Fabrication of a New Cold Electron Emitter Type (Metal- insulator -metal) Using (Al - Al_2O_3 – Pt)

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Summary

In this experimental work, a cold electron emitter of the type MIM (Metal-insulator-Metal) was fabricated. The study employed aluminum, insulating aluminum oxide and platinum. 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 insulation layer, which is 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 more than 1000 volts. This voltage is suitable for operating an X-ray tube. It is a physical phenomenon described using the famous Fowler-Nordheim equation that refers to 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 C^0.

And it turns out that the cold electronic emitter works at room temperature and in conditions of high discharge.

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 tube.

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ABSTRACT

The use of cold electronic emitters in the production of X-rays is one of the most promising new applications. In this research, a cold electronic emitter with three layers (metal - insulator - metal) was achieved using aluminum, platinum and aluminum oxide, respectively.

The results showed the effectiveness of this emitter in producing a stable current in microamperes. It works under the influence of high voltage difference of up to 2000 volts and maintains a stable state, where the relationship between current and voltage shows that it follows the Fowler-Nordheim curve.

The use of a cold electron emitter instead of a heated emitter in the X-ray tube makes the temperature of the X-ray tube significantly lower. It may also reduce the cost of producing an X-ray tube.

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, Bidadi 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 due to 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, Suzuki 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, Chen 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, Chen 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, Zhang et al. 2014). Al-AlOx-Ag was studied 2003 by Detlef Diesing (Diesing, Kritzler et al. 2003). Cu was used in Cu–SiOx–Cu by R G Sharpe (Sharpe and Palmer 1996).2006 , Au/Cef3/Au thin film studied by H. Ghaforyana(Ghaforyan, Bidadi et al. 2008) . Then in 2010 Au/MgF2/Au thin film was fabricated by Hossein Ghaforyana (Ghaforyan, Bidadi 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, Si 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. Not heated (Troyan 1995)
2. They are less susceptible to surface contamination than other cold cathodes(Martin, Trolan 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 a unformed sample, an electroforming process takes place and the device resistance is decreased(Ghaforyan, Bidadi et al. 2008).
6. MIM has been shown to exhibit an attractive longevity of electron emission(Hu, Zhang 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 1963).

Fowler –Nordheim Equation : Cold field emission of electrons is governed by the Fowler-Nordheim (FN) equation (Sharpe and Palmer 1996, Ghaforyan, Bidadi et al. 2008), 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).

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),(Ghaforyan, Bidadi et al. 2010) :

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

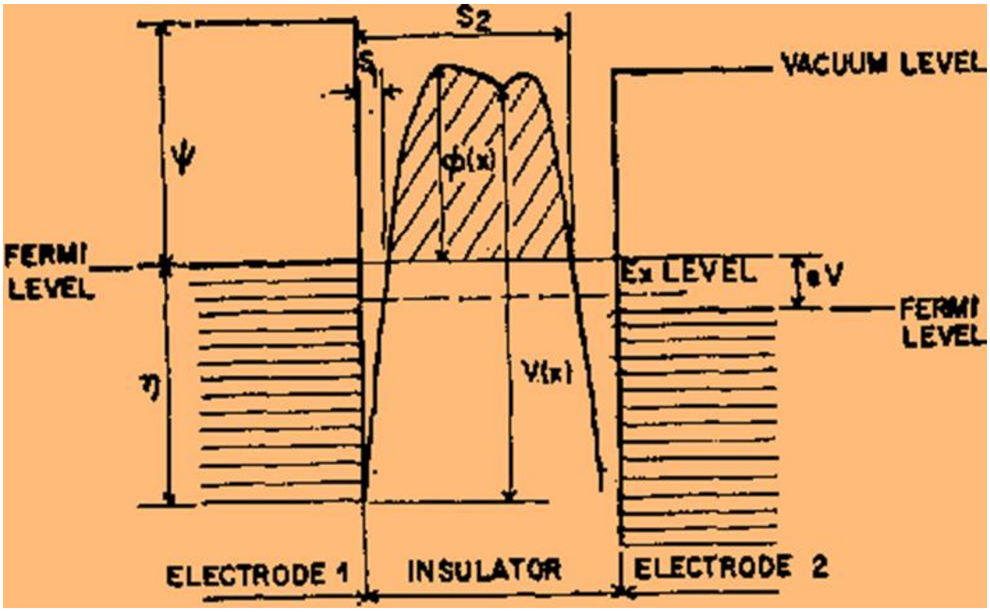

Figure 1 : General barrier in insulating film between two metal electrodes (Simmons 1963)

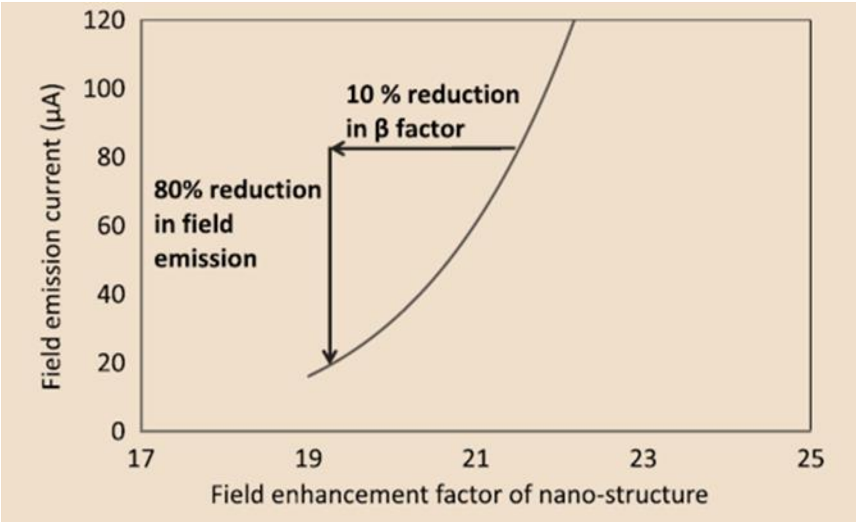

Figure 2. Calculation of the field emission using the Fowler-Nordheim equation from a cathode (Almaksour, Kirkpatrick et al. 2014)

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.

The 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. However, when J_{ox} was 500 μA/cm^2, the oxidation process was 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. Applying 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.

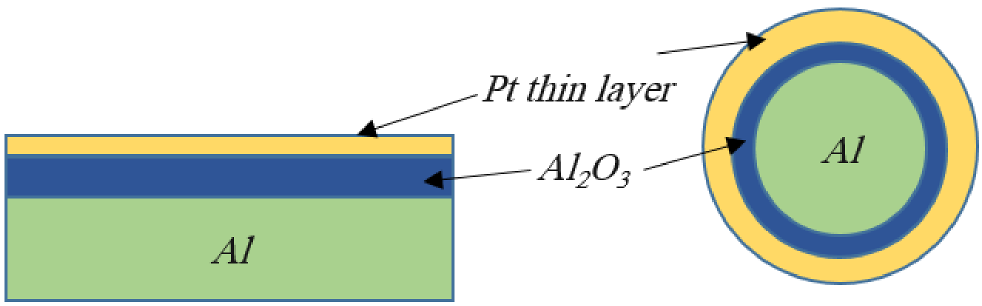

Figure 3:Cross section of bar sample

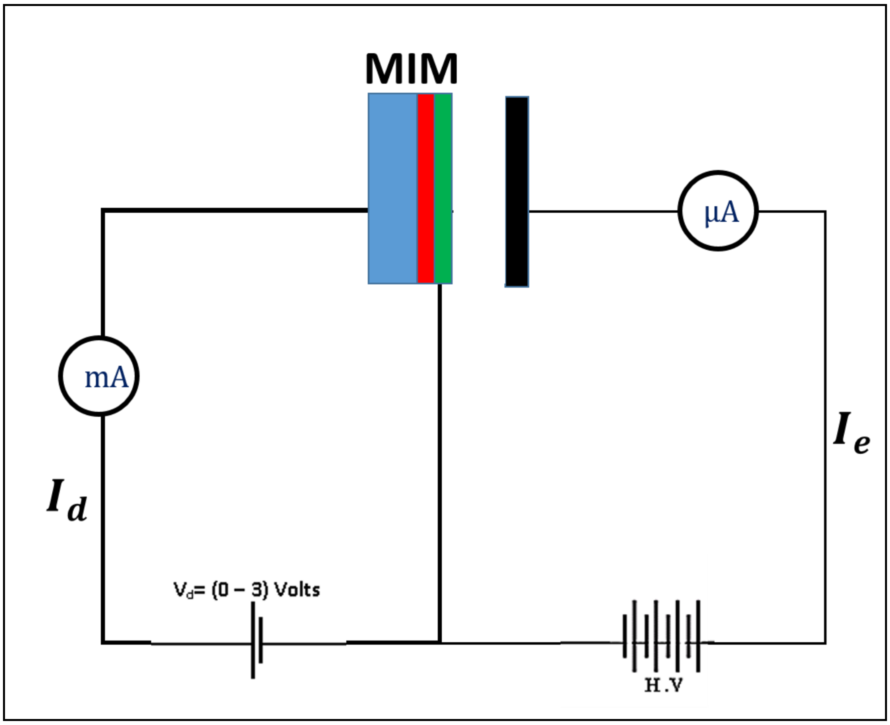

Figure 4 : DC High Voltage Circuit

Results and Discussion

The *I-V* output current from the MIM rod was studied using the circuit shown in Figure 5. 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 Figure 5. It is noted that the relationship of current with voltage is not a linear relationship, but rather it is clearly an exponential relationship.

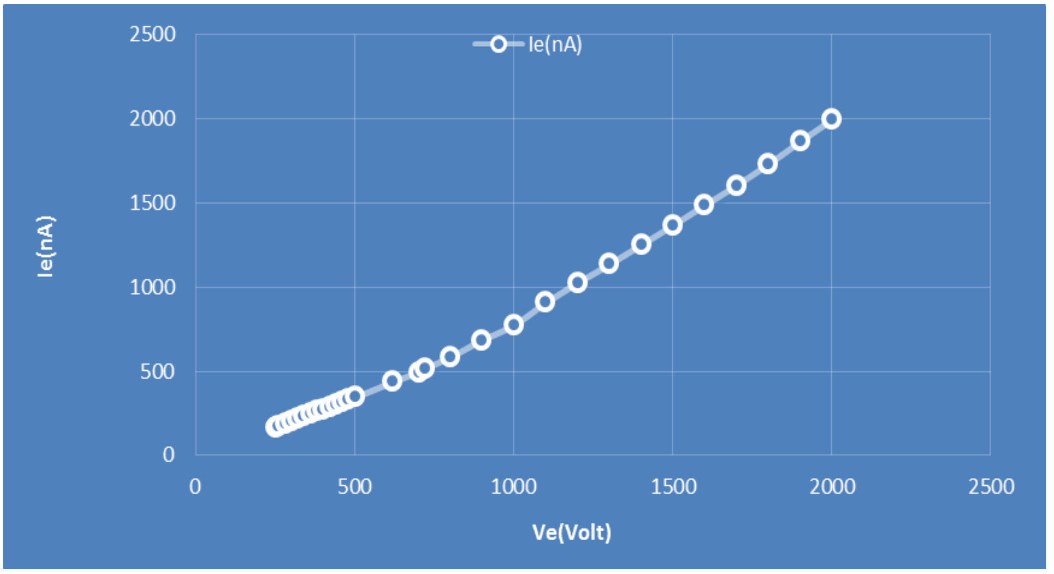

Figure 5: *I-V* Curve of MIM device

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 2) and the curve above (Figure 5). 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 1996).

Conclusion

Experimental results show that Al-Al_2O_3-Pt device has a high circulating current at room temperature and can be utilized for the production of commercial electroformed devices such as cold cathode. Furthermore, 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.

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الملخص

في هذا العمل التجريبي، تم تصنيع باعث إلكتروني بارد من النوع) MIM(معدن – عازل-معدن). في هذه الدراسة تم استخدام الألومنيوم وأكسيد الألومنيوم والبلاتين العازل. استخدام قضيب من الألومنيوم ثم أكسدة طبقة الألمنيوم لتكوين طبقة رقيقة من أكسيد الألومنيوم العازل التي يقاس سمكها بالنانومتر. ثم تبخر طبقة رقيقة من البلاتين فوق الطبقة العازلة ، وهي طبقة تقاس أيضًا بالنانومتر.

يحتاج هذا الباعث إلى العمل تحت تأثير ضغط منخفض جدًا ، أو في فراغ. وانبعاث الإلكترونات في هذه الحالة يكون تحت تأثير المجال الكهربائي وفرق جهد عالي جدًا يصل إلى 1000 فولت وأكثر ، وهذا الجهد مناسب لتشغيل أنبوب الأشعة السينية. إنها ظاهرة فيزيائية موصوفة باستخدام معادلة فاولر-نوردهايم الشهيرة التي تعطي العلاقة بين كثافة التيار J والمجال الكهربائي . وقد تبين بوضوح أن التيار الناتج يخضع لمعادلة فاولر-نوردهايم.

هذا باعث إلكتروني من الممكن أن يستخدم ككاثود بارد في معدات إنتاج الأشعة السينية ، مما يقلل درجة حرارة أنبوب الأشعة السينية بمقدار 1000 درجة مئوية.

واتضح أن الباعث الإلكتروني البارد يعمل في درجة حرارة الغرفة وفي ظروف التفريغ العالي. إنه باعث إلكتروني بارد بسيط يمكن تصنيعه بطريقة بسيطة. يمكن أن يعمل هذا الباعث بشكل فعال في أنابيب مفرغة تمامًا دون التسبب في ارتفاع درجة حرارة الأنبوب. لذلك ، فهي مناسب للغاية في أنبوب إنتاج الأشعة السينية.