k-Space Associates, Inc.

Application Note

Deposition Rate Monitoring with kSA RateRat Pro

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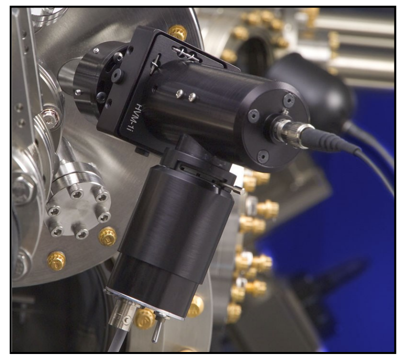
REAL-TIME MONITORING

- **Growth rate**
- **Layer thickness**
- **Optical constants (n,k)**
- **Successful GaN MOCVD results**
- **Multi-wafer triggering**
- **Real-time fitting**
- **Compatible with planetary rotation**
- **Spatially-resolved growth rate across wafer**
- **Easy integration with OEM control software**
- **Modulated, high-power laser source ensures high signal-to-noise ratio reflectance signal**

Introduction & Motivation

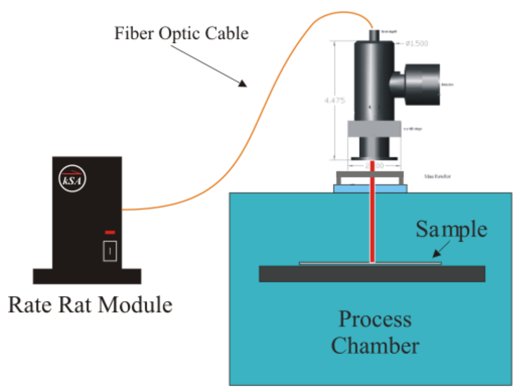
Many of today's optoelectronic and high-speed electronic devices are manufactured with advanced epitaxial growth techniques such as MOCVD or MBE. The ultimate device performance and characteristics depend heavily on a delicate balance of thin layers. Ideally, these layers would be grown using a process that can be controlled down to the atomic level. But with most compound semiconductor materials and device applications there is no real-time method for directly determining layer thickness, growth rate, and optical constants. Instead, this information is gathered via ex-situ characterization of the device post-process—a time-consuming, costly and reiterative task, but crucial for optimizing layer structures and/or maintaining yield tolerances.

Enter kSA RateRat Pro. In this application note, we present data showing the installation of the kSA RateRat thin-film deposition monitor for real-time analysis of GaN films commonly used for high-brightness LED's and radio frequency power electronics. The system was installed on a commercial, multi-wafer MOCVD reactor. Reflectance data was acquired to determine real-time growth rate, thickness, and optical constants (n,k) during both initial buffer layer growth on sapphire and subsequent homoepitaxial growth of GaN, simulating two different steps in optoelectronic device-layer deposition.



kSA RateRat Pro with standard 1.33" CF normal incidence mounting hardware.

RateRat Pro Reflectance Monitoring



kSA RateRat Pro Installation

Using sophisticated "Virtual Interface" algorithms originally developed at Sandia National Laboratories, the kSA RateRat Pro detects and analyzes surface reflectance in real-time to determine deposition rate, layer thickness, and optical constants with as little as 750 Å of material. With this real-time data analysis, kSA RateRat Pro provides real-time output for feedback into process control software—ideal input for MOCVD, MBE, sputtering, and evaporation control systems.

The kSA RateRat Pro system uses a modulated diode laser (658 nm standard with other wavelengths available depending on deposition materials), high-speed photo detector, and 16-bit data-acquisition board to acquire reflectance data during thin-film deposition. The modulated reflectance signal is acquired via analog input "blocks" at high speed. This block analog input is then Fast-Fourier Transformed (FFT) to extract the peak frequency amplitude. This improves signal-to-noise ratio because only signal detected at the laser modulation frequency is analyzed. Then, the peak frequency amplitude is converted to an absolute reflectance via a scaling factor, and the result is stored, fitted and plotted in real time as a function of acquisition time (Figure 1). All data acquired during a deposition run may be stored and loaded at another time for post-acquisition analysis. In this way, users can monitor key growth parameters in real-time, perform post-growth analysis, and make comparisons with other runs.

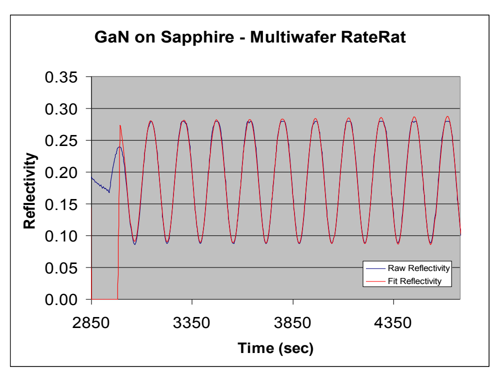


Figure 1: Raw Reflectivity and RateRat Pro Fit

Multi-Wafer GaN MOCVD Growth Results

RateRat Pro was installed onto an Aixtron production MOCVD reactor and configured to read the home pulse and one channel of a rotational encoder in order to acquire reflectance data from each wafer on the MOCVD platen. The home pulse was used as an angular zero point, and encoder pulses were counted with respect to the home pulse in order to acquire center wafer reflectance data from all wafers within the susceptor. (Note that data from all the wafers was clean, but only data from six wafers within the susceptor is presented here.)

Gas foil rotation and platen rotation did not affect measurement, as rotation wobble was effectively minimized by the collection optics and the high-spatial uniformity detector within the kSA RateRat Pro unit. The resulting high signal-to-noise ratio is a combination of high laser power, laser modulation, and the aforementioned Fourier transform technique.

Figure 2 shows the deposition rate dependence as a function of time. Note that the entire reflectivity data set at each point in time is used to calculate the deposition rate. Alternatively, the kSA RateRat Pro software can be configured to allow for data "windowing"—a rolling window of data used to calculate deposition rate. This is useful for monitoring small changes in deposition rate over time.

Initial growth rates, overall thickness, and optical constants were all determined within 750 Å of buffer layer growth. Data collection was re-initiated during homoepitaxial GaN deposition, simulating device layer growth. When growing a GaN device layer, kSA RateRat Pro obtains an initial fit more rapidly (about two-times faster) because the homoepitaxial GaN deposition surface is much smoother than the initial rough growth of the GaN buffer layer on sapphire (followed by coalescence and smoothing of the surface).

Table 1 shows the deposition rate and index of refraction determined for each wafer during the deposition. It is important to note that all reflectivity data obtained during buffer layer growth, subsequent growth modes, and epitaxial growth is available for 'fingerprinting' the device structure—both real-time and post-process.

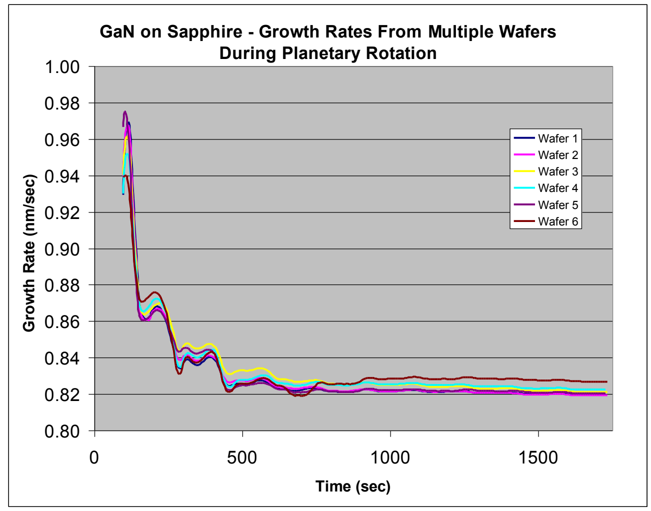


Figure 2: GaN on sapphire during multi-wafer growth. Growth rate converges after ~ 750 Å of deposition.

Wafer #	Steady state deposition rate (nm/sec)	Steady state index of refraction (η)
1	.813	2.459
2	.815	2.454
3	.809	2.443
4	.811	2.444
5	.810	2.442
6	.815	2.431
Ave	.812	2.445

Table 1: Real-time data analysis during multi-wafer MOCVD growth

kSA RateRat: Simple, Real-Time Deposition Monitoring

Through the data presenated in this note, we have shown the ability to monitor real-time desposition rate, layer thickness, and optical constant information with as little as 750 Å of material growth of GaN films on sapphire in a production MOCVD reactor. In addtion, we have successfully integrated kSA RateRat Pro with triggering hardware and software to acquire center point data from all wafers during planetary platen rotation. Due to the efficient optics and fast processing speed of the kSA RateRat Pro system, spatially-resolved reflectivity data within each wafer was also available. That data will be presented in a future application note. While this data was taken during typical GaN deposition, the technique applies to most transparent thin-film depsoition appliciations provided the sample has a surface reflectance of at least 2%.

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