

## Gaertner L117 Null Ellipsometer

### Theory:

When an electromagnetic wave reflects from a material it will change its phase and amplitude. This phase shift ( $\delta$ ) and amplitude change ( $|r|$ ) depends upon other things on the angle of incidence ( $\phi$ ), the refraction index of the material ( $n$ ), the extinction coefficient of the material ( $k$ ), and the polarization of the incident beam:

- The angle incidence is the angle between the normal and the incident beam (note that this definition is different from that used in X-ray analysis).
- The refraction index tells us something about the speed of the light in the material. The speed of light in vacuum is  $3 \times 10^8$  m/s:

$$n = \frac{c_{vacuum}}{v_{material}}$$

- The extinction coefficient tells us something about the penetration depth,  $d_p$ , of the light into the material:

$$k = \frac{\lambda}{4\pi d_p}$$

- Light linearly polarized parallel to the plane of incident is called p-polarized light. Light linearly polarized perpendicular to the plane of incident is called s-polarized light. Above mentioned phase shift and amplitude change is different for p and s-polarized light.

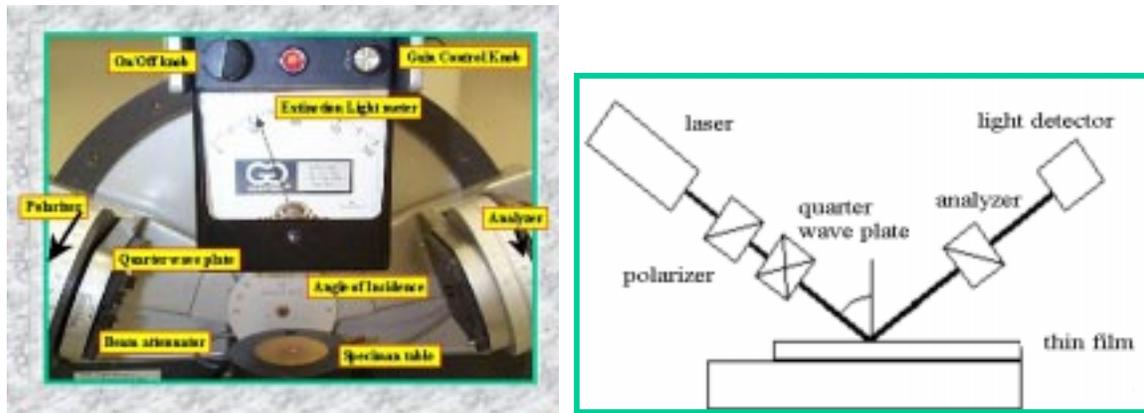
Although it is not possible to determine the absolute values of  $\delta$  and  $|r|$  by ellipsometry, it is possible to determine  $\delta_p - \delta_s$  and  $r_p/r_s$ . One ellipsometry measurements provides us with the ellipsometric parameters  $\Delta$  and  $\psi$ :

$$\Delta = \delta_p - \delta_s$$

$$\tan \psi = \frac{|r_p|}{|r_s|}$$

For bulk materials  $\Delta$  and  $\psi$  can be used to calculate the refraction index and the extinction coefficient if you know the angle of incidence. If you material does not absorb light,  $\Delta$  and  $\psi$  can be used to calculate the refraction index and the angle of incidence.

$\Delta$  and  $\psi$  can be measured with a null ellipsometer. A schematic drawing is presented in Fig. 1. By rotating the polarizer it is possible to change the phase shift between the p- and s-component of the incident light. The trick is to compensate for the phase shift that will occur at the surface so that the p- and s-component of the reflected wave will be again in phase and thus linearly polarized. By rotating the analyzer it should now be possible to null the detector signal. Polarizer and analyzer reading can now be used to calculate the  $\Delta$  and  $\psi$ . There are four different polarizer and analyzer settings for which the detector signal will be minimal. Normally we will determine two of those settings and take a kind of weighed average.



**Fig. 1: (a) Close-up Gaertner manual Null-ellipsometer (b) Schematic Diagram**

If your material is a thin film on top of an opaque substrate the calculation of the refraction index and the extinction coefficients becomes more complicated. Phase shift and amplitude change of the light upon reflection are now also influenced by the optical properties of the substrate and the thickness of the thin film. So now we have suddenly 6 parameters that can influence  $\Delta$  and  $\psi$ , i.e.  $n_{\text{sub}}$ ,  $k_{\text{sub}}$ ,  $n_{\text{film}}$ ,  $k_{\text{film}}$ ,  $\phi$ ,  $t$  (=film thickness). As each ellipsometric measurement will only give us two equations, we need to get the values of the other parameters somewhere else.  $n_{\text{sub}}$  and  $k_{\text{sub}}$  can be determined from an independent measurement of the substrate material. The angle of incidence  $\phi$  is often known. So this leaves us with three parameters,  $n_{\text{film}}$ ,  $k_{\text{film}}$ , and  $t$ . In order to determine all three parameters we need to do two independent ellipsometric measurements. This will provide us with four equations. We could measure at for example two different angles of incidence. This will provide us with  $\Delta_1$ ,  $\Delta_2$ ,  $\psi_1$ , and  $\psi_2$ , and will enable us to determine up to four unknown independent parameters.

### Measurement Recipe:

#### Preparation:

- Turn on the instrument and allow it to warm up (approximately 15 minutes).
- Place the specimen on the table and loosen table clamp screw (front end table).
- Rotate the knurled nut at back underside of table. Raise or lower table to direct reflected laser beam into analyzer pinhole.
- Observe meter and change table height to get maximum reading on meter. If meter reading exceeds 110, readjust gain control to bring maximum reading below 100. Tighten table clamp screw at maximum meter reading.

#### Measurement Procedure:

1. Adjust gain control until meter reads below 100.
2. Rotate analyzer (right hand drum) slowly in the RED numbered segment ( $0^{\circ}$ - $90^{\circ}$ ) and set this drum to give lowest reading on the extinction meter.
3. Rotate the polarizer (left hand drum) slowly within the RED numbered segment ( $315^{\circ}$ - $135^{\circ}$ ) and set this drum to give a new and even lower meter reading. If the meter reading exceeds 110, readjust to bring maximum reading below 100.

4. Repeat 2 and 3 to minimize the meter reading. If it falls below 25, use the gain control to bring the meter indicator reading up to 100.
5. If the meter reading can no longer be lowered by rotating the analyzer or polarizer, record the first analyzer A1 (right drum) and the first polarizer P1 (left drum). You need those values later to calculate the  $\Delta$  and  $\psi$ .
6. You are now ready to obtain the 2<sup>nd</sup> set of drum readings A2 and P2.
7. Add 90 degrees to the first polarizer drum reading P1, i.e.  $P1+90^0$ . Rotate the polarizer drum to this sum.
8. Subtract the first analyzer drum reading A1 from 180 degrees, i.e.  $180^0-A1$ . Rotate the analyzer drum to this difference.
9. Slowly rotate the polarizer drum to obtain lowest reading on the meter. It will not be necessary to rotate the drum more than a few degrees.
10. Slowly rotate the analyzer drum to obtain a still lower meter reading. Adjust the meter gain control if necessary.
11. Repeat 9 and 10 until lowest meter reading is obtained.
12. Record the analyzer and polarizer readings (A2 and P2). The 2<sup>nd</sup> set of values (A2, P2) will vary slightly from the calculated values ( $P1+90$ ,  $180-A1$ ), but should not differ by more than 4 degrees for accurate measurements.
13. Calculate  $\Delta$  and  $\psi$  using the equations given below:

$$\Delta = 360 - (P_1 + P_2)$$

$$\psi = \frac{180 - (A_2 - A_1)}{2}$$

If  $(P1+P2)$  is greater than or equal to  $360^0$ , subtract  $360^0$  from it before using it in the above equation.

Calculation of n, t, and/or  $\phi$  for a thin oxide film on a silicon substrate:

- Start up the Film-Wizard program (HP-computer in 181: Start – Programs-SCI-).
- Select File-New Project.
- Select Edit-Design Parameters. In the design parameters window select Physical Thickness, and make sure that the design wavelength is set to 632.8, auto coupling is checked, and the wavelength and physical thickness units are set to nm.
- The design window contains the information of the involved materials. In row 1 you will see AMB(CAUCHY) which is the ambient atmosphere. Row 2 shows SUB(CAUCHY). In order to tell the software that the substrate is silicon we double click in the empty cell in the 2<sup>nd</sup> column of the substrate row. Load the optical data of the substrate material, in this case silicon. The first cell in the substrate row will now show SUB[NK], and the 2<sup>nd</sup> cell will show Si.
- Define the thin film by typing for example 1H in the Design/Model Input Box located immediately below the tool bar. The number represents the thickness of the layer and the character represents the name. A new entry will appear in the Materials List. Double click in the empty cell of the 2<sup>nd</sup> column of the new entry and load the SiO2 file.
- Select Optimization-Targets. Fill out the measurement results (wavelength=632.8, weight=1, target=measurement data; do not forget to select the target type, to provide the angle of incidence, and to check the Use-box).

- Select Optimization-Thickness Variables. Provide the film thickness of the layers. If you want the software to calculate the film thickness please check the vary-box and provide a Maximum and a Minimum estimated value (Use the Constraint option on the toolbar).
- Select Optimization-Angle variables if you want the software to calculate the angle of incidence. The software assumes that all target values are measured at the same angle of incidence. Provide a Maximum and a Minimum estimated value.
- Select Optimization-Index variables if you want the software to calculate the index of refraction of the oxide layer. Provide a Maximum and a Minimum estimated value (use the Constraint option on the toolbar).
- To start the calculation select Optimization-Optimize.
- More details on how to use the software can be found in the manual.

