An Electron Beam Heated Evaporation Source

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Abstract

An electron beam evaporator has been assembled, tested and used for deposition of thin nickel films. Flux and deposition rates has been measured with an oscillating quartz crystal monitor (QCM), an ion sensor wire, and visible deposition on a mirror on front of the evaporator. A thin nickel rod of 2 mm diameter was found to improve the pressure in comparison to a 6-mm nickel rod. The flux was typically 3-4 Angstroms per minute during the test, but other flux rates can easily be achieved by changing the filament current and the acceleration voltage.
1. Introduction

Electron beam heating is an efficient way of achieving high temperatures when tungsten filament evaporators are not suitable, e.g., when the tungsten filament alloys with the evaporator material. A beam of electrons is produced by a hot tungsten filament. The beam of electrons is accelerated and electrostatically focused to a tip of a metal rod (nickel) held at a high positive potential. The electron beam creates high temperatures in the source material so that almost any material can be evaporated (melting point of nickel = 1453 degrees Celsius). Since the rate of evaporation for materials increases with greater power input, the highest rates are obtained with materials that have low evaporation temperatures and low thermal conductivity.

The magnitude of the pressure, which increases during evaporation, depends on the pumping capacity of the system and the cleanliness of the evaporated material. The outgassing of the surrounding surfaces was minimized by water cooling of the surrounding walls. The evaporator was tested in a small vacuum chamber with a base pressure of 8 x 10^{-10} Torr, using an ion pump of 20 l/s and a turbo pump of 60 l/s. The evaporator was later used at the ultrahigh vacuum (UHV) “MAX-II surface science” end station at beamline 8.0 at the Advanced Light Source (ALS), Lawrence Berkeley Laboratory (LBL). The base pressure in the surface science end-station is 2 x 10^{-10} Torr and kept in the 10^{-9} range during evaporation. Evaporation of monolayers of nickel on copper and nickel substrates are grown in order to study interfaces, using core-level spectroscopies.

2. Evaporator Design

Figure 1 shows a schematic view of the electron beam evaporator. The tungsten filament was spot-welded to its supports. An electrically isolated tungsten wire (sensor) was mounted in front of the evaporator in order to measure the flux. The current from the sensor was monitored using an amplifier (Keithley) with a gain = 10^9 and displayed on a multimeter with a range of 0-20 Volts. In order to display an accurate positive "current" reading it was tested to ground one end of the filament to the same ground as the Keithley. However, it turned out to be necessary to put the filament on a higher potential of at least 4-5 Volts using a battery to zero the current of electrons from the filament.

A typical "current" reading of the sensor during evaporation was 1.5 V DC being regulated by the filament current. During evaporation, the outer flange of the evaporator was water cooled to improve the pressure, but had only small effects. The base pressure before the test was 8 x 10^{-10} Torr in the vacuum chamber.

Outgassing was made over-night with an emission current of 1 mA and an acceleration voltage of 1 kV and a filament current of approximately 5 A. During evaporation, the filament had a current of 4.7 Amps and a voltage of 5.64 Volts. The emission current was typically 5.2 mA at an acceleration voltage of 2 kV. With these settings, an approximate film thickness of 2-3 Angstroms/min was measured with an uncooled quartz crystal at a distance of 15 cm from the evaporation source. Two different diameters of the nickel rod (6 and 2 mm) were tested and it turned out that a thin rod of 2 mm diameter was the best choice to minimize outgassing.
3. **Thickness/Rate monitor**

The thickness of the deposited film was measured with a *Sycon Instruments STM-100/MF* monitor (see fig. 2). The thickness monitor uses a resonant frequency of 6 MHz of an exposed quartz crystal 15 cm from the evaporator to sense the mass of deposited films attached to its surface.

There is a known relationship between the mass of such a film and the measured frequency of the sensor crystal. Its calibration is affected by three different parameters; 1) material density, 2) material Z-factor, and 3) tooling. “Tooling” is a deposition system geometry correction related to the location of sensor relative to substrate while density and Z-factors are material factors. The bulk density of nickel was set to be 8.91 g/cm$^2$ and the Z-factor 0.331. The heat load on the quartz crystal during evaporation was so large that the displayed thickness and flux became negative. After approximately one hour of cooling the thickness could be read. In order to improve the accuracy of the thickness reading it is necessary to use water cooling on the quartz crystal.

![Figure 1: Schematic view of the electron-beam evaporator.](image1)

![Figure 2: Schematic view of the quartz crystal monitor.](image2)
4. Results

Several evaporation tests were made in order to obtain reproducibility of the evaporation rate. With the values of acceleration and filament current/voltages given in table 1, a typical evaporation rate of 3-4 Angstroms per minute was achieved, using a quartz crystal monitor at a distance of 22 cm from the evaporator. Typically, the pressure raised up to $2.0 \cdot 10^{-7}$ Torr during an evaporation time of 10 minutes which was not in satisfaction. The ion "current" from the tungsten wire sensor decreased during evaporation from 1.9 to 0.9 Volts with a Keithley gain of $10^9$ with the lowest value at the end of the evaporation. During the first tests a high emission current of 20 mA and a 6-mm nickel rod was tested with an evaporation rate of approximately 20 Angstroms/min.

After long term evaporation, it was observed that the mirror gradually changed its reflection surface, from the back side, into a “double mirror”: and finally, with the reflection surface on the front of the glass. However, an emission current of 20 mAps caused the nickel rod to become soft and finally bend to cause a short-cut of the bias voltage. The evaporator was tested both with the water cooling on and off. The water cooling seems to have small effects on improving the vacuum. In order to improve the pressure during evaporation, a thinner nickel rod of 2 mm was tested. With this rod, the radiated area of the hot nickel was minimized and the outgassing significantly lowered.

Table 1: Typical values of currents and voltages for a 2-mm nickel rod during evaporation and outgassing.

<table>
<thead>
<tr>
<th>Filament settings</th>
<th>Acceleration settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage (V)</td>
<td>Voltage (kV)</td>
</tr>
<tr>
<td>Evaporation</td>
<td>5.64</td>
</tr>
<tr>
<td>Outgassing</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Conclusions

Thin film depositions of nickel metal have been successfully tested using an electron beam evaporator and a thickness rate QCM monitor. As the material is melted and consumed when electrons are accelerated towards the tip of the rod, new material can be fed using the linear feedthrough. Generally, metals and refractory materials with high melting temperatures can be efficiently deposited by using water cooling to minimize outgassing during evaporation. This evaporator will be useful in thin films physics and surface science.

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