THICKNESS MEASUREMENTS USING PRISM COUPLING

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ABSTRACT

A HeNe laser and a 45-90 degree prism with an index of refraction of 1.51 were used to study the prism coupling method of determining the thickness and index of refraction of thin films. This project involved the design and construction of a set-up that allowed for simple adjustment of the incident angle of the light. Based on the available prism, SiO2 films were testable.

INTRODUCTION

It is possible to very accurately determine the thickness and index of refraction of a thin film by using a prism coupler. A typical system is shown in Figure 1. This is accomplished by placing a prism in close proximity to the thin film that is to be measured. A monochromatic beam is incident on one face of the prism. Normally there is almost total internal reflection at the interface between the bottom of the prism and the air gap that exists between the prism and thin film. However, a small field will exist at the interface and reach outside of the prism. This field is called an evanescent field and it decays exponentially to zero within a few wavelengths.[2] If the air gap is made small enough, (on the order of one half to one wavelength of the light) the evanescent field will extend into the thin film.[3] If the horizontal component of the evanescent field (ie. the component

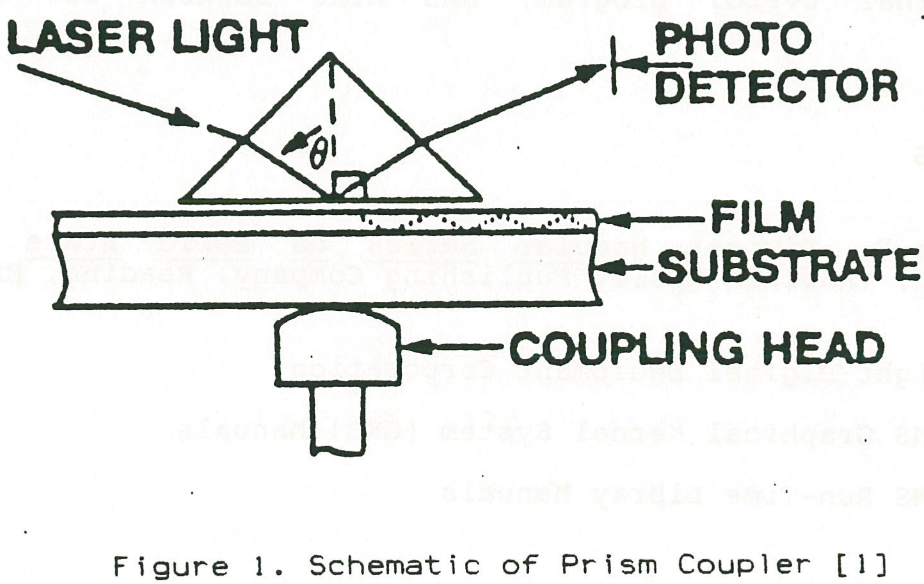

Figure 1. Schematic of Prism Coupler [1]

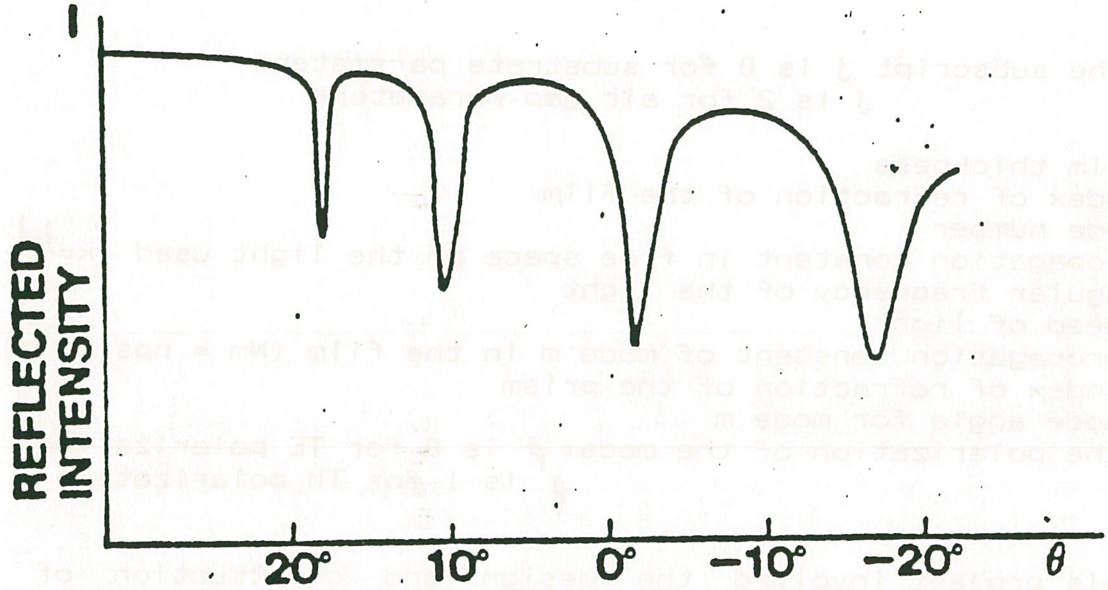

Figure 2. Intensity (I) of Reflected Light
VS. Angle of Incidence (θ) [1]

parallel to the interface) is equal to one of the modes of the thin film waveguide, light will couple into the film. Furthermore, if this condition is met, the light propagating in the film will combine constructively with light entering the film further away. This will cause more of the incoming light to be coupled into the film.[4] The net result will be a significant amount of light traversing the air gap and propagating horizontally inside the thin film.

It is possible to adjust the horizontal component of the evanescent field by adjusting the incident angle of the laser. If the intensity of the light coming out of prism is measured, there will be a drop in intensity at the angles of theta where this coupling occurs. These angles are called mode angles, and are characteristic of the film's index of refraction and thickness. If the intensity of the reflected beam is plotted as a function of the angle of incidence, a plot similar to the one shown in Figure 2 would be expected. If two or more of these mode angles are obtained, the index and thickness of the film can be calculated using the following equations.[5]

$$kW\ (n^2 - Nm^2) = m\pi + \phi 0(n,Nm) + \phi 2(n,Nm) \qquad (1)$$

$$\text{where } \phi j(n,Nm) = \arctan \sqrt{\left(\frac{n}{nj}\right)^{2\rho} \left(\frac{Nm^2 - nj^2}{n^2 - Nm^2}\right)} \qquad (2)$$

where the subscript j is 0 for substrate parameters
j is 2 for air gap parameters

W is film thickness
n is index of refraction of the film
m is mode number
k is propagation constant in free space of the light used ($k=\frac{\omega}{c}$)
ω is angular frequency of the light
c is speed of light
Nm is propagation constant of mode m in the film ($Nm = np\sin\theta m$)
np is index of refraction of the prism
θm is mode angle for mode m
ρ is the polarization of the mode: ρ is 0 for TE polarization
ρ is 1 for TM polarization

This project involved the design and construction of a preliminary test apparatus to investigate this phenomena for silicon dioxide films.

EXPERIMENTAL

A Helium-Neon laser with wavelength of 6328 angstroms was used as an incident light source. A right angle prism with index of refraction of 1.51 provided the necessary coupling medium. The set-up, shown in Figure 3, was constructed. The laser is stationary, the thin film/ prism apparatus pivots so that it is possible to adjust the angle of incidence, and the photodetector must be moved to collect the reflected wave. The wafer slides into the slot and is held in place by the vacuum (not shown). The shelf supports the prism. The clamp can be adjusted to vary the pressure (and thus the air gap distance) between the prism and thin film. The intensity of the reflected light was recorded by hand and plotted as a function of the incident angle.

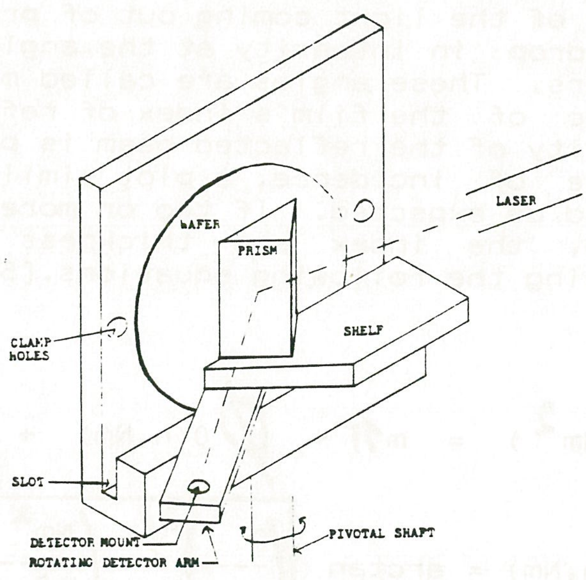

Figure 3. Prism Coupler Test Set-up

RESULTS/DISCUSSION

A plot of the intensity of reflected light versus the angle of incidence can be seen in Figure 4. This data was obtained from a wafer that had 5000 angstroms of oxide and an index of refraction of 1.46. Clearly, this plot lacks the mode angles that are so prevalent in Figure 2. The angle of incidence is limited to +6 and -20 degrees due to the physical make-up of the apparatus. If we increase the angle past +6 degrees, the light enters the prism and strikes the prism/air gap interface at an angle that does not exceed the critical angle needed for total internal reflection. The light will enter the thin film regardless of its thickness and index of refraction. If we increase the angle past -20 degrees, it becomes impossible to collect the reflected light due to the size of the detector.

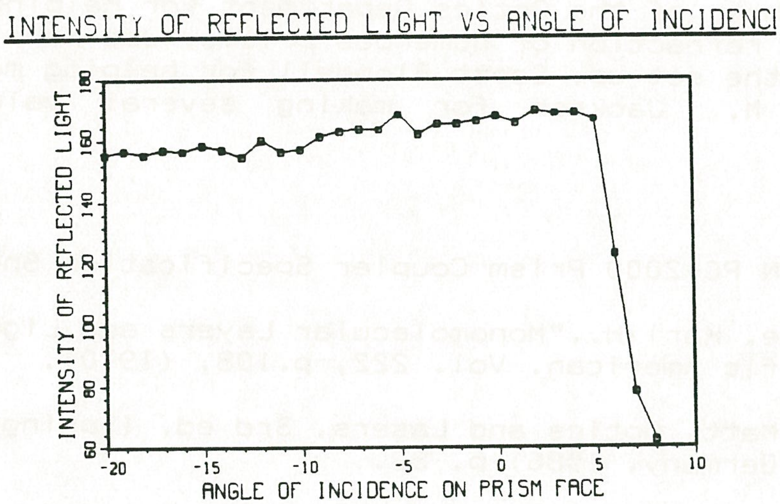

Figure 4. Results for a Silicon Dioxide Film

The reason that no mode angles were observed could be the result of several factors. The small difference in the index of refraction between the film and prism makes it crucial to have the correct air gap spacing. This however is impossible to measure and it is necessary to rely on trial and error. Several different pressures between the prism and film were tried with similar results. Another possible reason why no mode angles were observed is decoupling of the light back into the prism. Once the coupled light propagates past the incident laser beam it may decouple back into the prism if the prism and film remain in close proximity. It may be necessary to separate the prism and film after the point where the laser strikes the interface. Finally, it may be possible that the silicon dioxide film that was tested was too thin to support more than one mode angle. If the only mode angle that was supported falls outside the limitations of the apparatus, no mode angles would be observed.

CONCLUSIONS

The set-up that was designed and constructed allowed for easy and accurate measurements of the reflected intensity versus incident angle. Some limitations on the measurable angles of incidence were observed due to the size and location of the detector.The use of an equilateral prism will increase the total range of incident angles that can be measured. Mode angles were not observed due to decoupling of the coupled light, the prism had too low of an index of refraction, or the film was too thin. This technique would be better suited for measuring the thickness of photoresist. This would be possible if an equilateral prism with a sufficiently high index of refraction were used.

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REFERENCES

[1] METRICON PC-2000 Prism Coupler Specification Sheets.

[2] Drexhage, Karl H.,"Monomolecular Layers and Light." Scientific American. Vol. 222, p.108. (1970).

[3] Young, Matt, Optics and Lasers, 3rd ed. (Springer-Verlag, Berlin Germany, 1986) p. 82.

[4] Palais, Joseph C., Fiber Optics Communications (Prentice-Hall, Inc. Englewood Cliffs, New Jersey) p. 202.

[5] Ulrich,R. and Torge,R., "Measurement of Thin Film Parameters with a Prism Coupler," Applied Optics. Vol.12, No.12 (December 1973). p.2906.