Ellipsometry (30 points)

Objective: The objective of this online lab is to evaluate the ellipsometer. Multiple ellipsometers will be presented and compared. The procedural operation and working mechanisms of the ellipsometer will both be discussed.

Background:

The Gaertner Scientific L115S-8 Ellipsometer (Figure I) is capable of measuring the index of refraction and material thickness for transparent thin films. Film thicknesses up to several micrometers can be measured with sub-angstrom precision. Many thin films can be analyzed with this instrument including oxides, nitrides, and transparent conducting oxides. As a non-contact optical technique ellipsometry is non-destructive.

On the downside, the ellipsometer is not able to measure films with extremely fine patterns or opaque films such as metals. The Gaertner Ellipsometer also requires a reflective substrate (e.g. Si) since ellipsometry is based on the measurement of the light polarization change upon reflection from a sample surface or interface.

Figure I: Gaertner Scientific L115S-8 Ellipsometer

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Please watch the following video which shows the operation of the ellipsometer shown in Figure I.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=409bbc03-1c3a-4107-be2e-5

By becoming familiar with the operation of the Gaertner Scientific L115S-8 Ellipsometer students can apply these fundamentals to facilitate the operation of similar ellipsometers. Figure II below shows an image of a different ellipsometer produced by Gaertner:

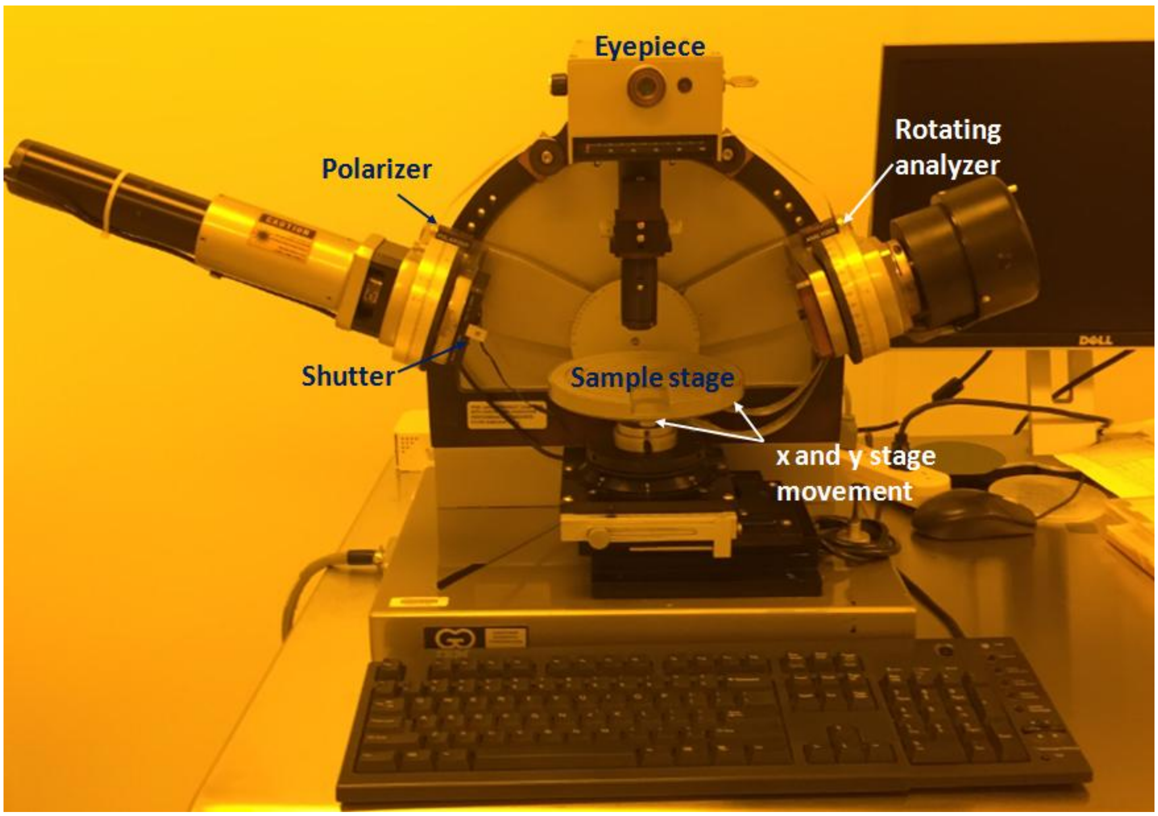

Figure II: A second model of a Gaertner Ellipsometer

Figures I and II show physical layouts of different ellipsometers and assist to show operational similarities. However, in order to understand the working mechanism of the ellipsometer requires a strong background in electromagnetics. Figure III shows the key components on the ellipsometer which are necessary for understanding how the tool works. Here, a beam of monochromatic light is linearly polarized. This beam of light has electric and magnetic fields which are mutually orthogonal to the direction the beam is traveling. In ellipsometry we are interested in monitoring the electric field component of the beam before and after substrate interaction.

In Figure III it is shown that the electric field vector, **E**, can be broken down into two components: E_P and E_S. Here, E_P is the part of the electric field that is parallel to the plane of incidence and E_S is the part of the electric field that is perpendicular to the plane

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of incidence. Once the incident light has been linearly polarized the values of $E_{P,inc}$ and $E_{S,inc}$ are known. Following reflection of the incident beam from the substrate the analyzer will then measure the new values of $E_{P,ref}$ and $E_{S,ref.}$ Next, through a series of equations known as the Fresnel equations the ellipsometer will calculate the polarization parameter (ellipsometer parameter) using the measured values of $E_{P,inc}$,$E_{S,inc}$,$E_{P,ref,}$ $E_{S,ref,}$ the incidence angle (commonly 50° or 70°), and the film's index of refraction.

The ellipsometry parameter, ρ, is shown in the following forumula, here, Δ is the phase change and φ is the amplitude change between the incident beam and the reflected beam:

$$\rho = tan\varphi e^{i\Delta}$$

From here, the measured values of Δ and φ coupled with the film's index of refraction can be used to calculate the film's thickness. In other words, the analyzer (detector) converts the reflected light into an electronic signal to determine the change in polarization as a result of the beam-sample interaction by comparing it to the known input values. This is the ellipsometry measurement of Δ and φ.

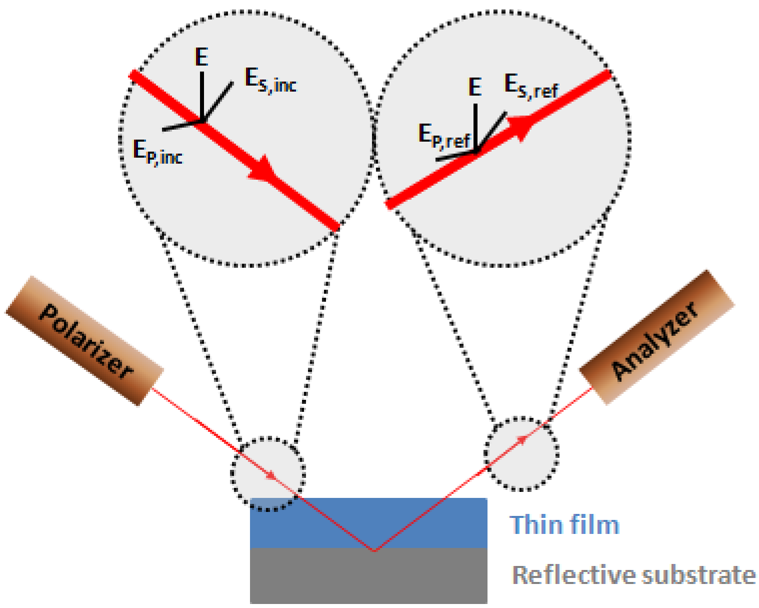

Figure III: A generalized depiction of the ellipsometry setup

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Questions (30 points):

1. How is the light detected once it has reflected off the sample's surface? (3)

2. How are the angles of the laser and detector adjusted? (3)

3. When should the laser shutter be opened? (3)

4. What wavelength light is used for the ellipsometer shown in Figure 1? (3)

5. What is a difference between the layout of the two ellipsometers? (3)

6. In which case could the ellipsometer be used? (3)

7. Before calculating the value for the film thickness, what does the ellipsometer first calculate? (3)

8. At the most fundamental level, what is actually changing as a result of the interaction of the beam with the surface? (3)

9. What are the names of the equations used to calculate the ellipsometry parameter? (3)

10. What is the most likely reason one ellipsometer (Figure I) is in a white room and the other ellipsometer (Figure II) is in a yellow room? (3)

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