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SSD CAPSULE PROJECT 2 REPORT

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DESINGNING AN ELLIPCOMETRY SYSTEM

I. INTRODUCTION

Have knowledge about features of instruments and materials that using in optical system has a serious importance like any other scientific areas. An ellipsometer can provide information about thin films' reflective index, amplitude component Ψ, phase difference Δ by measuring complex reflectance ratio ρ of the system. Also, film thickness can be measured. Two of these parameters can be find with other known 2 parameters. While film thickness and thin film's reflective index are known, amplitude component and phase difference can be determined. Similarly, while amplitude component and phase difference are known, film thickness and film's reflective index can be found.

II. DESIGNING PART

Ellipsometry measures the polarization of light which is reflected or passing through something. The change of in polarization can be expressed as amplitude rate and phase changes. The obtained values are parameters of optical features of material and thickness of film. In this way, ellipsometry can be used to find thickness of film or optical constant.

Components Selection

The schema of components of an ellipsometer is shown below. In this project a light source, a polarizer and an analyzer, a detector were selected according to their specifications.

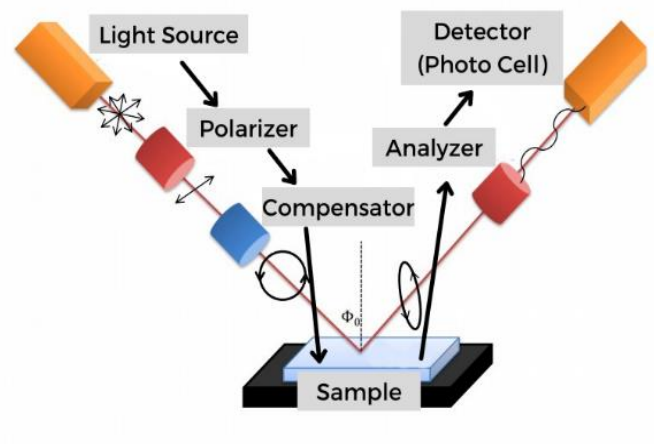


Figure 1

A. Light Source

Due to select two monochromator light sources according to two different needed wavelength, CPS635 and CPS670Fa light sources were selected for 635nm and 670nm wavelengths respectively.

Figure 2 CPS635

Figure 3 CPS670Fa

To supply these lasers, an adaptor LDS5-EC that gives 5VDC power output was selected.

Figure 4

B. Polarizer and Analyzer

As polarizers (polarizer and analyzer), 10mm diameter high contrast glass linear polarizers were selected for the system. The wave length range was arranged according to the lazers' wavelength. The wave length interval of polarizer and analyzer is 400 nm to 700 nm. The selected polarizer is shown below.

Figure 5

A typical linear polarizer is used for polarize incoming light. Linear polarizers filter the light and let one plane oscillating light pass through it. The representation of working principle of linear polarizer shown below.

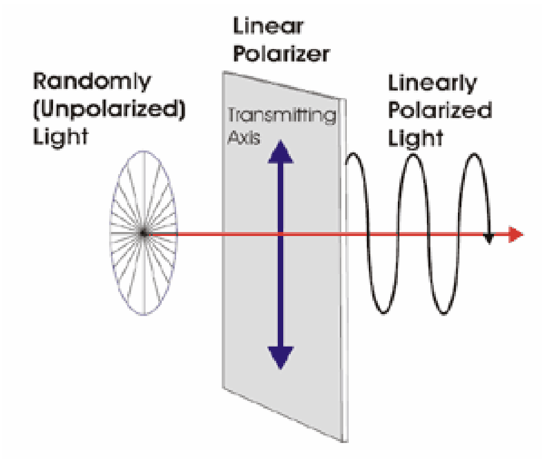


Figure 6

As mentioned above, the analyzer component is as same as polarizer's. Due to the angel of analyzer such as 0, 45 and 90 degree, the needed waves can pass through it. To determine the intensity of p component of the light de polarizer should be turned in 0 degree, to determine the intensity of it should be turned in 90 degree, finally if the intensity of summation of the two component the angle should be 45 degree.

C. Detector

Detection of power of the light coming from analyzer is made by FDS025 photodiode. The photodiode can measure 400 - 1100 nm wavelength interval and has Ø0.25 mm active area. The wavelength interval was selected according to rest of the system's wavelength interval. The photodiode and its spectral response are shown below.

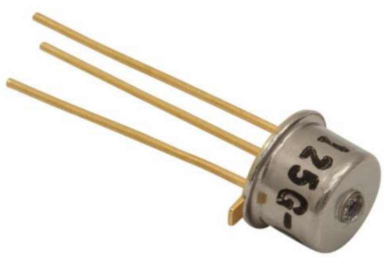
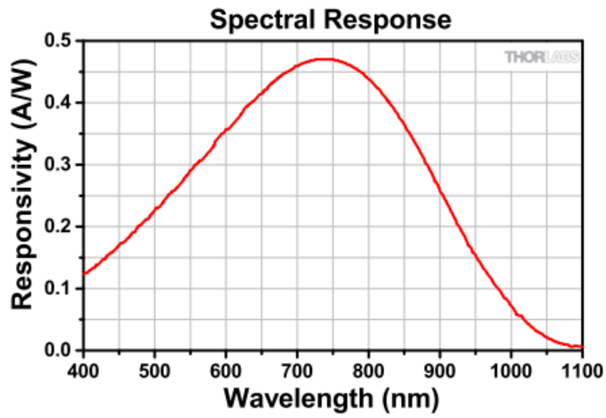


Figure 7



Graph 1

S and P Components of The Light

The electric field component of the light which coming from the laser can be divided into two components as s-polarized and p-polarized components. The representation is shown below.

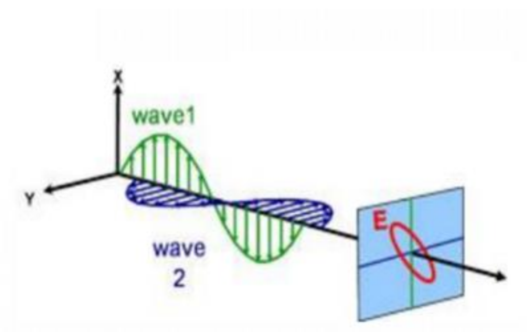


Figure 8

III. METHODS

The mathematical expression, modeling, circuitry design, coding parts of the ellipsometer were explained in this part.

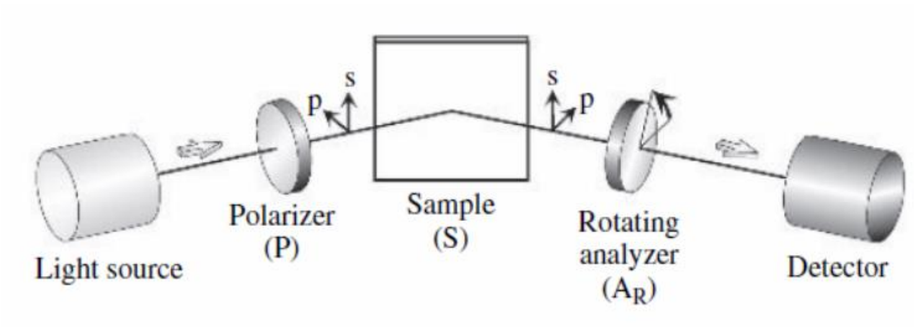


Figure 9 Modeling of an Ellipsometer

The light coming from the laser is a unpolarized light. As explained in polarizer part, the light is linearly polarized in the polarizer.

In s- polarized and p- polarized plane, respectively, Eis and Eip are incident electric field vectors.

When θ = 90°(the angle between incidence and reflected light), the incidence and reflection sides vectors completely overlap. The coming light is polarized 45° due to Eip axis. Because p- and s- polarizations' amplitudes are the same and the difference in the phases of these two components is zero, Eip = Eis. The reflection of the light on a thin film, s- and p- polarizations behave different changes in phase and amplitude. With ellipsometer, the two parameters which are Ψ (amplitude ratio), Δ (phase difference between s- and p- polarizations) can be measured.

The amplitude of reflection can be defined for p and s polarization in the equation below.

$$\rho = \tan(\Psi)\, \mathrm{e}^{\mathrm{i}\Delta} = \frac{\rho p}{ps} = \frac{Erp/Eip}{Ers/Eis}$$

ρp and ps calculation formulas are shown below. The θ angles are coming from figure 10.

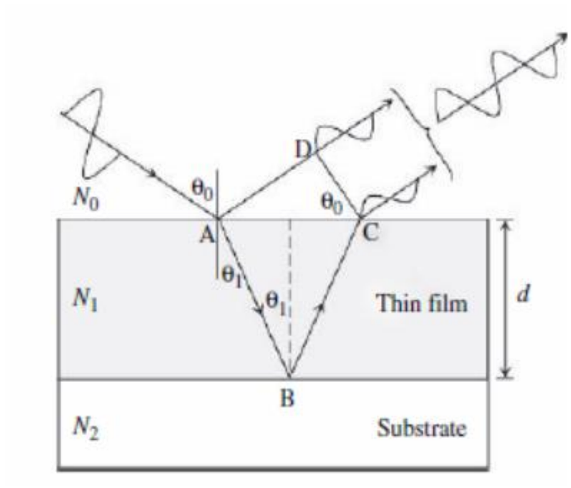


Figure 10

$$\rho p = \frac{n_1 \cos(\theta_0) - n_0 \cos(\theta_1)}{n_1 \cos(\theta_0) + n_0 \cos(\theta_1)} \quad \rho s = \frac{n_0 \cos(\theta_0) - n_1 \cos(\theta_1)}{n_0 \cos(\theta_0) + n_1 \cos(\theta_1)}$$

Most of the time ρ is a complex quantity, it equals $\tan(\Psi)\ e^{i\Delta}$ where Δ and Ψ are real. The aim of the ellipsometry is to determine the two angles (Ψ, Δ) experimentally.

A rotating analyzer is used to obtain intensity at different angles according to analyzer angle as explained before. Intensities depend on Ψ and Δ parameters.

When linearly polarized light reflects on a thin film and because there are two different reflective index, the light is elliptically polarized. And a phase difference Δ occurs. These are shown below.

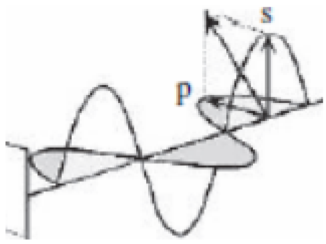


Figure 11 Linearly Polarized Coming Light

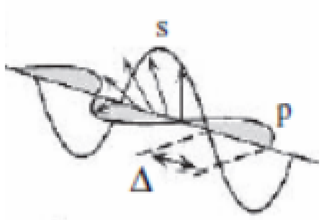


Figure 12 Reflected Light From Thin Film

As an output of the two waves' polarization, Ψ can be determined. The equation and virtual representation are shown below.

$$\Psi = \arctan\left(\frac{Erp}{Ers}\right)$$

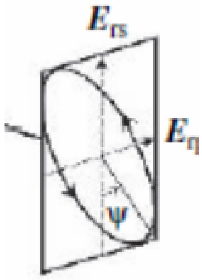


Figure 13

The light coming from analyzer creates an electric field at the detector. The electric field can be express with Jones matrix formalism like below.

$$E_0 = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \cos(\alpha_2) & \sin(\alpha_2) \\ -\sin(\alpha_2) & \cos(\alpha_2) \end{bmatrix} \begin{bmatrix} \rho_\pi & 0 \\ 0 & \rho_\sigma \end{bmatrix} \begin{bmatrix} E_i \cos(\alpha_1) \\ E_i \sin(\alpha_1) \end{bmatrix}$$

$$E_0 = \begin{bmatrix} \cos(\alpha_2)\rho_\pi E_i \cos(\alpha_1) + \sin(\alpha_2)\rho_\sigma E_i \sin(\alpha_1) \\ 0 \end{bmatrix} = \begin{bmatrix} E_\pi \cos(\alpha_2) + E_\sigma \sin(\alpha_2) \\ 0 \end{bmatrix}$$

Equation 1 $\Pi = p, \sigma = s$

The intensity of the light can be expressed the equation below.

$$I_0 = E_0 * E_0 \rightarrow I_0 = \frac{1}{2}[s_0 + s_1 \cos(2\alpha_2) + s_2 \sin(2\alpha_2)]$$

$$s_0 = E_pE_p + E_sE_s, s_1 = E_pE_p - E_sE_s, s_2 = E_pE_s + E_sE_p$$

Intensities at different angles can be expressed as following equations.

$$I_0(0^o) = \frac{1}{2}(s_0 + s_1)$$
$$I_0(45^o) = \frac{1}{2}(s_0 + s_2)$$
$$I_0(90^o) = \frac{1}{2}(s_0 - s_1)$$

For instance, if $\tan(\alpha_1) = 45$,

$$\cos(2\Psi) = \frac{I_0(90) - I_0(0)}{I_0(90) + I_0(0)}$$
$$\sin(2\Psi)\cos(\Delta) = \frac{2I_0(45^o) - I_0(90) - I_0(0)}{I_0(90) + I_0(0)}$$

At this point, the Ψ and Δ will be found with respect to this equation.

IV. RESULTS AND SIMULATIONS

Because the ellipsometry system is occurred by optical and electrical parts, the circuitry and code design and the simulation results were given in this part.

The circuitry representation is shown below.

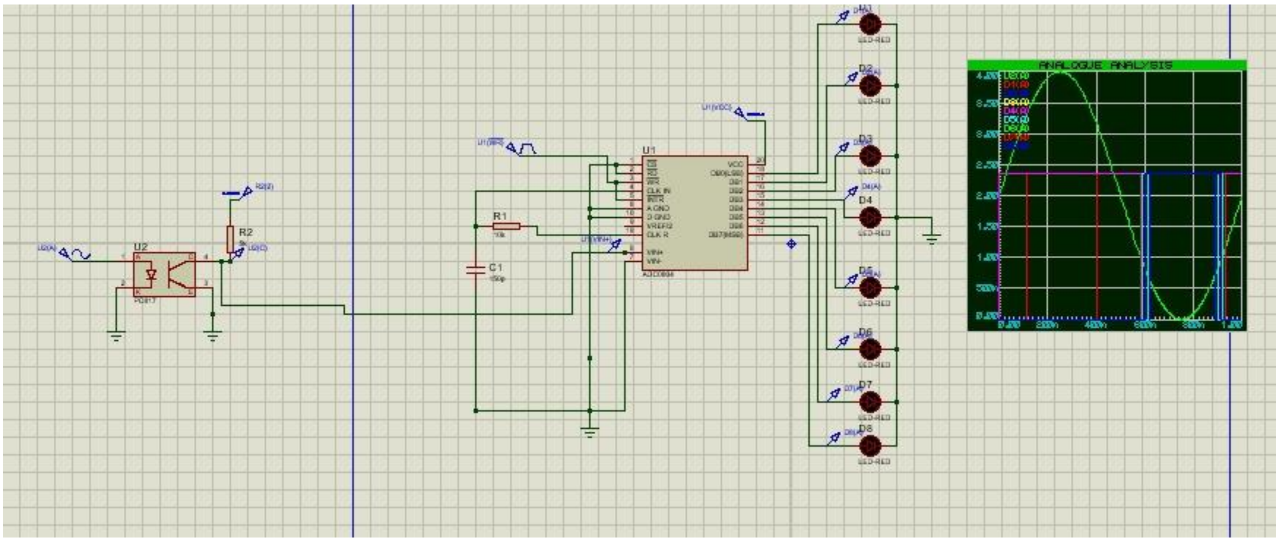
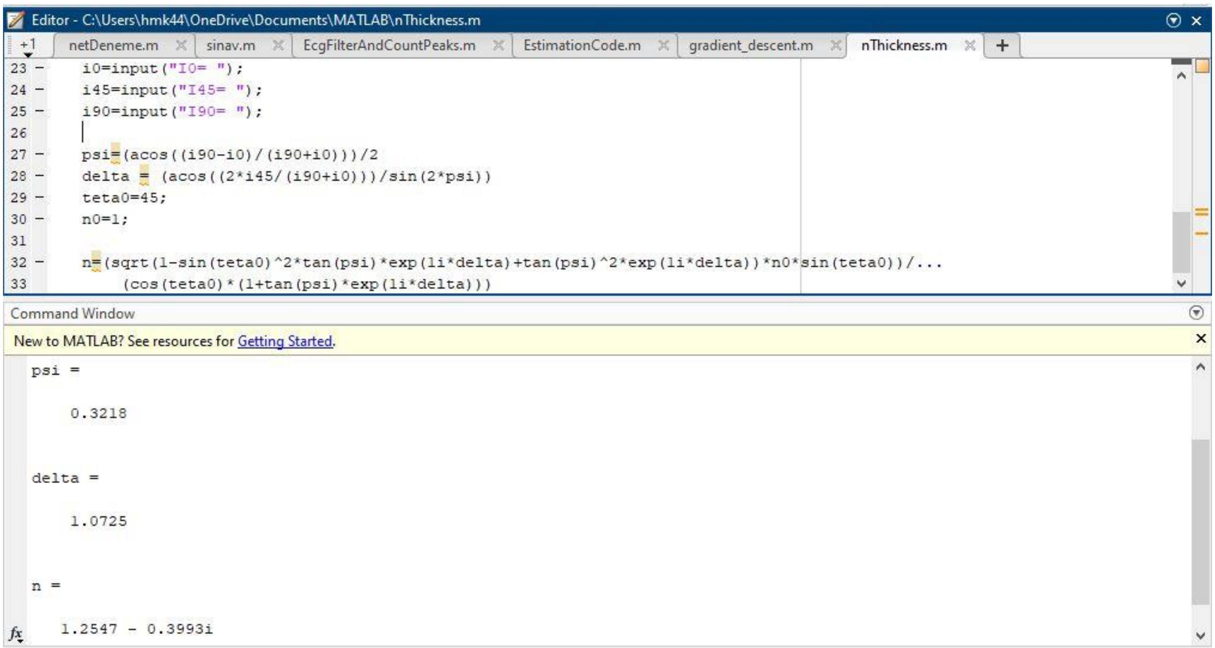


Figure 14

In-circuit there is one phototransistor and photodiode that provide the simulation of after phototransistor the current will convert to voltage with a phototransistor. After all the signal goes to the ADC0804. The signal is converting to analog signal to digital signal right here.

Figure 15 Output of the ADC

In the Matlab part, I(0), I(45), and I(90) would be requested from the user with respect to a datasheet of the photodiode after this MATLAB result shown below.



I0= 50e-12

I45= 200e-12

I90= 450e-12

V. CONCLUSION

In this project, ellipsometry was designed and all parts were simulated in the simulation environment except the optical part. The optical part was proved mathematically and calculation was done in MATLAB. Ellipsometry is a system that measures the polarization of the light with parameters which are psi and delta. Furthermore, those values can be used to find film thicknesses.

VI. REFERENCE LIST

[1] https://www.thorlabs.com/drawings/be526025bb0c78bb-B2E43B7F-0945-0BFF-31717FE4A5D9EE2F/FDS025-SpecSheet.pdf

[2] https://homepages.spa.umn.edu/~chauh043/files/elips.pdf

[3] https://en.wikipedia.org/wiki/Ellipsometry