

Dielectric Charging on Bottom Surface of Electron Hop Funnels

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Abstract—Current work on electron hop funnels has identified a hysteresis when measuring the IV curve. The source of the hysteresis is the focus of this work. It is believed that the source of the hysteresis is a charging of the dielectric on the bottom of the device. This hypothesis will be tested by constructing new hop funnels with and without a metal layer on the bottom surface to bleed away any charge. The results of the study are presented here.

Index Terms—Field emission arrays, secondary electron emission, surface charging, vacuum microelectronics.

I. INTRODUCTION

FIELD emission arrays (FEAs) have many benefits over thermionic cathodes as an electron source. A FEA can be spatially controlled, modulated at a higher frequency, and controlled with much lower turn on voltages [1] than a thermionic cathode. However, FEAs suffer from poor emission uniformity and lifetimes. By overcoming these disadvantages, FEAs could be used in a variety of applications such as integration into microwave vacuum electron devices (MVEDs).

Hop funnels and FEAs have been studied and proposed for integration into various devices. Previous work has included simulation work and experimental studies [2]-[4]. The use of hop funnels has been proposed for crossed field amplifiers [5], faceted cold cathode magnetrons [6], and field emission displays [7].

This work investigates a hysteresis that was observed in previous experimental work on electron hop funnels. A hop funnel is a dielectric material that has been milled into a funnel shape. A cross-sectional diagram of a hop funnel is shown in Fig. 1. The device operates by placing the funnel on top of a FEA array. The array injects electrons into the wide end of the funnel and, through electron-hopping transport [8], the current is sustained along the funnel wall until it reaches the funnel exit. Electron-hopping transport is the phenomenon where current is sustained along a dielectric surface by electrons hopping along the surface via secondary electron emission [8]-[11].

An electrode is placed around the funnel exit, labeled here as the hop electrode, and provides the necessary electric field to pull electrons through the funnel and sustain secondary electron emission on the funnel wall. When the potential of the

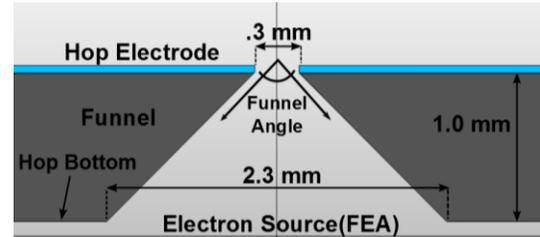


Fig. 1. A cross sectional view of a hop funnel showing the dimensions used for the constructed 90° funnels.

hop electrode is sufficiently high, the amount of current leaving the funnel is the same as the current injected into the funnel; this is known as unity gain [8]. When the potential of the hop electrode is low, the electric field in the funnel is not sufficient enough to sustain the current on the wall and no current is transmitted. The relation between the hop voltage and the transmitted current is referred to here as the I-V characteristic.

This work will focus on the I-V characteristic and a hysteresis that was observed when ramping the hop electrode voltage. When the hop voltage was ramped from a low (0V) to a high voltage (550V) the transmitted current behaved differently then when the opposite ramp was performed (550V to 0V).

It was believed that charging on the hop bottom, labeled in Fig. 1, was the source of the hysteresis. To test this hypothesis a metal charge bleed layer, referred to here as the hop bottom electrode, was deposited on the bottom of the hop funnel to prevent charging of the dielectric on the bottom of the hop funnel.

For this work hop funnels have been constructed out of Low Temperature Co-fired Ceramic (LTCC) [12]. Fig. 2 shows an image of the constructed funnels. The hop funnels have been constructed, tested, and analyzed. The results of this work are presented here.

II. EXPERIMENTAL SETUP

The experiments for this work focused on studying the current transmitted through the funnel versus the potential on the hop electrode or the I-V characteristic of the hop funnel. This work was done by ramping the DC voltage on the hop electrode and measuring the current to the anode. Fig. 3 shows a representative picture of the experimental setup.

A. Field Emission Array

The FEAs used in the experiments presented here were

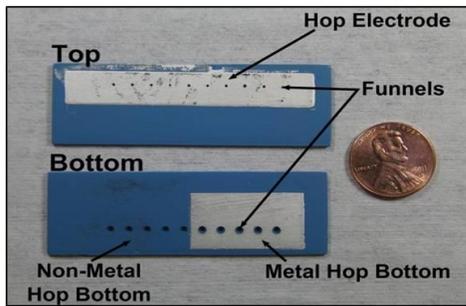


Fig. 2. A cross sectional view of a hop funnel showing the dimensions used for the constructed 90° funnels.

constructed by PixTech for use in field emission displays (FEDs). These cathodes contain Spindt type field emitters [13] and were obtained in their original FED packaging; therefore they had to be de-packaged. Once de-packaged, the cathodes had to be scribed and broken to remove portions that were not essential to this work.

Scribing of the cathode usually created unwanted resistive paths in the cathode resulting in a high leakage current between the gate and emitter electrodes. Reverse biasing of sections that were meant to be off was often not possible due to the large leakage current; therefore these sections were left floating, and they were commonly seen to emit current.

B. Hop Funnel Construction

Two different hop funnels were constructed for this work: one funnel was constructed with a metal hop-bottom and one without. Both of the constructed funnels had a funnel angle of 90° .

The funnels were constructed of LTCC, which is sold in thin flexible sheets. The sheets are heat pressed together to the desired thickness and can be milled to form holes or slits. A 90° bit was used to mill the funnel shapes into the LTCC. After milling, the structure was fired to cure it. Finally, the hop electrode and metal hop bottom were applied by using a silver paint that was applied by hand to the LTCC.

C. Experiment Configuration

The experimental setup is shown in Fig. 3. The FEA cathode is placed on a metal block biased at V_{cathode} . The hop funnel is then placed on top of the cathode, suspended as closely as possible ($<1\text{mm}$). An anode biased at earth ground is placed over the funnel exit (anode to funnel gap $\approx 1\text{cm}$) to measure the transmitted current. The gate voltage is held constant ($\approx 80\text{ V}$) to emit a constant current from the FEA. The hop funnel voltage is swept from 0 to 550 V and then back to 0 V over a period of 20 s.

III. RESULTS AND DISCUSSION

The I-V measurement results were found to be very consistent within one setup but very different from setup to setup. Each time the structure was removed from the chamber to recreate the same experiment on a different location of the cathode or using a different funnel of the same type, the I-V curves would show different behavior. The “new” behavior, however,

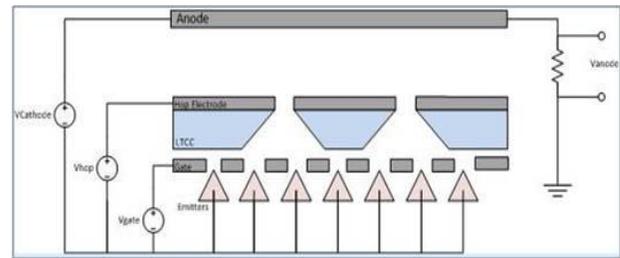


Fig. 3. Experimental setup showing the anode, field emission array, and hop funnel.

would be consistent within that setup. Many different setups were tested with and without the metal hop bottom. Fig. 4 shows the results that were most commonly observed for the hop funnels with and without the hop bottoms.

It is immediately apparent that the hysteresis is present with and without a metal hop bottom. In Fig. 4 it can be seen that the metal hop bottom has little effect on the hysteresis. The IV curves with and without the metal had very similar results.

An evolution of the curve was also often seen in all cases. The amount of current that was transmitted through the device would decrease with each subsequent ramping sequence. In some cases, the curve would evolve to the point that no current would be observed at any hop voltage. The current would then “reset” itself if an arc occurred near the cathode or if the device was not operated for a few hours. This behavior is evidence of unwanted charging of a dielectric somewhere in the experimental setup.

In Fig. 4 it is possible to see that the ramp down transition occurs at a higher voltage than the ramp up was most common. While this was the most common behavior, it was not always the case. Fig. 5b shows a case where the 90° funnel exhibited the opposite type of behavior as the ramp up transition occurred at a higher voltage. This is the only example of this behavior in this paper, but this phenomenon occurred often and is not an outlier.

Some I-V curves, Figs. 5a and 5b, also show discrete levels of transmission. This behavior was very common, and it is thought that these levels may be caused by ridges or bumps on the surface of the funnel wall. To confirm this, a cross section of the funnels will be studied in future work and then simulated.

The wide range of results is discouraging, but is not uncommon when dealing with secondary electron emission [14]. Hopping transport is very susceptible to external forces [8] and slight changes in the setup can drastically change the results. Monolayers, gas or contaminants, formed on the funnel wall will change the SEY characteristic of the material which will affect the I-V curves. Removing the structure from vacuum to modify the structure will result in an inconsistent surface. Also, monolayers on the cathode will affect the emission properties, resulting in an inconsistent electron beam. Spontaneous current near the interaction region, caused by leaving the unused pixel lines floating, may also modify the results. All these factors contribute to the differences observed in the results.

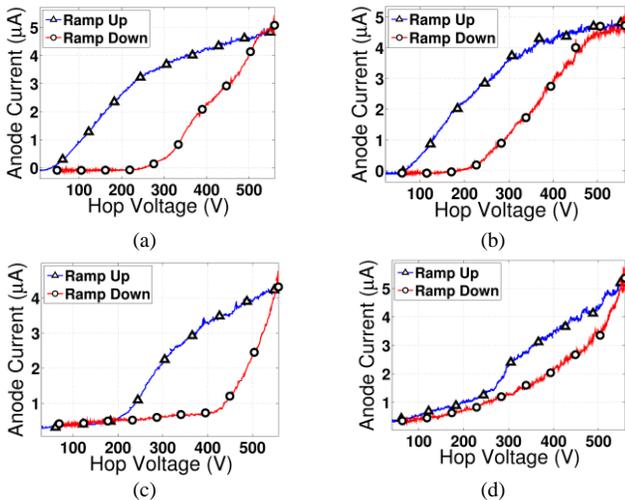


Fig. 4. I-V curve behavior that was most commonly seen with the funnels where (a,b) are funnels without a metal bottom and (c,d) have a metal hop bottom. A more linear behavior was seen with these funnels, but was not always the case.

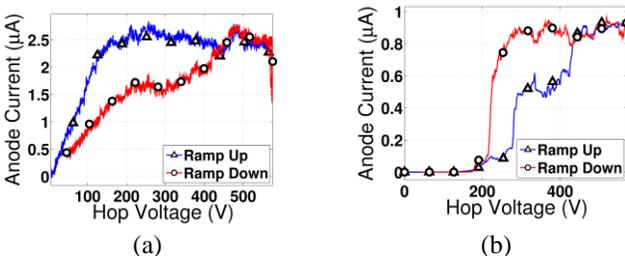


Fig. 5. I-V curves showing the range of results that were observed. (a) is a funnel with a metal bottom; notice that the funnel reaches unity gain at a much lower voltage than common results shown in Fig. 4. (b) is a 90° funnel without a metal bottom; this specific case showed more of a 'knee' type behavior. Also, notice that the ramp down had a lower transition voltage than the ramp up.

IV. CONCLUSION

Overall, the experiments show a wide range of results, but it is clear that hysteresis is still present and that the metal hop bottom has little effect on the hysteresis. Future work will include the simulation of the hop funnels to examine if hysteresis can be simulated.

Future work could be improved by maintaining the integrity of the samples. Working in a clean room and using vacuum heating elements would both reduce contaminants and improve the experiment. While this would decrease some of the variability in this work it is not feasible in our current setup.

This work has advanced the understanding of how electron funnels operate and indicated that there still exists another source of hysteresis. Through further investigations the use of hop funnels would allow for using FEAs in devices such as MVEDs, charge neutralizers, and even allow for a new method to determine secondary electron parameters of dielectrics.

Parts of this work are to be submitted for publication in the IEEE Transactions on Plasma Science.

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