h  =  6.62607*power(10,-34);
q  = 1.602*power(10,-19);
Wlength = h./power(2*mp*q.*V,0.5);
R = 0.61.*Wlength./0.001;
semilogx(V,R)
title('Rayleigh Criterion of an SEM based on Accelaration Potential (Using
Hydrogen Ions)')
xlabel('Acceleration Potential (V)')
ylabel('Rayleigh Criterion')
```

3.0 CONCLUSION

This lab focused on simulating the behavior of a Scanning Electron Microscope (SEM) and how its results would vary based on variation in different criteria. In section 2.1 it was found that the current density increased with the temperature. Section 2.2 depicted a correlation between the relative number of electrons at various energies at various temperatures. It was found that at a given temperature relative number of electrons found decrease with the increase in energy. It was also observed that this variation diminished with increase in temperature. Section 2.3 was supposed to focus on variation in the chromatic aberration due to variation in temperature, unfortunately this section was not completed successfully, but the expected results for this section were supposed to depict that with increase in temperature the chromatic aberration increases. Further in section 2.4 current density as a function of applied potential was plotted, it was found that the current density increases exponentially with increase in temperature. Section 2.5 depicted the relation between current density on varying the tip radius, it was found that it decreases dramatically on increasing the radius. Section 2.6 and 2.7 depict variation of in Rayleigh criterion with respect to acceleration potential, in both the sections it is observed that with increase in potential the Rayleigh criterion decreases, but the difference in the observations is that for a hydrogen ion, the maximum value of Rayleigh criterion is much smaller that that for an electron, this is a result of a higher mass of the hydrogen ion.

This lab provided an in depth knowledge of working on a scanning electron microscope and how various factors affect it.