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Determination of the Effect of Temperature on Electron Emission from the Surface of a Metal Using Emperical Approach

Ilo Frederick U*
Department of Electrical and Electronic Engineering, Faculty of Engineering, Enugu State University of Science and Technology (ESUT), Nigeria

Original Research Article

***Corresponding author**
Ilo Frederick U

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Abstract: The purpose of this study is to depict the changes that occur when the temperature of a metal is varied with respect to the emission current density with temperature. The investigation was done at the Electrical and Electronic Engineering workshop Enugu State University of Science and Technology. The study begins with introduction and general view of atom, its composition, electron emission and Temperature effect on electron emission. From the study, it was discovered that emission current density largely depends on temperature to the extent that any increase in temperature yields significant change in the current density. The graph obtained was a curve type. From the graph, it is clear that, the emission current density is directly proportional to temperature even though there is a slight deviation due to other factors.
Keywords: Temperature, Electron Emission, Surface Metal, Emperical Approach.

INTRODUCTION

The quest to know how temperature affects electron emission from the surface of a metal gave birth to this paper. There are many methods that can be used to determine how temperature affects electron emission such as experimental approach or by using Simulation Techniques. The technique used in this paper is empirical approach because of its simplicity, reliability and cost effectiveness. The valence electrons of the conductor atoms are loosely bound to the atomic nuclei. At room temperature, the thermal energy in the conductor is adequate to break the bonds of the valence electrons and leave them unattached to any one nucleus Jones and Langmair [1]. These unbound electrons move at random within the conductor and are known as free electrons Johannes Voss [2].

If an electric field is applied across the conductor, these free electrons move through the conductor in an orderly manner, thus constituting electric current. This is how these free electrons move through the conductor or electric current flows through a wire Manura D [6]. Many electronic devices depend for their operation on the movement of electrons in an evacuated space. For this purpose, the free electrons must be ejected from the surface of metallic conductor by supplying sufficient energy from some external source. This is known as electron emission Potter J.G [9]. The emitted electrons can be made to move in vacuum under the influence of an electric field, thus constituting electric current in vacuum.

MATERIALS AND METHODS

Materials needed for the study of electron emission include Cathode, Anode, Vacuum tube, Thermometer, power source etc. At extreme high and low temperatures, the values obtained from measuring temperature becomes tricky. But in order to be sure of the experimental values obtained, the instrument that can measure high or low temperature in a vacuum is needed, so we do not have such instrument in our Laboratory. The FP-400 tube we have in our laboratory was not built by us, so we have limited information about the device. For that, an empirical approach was adopted in order to determine the effect of temperature on electron emission.

Properties of electron emitter

The substance used for electron emission is known as an Emitter or cathode. The cathode when heated in an evacuated space will emit electrons. If the cathode were heated to the required temperature in open air, it would burn up because of the presence of oxygen in the air. For cathode to function properly, it should have the following three properties such as low work function, high melting point and high mechanical strength Murphy E.L [3]. In the case of Low work function, the substance selected as cathode should have low work function so that electron emission takes place by applying small amount of heat energy. Again for High melting point, the electron emission must takes place at very high temperatures say (>1500ºC), therefore, the substance used as a cathode should have high melting point Usmanni R [7]. For a material such as copper, which has the advantage of a low work function, it is seen that it cannot be used as a cathode because it melts at 810ºC. Consequently, it will vaporize before it begins to emit electrons. That is why copper cannot be recommended as a cathode. Finally, the emitter should have high mechanical strength to withstand the bombardment of positive ions. In any vacuum tube, no matter how careful the evacuation, there must always be some presence of gas molecules which may form ions by impact with electrons when current flows. Under the influence of electric field, the positive ions strike the cathode. If high voltages are used, the cathode is subjected to considerable bombardment and may be damaged Meir T and Stphanos C [5].

MODEL OF THERMIONIC EMISSION

The process of electron emission from a metal surface by supplying thermal energy to it is known as thermionic emission. At ordinary temperatures, the energy possessed by free electrons in the metal is inadequate to cause them to escape from the surface. When heat is applied to the metal, some of the heat energy is converted into kinetic energy, causing accelerated motion of free electrons. When the temperature rises sufficiently, these electrons acquire additional energy equal to the work function of the metal. Consequently, they overcome the restraining surface barrier and leave the metal surface. The commonly used materials for electron emission are tungsten, thoriated tungsten and metallic oxides of barium and strontium. In this study tungsten was used due to its availability and it is most common in the market. It may be added here that high temperatures are necessary to cause thermionic emission. For example, pure tungsten must be heated to about 2300ºC to get electron emission Schwede . J. W *et al*. [4]. However, oxide coated emitters need only 750ºC to cause thermionic emission Hidnert. P and Blair M.G [10].

Richardson-Dushman equation

The amount of thermionic emission increases rapidly as the emitter temperature is raised. The emission current density is given by Richardson-Dushman equation given below:

$$J_s = AT^2.e^{\frac{-b}{T}}(amp/m^2) - - - - - - - 1$$

where Js = emission current density *i.e*. current per square metre of the emitting surface
T = absolute temperature of emitter in K
A = constant, depending upon the type of emitter and is measured in amp/m2/K2
b = a constant for the emitter
e = natural logarithmic base
The value of b is constant for a metal and is given by:

$$b = \frac{\varphi.e}{k} - - - - - - - - - - 2$$

where φ = work function of emitter
e = electron charge = 1.602×10^{-19} coulomb
k = Boltzmann's constant = 1.38×10^{-23} J/K
By substitution into equation 2, we get

$$\therefore\ b = \frac{\varphi \times 1.602 \times 10^{-19}}{1.38 \times 10^{-23}} = 11600\ \varphi\ K$$

Putting the value of b into equation (*1*), we get, $Js = AT^2 e^{-11600\ \varphi/T}$ ………(*3*)

Empirical Analysis of Electron Emission using Tungsten

In this paper, Tungsten material was used to investigate the effect of temperature on the electron emission density. The properties of tungsten material used according to the manufacturer`s specification is shown in table 1. The analytical result computation of electron current density with varying Temperature is shown in table 2 while the graph is shown in Figure 1

Table-1: Properties of Tunsten

Metal/Emitter	Work Function	Operating temperature
Tungsten	4.52 Ev	2327ºC

We are going to consider a particular material (metal) and see how a change in the temperature will affect the emission current density.

The material (metal) to consider is **Tungsten**.
A ($A/m^2/K^2$) ➔ 602×10^3
b (k) ➔ 11600φK
φ (eV) ➔ 4.5

T (Operating temperature in K) ➔ 2300

Using Richardson Dushman's equation and
Applying substitution technique we have,
At operating temperature (2300);

$J_S = AT^2e^{-b/T}$

Note: b = 11600φ(K)
= 11600 x 4.5 = 52200k
$J_S = 602 \times 10^3 \times (2300)^2 \times e^{-52200/2300}$
$J_S = 602 \times 10^3 \times 5290000 \times e^{-22.6967}$
$J_S = 3.1846 \times 10^{12} \times 1.3912 \times 10^{-10}$
$J_S = 3.1846 \times 1.3912 \times 10^{12-10}$
$J_S = 443.06\ A/m^2$

Now we are going to keep work function of emitter constant but vary the temperature of the metal (Tungsten);
At temperature 2320K, $J_S = AT^2e^{-b/T}$
$J_S = 602 \times 10^3 \times (2320)^2 \times e^{-52200/2320}$
$J_S = 602 \times 10^3 \times 5382400 \times e^{-22.5}$
$J_S = 3.2402 \times 1.6919 \times 10^{12-10}$
$J_S = 548.21\ A/m^2$

At temperature 2350K, $J_S = AT^2e^{-b/T}$
$J_S = 602 \times 10^3 \times (2350)^2 \times e^{-52200/2350}$
$J_S = 602 \times 10^3 \times 5522500 \times e^{-22.21}$
$J_S = 3.3245 \times 2.2611 \times 10^{12-10}$
$J_S = 751.71\ A/m^2$

At temperature 2380K, $J_S = AT^2e^{-b/T}$
$J_S = 602 \times 10^3 \times (2380)^2 \times e^{-52200/2380}$
$J_S = 602 \times 10^3 \times 5664400 \times e^{-21.93}$
$J_S = 3.4100 \times 2.9917 \times 10^{12-10}$
$J_S = 1020.17\ A/m^2$ (Ans)

At temperature 2420K, $J_S = AT^2e^{-b/T}$
$J_S = 602 \times 10^3 \times (2420)^2 \times e^{-52200/2420}$
$J_S = 602 \times 10^3 \times 5856400 \times e^{-21.57}$
$J_S = 3.5256 \times 4.2881 \times 10^{12-10}$
$J_S = 1511.81\ A/m^2$

At temperature 2460K, $J_S = AT^2e^{-b/T}$
$J_S = 602 \times 10^3 \times (2460)^2 \times e^{-52200/2460}$
$J_S = 602 \times 10^3 \times 6051600 \times e^{-21.22}$
$J_S = 3.5256 \times 4.2881 \times 10^{12-10}$
$J_S = 2216.86\ A/m^2$

Table-2: The analytical result computation of electron current density with varying Temperature

Material (metal)	b (K)	φ (ev)	T (K)	J_S (A/m^2)
Tungsten	52200	5.0	2300	443.06
Tungsten	52200	5.0	2320	548.21
Tungsten	52200	5.0	2350	751.71
Tungsten	52200	5.0	2380	1020.17
Tungsten	52200	5.0	2420	1511.81
Tungsten	52200	5.0	2460	2216.86

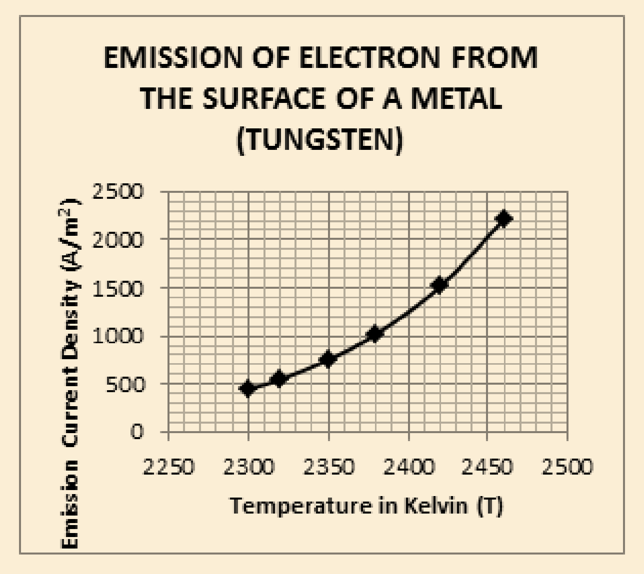

Fig-1: The graph of emission of electron from the surface of a metal (Tungsten)

The following points may be noted from eqn (3):

- The emission is markedly affected by temperature changes. Doubling the temperature of an emitter may increase electron emission by more than 107 times. For instance, emission from pure tungsten metal is about 10^{-6} ampere per sq. cm. at 1300ºC but rises to enormous value of about 100 amperes when temperature is raised to 2900ºC.
- Small changes in the work function of the emitter can produce enormous effects on emission. Halving the work function has exactly the same effect as doubling the temperature.

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