CHAPTER 3
EXPERIMENTAL SETUP AND INSTRUMENTATION

3.1. Introduction

In this chapter, the experimental setup and measurement electronics are presented. The effect of O\textsubscript{2} exposures on Au coated field emission arrays (FEAs) was examined by studying the degradation in anode current for Au coated arrays and comparing them to the results obtained for uncoated arrays.

3.2. Gas Exposures on FEAs – Emission Studies\textsuperscript{1}

The UHV system shown in Figure 3.1 consists of a Perkin-Elmer TNB-X/1000 ultra high vacuum (UHV) analytical chamber equipped with an ion pump and a titanium sublimation pump. A turbo molecular pump was used for initial pump down to the UHV range. After a 24-hour bake out at 100 °C, a base pressure of 8 \times 10^{-9} torr was attained.

This low operational base pressure assures control of the residual species for the field emission array ambient. A sapphire sealed variable leak valve was used for introducing the gases into the system. The total pressure in the system was measured using a UHV nude ionization gauge. This permitted control of gas partial pressures from 1 \times 10^{-8} to 2 \times 10^{-6} torr.

The field emitter array is mounted on a FEA holder, which has a provision for attaching an anode. The spacing between the cathode and anode is 1 cm and the terminals are electrically isolated. The cathode is grounded while the gate electrode is positively biased for field emission.
Figure 3.1 Schematic layout of the experimental apparatus for studying the effects of gas exposures on active field emitter arrays.\(^1\)

The effects of contamination of the cathode array from anodes coated with cathodoluminescent or metal-oxides have been reported.\(^2\) To avoid such spurious effects, the emitted electrons in this study are collected on an inert platinum coated silicon anode. The gate to cathode potential (\(V_g\)) and the anode current (\(I_a\)) are monitored throughout each experiment.

The instrumentation and data acquisition electronics setup are shown in Figure 3.2. The power supplies and measurement electronic devices, equipped with the IEEE-488 interface are connected to a personal computer with a GPIB (IEEE-488) card. Automated data acquisition and control is accomplished with Labview 6.0i software.\(^3\)
which uses the IEEE-488 interface bus. Labview is a user-friendly graphical program with the ability to control and read data from up to 14 instruments.

Figure 3.2 Schematic of the instrumentation and data acquisition electronics setup used for measuring the effects of gas exposures on active FEAs.¹
3.3. Electrical Connections

3.3.1 Gate Power Supply & Programmer

The circuit diagram in Fig 3.2 shows the HP 59501B\(^4\) power supply programmer as a controller for the HP 6209B\(^5\) DC power supply. The HP 59501B is controlled by the GPIB interface and an output voltage signal (0 – 10V) is sent to the HP 6209B power supply, which is amplified to get the output gate voltage (0-100V).

The amplification, or gain, is determined by the value of the resistors used. For all our experiments, \( R_p = 10k\) and \( R_R = 1k\). This gives a gain of about 10 and a range of approximately 0 – 100V. The HP 59501B voltage programmer and HP 6209B power supply were calibrated (see appendix) and tested for the output voltage. The accuracy of the power supply was approximately 0.5%, so the error in voltage was less than 0.5V up to 100V.

\[ \text{Voltage Gain:} \]
\[ ? = \frac{V_{Output}}{V_{Input}} = \frac{R_p}{R_R} = 10 \]

**HP59501B Power Supply Programmer:**
*Output Range is 0 – 10 V DC*

**HP6209B Power Supply:**
*Output Range is 0 – 100 V DC (Limited by the Gain of the above Setup)*
3.3.2 Anode Power Supply, Programmable Pulse Generator & Oscilloscope

A 330\(\Omega\) resistor was connected as shown in Fig 3.2. The voltage pulse was measured across the ends of the resistor. The anode current was calculated by dividing the voltage (oscilloscope) by 330. There was some reduction in the total anode current due to the resistor, but it can be neglected as it is less than 1%. The anode voltage was kept constant at 300V with respect to the cathode.

In the pulsed mode of operation, the gate voltage, \(V_g\), was switched on and off at the desired rate (duty cycle) using a high speed switching circuit (Figure 3.4). A
programmable pulse generator SRS DG-535\textsuperscript{6} provides the necessary control signals to the high speed switching circuit, whose output modulates between 0 and $V_g$. The anode current waveform measurements were performed using a Lecroy 9310 digital oscilloscope.

Figure 3.4 A high speed switching circuit designed for the pulsed mode operation
An example of the voltage pulse measured by the oscilloscope is shown in Figure 3.5. Each square represents 50\(\mu\)s (X - time) and 0.64V (Y – voltage). The pulse shown below is not a perfect square wave and has a rise time of approximately 28\(\mu\)s, an ON time of approximately 20ms and a fall time of 2\(\mu\)s.

![Waveform graph showing the 50\(\mu\)s Anode Current pulse at 0.5% Duty Cycle](image)

**3.4. Evaporation**

3.4.1 Introduction

The schematic of the evaporator system used is shown in Fig 3.6. The film thickness calibration is done by depositing Au on a (100) Si sample for different periods of time. The temperature of the evaporation cell is set to 1300°C, and the time varies between 10 - 30 minutes (depending upon the desired Au thickness). After deposition, the film thickness is determined using RBS (Rutherford Back Scattering). Once the RBS thickness (\(\rho\) g/cm\(^2\)) is determined, the physical thickness (Å) can easily be calculated using the film density (g/cm\(^3\)).
3.4.2 Evaporation Theory

The thickness of the evaporated film is a function of the vapor pressure and the sticking coefficient (metal-substrate). For the same metal film (Au), the film thickness is proportional to the deposition time and vapor pressure, which is a function of the cell temperature. The temperature - vapor pressure curve for Au is shown in Figure 3.7.

At a temperature of 1300°C, the vapor pressure of Au is about $2.2 \times 10^{-3}$ torr.
providing a deposition rate of 3Å/min. The primary equation, which relates the incident flux \((F)\) to the pressure \((P)\) of the metal vapor and temperature \((T)\), is:\(^{8}\)

\[
F = P / (2 \ ? \ m \ k \ T)^{0.5}
\]  

(3.1)

Where, the units of \(F\) are molecules/m\(^2\)s, \(P\) in torr and \(T\) in K.

Figure 3.7 Graph showing the vapor pressure (torr) of Au versus temperature (°C). The vapor pressure is plotted on a logarithmic scale.\(^{7}\)

The minimum estimate for the time to deposit a monolayer of metal film on a clean surface (assuming a unit sticking probability i.e. \(S = 1\)) is shown below. The monolayer coverage is generally on the order of \(10^{15}\)/cm\(^2\). We now have

\[
t = (10^{19} / F)\]

(3.2)
where,

\[ t = \text{Time to deposit a single atomic layer} \]

\[ F = \text{Incident Flux (molecules/m}^2\text{s)} \]

The deposition rate (Å/min), is calculated knowing the molecular density (atoms/cm\(^3\)).

### 3.4.3 Coating Field Emitter Arrays with Au

The FEA to be coated is first cleaned using an ultrasonic cleaner. This should be done to remove any small particulates attached to the Mo surface and also to reduce any electrical shorts between the gate and cathode columns. After the array has been cleaned, it is removed and dried with N\(_2\) to evaporate the isopropanol from the FEA surface. The FEA is then securely attached to a shadow mask, which includes a spectator sample. The shadow mask ensures that the Au is deposited only within the emission area so as to not create an electrical short between the gate and cathode (Figure 3.8). The thickness of the deposited gold layer is determined by the deposition rate and time.

![Diagram of FEA](image)

**Figure 3.8** An FEA coated with Au on half the area.
The actual thickness of Au deposited on the cone, will not be the same as the gold thickness on a flat surface spectator sample (Figure 3.9). The relation between the Au film thickness deposited on the Mo cone and that deposited on the flat surface of the spectator sample is presented in equation (3.3).

\[
d_a / d = \left( \frac{\text{Base Area of Cone}}{\text{Curved Area of Cone}} \right)
\]  

(3.3)

Figure 3.9 Diagram showing the section of a field emitter tip, coated with Au. The Au thickness on the gate (flat surface) and on the emitter tip is related to its aspect ratio.

**Aspect Ratio (??) = 2R/H = 1.2**

\[
\tan ?? = \frac{R}{H} = \frac{?}{2} = 0.6
\]

?? = 30.96°

\[
\frac{R}{L} = \sin ??? = 0.515
\]

Figure 3.9 Diagram showing the section of a field emitter tip, coated with Au. The Au thickness on the gate (flat surface) and on the emitter tip is related to its aspect ratio.

Unless specified, the Au film thickness listed below is the thickness on the spectator sample, as determined by RBS. We coated six FEAs with Au films of different thickness. Out of these, only two FEAs had half their emission area coated with Au and the other half was left uncoated.
REFERENCES

1 B.R. Chalamala, Thesis (PhD.), University of North Texas 1996.
3 Labview™ 6.0i is a registered trademark of National Instruments Inc., Austin, Texas (2000).
6 Stanford Research Systems, Inc., 1290-D Reamwood Avenue, Sunnyvale, CA 94089.