

Characterizing Processes with EASE™

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The application of *in situ* Spectroscopic Ellipsometry (*in situ* SE) to process monitoring and control has long been recognized. However, did you know that *in situ* SE can simplify everyday process characterization and development? Recent innovations incorporated into the Woollam Co.'s EASE™ software use Virtual Interface (VI) models to readily determine deposition (or etch) rates and optical constants of the top-most film without requiring a detailed model of underlying layers.

VI models allow sequential analysis of each layer of a multi-film stack as they are deposited during a single run. By varying process parameters (e.g. gun current, gas flow rates, ...) for each layer during the run, one can easily characterize film deposition rates and optical constants for various conditions.

Why use a Virtual Interface?

Characterization of film deposition, etching or other processing consists of determining film growth (or etch) rates and optical constants, $n(\lambda)$ and $k(\lambda)$, for various process conditions. Obviously, film growth rates can be readily determined from *in situ* SE data by calculating the change in film thickness over time. Simultaneously, one can also extract the optical constants from *in situ* SE data.

In traditional applications the quality of the analysis depends on optical model accuracy. Unfortunately, modeling errors are often introduced in the underlying layers. The effect is cumulative, making analysis of more than a few layers very difficult unless underlying films are well understood.

'Virtual Interface' models simplify analysis by combining the optical response of underlying layers into a 'pseudo substrate', as shown in Figure 1. During analysis, the layer above the VI is modeled, while the VI itself remains unchanged. Characteristics of the near surface film can be continuously tracked by constantly updating the location of the VI, placing it at some fixed time interval prior to the most recent *in situ* SE data. The "depth" of the VI is then determined by the time interval and deposition rate.

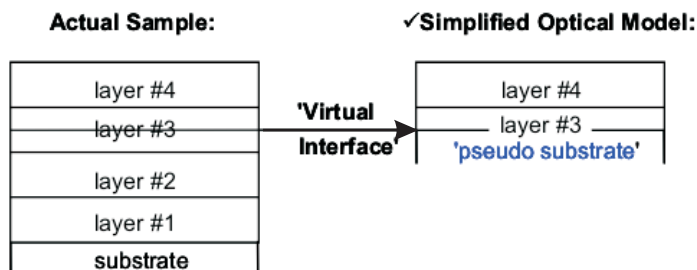


Figure 1. Schematic of a Virtual Interface model.

The GROC and Gen-VI Layers

EASE™ incorporates the VI concept in two different models, the Growth Rate Optical Constant (GROC) and Generalized Virtual Interface (Gen-VI) layers.

The GROC layer utilizes the common pseudo-substrate approximation (CPA), which works well for semiconductors, high-index dielectrics, metals, and highly absorbing materials. However, the simplifying assumption used by the CPA to calculate the VI parameters does not work for dielectric stacks.

The Gen-VI layer uses exact thin film equations in the VI calculation, making it valid for dielectric materials, semiconductors, metals, or any arbitrary isotropic layer structures, over any time/thickness range.

Besides determining the optical properties of the VI, both the GROC and Gen-VI layers calculate the top-most film deposition rate and optical constants $n(\lambda)$ and $k(\lambda)$. Both layers assume the film's growth rate and optical constants do not vary throughout the selected time range.

EASE Process Characterization Example

Depositions were conducted in a 2-gun DC sputtering chamber connected to argon and oxygen gas sources, with sputter targets of silicon and tantalum. Depositions can include one or both targets, combined with various gun currents and oxygen flow rates. The system can produce films of a-Si, Ta, Si-Ta alloys, as well as silicon and tantalum oxides of varying composition and stoichiometry.

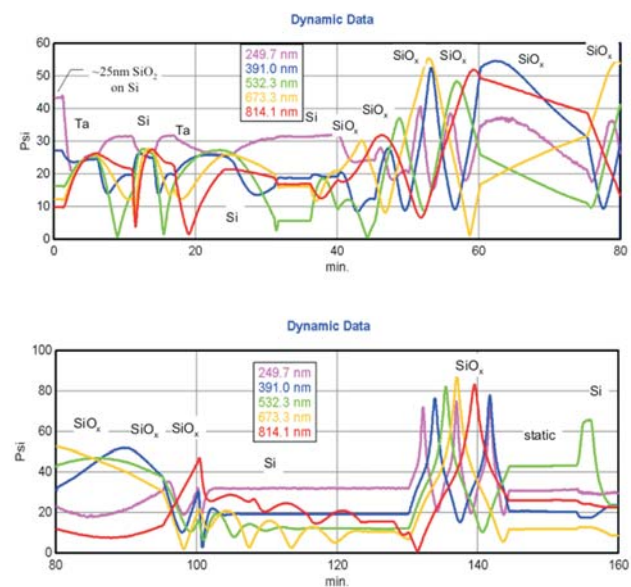


Figure 2. Evolution of ellipsometric Ψ at five wavelengths acquired during a 160min. deposition of 19 different films of Ta, Si, or SiO_x using various gun currents and O_2 gas flow rates.

Figure 2 shows the evolution of Ψ at 5 wavelengths, as 19 different layers are sequentially deposited on a starting substrate (consisting of ~25 nm thermally-deposited SiO₂ on silicon). The 19 layers included Ta and Si films deposited at sputter-gun currents of 0.1 to 0.5 amps, and the SiO_x films deposited using O₂ flows of 0 to 16 sccm.

Figures 3a and 3b show the GROC layer model for the third and sixth layers of the deposition run. As the figures indicate, the 3rd layer was tantalum deposited at a rate of 2.62 Å/second, while the 6th layer was a-Si deposited at a rate of 0.46 Å/second. In the figures, the optical constants for each film are shown in the bottom-left graphs.

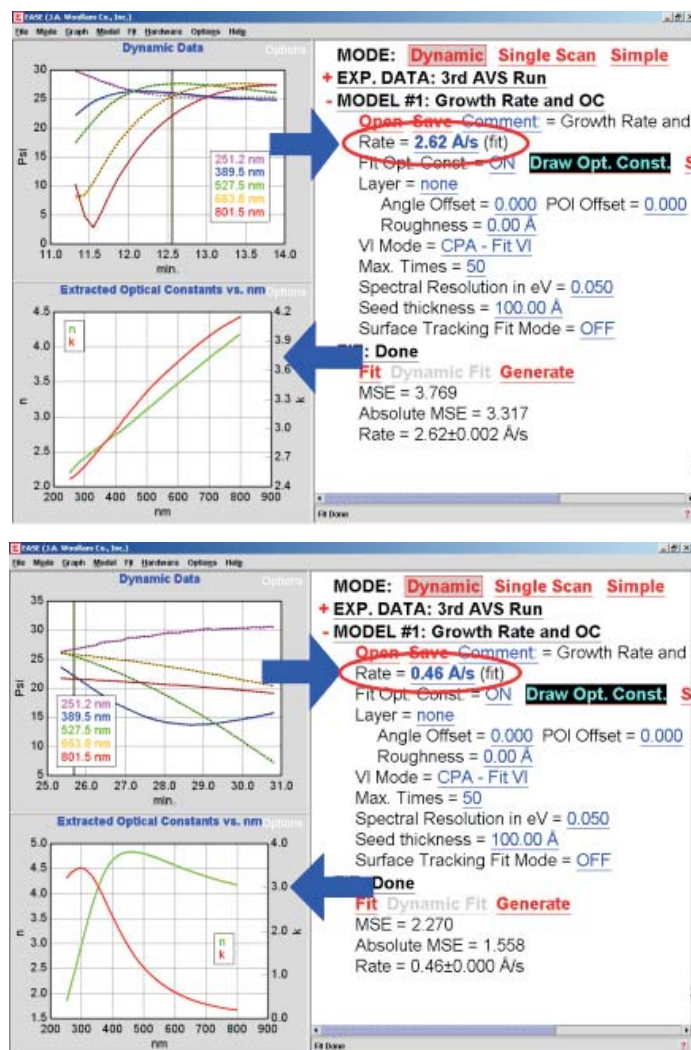


Figure 3a and 3b. GROC layer model for 3rd layer (run time 11 to 14 min.) and 6th layer (run time 25 to 31 min.) respectively, using a Ta gun (I_{Ta-gun} =0.4Amps) and Si gun (I_{Si-gun} =0.15Amps). Arrows indicate deposition rate and optical constants.

Figures 4a and 4b show the optical constants and

deposition rate for the eleventh and twelfth layers of the deposition run. As the figures indicate, the deposition rate was 3.95 Å/sec when the O₂ flow rate = 8 sccm, compared to 0.45 Å/sec for an O₂ flow rate=16 sccm, a 9x difference that can be attributed to oxygen poisoning of the Si sputter target.

Once modeling of all the different layers is completed, chamber performance is analyzed. As an example, the Ta and Si deposition-rate calibration chart is shown in Fig. 5.

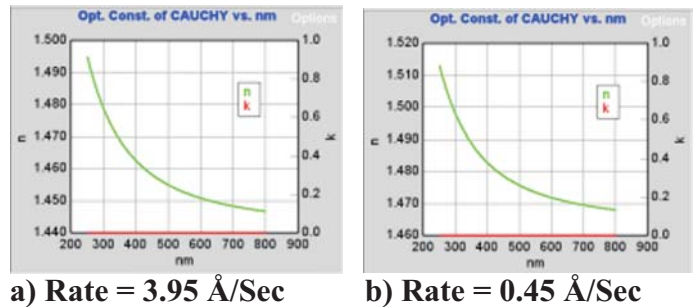


Figure 4a and 4b. SiO_x optical constants and deposition rates for 11th layer (run time 55 to 60 min.) and 12th layer (run time 60 to 70 min), using Si gun and O₂ gas (I_{Si-gun} =0.5A, O₂ flow=8 and 16 sccm respectively).

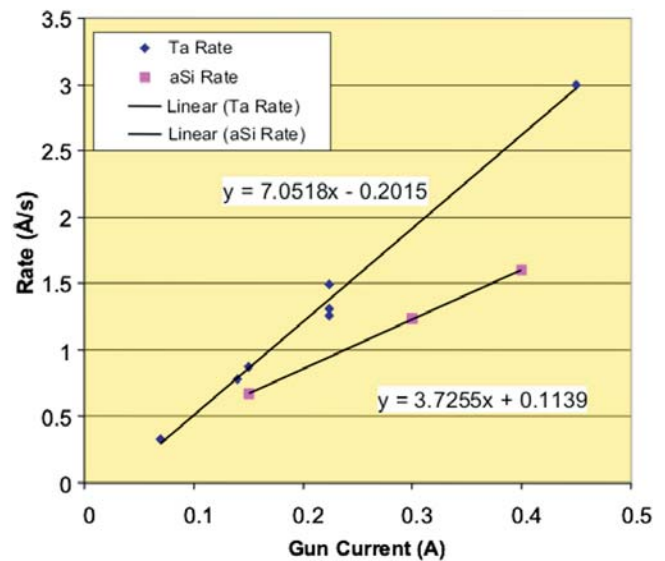


Figure 5. Ta and a-Si film deposition rate calibration chart

References:

1. B. Johs, J. Hale, N.J. Ianno, C.M. Herzinger, T.E. Tiwald, and J.A. Woollam, Proc. SPIE **4449**, 41(2001).
2. B. Johs, presented at ICSE-3, accepted for publication (Thin Sol. Films).