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Optical Characterization of a Silicon Wafer Semiconductor

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ABSTRACT: *Semiconductor materials have technological and strategical importance, because they enable to obtain efficient and relevant devices in the globalized world. Silicon wafers are, therefore, largely used by different types of industry. So, studying their properties is important because these are closely related to their structure and dictate the best way of application. This work evaluates silicon wafer properties by a nondestructive ellipsometric characterization, which allowed us to assess the thin layer thickness deposited on the substrate and the interaction properties with the light for both layer and substrate.*
Keywords *–Extinction coefficient, Semiconductor, Silicon wafer, Refractive index, Thickness.*

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I. INTRODUCTION

According to Callister [1], semiconductors are materials that have their characteristics associated with electrical conductivity as interim, with aspects of conductive materials and insulators ones. Those materials have revolutionized the modern industry.

Currently the silicon wafer is a very important material for the tech sector. Thanks to its properties – highlighted the semiconductor material - its main applications include components which are essential to the electronics industry, like chips and processors. As an example, Zarzycki[2] describes its use on devices in Micro-Electro-Mechanical Systems (MEMS). It's worth mentioning the importance of these materials has grown steadily, considering unique applications in optoelectronics [3].

According to Reinhardt [3], the Si wafers can be coated with an epitaxial layer of Si with different dopant type and concentration, or they may be coated with a film of uniform or patterned Si dioxide (SiO_2).

The silicon wafer figures as input of solar technology, participating in the productive chain of the photovoltaic industry, being raw material of photovoltaic cells and modules used in the capture of energy from the Sun to solar energy production. In this context, Tsuruda [4] claims that its use is increasingly evident, as it is aligned the world trend to achieve diversity in the energy matrix. Zanesco [5] evaluates the influence of thickness of SiO_2 in the silicon substrate for solar applications.

In the case of ellipsometry, Fujiwara [6] argues that it is a technique that makes possible to determine non-destructively optical properties of a material, resulting from the interaction of the material with the incident light. Fujiwara [6] elucidates those measured parameters are essential to obtain the optical properties (n) refractive index and extinction coefficient (k). These refer to the change in light speed when interacting with the material, causing its deviation, and the extinction of light when it focuses on the material. The optical properties are obtained regarding wavelengths and they may exemplify the behavior of material in various spectrums of light like ultraviolet, visible and infrared.

According to Gonçalves [7], the technique measures the change in the state of polarization of light when it interacts with the surface of the sample. This espectometric method considers the Maxwell concept that the light can be represented by an electric and a magnetic field vector. However, only the electric field interactions are considered, where are measured ellipsometric constants ψ tangent and Δ cosine. Gonçalves [7] mentions the application of ellipsometry in glasses and polymers as well as semiconductors. Aiming to use its example in metallic materials, Nunes [8] employed the technique to characterize metallic niobium.

II. MATERIALS AND METHODS

The silicon wafer object of this study consists of a thin layer of SiO_2 deposited on a substrate of high purity silicon. This work aims to determine the thickness of deposited layer, as well as the optical properties, given by both layer and substrate refraction index (n) and extinction coefficient (k), in terms of wavelengths ranging from 248.39 nm to 1000.28 nm, comprising part of the ultraviolet spectrum, the visible spectrum and part of infrared spectrum of light.

For the characterization of the material, we used an ellipsometer SEMILAB GES 5S, focusing the light from a Xenon lamp under a 70° angle with the normal direction. It uses the softwares SOPRA, SEA and WINELLI II.

Ellipsometric parameters of ψ tangent and Δ cosine of the silicon wafer were obtained experimentally. In order to optimize the characteristics of this sample, obtaining the best mapping it is possible, we continued the modeling of measured data by comparing them with data from the equipment information, where there are models for the same material class. Modeling includes the manual adjustment of the experimental curve with the theoretical curve, maximizing the regression R^2 content and thereby getting the best fit between those ones.

III. RESULTS AND DISCUSSION

Silicon wafer structure was determined considering individual properties of each layer that makes up the material. Figure 1 shows an overview of the sample, impossible to see with the naked eye.

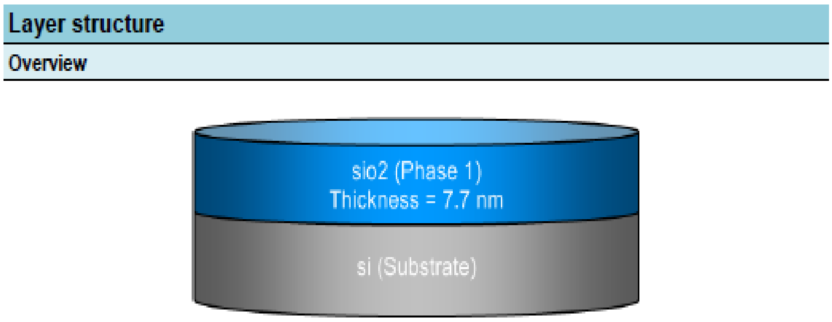

Figure 1: Overview of the structure of the semiconductor sample.

Ellipsometric characterization showed that the thickness of the thin film of silicon dioxide deposited on silicon substrate had 7.7 nm.

As indicated in Figure 2, it was possible to obtain a high quality of fit between the modeled curves and experimental, as provided by the software experiment report SEMILAB SEA.

Fit quality	
R^2	0.92432

Figure 2: Coefficient of determination between the curves.

This determination coefficient indicates there is a great compatibility between the experimentally measured data and the data suggested by computational model for the silicon wafer. This result validates the optical properties that will be subsequently obtained.

Figures 3 and 4 shows the results of the parameters measured experimentally and the fit curve modeling.

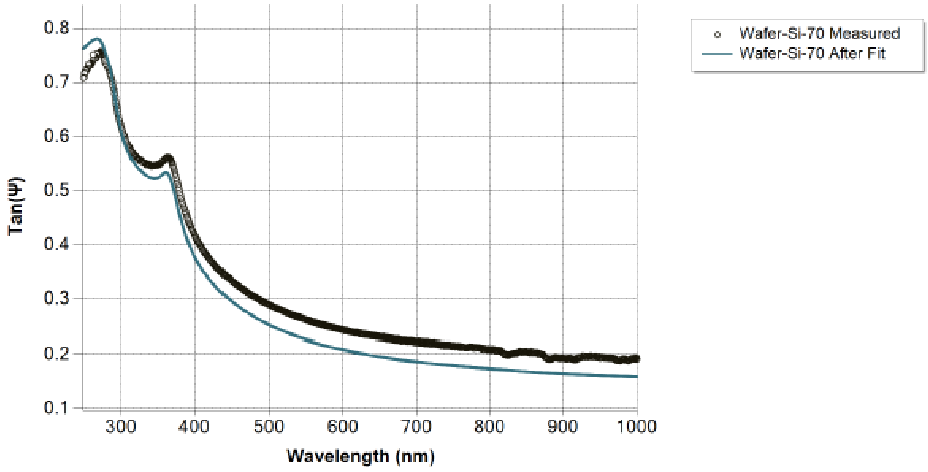

Figure 3: Relationship between experimental and theoretical ψ tangent.

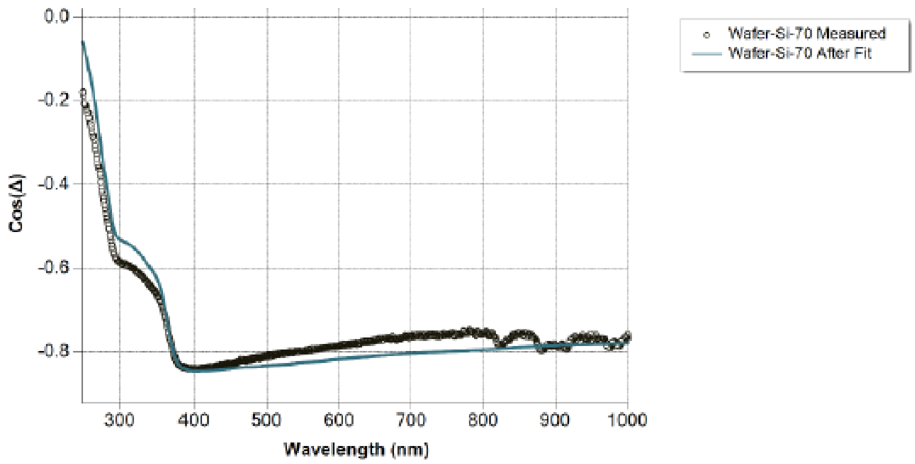

Figure 4: Relationship between experimental and theoretical Δ cosine.

With those values, it is possible to get the optical properties inherent to each layer of silicon wafer sample analyzed.

Figure 5 shows the results of the refractive index of the layer of silicon dioxide in several wavelengths.

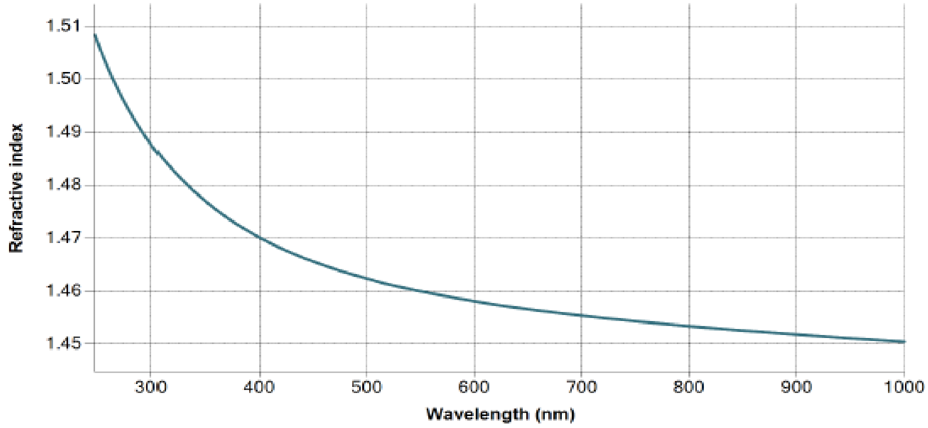

Figure 5: Refractive index for layer vs. Wavelength.

We can observe that the sample has increased refractive index to smaller wavelengths, corresponding to one of the regions analyzed, the ultraviolet spectrum. The n tends to decrease as increase in wavelength, showing the smallest indexes in the infrared spectrum.

Figure 6 shows the results of the extinction coefficient of the silicon dioxide layer in several wavelengths.

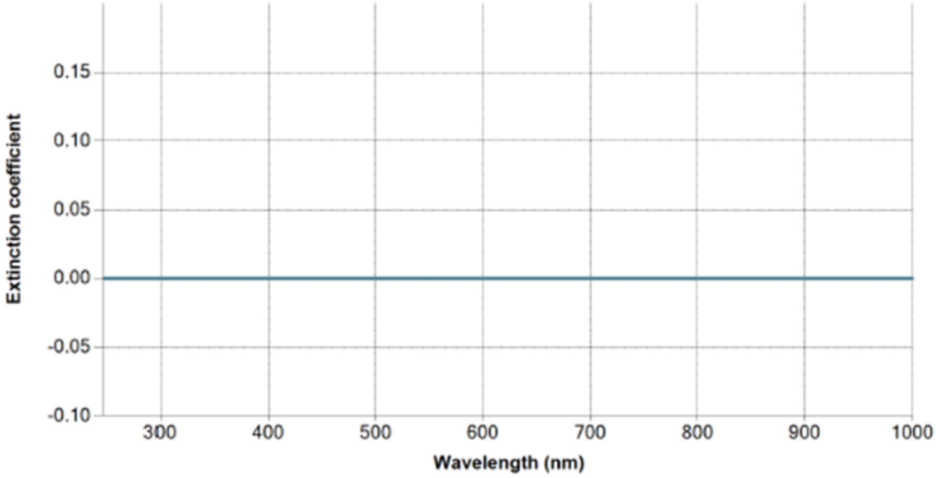

Figure 6: Extinction coefficient for layer vs. Wavelength.

For a wavelength, a null extinction coefficient implies in the absence of light extinction upon reaching the material. It is thus seen that the silicon dioxide film does not extinguish light at any wavelength considering the three analyzed spectra. It means that no light has attenuation.

Figure 7 shows the results of the refractive index of high purity silicon substrate over several wavelengths.

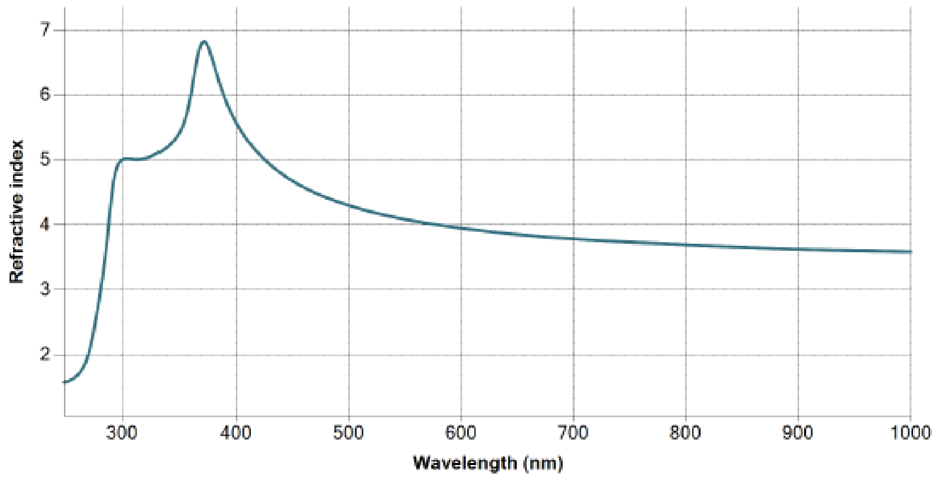

Figure 7: Refraction index for substrate vs. Wavelength.

There is an increase in the refractive index for wavelengths near 300 nm, with a peak at approximately 380 nm. Approaching the visible spectrum, around 400 nm, n starts to decrease while remaining in this trend as wavelength increases until the end of the spectrum, nearly corresponding to infrared range, close to 1000 nm.

Figure 8 shows the results of extinction coefficient of high purity silicon substrate over several wavelengths.

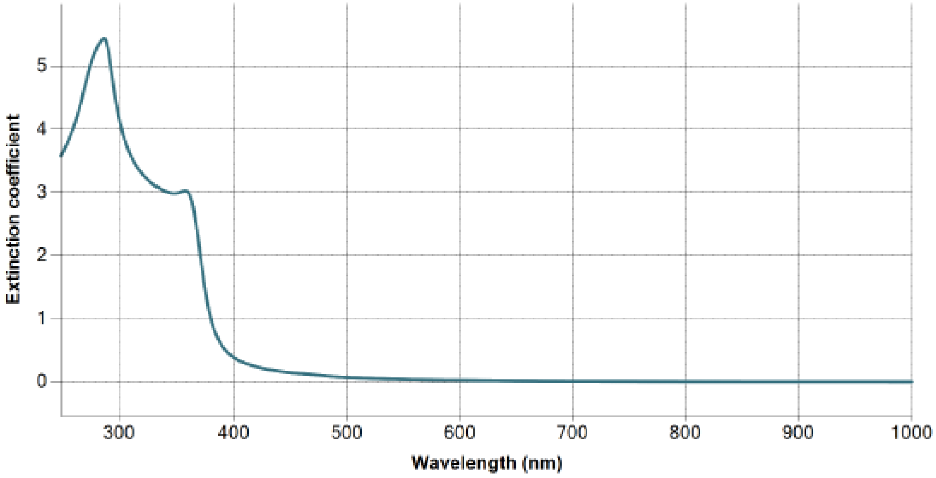

Figure 8: Extinction coefficient for substrate vs. Wavelength.

The extinction coefficient of substrate displays increase for small values of wavelength, where light has the greater attenuation. After approximately 300 nm, k comes into sudden decay up to 500 nm, tending to zero by the end of the spectrum analyzed.

IV. CONCLUSION

By using ellipsometric techniques was possible to map the semiconductor sample morphology, such as the gauge thickness of silicon dioxide layer and the optical properties of both silicon layer and substrate that compose the wafer. The ellipsometer is an important tool to the characterization of thin layers, since it allows the determination of thickness, refractive index (n) and extinction coefficient (k) of such material. The measures are obtained due to incidence and polarization of a beam of light on the sample, and the reflection of that light. Being a nondestructive technique facilitates its use for characterization of various materials in different industrial segments. The inherent properties of silicon wafer were obtained with high performance, which is attested by the high level of correlation between the experimental and theoretical curve. The optical properties of the material are important for its applications. The layer of SiO_2 showed lower n and k than the silicon substrate. It means the layer refracts less incident light and also attenuates less light than substrate, making the silicon wafer an indispensable material for the tech industry.

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