Production Performance Success with a High Throughput PECVD System

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The economics of nearly all device production require concern with the myriad of variables included in cost-of-ownership calculations. As might be expected, process system performance provides many of the critical inputs for this calculation. Obtaining a favorable cost analysis for tool operation implies systems with high uptimes and throughput while maintaining low scrap. Although the data is critical for making decisions relating to production and especially capacity, collecting it, is often tedious and thus, unavailable. This article provides an example where extensive data in a production environment was accumulated.

Several years ago, Unaxis introduced a new production silicon nitride batch plasma-enhanced chemical vapor deposition (PECVD) module as an extension of an earlier system that had found acceptance in GaAs device fabrication. Using the same basic technology and process regimes of the first systems, this larger batch PECVD module has now proven itself under production conditions. The data presented here support this conclusion.

Process Performance

A silicon nitride (SiN_x) deposition process was developed for MMIC devices as a high throughput batch PECVD production solution. PECVD is well-suited to the low temperature constraints required for GaAs device manufacturing. With this technique, high quality SiN_x films can be deposited at temperatures less than 400°C. PECVD SiN_x is used in many different III-V based devices such as MESFETs, HBTs, and HEMTs in the roles of passivation, encapsulation, and capping layers. In addition, the large dielectric constant of SiN_x makes it attractive for use as the intermetallic dielectric material in MIM capacitors.

The system utilizes a conventional parallel plate configuration operating at 13.56 MHz. Dilute silane (SiH_4 in nitrogen) and ammonia (NH_3) are combined in a plasma to form the SiN_x film. Nitrogen is used as a carrier gas and is also introduced as a separate gas in the process. By modification of the plasma chemistry it is possible to control the film stress over a range of about +300 MPa tensile to –300 MPa compressive [ref.1].

Film specifications for the batch PECVD production solution exceed the requirements for most MMIC applications. General SiN_x film specifications include within wafer, wafer-to-wafer, and batch-to-batch film thickness targets and uniformities of less than 2.5% one sigma. Highly uniform target film thickness is essential for meeting capacitance design criteria. Deposition rate is approximately 10 nm/min at a temperature of ≤ 300°C. Additionally, refractive index control within the range of 1.95-2.05 is readily achieved. Process induced damage, always an important consideration with devices [ref. 2, 3, 4,5], is kept at a minimum with low power densities of less than 50 mW/cm^2.

Figure 1 provides data with statistically relevant sample sizes (N>1700) collected over a period of more than a year. The data correspond to SiN_x films deposited on five different systems and have been normalized to the target thicknesses.

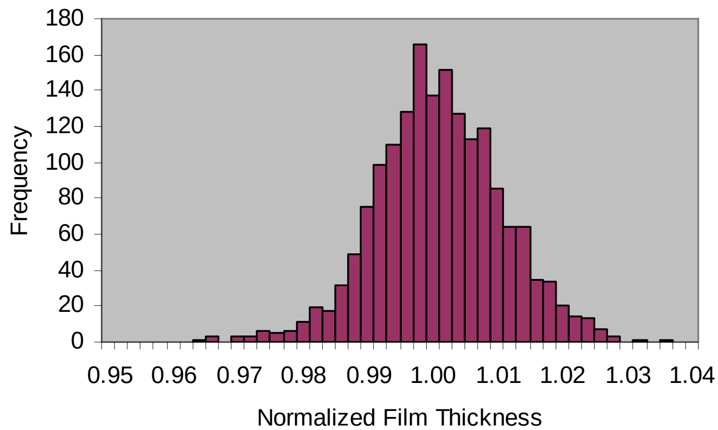

Figure 1. Histogram indicating high reproducibility for film thickness.

The narrow and near Gaussian distribution shows a normalized standard deviation of 0.0097 and exemplifies the very tight distribution for obtaining target thickness.

Similar work was done with three other thickness goals that spanned a range of nearly 10 times the thinnest film. For proprietary reasons the film thicknesses have been normalized to the thinnest film (i.e. film thicknesses were two, four, and nine times the thinnest film). The data in Figure 1 are for the film thickness target nine times the thinnest film studied.

Wafer-to-wafer thickness reproducibility was demonstrated as ≤ 2.5% one sigma as shown in Figure 2. Importantly, the within wafer uniformity over the measured production runs is also ≤ 2.5%.

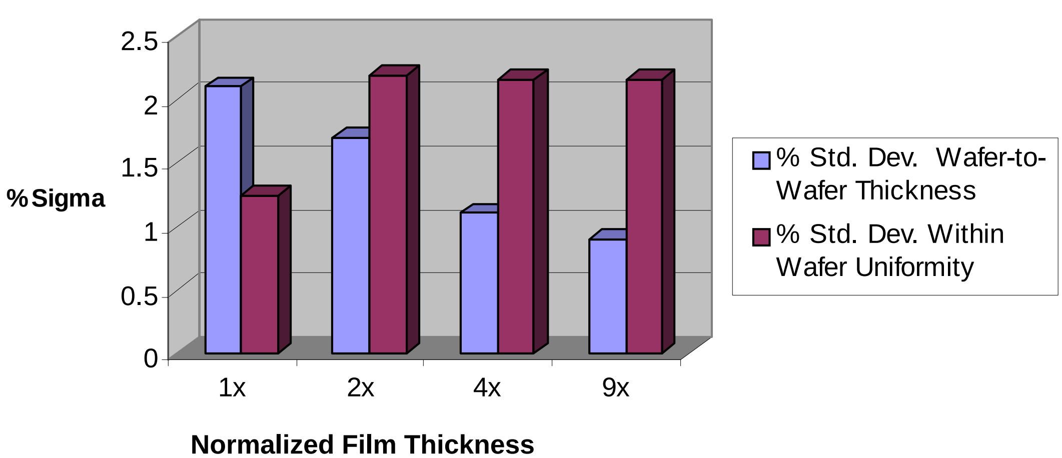

Figure 2. Wafer-to-wafer reproducibility of film thickness (blue) and uniformity (red).

Ensuring reproducible film quality is as important as meeting film thickness targets. In this case study the films are being used as a capacitor dielectric. As with film thickness, the capacitance density figures were normalized to the smallest value. In Figure 3, wafer-to-wafer capacitance density reproducibility is presented for three different films. Again, the reproducibility surpasses the specification goal of ≤ 2.5% one sigma for the capacitance density and ≤ 2.5% one sigma for the wafer-to-wafer uniformity. By achieving the process stability desired there is less opportunity for scrap and thus, more product.

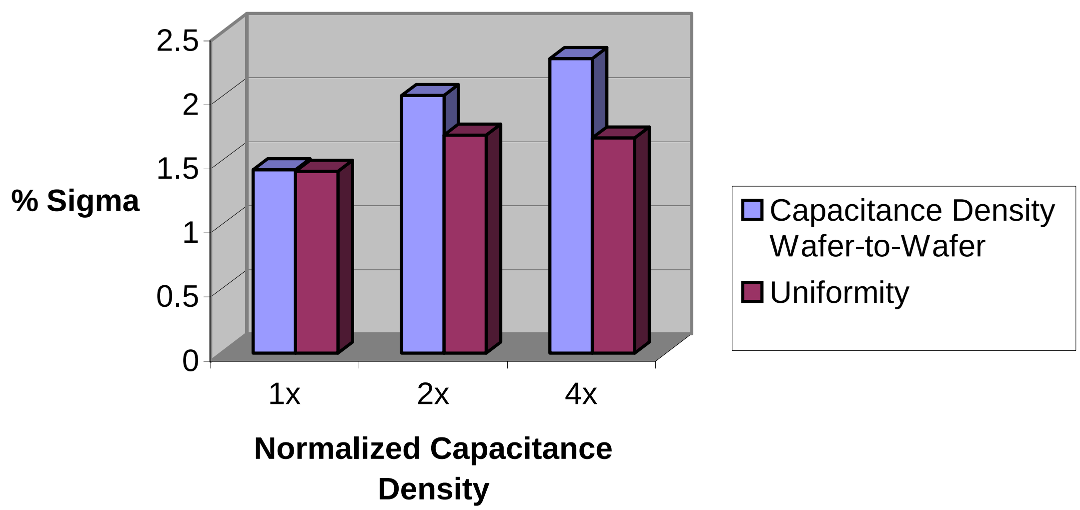

Figure 3. Wafer-to-wafer reproducibility of capacitance density (blue) and average uniformity (red).

System Performance
The module used in this work was intended not only to provide the required quality SiN_x, but also to enhance throughput. For the task of increasing throughput, the module utilizes an appreciably larger chamber than typical and can accommodate significantly more wafers in each batch. The two standard batch sizes are eight 100-mm wafers and five 150-mm wafers. Available on a cluster tool platform, the large area PECVD batch systems offer fully automated, cassette-to-cassette processing. Batches are loaded from the cassettes using a rotating indexer in the process chamber. A Windows-based operating system provides complete system control.

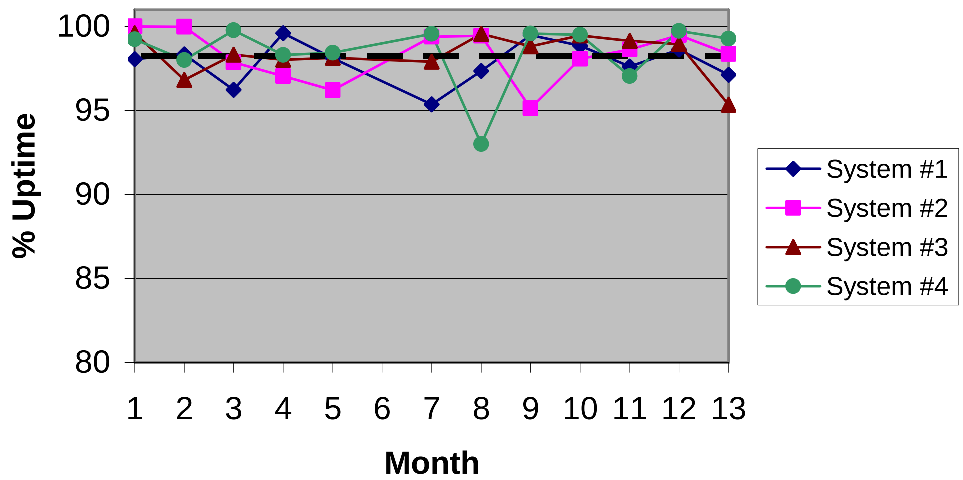

Figure 4. Monthly operational uptime for four batch PECVD systems and average (dashed line).

Equally important to the throughput figures used in cost-of-ownership calculations is system operational uptime. Figure 4 shows the uptime for four different batch PECVD systems recorded over a period of a year. The data was calculated using a widely accepted definition of operational uptime, (equipment uptime x 100) / (operations time). Except for a single month on System #4, the uptime performances were consistently above 95% with an average greater than 98%. Scheduled maintenance time is counted as downtime per Semi E10-0701. The preventative maintenance averaged approximately 2% downtime per system over the reviewed period.

Arriving at these uptime figures requires at least a rudimentary understanding of the maintenance cycle and practices. The PECVD reactor includes several features to maintain system cleanliness that enhances yield and minimizes system downtime. For example, both the chamber walls and the upper gas distribution electrode of the reactor are heated to minimize particulate formation during the SiN_x deposition process. As might be expected, SiN_x is deposited on the wafer and also on many of the exposed surfaces within the chamber. If this material were allowed to build up indefinitely, issues with process repeatability and particulate control would arise. To prevent these problems from occurring, the standard PECVD SiN_x process utilizes an in-situ clean and a manual cleaning process. The in-situ clean is performed more frequently (after approximately 1.5 µm of deposition) utilizing a fluorine-based plasma etching chemistry. To achieve and consistently maintain the reactor in a clean and known state, an automatic plasma etchback sequence is integrated with an optical emission spectrometer (OES). The OES ensures an effective in-situ cleaning is completed in a minimum time. For this application a manual clean is only required annually. At that time, the chamber is opened to atmosphere and a thorough inspection and clean is conducted by maintenance personnel.

A number of important features are available on the batch PECVD system to improve system maintainability/uptime. These were all implemented based upon experience with the standard PECVD system and include clean chamber design. Modifications were made to reduce areas that collect deposition and become difficult to clean. Heated top electrode improves process ability and system cleanliness and port access to the main pump manifold allows for easier manual cleaning of the main vacuum manifold.

Summary

Proven at various customer production sites, the Batch PECVD system provides advanced III-V manufacturers with a high throughput solution for depositing high quality silicon nitride at low process temperature. Additionally, extensive testing has demonstrated that these results are not only extremely repeatable for 150-mm diameter substrates but are achieved with uptimes of approximately 98% with negligible scrap.

Further Reading

[1] K. D. Mackenzie, B. Reelfs, M. Devre, R. Westerman, and D. J. Johnson, Proc. CS Mantech Technical Digest, pp 319-322 (2004).

[2] Y. B. Hahn, J. W. Lee, K. Mackenzie, D. Johnson, D. Hays, C. R. Abernathy, and S. J. Pearton, Electrochem. and Solid-State Lett. **1**, 230-232 (1998).

[3] J. W. Lee, K. D. Mackenzie, D. Johnson, R. J. Shul, Y. B. Hahn, D. C. Hays, C. R. Abernathy, F. Ren, and S. J. Pearton, J. Vac. Sci. Technol. A **17**, 2183 (1999).

[4] B. Luo, F. Ren, C. S. Wu, S. J. Pearton, C. R. Abernathy, and K. D. Mackenzie, Solid-State Electron. **46**, 1359-1365 (2002).

[5] W. S. Tan, P. A. Houston, G. Hill, R. J. Airey, and P. J. Parbrook, J. Electron. Mat. **33**, 400 (2004).