3.5.2 Important Techniques

Thickness

- The film thickness is without doubt the first parameter you must measure and there are many methods for that. Neglecting exotic or expensive methods like, for example, **Rutherford back scattering** (***RBS***) and more indirect methods like "bevelling" plus optical microscopy, we are left with two basic cases:
  - The thin film is transparent in the optical region (including ***IR*** and ***UV***). Then we use *optical methods*.
  - The thin film is opaque (i.e. metal films). Then we have a problem.
- Let's deal with transparent films first. What we generally do is to use interference effects; which give clear signals if the phase difference between two interfering beams is just a fraction of the wavelength.
  - The most simple experiment, evaluating interference colors as shown in the link, already suffices to measure film thicknesses if you are not too demanding. Far more advanced methods exist, however, which we will treat very cursorily here.
  - **Reflectometry**: Measure the intensity of the reflected light as a function of the wavelength. You can even do this through a microscope, so you measure the thickness of a small spot. The intensity of the reflected light as a function of wavelength can have a complicated shape, depending on the film refractive index, its thickness, and the properties of the substrate (it might be transparent, too). The method still gives (even more complicated) spectra if several (more or less transparent) films are on top of each other. Except for the simplest cases, an evaluation of the spectra obtained needs powerful software. If such a software exists, matching the measured data against models of the layer system often allows to extract the information desired.
  - **Ellipsometry**. The probably most powerful technique - an **ellipsometer** is standard equipment in any thin film environment. A monochromatic polarized light beam is directed under a certain angle α on the specimen; the intensity and the change of the polarization cause by film(s) and substrate is measured. For simple systems (transparent film of suitable thickness on known flat substrate), it is comparatively easy to extract the film thickness *and* its index of refraction directly from the data. Even a film thickness as small as $\approx$ **1 nm** can be assessed. For more complicated systems - see above. If the wave length and / or the angle of incidence can be changed, too, the method becomes extremely powerful and extremely complicated.
- Now let's look at opaque films.
  - If you have an area on your sample where you have no film, just run a stylus across the sample and measure the step height as you hit the film. This is a major and mature technique that was (and still is) linked to the brand name "Dektak". Don't confuse a "Dektak" with an **AFM** or **STM**!
  - Measure the resistivity of the thin film - directly or indirectly. Assuming that its specific resistivity it is that of the bulk material, and knowing the lateral dimensions, you can calculate the thickness. There are many and partially quite sophisticated ways of measuring thin film resistivity. Even if you are not sure about the specific resistivity, you may simply calibrate your measure values for various thicknesses by comparison with an absolute standard. Of course, this works best it your thin film is on an insulating substrate.
  - Your absolute standard comes from looking at a cross section with an electron microscope that has sufficient resolution. Look at the **TEM** picture of the **SiO_2** layer in the link. You build-in ruler is the lattice constant; you can't get much more precise than that.

Density / Porosity / Uniformity

- The last topic - **uniformity** - is the simplest one in principle: just measure whatever at many points. It may not be so easy in practice, however, but we will not go into details because what you do depends very much on what you have and what you want.
- This leaves us with **density / porosity**. Both term are almost inverse synonyms: if the density is not what it should be, your film must be porous in a very general sense.
  - Since the index of refraction is simply a relatively straight forward function of porosity as long as the pores are far smaller than the wavelength of the light, ellipsometry gives you already some ideas about that.
  - There are many other methods. Often you take the property that is sensitive to porosity as the vehicle for characterization of porosity or density. For example, there are many ways of producing thin films of **SiO_2** that are very similar in many properties but may show quite different etch rates in **HF** (the almost only chemical dissolving **SiO_2**). Somehow the etching rate is tied to "porosity" (with "pores **< nm**) or the structural integrity, or to whatever you like to call it.

Conditivity

- We will deal with this later.

Special Properties

- Special properties are often the properties you are after when you make use of a thin film. We haven't listed any above, so let's do it here - and take note at the same time that the property and its measurement are mostly inextricably tied together. You can talk about the thickness of a thin film quite generally without having measured it, but you cannot talk about electrical breakdown field strength being special without having some number in mind
- What do we have:
  - **Electrical breakdown field strength**.
  - **Critical current density**.
  - Negative index of refraction.
  - Electromigration resistance.
  - Tunnel barriers.
  - Diffusion barriers.
  - Adhesion promoters.
  - OK. Enough of that - you can't possibly know what this is all about (but you can have a glimpse as soon as the links are in place). It is obvious that we will have to go deeper into properties of materials in general and of thin films in particular before we can discuss this topic in a sensible way.

Summary

- The whole module just served to make you aware of a few basic and rather simple truth:

1. Thin films have just as many properties as bulk materials, but they might be far more difficult to measure. **2. Thin films may have additional properties not defined for bulk materials with specific measurement techniques** **3. A lot of measurement and characterization techniques have been developed just for thin films**