# In-Situ Optical Thickness Control of Ion Beam Deposited Coatings for the Telecommunication Industry

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**Abstract**

**Several techniques for in-situ thickness control of Ion Beam Deposited optical thin films were investigated. These included simple light monitors using a single wavelength and multiple wavelength light sources as well as in-situ ellipsometry. It was found that ellipsometry provided the best solution, with the most accurate and reproducible control of film deposition. Repeatabilities of less than 0.2% were easily obtained for multilayer films. The traditional light monitors, resulted in repeatabilities of > 0.5% and typically well over 1%. Furthermore, ellipsometry proved to be extremely flexible in its ability to monitor various types of films including absorbing films like amorphous silicon and multilayer stacks of different layer thicknesses.**

## INTRODUCTION

In recent years, the demand for high performance optical coatings has greatly increased. Applications for these films include antireflective (AR) and highly reflective (HR) coatings for lasers (pumps and source lasers), optical modulators and dense-wave-division-multiplexing filters. Ion Beam Deposition (IBD) is proving to be the preferred technique for the most demanding of these applications, as it provides stable dense films.[1] In this paper, we will focus on IBD for laser facet and optical modulator coatings.[2]

Due to the stringent performance requirements for these devices, both in terms of the center wavelength and the reflectivity needed, accurate control of the layers deposited is essential. In order to achieve the type of control and repeatability that is desired, some form of in-situ control of the deposition is desirable. Traditionally, optical light monitors have been used in evaporators for this function. In this paper, we examine the use of this technique in addition to in-situ ellipsometry.

## EXPERIMENTAL SETUP

### *Deposition Equipment*

Veeco Ion Beam Deposition tools were used for these experiments. The main features of these tools are illustrated in Figure 1. The tool consists of a substrate fixture, which holds the substrate to be deposited on. This fixture rotates as well as tilts. Using this feature, extremely good within wafer film uniformities can be achieved (<0.5% over 150 mm). The tool has two ion sources, the primary source is the deposition source, and the secondary source is the assist source. By optimizing the beam energies for each source and by varying the fixture angle, optimum film properties can be obtained. This flexibility of changing the deposition angle also makes it difficult to configure an optical monitor in an appropriate fashion due to the changing position of the substrate. In addition, at certain optimized fixed angles, the only mode that can be used is reflection due to constraints in mounting optical components and line of sight issues. Three optical monitors were investigated, and they are described in detail below.

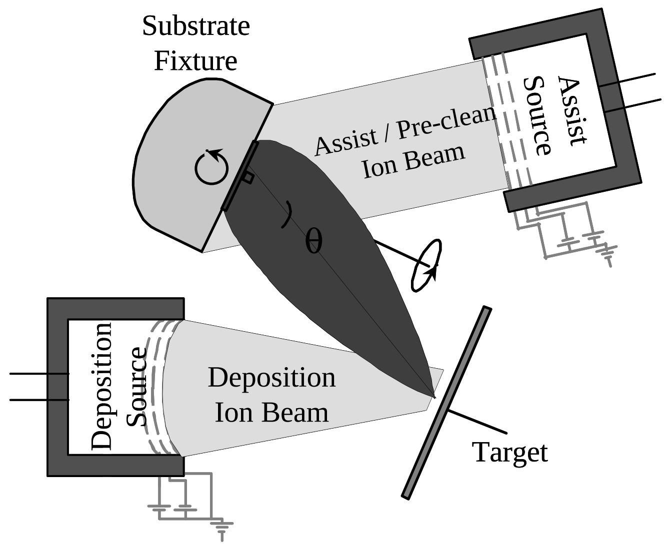


Figure 1 Schematic of Veeco Ion Beam Deposition Tool

### *Single Wavelength Optical Monitor*

This is the least complex of the three monitors that were investigated. In simple terms, this optical monitoring system (OMS) consists of a laser light source operating at 670 nm, a

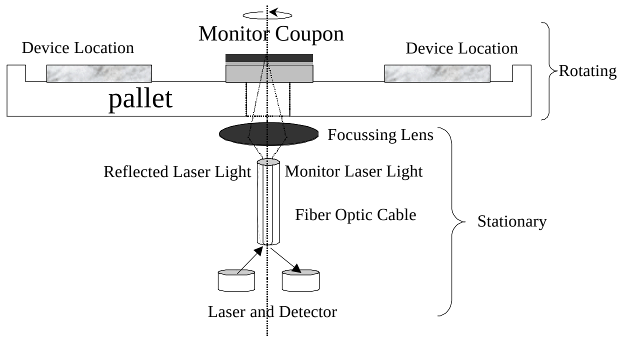


Figure 2 Schematic of "backside" reflectance OMS

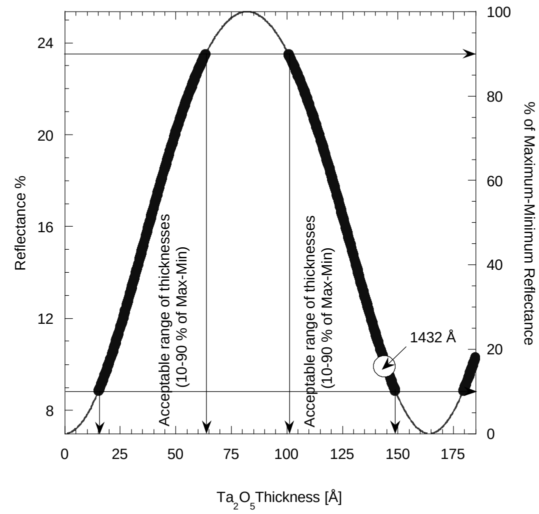


Figure 4 Reflectance curve of $Ta_2O_5$ on glass. Shown in bold is the limited range for effective operation of the single λ OMS.

fiber optic bundle that carries the incident and reflected light to and from the monitor coupon, focusing optics, a detector and a computer which processes the raw data. The monitor coupon can be of any transparent material and is located at the center of the substrate pallet. The termination point is determined by comparing the intensity of reflected light with the values programmed into the OMS software that correspond to the desired thickness. This data is input into the software by offline modeling with any commercially available thin film program like TFCalc. The OMS collects data once every revolution of the substrate, which in this case is once every 1.5 seconds (40 rpm), on the same spot on the witness coupon. This ensures that the "wobble" effect due to the non-planar rotation of the pallet does not affect the measured signal. The reflectance data is then filtered and processed by the OMS software. A schematic of the system is shown in Figure 2. This configuration is also called "backside" reflectance, since the monitor light enters through the back surface of the monitor coupon (the surface opposite to where the film is being deposited) and then traverses the film being deposited and reflects off of the front surface of the film being coated. A typical reflectance curve obtained with this OMS is shown in Figure 3. A major limitation with this single wavelength system, is the lack of flexibility of the OMS. The thicknesses that can be accurately terminated are limited to those that correspond to a region of the reflectance curve that is sufficiently sensitive. Thus, thicknesses that fall in the peaks and valley region will not be accurately deposited. This is illustrated in Figure 4. The plot shows the regions that can be effectively monitored with this type of OMS in bold and have been chosen as the band that falls in the 10-90% range of the peak to valley reflectance. A solution to this is to use a different wavelength, which was not possible for this particular system, or use alternative substrates to change the termination point. Either solution was not acceptable for a manufacturing environment and would lock the system into certain ranges of thicknesses. This leads us to the second type of OMS that was investigated.

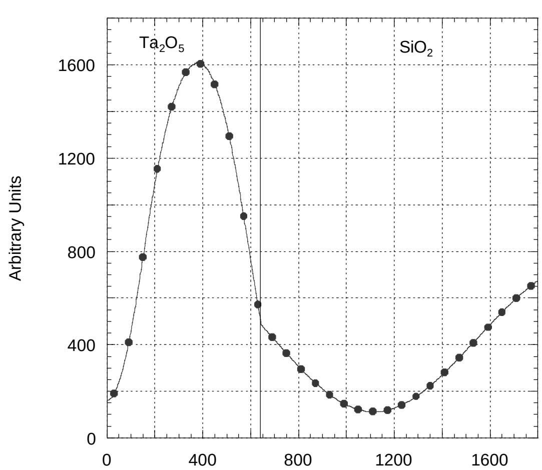


Figure 3 Typical reflectance curve from a single wavelength backside reflectance OMS

*White Light Optical Monitor*

In order to address the concerns of the lack of flexibility of the single wavelength monitor, a white light system was investigated. Since this would afford us the ability to use multiple wavelengths (which is user selectable). It would allow us to successfully terminate at any film thickness by choosing the appropriate wavelength. The configuration of the system was identical to that shown in Figure 2 with the exception of a white light (350 to 800 nm) source being used instead of the laser. Due to the lower signal levels of the white light source, the reflected signal had to be continuously monitored and not sampled once every rotation as in the single wavelength case. Due to the unavoidable "wobble" in the substrate stage, the signal had to be heavily filtered to avoid false termination points being detected.

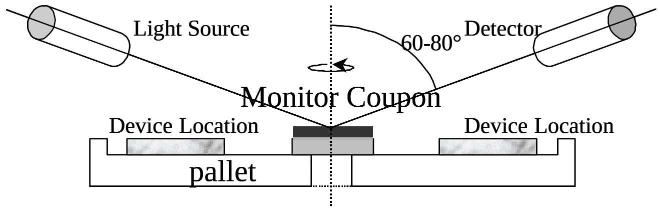


Figure 5 Schematic of in-situ ellipsometry configuration

This decreased the sensitivity of the system and therefore yielded rather poor repeatabilities.

*In-Situ Ellipsometry for Thickness Control*

The last technique investigated was in-situ ellipsometry. This method is more complex than the other methods investigated, but for this application proved to be the most suitable. It is extremely flexible in the types of materials that can be monitored – both absorptive films like amorphous Si and transparent films like $SiO_2$, $Ta_2O_5$ etc. The ellipsometer had a white light source and detectors, which collected data in the spectral range of 350 to 800 nm. Data was continuously collected (not sampled) and the effect of the wobble of the substrate is less of an issue here since the detector sees some of the reflected light always. The angles that the ellipsometer works at is fixed and was chosen to correspond to optimized deposition angles. The termination point of the deposition was determined by real time modeling of the raw $\Psi$ and $\Delta$ data to obtain thickness and index information. The cut point, can be based on either the thickness or the thickness-index product (optical thickness). Furthermore, the choice of which method is used and what wavelength is chosen, is user selectable. A schematic of the configuration used is shown in Figure 5.

A summary of the three configurations investigated is shown in Table I.

Table 1 Summary of Optical Monitor configurations

| | Single λ | White Light | In-Situ Ellipsometry |
|---|---|---|---|
| Configuration | Backside reflectance light monitor | Backside reflectance light monitor | Frontside Spectroscopic Ellipsometry |
| Wavelength | Single λ: 670 nm | White Light: 350-800 nm | Spectroscopic 350-800 nm |
| Angles | All deposition angles | All deposition angles | Fixed angle |
| Film Limitations | Must be transparent at operating λ | Must be transparent at operating λ | None (software model must exist for film) |
| Film Thickness and Multilayers | Limited to thicknesses that are not at the peak or valley of reflectance curve | No Limitations | No Limitations |
| Rotation and Wobble | Reflectance sampled once every revolution | Reflectance sampled continuously | Data averaged over rotation |

Table 2 Summary of film repeatabilities for the three optical monitors investigated

| | Single λ | White Light | In-Situ Ellipsometry |
|---|---|---|---|
| Single Layers $SiO_2$ | - | - | 0.11 % |
| Single Layers $Ta_2O_5$ | 1.27 % | 4.28 % | 0.10 % |
| Single Layers $Al_2O_3$ | 1.54 % | - | - |
| Single Layers amorphous-Si | - | - | 0.16 % |
| Bi-Layers: 1st Layer: $Ta_2O_5$ | 0.55 % | 0.82 % | 0.15 % |
| Bi-Layers: 2nd Layer: $SiO_2$ | 0.86 % | 7.92 % | 0.18 % |

## RESULTS

For the optical monitor to be successful, it must be both accurate and repeatable. Accuracy can be achieved by a combination of appropriate programming of the OMS software and empirical adjustments to account for tooling factors. Repeatability is more intrinsic to a particular OMS and thus this is the parameter that we concentrated on. A summary of the film repeatabilities obtained for the three types of monitors investigated are shown in Table 2. The data shows that the single wavelength OMS has a repeatability of <1.5 % in most instances, which is not very good and in fact is worse than the intrinsic repeatability of the deposition tool of <1 %. The white light monitor had the worst repeatability and this was primarily due to the

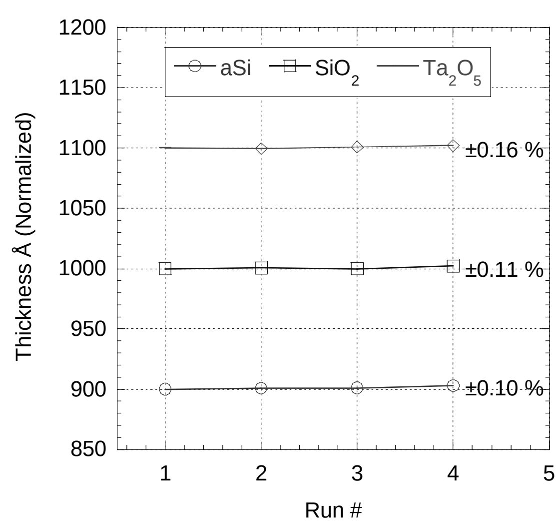


Figure 6 Repeatability of single films obtained with in-situ ellipsometry control

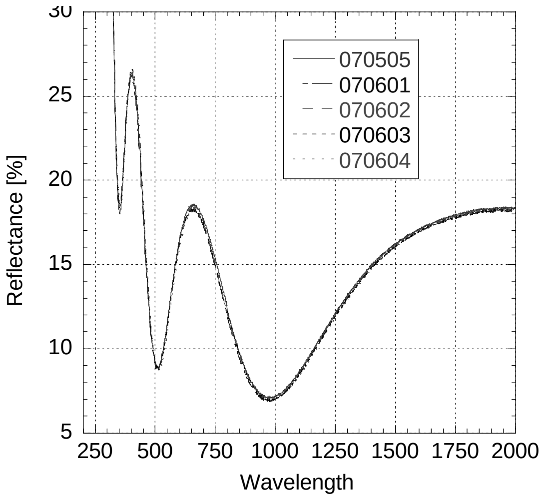


Figure 7 Spectral response of a $Ta_2O_5/SiO_2$ bilayer on glass showing the repeatability of the in-situ ellipsometry controlled process.

difficulty in obtaining a large enough reflected signal from the substrate. As mentioned earlier, mounting the various optical components is challenging in this particular tool's geometry due to the rotation and tilt of the substrate and line of sight issues.

Based on these results, it is clear that in-situ ellipsometry provides the best repeatability at <0.2%. This is shown graphically in Figure 6. Furthermore, it is able to accurately control absorptive films like amorphous Si.

The spectral response of a bilayer film of $Ta_2O_5$-1232 Å/$SiO_2$-1673 Å (1550 nm Bi-layer AR coating for InP) deposited on glass is shown in Figure 7. The plot shows that it is hard to discern any spectral differences in the five films. This data is re-plotted with peak values and positions as a function of the run number in Figure 8. This data shows that the peak position varies from 980 to 985 nm and the

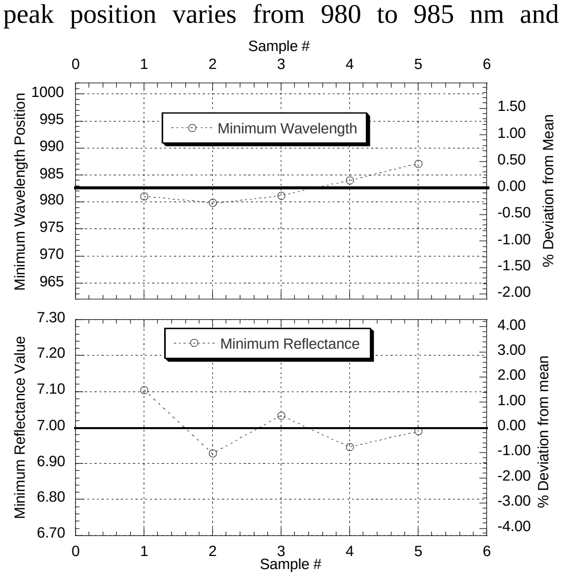


Figure 8 Wavelength peak position and value as a function of the run number

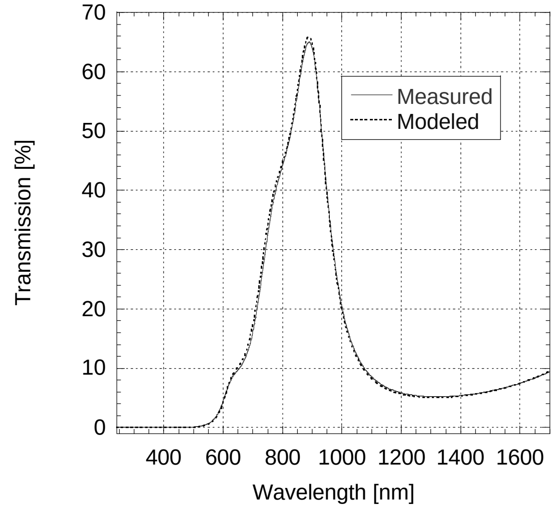


Figure 9 Spectral response of a stack with the structure $SiO_2$/-2220 Å/a-Si-840 Å)x2/$SiO_2$-300 Å

minimum reflectance value from 6.9 % to 7.1 %. The spectral response of an amorphous Si based multilayer sample is shown in Figure 9. The plot shows the close agreement between modeled and measured data for a highly reflective (HR) stack of: ($SiO_2$/-2220 Å/a-Si-840 Å)x2/$SiO_2$-300 Å designed for 1310 nm.

## SUMMARY AND CONCLUSIONS

We investigated three types of optical monitors: a single wavelength laser based system, a multi-wavelength white light system and a spectral in-situ ellipsometer. The best system proved to be the ellipsometer with repeatabilities less than 0.2%. This technique also proved to be very flexible and capable of measuring a variety of films including absorptive films and multilayer stacks with great accuracy and repeatability. The other two techniques, while simpler in concept and implementation, were not able to achieve the types of repeatabilities that were desired. In a simpler tool geometry, which allows for better placement of optical components (perhaps in transmission mode etc.), these systems may have performed better.

## REFERENCES

[1] J.J Cuomo, J.M.E. Harper, C.R. Guarnieri, D.S. Yee, L.J. Atanasio, J. Angilello C.T. Wu, and R. H. Hammond, *J. Vac. Sci. Technol.* **2**0, 349 (1987).

[2] Adrian J. Devasahayam et al, "Material Properties of Ion Beam Deposited Oxides for the Opto-Electronic Industry", 10th Canadian Semiconductor Conference, Paper CTh1.3, Ottawa, Canada 2001.

## ACRONYMS

AR: Anti-Reflective
HR: Highly Reflective
IBD: Ion Beam Deposition
OMS: Optical Monitoring System