ELECTRON EMISSION FROM SURFACE ROUGHNESS ON CAVITY IN LOW TEMPERATURE*

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Abstract

Electron emission phenomenon from surface roughness on cavity is investigated. The distribution of the electric field from the surface roughness can be obtained on cavity surface. The field emission is calculated from the electric field distribution. The generalized electron emission from electric field and temperature effect is also calculated on the surface roughness of the cavity.

INTRODUCTION

When a body is heated, it generates thermal radiation. Blackbody radiation is used to measure the temperature of the heated body for all range of temperature. Size effect of thermal radiation [1-3] and the effective temperature for non-uniform temperature distribution were investigated [4-6]. Ionization efficiency of helium gas was investigated as a function of pressure and applied voltage with the use of a tungsten tip [7]. Unified theory of field and thermionic emission was constructed with a free electron gas model [8]. Properties of the thermal radiation from arbitrary fractional dimension were investigated [9]. Sheet resistance of graphene grown on different surface roughness of Cu films was measured [10].

In this research, we show total electron emission which includes electric field effect, temperature effect, and surface roughness effect on cavity. General electron emission is introduced and electron emission can be limited with a resistor. Effect of surface roughness causes the increased fractional dimension and focused electric field. Total electron emission can be calculated from thermionic and field emission.

GENERAL ELECTRON EMISSION

Electrons can be generated from heating, electric field, and UV light. Electron current density from thermionic emission, field emission and UV light can be expressed as

$$J = J_{therm} + J_{field} + J_{UV} , \quad (1)$$

where J_{therm}, J_{field} and J_{UV} represent the current density of thermionic emission, field emission, and UV, respectively.

Electrons come out of the metal when they get enough thermal energy to overcome the work function. The current density of thermionic emission is

$$J_{therm} = \frac{4\pi m e k_B^2}{h^3} T^2 e^{-\Phi_w / k_B T} , \quad (2)$$

where Φ_w is the work function, h is the Planck constant, m is the electron mass and k_B is the Boltzmann constant. Electrons make thermionic emission when they have higher energy than work function.

Electrons come out of the metal to which strong electric field is applied. Electron current density of field emission for zero-temperature approximation is

$$J_{field} = \frac{e}{2\pi h} \frac{\sqrt{E_F}}{(\Phi_w + E_F)\sqrt{\Phi_w}} F^2 e^{-4k\Phi_w^{3/2}/3F} , \quad (3)$$

where $k = \sqrt{\frac{8\pi^2 m}{h^2}}$ is electron wave number and F is the electric field. This is the well-known Fowler-Nordheim equation.

LIMITATION OF ELECTRON EMISSION

Electron emission can be limited by applying a

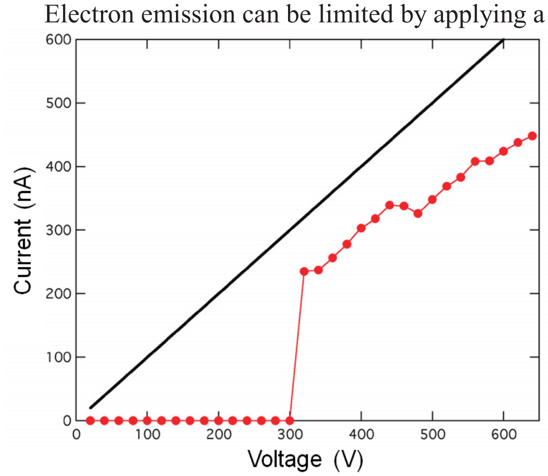

Figure 1: Current measurement is shown as a function of applied voltage.

resistor. The resistor having 1 G ohm is connected to carbon nanotubes. Carbon nanotubes are connected with an electrode by using epoxy. Electron collector is made of copper and the chamber is being pumped. Fig. 1 shows the electron current as a function of applied voltage. The

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line in Fig. 1 represents the maximum possible current. Field emission is rapidly increased at the critical voltage of 310 V as applied voltage increases.

ELECTRIC FIELD FROM SURFACE ROUGHNESS

The root mean square (RMS) roughness is defined as follows [10].

$$R_q = \sqrt{\frac{1}{L}\int_0^L z^2(x)dx}\,, \tag{4}$$

where L is the evaluation length, z is the height and x is the distance along measurement.

Flat surface shows two-dimension, but surface roughness shows fractional dimension which is higher than two-dimension. Fractal dimension for Koch curve can be calculated as

$$D = \frac{\ln N}{\ln(\frac{1}{S})}\,, \tag{5}$$

where D is the dimension, N is the number of pieces, and S is the scaling factor.

Electric field on tungsten tip can be approximated to [11]

$$F \approx \frac{V}{5r}, \tag{6}$$

where F is the electric field of the tip, r is the radius of the curvature of the tip and V is the voltage which is applied to the tip.

Curvature is a measure of how sharply a curve is turning as it is traversed. The curvature of a straight line is defined to be zero. The curvature of a circle of radius r should be large if r is small and small if r is large. Thus the curvature of a circle is defined to be reciprocal of the radius:

$$\kappa = \frac{1}{r}. \tag{7}$$

At each point on a curve, with equation $y = f(x)$, the tangent line turns at a certain rate. The curvature which measures the rate of turning is

$$\kappa = \left|\frac{f''(x)}{(1+[f'(x)]^2)^{3/2}}\right|. \tag{8}$$

The electric field intensity near the surface of a conductor can be expressed as [12]

$$F = F_o \exp(2\kappa n), \tag{9}$$

where $\kappa = (k_x + k_y)/2$ is the average curvature and F_o is the electric field of flat surface. Eq. (9) shows that the electric field is increased exponentially with curvature.

Particles on cavity can be electron emission sites. Metal particles can generate electron emission while insulating particles do not generate electron emission.

TOTAL ELCTRON EMISSION

Free electrons in metal obey Fermi-Dirac distribution and the electron density in 3-dimensions in terms of energy can be written as

$$n(E) = \frac{8\sqrt{2}\pi m^{3/2}\sqrt{E}}{h^3(1+\exp(-\frac{E-E_F}{k_B T}))}\,, \tag{10}$$

where E_F represents Fermi energy, E the energy of electron, m the mass of electron, h Plank constant and k_B Boltzmann constant. The electron density is filled up to Fermi energy at T=0 K. The distribution of electron density is changed a lot around Fermi energy when temperature is increased.

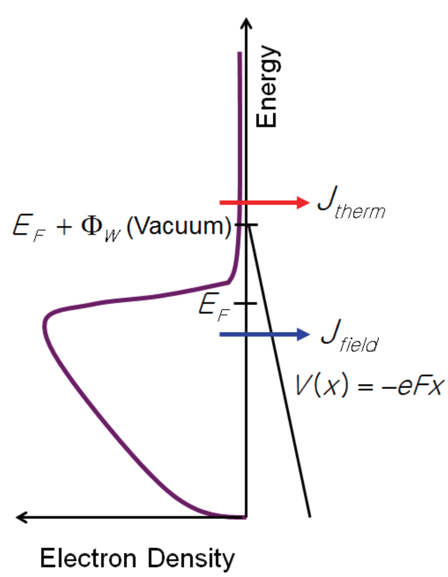

Figure 2: Schematic for electron emission theory.

Fig. 2 shows the schematic for electron emission theory. The electric field intensity is increased with the curvature of the cavity. Total electron emission consisting of thermionic emission and field emission can be expressed as

$$J_{tot} = J_{therm} + J_{field} \tag{11}$$

where J_{field} and J_{therm} are the current density of field emission and thermionic emission, respectively. Electrons above vacuum make thermionic emission and electrons below vacuum make field emission as shown in Fig. 2. Field emission which is considered at arbitrary temperature becomes [8]

$$J_{field} = \frac{16\pi m e k_B T}{h^3 (E_F + \Phi_w)} \int_0^{E_F+\Phi_w} dE \sqrt{E} \sqrt{E_F + \Phi_w - E} \ln\left(1 + \exp\left(-\frac{E - E_F}{k_B T}\right)\right) e^{-4k(E_F+\Phi_w-E)^{3/2}/3F}, \qquad (12)$$

where Φ is the work function. Thermionic emission becomes

$$J_{therm} = \frac{4\pi m e k_B^2}{h^3} T^2 e^{-\Phi_w / k_B T}, \qquad (13)$$

Total electron emission consists of field emission and thermionic emission.

SUMMARY

We have shown the total electron emission from electric field and temperature effect on the surface roughness of cavity. Electron emission can be limited by applying a resistor. The effect of surface roughness caused the increased curvature which focused electric field on cavity. Total current density of electron emission coming from field emission and thermionic emission was derived using free electron gas in metal, which works for arbitrary temperature and electric field.

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