Manufacturing New Cold- Electron Emitter (Al- Al 2O3 – Pt)

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Abstract

In this experimental work, a cold electron emitter of the type MIM (Metal-insulator-Metal) was fabricated. In this study, aluminum, insulating aluminum oxide and platinum were used. Using an aluminum rod and then oxidizing the aluminum layer to form a thin layer of insulating aluminum oxide whose thickness is measured in nanometers. And then evaporating a thin layer of platinum over the insulator layer, which is a layer also measured in nanometers.

This emitter needs to work under the influence of very low pressure, or in a vacuum. And the emission of electrons in this case is under the influence of the electric field and a very high voltage difference, which goes up to 1000 volts and more, this voltage is suitable for operating an X-ray tube. It is a physical phenomenon described using the famous Fowler-Nordheim equation that gives the relationship between current density J and electric field E. It was clearly shown that the resulting current is subject to Fowler-Nordheim equation.

This is an electronic emitter that is used as a cold cathode in X-ray production equipment , which reduces the temperature of the X-ray tube by 1000 C0.

Introduction

The cold electronic emitter is one of the promising fields that may soon replace the thermoelectric emitters, because the cold emitters do not cause a high temperature of the discharge tubes used in many devices such as X-ray tubes.

The phenomenon of electroforming, or simply forming, of thin-film Metal-Insulator-Metal (MIM) structures has been known for half a century (Ghaforyan et al., 2008). Cold emitters based on thin film metal-insulator-metal (MIM) structures are of some interest to vacuum microelectronics purposes because of their low response time, ability to work under rough vacuum conditions, low operating voltages and reasonable lifetime.(Troyan and Katkova, 1996) Emission characteristics of MIM structures depend to a large degree on electroforming, the final step in the MIM emitter fabrication sequence. Despite the fact that we studied many features of this process because of their possible application as switching devices or cold cathode emitters(Biederman, 1976). Despite the fact that we studied many features of this process, its mechanism is not yet completely understood and calls for further investigation.

These cold cathodes require electric fields to deform the potential barrier between the emitting material and vacuum to let the electrons tunnel out of the material by Fowler-Nordheim emission(Marrese, 2000). Fluctuation-free electron emission is obtained from Metal-Insulator-Metal (MIM) cathodes(Kusunoki et al., 1993). The cathode used here is a cylindrical Al bar. The Al_2O_3 layer is formed by anodic oxidation with a low electrolysis current density, which leads to a low oxidation rate. The slow oxidation process improves the insulation of the Al_2O_3 layer, and allows the MIM cathodes to work in the non-formed state. Using a thin Al_2O_3 layer. The diode voltage needed for the cathode operation is minimized to values slightly above the work function of the top electrode (Pt).

Literature review

A metal/insulator/metal (MIM) cold cathode structure consists of two metal electrodes with an insulator between them. MIM cathodes have been widely investigated as a promising source of electron emission for FEDs due to their nearly fluctuation-free emission current, emission uniformity, highly directional electron beam and inherent insensitivity for surface contamination (Liu et al., 2011)

The thickness of the first layer of the Au film (inner electrode) was controlled to be less than 10 nm to ensure electron tunneling. The actual

thickness of the insulator layer ranged from 5 to 20 nm because the sputtered film was not uniform. The field-emission tests were carried out in a vacuum chamber with a vacuum greater than 3×10−4 Pa (Liu et al., 2011)

The oldest documented emitter MIM was accomplished using aluminum, aluminum oxide, and aluminum by R.E.Collins and L.W.Davies (Collins and Davies, 1964).

The base was aluminum as a metal and aluminum oxide as an insulator with distinctive properties(Rousina and Shivakumar, 1988), while the third metal was chosen and the characteristics of the resulting current were studied. Au is used in most experiment since 1962 (Kanter and Feibelman, 1962, Hu et al., 2014). Al-AlOx-Ag was studied 2003 by Detlef Diesing (Diesing et al., 2003). Cu was used in Cu–SiOx–Cu by R G Sharpe (Sharpe and Palmer, 1996b).2006 , Au/Cef3/Au thin film studied by H. Ghaforyana(Ghaforyan et al., 2008) . Then in 2010 Au/MgF2/Au thin film was fabricated by Hossein Ghaforyana (Ghaforyan et al., 2010). Also a tungsten/silica/tungsten (W/SiO2/WW/SiO2/W) structure on a tungsten substrate as a thermophotovoltaic emitter was studied by Jinlin Song (Song et al., 2016). Ghaforyan discussed of the electroformed metal-insulator-metal structures Au-MgF2-Au and comparison with other Au-SiO/CeF3-Au, Cu-CeF3-Cu, Cu-SiO-Cu, Au-CeF3-Au specimens (Ghaforyan and Ebrahimzadeh, 2011).

Theory

MIM cathodes advantage : Cold electronic emitters MIM have important characteristics that made them receive great attention from researchers, the most important of which are:

1. Non-heated(Troyan, 1995)
2. They are less susceptible to surface contamination than other cold cathodes(Martin et al., 1960).
3. Continue work on developing an emitter array for emitter applications. The simplicity of design and fabrication technique (Troyan, 1995)
4. Considering the fact that their response time is less than 10/sup -8/ s and operating pressure is about 10/sup -5/ torr, MIM cathodes are quite competitive with other types of non-heated emitters (Troyan, 1995).

5. When a bias voltage is applied across an unformed sample an electroforming process takes place and the device resistance is decreased(Ghaforyan et al., 2008).
6. MIM has been shown to exhibit an attractive longevity of electron emission(Hu et al., 2014)

The theory of the electric tunnel effect is used for asymmetric junctions—i.e., junctions having electrodes of different materials as MIM device (Simmons, 1963a).

Fowler –Nordheim Equation : Cold field emission of electrons is governed by the Fowler-Nordheim (FN) equation(Ghaforyan et al., 2008, Sharpe and Palmer, 1996a), and when the tunneling barrier includes the image potential the calculation of emission current density involves evaluation of elliptic integrals (Forbes, 1999). The Fowler-Nordheim equation in solid state physics relates current, work and electric field strength to determine field emission. It has two parts: an equation for field emitted current density, and the equation for total current. It is named after Ralph H. Fowler and Lothar W. Nordheim (Jensen, 2003). For M-I-M cathodes (Fig. 2(a)), on the other hand, the potential difference determining the mean field is known and can easily be directly changed.

The current density flowing through a thin oxide layer due to Fowler-Nordheim tunneling is a function of the electric field across the oxide(Jensen, 2017). The electric field is the voltage divided by the distance. This article describes how quickly current increases with voltage(Forbes, 1999).

V = voltage, volts $E = V/t$ electric field, volts per meter
I = current, amperes $J = I/A$
J = current density in amperes per square meter
K_1 is a constant described in the reference
K_2 is a second constant, also described in the reference

For the Fowler-Nordheim tunneling current density (Jensen, 2003) :

$$J = K_1 . E^2 \exp(-\frac{K_2}{E})$$

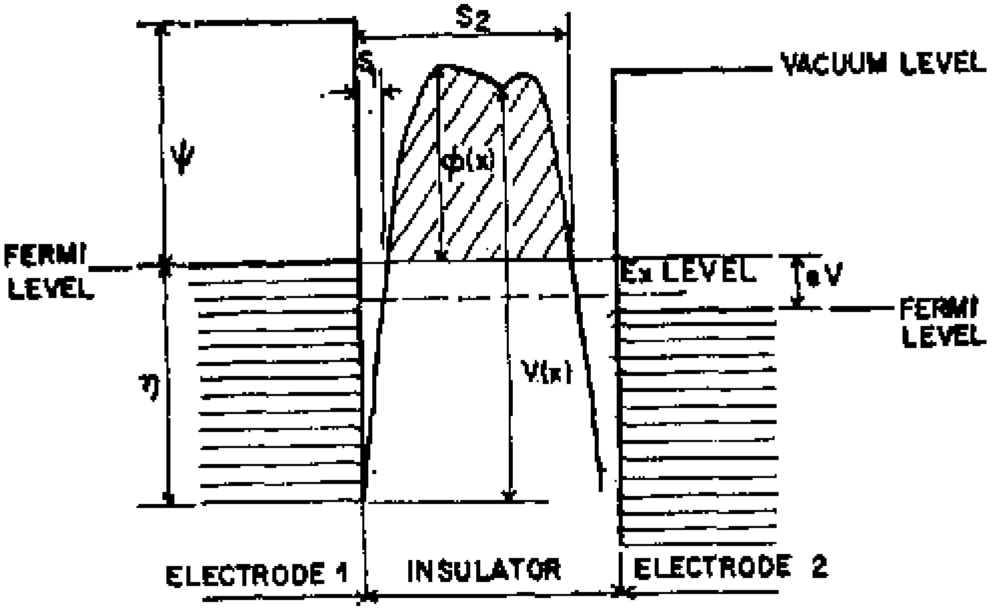

Figure 1 : General barrier in insulating film between two metal electrodes (Simmons, 1963b)

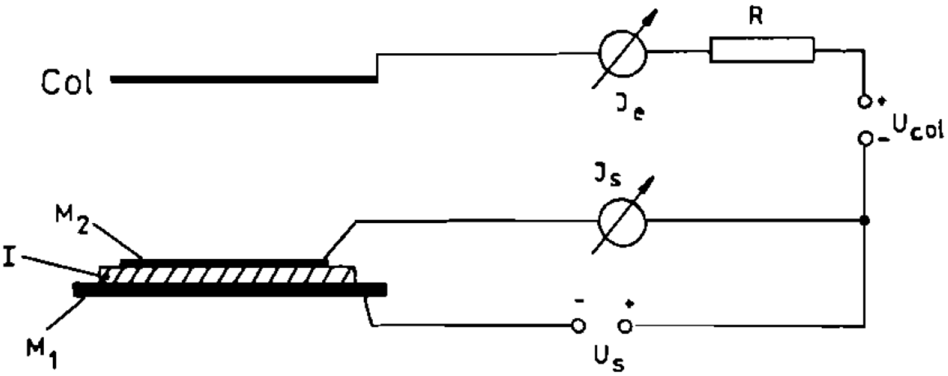

Figure 2: MIM cathode circuit (ECKERTOVÁ, 1990)

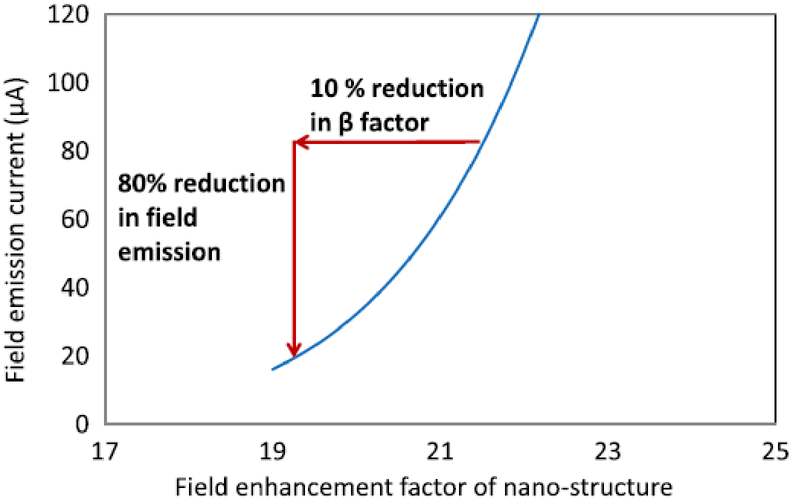

Figure 3. Calculation of the field emission using the Fowler-Nordheim equation from a cathode (Almaksour et al., 2014)

The point is that the current increases with the voltage squared multiplied by an exponential increase with inverse voltage. While the second factor, E^2, obviously increases rapidly with voltage, the third factor, the exponential, deserves another sentence. For people who are not familiar with exponentials of negative inverses, the following sentences are helpful.

Assume, temporarily, that K_2 is normalized to be 1.

Experiment

The Al-Al_2O_3-Pt structure was fabricated .A cylindrical Al bar was brought with the diameter of 2.97mm and the length of 5 cm

1. Cleaning the Al Bar

The aluminum column was washed with distilled water and exposed to HF acid to remove any oxide layer.

2. Chemical oxidation

The Al bar was anodically oxidized in a tartaric acid solution neutralized with ammonia (pH 6.3). The rate of oxidation was determined by limiting the electrolysis current density J_{ox}, which was kept constant during the oxidation process. When J_{ox} was 0.4μA/cm^2 it took 10 hours to create a 5.-nm-thick Al_2O_3 layer, but when J_{ox} was 500 μA/cm^2, the oxidation processed in only 20 seconds.

3. Sputtering Pt on Al_2O_3

A 10-nm-thick platinum film was then sputtered on the Al_2O_3 layer with spurting machine (**The BOC Edwards Auto 500 box chamber system).**

4. Metallization

The Pt and Al layer is connected with circuit by thin copper wire by silver liquid

5. Applied the voltage

The MIM cathodes were fixed in a vacuum chamber evacuated to a pressure of 2×10^{-5} torr , at room temperature . Diode voltage – V_d was applied to the base (Al) electrode while the top (Pt) electrode was grounded. Emitted electrons were collected by a semi-cylindrical anode (Aluminum foil) with a radius of 7 mm surrounding the aluminum bar which is in the axis center.

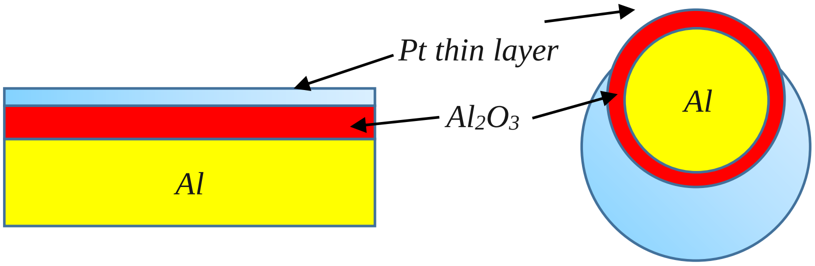

Figure 4:Cross section of bar sample

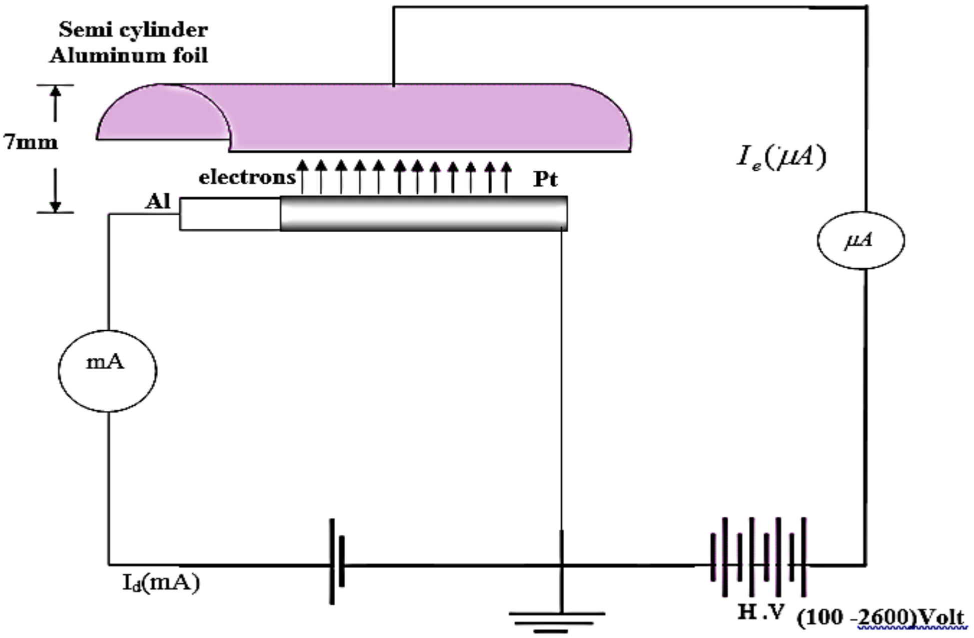

Figure 5 : DC High Voltage Circuit

Result and Discussion

The researchers reported that to improve the insulator they firstly, decreased the thickness to 5 – 7 nm without the occurrence of the forming process or electrical breakdown. Secondly, they obtained an emission current density of 1-50µA/cm^2.

The I-V output current from the MIM rod was studied using the circuit shown in Figure 4. The study was carried out under very low and constant pressure , at room temperature. When fixing the value of the current I_d, and changing the voltage V_d, we get the ascending values of the current I_e with the voltage according to Table 1. It is noted that the relationship of current with voltage is not a linear relationship according to graph 4, but rather it is clearly an exponential relationship.

Table 1 : Data of Cold Emitters Metal-Insulator-Metal (MIM) for I_d= 1A and V_d=3 Volt

Ve(Volt)	Ie(nA)	Ln(Ie)
200	152	5.023881
250	182	5.204007
300	222	5.402677
350	260	5.560682
400	300	5.703782
450	332	5.805135
500	372	5.918894
550	414	6.025866
600	450	6.109248
650	482	6.177944
700	525	6.263398
750	570	6.345636
800	610	6.413459
850	650	6.476972
900	694	6.542472
950	755	6.626718
1000	800	6.684612
1100	928	6.833032
1200	1000	6.907755
1300	1145	7.04316
1400	1260	7.138867
1500	1380	7.229839
1600	1518	7.325149
1700	1635	7.399398
1800	1780	7.484369
1900	1911	7.555382
2000	2117	7.657755

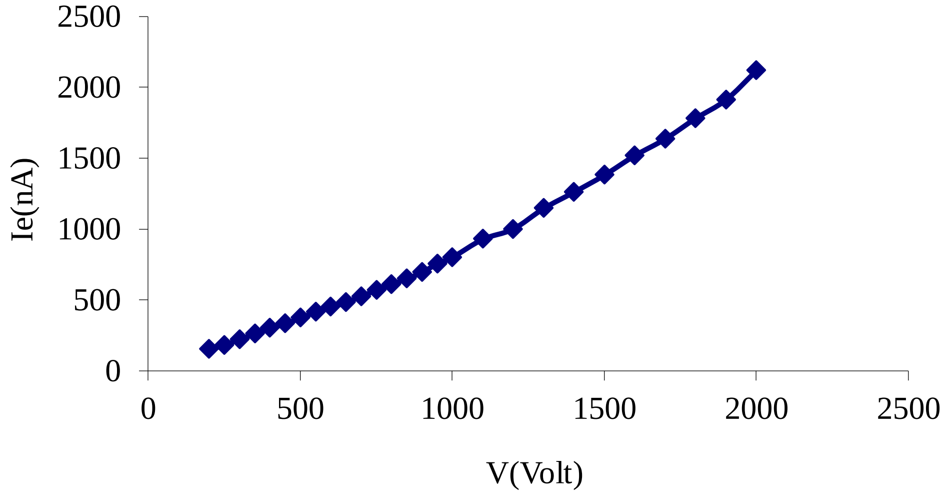

Figure 6: *I-V* Curve of MIM device

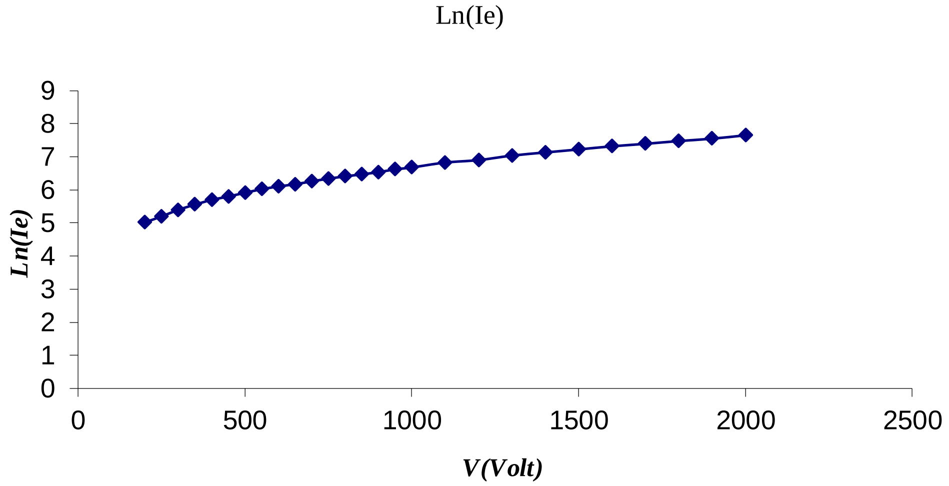

Figure 7:*LnI-V* Curve of MIM device

The current is stable, fluctuation-free electron emission. And possibly the current follows Fowler-Nordheim mechanism, we can see corresponding between theoretical curve of Fowler-Nordheim (Figure 3) and expermintal curve above (Figure 6). Filaments are thought to be created between the metal electrodes which bridge the insulating gap, and the device is said to be electroformed (or simply formed). This process can lead to the emission of energetic electrons from the device into the vacuum(Sharpe and Palmer, 1996a).

Conclusion

Experimental results show that Al-Al_2O_3-Pt device have high circulating current at room temperature and can be implication for the production of commercial electroformed devices such as cold cathode. And it turns out that the cold electronic emitter works at room temperature and in conditions of high discharge. Also, the characteristics of the emitter current showed that it clearly follows the Fowler-Nordheim equation.

It is a simple cold electronic emitter that can be manufactured in a simple way. This emitter can work effectively in completely vacuum tubes without causing the tube temperature to rise. Therefore, it is very effective in X-ray production tubes.

Recommendations and suggestions for future studies

1. It is highly suggested that the device be used in an experiment to produce X-rays and to test the effectiveness of the device.
2. It also suggested testing the effectiveness of other metals and different insulators and testing the characteristics of the output current in each case.
3. It is also possible to change the thickness of each layer in the device and test the properties in each case separately to reach the best cold type MIM emitter.

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