Issues in scaling production nitride MBE systems

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Abstract

In recent years, gallium nitride-based (GaN) electronics have shown great promise for high-power RF devices in university and industrial research laboratories. Single-wafer molecular beam epitaxy (MBE) systems have been the preferred epitaxial tools for growing these electronic materials. However, moving these GaN-based devices into high-volume production requires uniform, repeatable growth on large (100mm) substrates. This presentation will address the issues involved in scaling MBE growth of nitrides from single-wafer R&D demonstrations up to production on multiple 100mm wafers.

INTRODUCTION

Molecular Beam Epitaxy systems capable of growing up to four 100mm wafers simultaneously have been well proven for GaAs and InP growth. However, the GEN200 system installed at the Veeco Process Integration Center is one of the largest high-volume production MBE tools dedicated to the growth of GaN-based materials. This presentation will discuss the scaling of RF plasma sources for larger areas, and present results of both computer modeling of flux uniformity and experimental evaluation. The repeatability and control of Ga/N flux ratio will also be addressed through evaluation. Finally, the importance of heater design and *in-situ* temperature monitoring to ensure repeatable and uniform temperature control is discussed.

EXPERIMENTAL DETAILS

All wafers were grown in a Veeco GEN200 MBE system. Standard solid sources were used for the group III materials (gallium, aluminum and indium in high-capacity SUMO cells) and dopants (silicon and magnesium in standard conical and SUMO cells). Atomic nitrogen was provided with a Veeco UNI-Bulb RF Plasma source with a replaceable aperture plate. The system is pumped with two CTI-10 cryopumps and a liquid nitrogen cryopanel. Typical growth temperatures used were around 500°C for the nucleation layers and 750-800°C for the main layer growths. Temperatures were measured using an optical pyrometer and a backside thermocouple. To facilitate substrate heating, the backside of the substrates was coated with 1 µm of Ti deposited by sputter coating. The growths were done on sapphire substrates, either directly or on MOCVD grown template layers. For growths directly on sapphire, the sapphire was first nitrided at 250ºC for 30 minutes using an RF power of 500 watts and an N_2 gas flow of 5.0 sccm. The main GaN layer is then deposited either directly on the nitrided surface or on an AlN buffer grown in the temperature range of 500-800ºC. No *ex-situ* cleaning was done for any of the substrates, but all substrates were outgassed in the sample preparation chamber at 500°C prior to growth. The majority of growths were done on 2" substrates in a specially designed platen that has wafers along the entire radius. (Figure 1) By measuring material properties across several wafers, the cross platen growth uniformity could be measured.

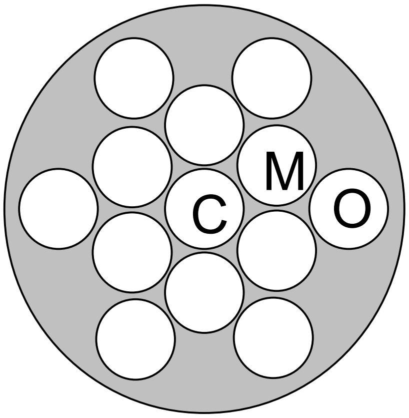

Figure 1: Wafer carrier designed to allow characterization along the entire radius by measuring three two-inch wafers in positions C, M, and O.

1) Nitrogen Flux

One of the most difficult aspects of MBE growth of Gallium Nitride is that the material must be grown within a very narrow range of Ga/N flux ratios. For optimum surface morphology, there must be a slight excess of Gallium on the growth surface, but not enough to form droplets. [1] This process window is difficult to hit even in research sized growth systems. In a large production system, where run-to-run repeatability and cross-platen uniformity are critical, this becomes an even larger problem. As mentioned before, the primary source of nitrogen is a Veeco UNI-Bulb RF Plasma source with a replaceable aperture plate. In order to study the baseline growth rate and uniformity, experiments have been performed using a standard 253-hole aperture plate (normally used in single wafer growth systems) and a 308-hole aperture plate designed for this reactor. Figure 2 shows the thickness uniformity along the radius of the GEN200 platen, measured on three separate 2" substrates for growths performed using both apertures. The measured thickness uniformity (solid data points) corresponds well with the modeled nitrogen flux uniformity (solid black line). By redesigning the aperture plate, a much more uniform nitrogen flux can be obtained (solid grey line). This improved plate provides improved nitrogen flux uniformity without significantly reducing the nitrogen flux in the center of the platen. This should allow for improved uniformity without sacrificing growth rate.

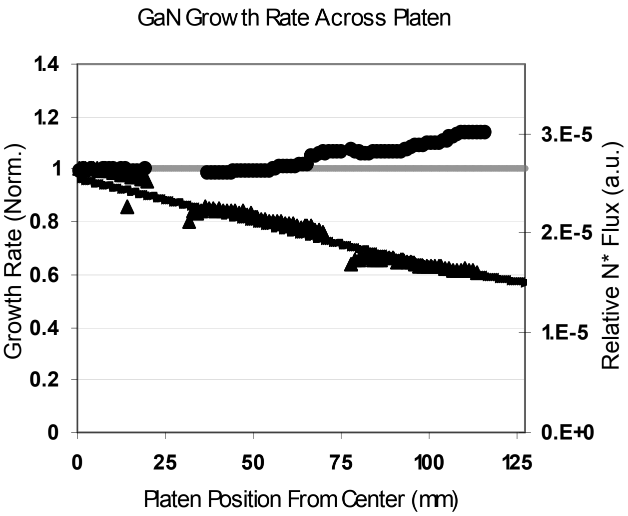

Figure 2: Graph of measured and modeled nitrogen fluxes across the wafer platen. The solid points are experimental data and the solid lines are the modeled results

In some systems, the Group III (Ga, Al, In) flux uniformities may also lead to issues. However, while this system is unique in the world of nitrides, there are several GEN200 As/P systems in production and the Group III uniformities across platen are well characterized and are typically less than +/- 1% for all materials.

2) Substrate Heating

The other major consideration for nitride MBE is temperature control and uniformity. Temperature control for GaN growth is more complicated than in tradition III-Vs for several reasons. First, the high growth temperatures needed lead to higher radiative losses from the substrate and complicate the design of the heater and manipulator. Second, the most common substrates, sapphire and silicon carbide, are both transparent, requiring a backside coating to absorb the radiative energy. Finally, as mentioned before, the surface V/III ratio is critical and at typical growth temperatures, the evaporative losses of gallium are significant (as shown in figure 3) and exhibit and Arrhenius temperature dependence.[1] Therefore, even minor temperature variations can lead to poor quality growth.

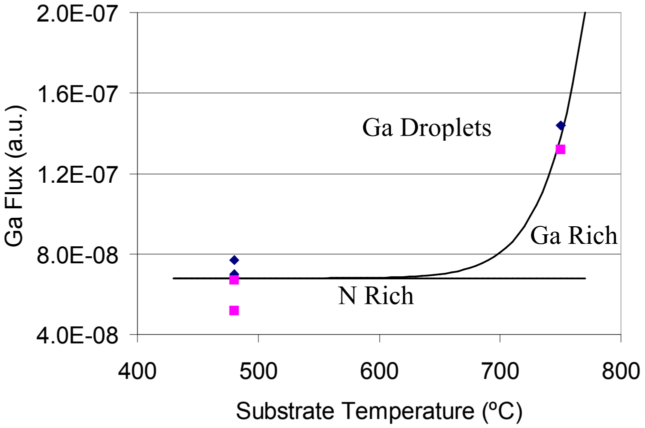

Figure 3: Graph of surface morphologies for GaN grown with fixed plasma conditions, but various gallium fluxes and growth temperatures. The narrow transitions regions can be observed.

Another issue in temperature uniformity is the design of the wafer carrier or platen. One of the effects observed in this work is that the backing rings which are used to hold the wafers in the platen have a much stronger effect on the temperature uniformity than is normally experienced in tradition GaAs epitaxy. With backing rings correctly designed and installed, the temperature gradient at the edge of the substrate is very clear and abrupt. However, when backing rings are not used, the temperature gradient, as observed by variations in the Ga droplet coverage can extend up to 10mm from the edge of the wafer. While this is not a critical issue for research, for a production system, this variation is unacceptable, especially with the small wafer sizes typically used. In the case of device wafers, this temperature gradient causes GaN HEMT sheet resistance deviation to increase to over 2% from a normal uniformity of 0.5%.

The need for accurate temperature measurement and control is made even more difficult for nitride MBE because of the high growth temperatures involved. Traditional As/P MBE systems typically operate between 450°C and 600°C, however GaN MBE is sometimes done at growth temperatures above 800°C. The system installed at the Process Integration Center is equipped with an advanced heater assembly that has been designed to reliably operate at these extreme temperatures. In initial testing, substrate temperatures (as measured by pyrometery) of over 1100°C were achieved. While one of the great advantages of MBE is the relatively low growth temperature compared to other techniques such as MOCVD, this added temperature capability allows more flexibility in process design and opens up new production techniques such as *in-situ* wafer cleaning and oxide removal.

CONCLUSIONS

As MBE growth of gallium nitride moves from the research laboratory towards production, scaling growth to larger, production-ready MBE systems becomes important. We have demonstrated growth of GaN materials on an MBE system capable of producing nearly 500 4” wafers per month. Initial work on improvements in nitrogen and temperature uniformity has shown very encouraging results. Work is now continuing on improving the material quality, increasing growth rates, and extending the automated batch capabilities of the growth system.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Heying B, Averbeck R, Chen L F, Haus E, Riechert H, Speck J S 2000 J. Appl. Phys. **88**-4 1855-60

ACRONYMS

MBE: Molecular Beam Epitaxy
MOCVD: Metal-organic Chemical Vapor Deposition