Electron Beam and Sputter Deposition
Choosing Process Parameters

General Introduction

The choice of process parameters for any process is determined not only by the physics and/or chemistry of the process, but by choices the manufacturer of the equipment has made and/or practical issues with measurements or simply 'it's a reasonable number'. In reality, the physics and chemistry define a region where operation is possible and the actual choice of conditions are arbitrary or depend on optimizing a specific parameter. For example, a choice that a manufacturer would make would be maximum voltage a power supply can supply (our DC sputter sources can supply a maximum of 700 V). An example of a measurement issue is with RF power, where all measurements are of the RF power, rather than the RF voltage or current. The reason is that RF power is 'easy and cheap' to measure, while RF voltages and currents at high powers (i.e. > 10 watts) is difficult.

Sputtering

A 'standard' process recipe for sputtering a thin film in the NanoFab is:

- Base Pressure: less than $1x10^{-5}$ torr
- Argon flow rate: 30 sccm (standard cubic cm/minute) (1sccm = $2.7x10^{19}$ atoms/cm^3)
- Ar Pressure: 7 mTorr
- Power: 300 watts

The reasons why these conditions were chosen are:

- Base Pressure: Limited time for pump down in this lab (below 10^{-6} torr preferred), but copper doesn't oxidize easily, so we can get away with this
- Argon Flow Rate: Want it to be not too little (accumulate byproducts) or too large ('fills' the cryopump). 10 to 50 sccm is commonly seen as the best compromise (complete gas change in the sputter chamber every 1 to 10 seconds)
- Argon Pressure: Sputter source will not operate below 1 mTorr (this sets the low end) and above 20 mTorr, the gas scatters too much of the sputter flux to get a reasonable deposition rate. 7 mTorr was chosen as a compromise (low enough to get a good sputter flux and higher density films, but high enough for the gun to operate). Varying the sputter pressure strongly affects the film properties. The two main properties that vary are stress in the thin film and the step coverage
- Power: High enough to give a good deposition rate and not too high that the magnets get too hot or the target melts. 300 W was chosen as a compromise

We do not actively monitor the deposition rate from sputtering because it is a very stable process. It will vary 10 to 20% over the life of a target (and much less during a run).

In sputtering, the sputter gun can be operated at constant power, current, or voltage.

i) We have chosen to operate at constant power mode because it allows us to know immediately if we are heating the target too much.
ii) Constant current was used in the past because the ion current is a close measure of the deposition rate. However, it was possible to accidently have the power supply provide enough power to damage the gun. At the time, it was only possible to construct DC sputter power supplies as constant current.
iii) Constant voltage is rarely used, because the plasma conditions 'set' what voltage is required to reach a desired current or power. For the plasma to 'light' and operate at the deposition rate that is desired, the voltage would need to be chosen with care. It is easier and you will have fewer problems to operate in constant power or current mode and let the plasma determine the required voltage

Electron Beam Evaporation

The recipe for e-beam evaporation of silicon dioxide is:

Base Pressure: < 10^{-5} Torr
Emission Current: 150 to 200 mA
Sweep Size: Entire crucible
Accelerating Voltage: 10KV

For Silicon dioxide, the base pressure does not need to be that low, since we are depositing a oxide and the residual gases in the chamber form oxides. However, e-beam evaporation is an extremely 'hot' process. For SiO_2 to evaporate, it needs to reach 2400C. This will heat the chamber significantly, releasing a tremendous amount of adsorbed water vapour. It is extremely common for the base pressure during deposition to increase by an order of magnitude during deposition as the chamber heats up.

The emission current is determined by simply increasing it from zero until the desired deposition rate is achieved (usually 5 to 10 A/sec on the crystal monitor). This number is only roughly consistent from run to run, because any slight changes in the thermal conductivity of the melt/crucible/copper hearth will strongly affect the temperature of the hearth. The 10KV accelerating voltage was chosen by the power supply and e-gun manufacturers as the 'best' voltage (6 and 20KV also exist)

The sweep is how much of the crucible is 'swept' by the electron beam. The deposition rate will depend on how much of the crucible is 'swept'. Usually, as much of the melt can possible is swept with the beam to ensure uniform thin deposition .

In E-beam evaporation, the deposition rate needs to be constantly monitored and the emission current adjusted to maintain a constant deposition rate. This is why there is typically a crystal thickness monitor on e-beam evaporators and not on sputter systems.

PECVD

The process recipe for Trion PECVD of Silicon dioxide from TEOS is:

Temperature: 350C
He Flow: X sccm
O_2 Flow: Y sccm
RF Power: Z Watts
RF Reflected < 10 watts

The process parameters are chosen because:

-Substrate Temperature: High enough to grow 'reasonable' quality films, but low enough that films can be deposited on glass substrates or onto Aluminium metalization. If the chuck temperature is too low, the films will contain too much Hydrogen and very poor quality. 350C is commonly seen as the best compromise ('hot enough')

- He Flow: This determines amount of TEOS that enters the chamber. The HE is bubbled through the liquid TEOS, picking up TEOS vapour.

-O_2 flow : The oxygen is added to ensure that there is sufficient oxygen in the plasma for form SiO_2 from the TEOS. Though TEOS contains oxygen, adding O_2 ensures the films will not be deficient in O_2

- RF Power: Chosen to give the deposition rate we desire.

- Reflected Power: The reflected RF power needs to be kept low (a few watts) for three main reasons: safety, damaging equipment, and process reproducibility.

At high reflected RF powers, the system will emit large amounts of RF power into the room. This is usually first observed when the electronics on the equipment does not work correctly (RFI problems), but you are also absorbing this energy. Secondly, the reflected power can damage the RF power supply if the reflected power is high enough and left on for a long time. Plasma power supplies are designed to take the abuse of high reflected powers, but there is a limit. Finally, a high reflected powers, the RF voltage and current waveforms are severely distorted (i.e. no longer sine waves). This causes the plasma conditions to change dramatically in the system. Even if the same 'amount' of power is being deposited into the plasma (Forward Power-Reflected Power), at moderate to high reflected powers, the distortion of the RF wave forms will not create the same plasma conditions are at low reflected powers (ie. Different plasma conditions = different film qualities)

Thermal Oxidation

The process recipe for thermal oxidation is:

Temperature: 950 C (set point on controller = 640)
Bubbler Temperature: 94 C
Flow: "Moderate amounts of bubbles (20 on the scale)

One of the major issues in processing is not that we accurately know what the process parameters actually are, but rather that whatever we get the machine to is extremely reproducible. This is the very much the case with thermal oxidation. We know there is systematic error in the temperature measurement, we have no idea how ‘saturated’ with steam the N2 coming out of the bubbler is and we have a arbitrary N2 flow (which we don’t know exactly what the flow is). However, with all of this, we know that a 5 hour run will give us exactly 0.6 um of oxide and that is all that counts.

> Temperature: The oxidation temperature was chosen to hot enough for oxidation, but not near the softening point of the quartz (which reduces the life of the tube and the heating elements – about 1200C). 950C was chosen as a conservative compromise.
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> Bubbler Temperature: For oxidation to occur we require a stream of N2 that is saturated with steam. We don’t want the water in the bubbler to boil, that adds too much water too quickly. For fabs located at sea level, a temperature of 98C is used to ensure saturation. The NanoFab (located at 2400 feet above sea level and has a boiling point of 98C) we use 94 C. This is slightly cooler than required for saturated steam, but it ensures the bubbler does not boil dry during the ‘standard’ oxidation (which can cause a fire)
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> N2 Flow: Want just enough flow to get the required steam into the chamber. Too high a flow rate and the water is ‘blown’ into the tube and too low, not enough steam enters the tube. The rate we use was chosen after some experimentation as a good compromise.