

In Situ Monitoring of HBT Epi Wafer Production: The Continuing Push Towards Perfect Quality and Yields

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Abstract

Heterojunction Bipolar Transistor (HBT) epi wafer manufacturing at thousands of wafers per week requires careful monitoring and control to ensure excellent quality and high yields. All product epi wafers undergo non-destructive testing which gives data on epi wafer sheet resistance, particle density, and surface roughness. These non-destructive measurements give only a limited view of wafer quality, therefore periodic destructive testing of selected epi wafers (HBT device fabrication and measurement) is required. It is highly desirable to directly measure key epi layer parameters on each product wafer in order to continue pushing toward the goals of perfect quality and yields. Therefore we have been working with the Laytec EpiTT in situ optical reflectance monitoring system. These data allow for immediate detection of shifts in the epi layers. Therefore problems can be detected and corrective actions taken before failed wafers are grown.

INTRODUCTION

The production of heterojunction bipolar transistors is able to reach high yields through continuous improvements throughout the supply chain. During the epitaxial growth process many layers are sequentially deposited on the starting GaAs wafer. Once these layers are complete only the full structure can be analyzed. Analysis is generally

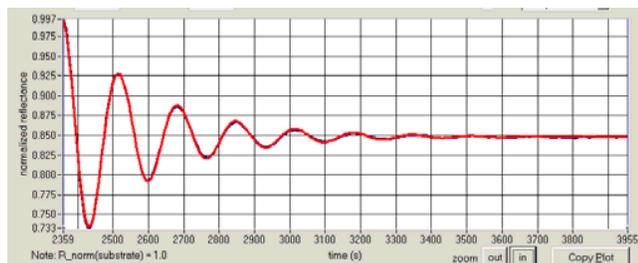


Figure 1. Reflectance oscillations of an epi layer during deposition. As a general rule the period indicates the growth rate, the amplitude indicates the refractive index change from underlying layers, and the damping indicates the absorption of the film. The red line is the theoretical fit that nearly perfectly overlays the experimental data of the blue line.

confused by the presence of many similar layers that cannot be clearly identified. In practice quality systems rely heavily on non-contact sheet resistance measurements and wafer surface roughness. These techniques are surprisingly sensitive to changes that may occur in the production process. Their sensitivity varies depending on the layer and depending on what parameter may be changing (growth rate, composition, roughness, doping, etc.).

Over the last decade multiple vendors have developed optical reflectance tools to be integrated with a growth system. These tools allow films to be analyzed during their growth [1-2]. An additional capability of an *in situ* system is its ability to perform an emissivity corrected pyrometry based temperature measurement [3-5]. This temperature measurement can be calibrated in the growth system leading to more accurate temperature measurements over time and between film growth systems.

We have undertaken a program to implement a Laytec EpiTT onto an Aixtron 2600/IC growth system. This system can measure the reflectance oscillations of growing epi layers as shown in Figure 1. In this plot several oscillations are present allowing the real, n , and imaginary, k , refractive index and the growth rate to be accurately determined. The challenging aspect of this technique for HBT production is that the most important layers are very thin. The reflectance during film growth generally is closer to that shown in Fig. 2, where only a fraction of an oscillation is present. The data can be fit accurately even with only a limited fraction of an oscillation. This close fit is sensitive to changes in the growth process. The ability to identify small run-to-run or wafer-to-wafer variations in real time is the core capability

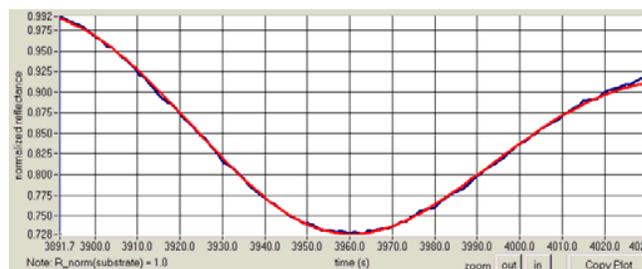


Figure 2. Devices have thin films and only partial reflectance oscillations. This limited data still contains considerable information.

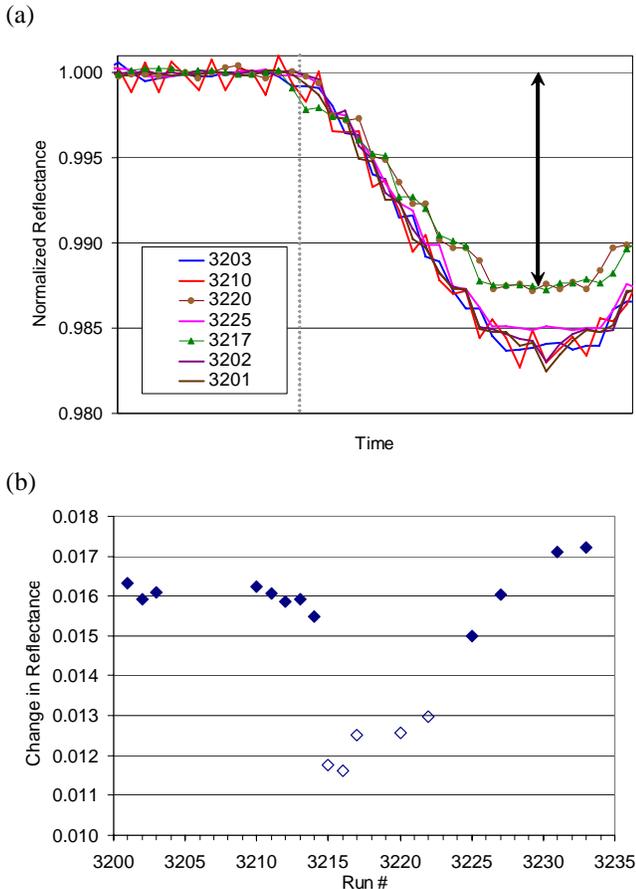


Figure 3. Monitoring of reflectance during the HBT base layer during production. In (a) the reflectance curve recorded during the base layer growth of several runs is shown. The layer growth began at the dotted line. The depth of the oscillation is plotted in (b). The open datapoints identify the runs with the source problem.

that this tool offers. These small variations are otherwise invisible to traditional non-destructive metrology.

The utility of the *in situ* data goes far beyond HBT production. Device designers are constantly pushing for more capabilities with new structures integrating HBT layer structures with FET or PHEMT structures. The accumulation of more layers makes identifying the characteristics of any one layer more challenging for analysis performed after the structure is grown. The *in situ* monitoring measures only the layer being grown at the very moment. Extra layers can be added above or below without complication. This makes *in situ* monitoring a powerful tool for these structures.

In situ monitoring also plays an important role outside of production. *In situ* monitoring can greatly speed the assessment of a machine and its release to production after maintenance is performed. This is made possible by the direct measure of the surface temperature of each wafer, as

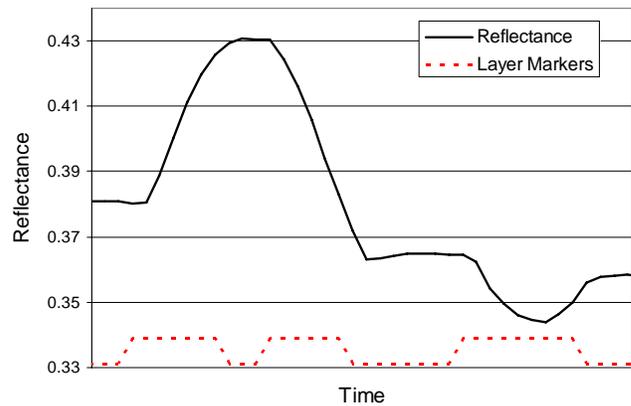


Figure 4. This shows reflectance data during PHEMT deposition. In spite of being extremely thin information can be collected from the InGaAs and AlGaAs layers.

well as the temperature, growth rate, and composition profile across each wafer. A tremendous amount of data is available from each run. Kopin has developed a completely automated data system to deliver SPC charts to the engineer.

RESULTS AND DISCUSSION

The base layer of the HBT is often the most challenging yet critical layer to control. Slight variations in growth conditions can result in shifts of doping or growth rate and ultimately base sheet resistance and device gain. While traditional non-destructive, in-line measurements are sensitive to changes in the total HBT resistivity, these measurements are blind to the thin base layers as its contribution to the overall HBT resistivity is negligible. Non-destructive monitoring of base layer doping and thickness is highly desirable. However, historically, this has not been feasible in a high volume production environment.

Here we show the capability of *in situ* reflectance measurements for verification of the base layer. In Fig. 3 (a) the reflectance curve during base layer deposition is plotted from several runs. The dotted line indicates the initiation of growth of the layer. This oscillation is very shallow and incomplete making data extraction challenging, yet a shift in the depth of the oscillation is clearly visible. In Fig. 3 (b) the depth of the oscillation across these runs is shown. The depth of the oscillation is normally near 0.016. For several runs the oscillation became shallower with a depth of only 0.013. During this time there was a source problem causing the doping to decrease. This was identified through conventional HBT fabrication and measurement several runs after the event. After fixing the problem the reflectance returned to normal values.

Data from a PHEMT is shown in Fig. 4. PHEMT structures consist of many thin layers. These layers do not produce the well formed oscillations for simple data

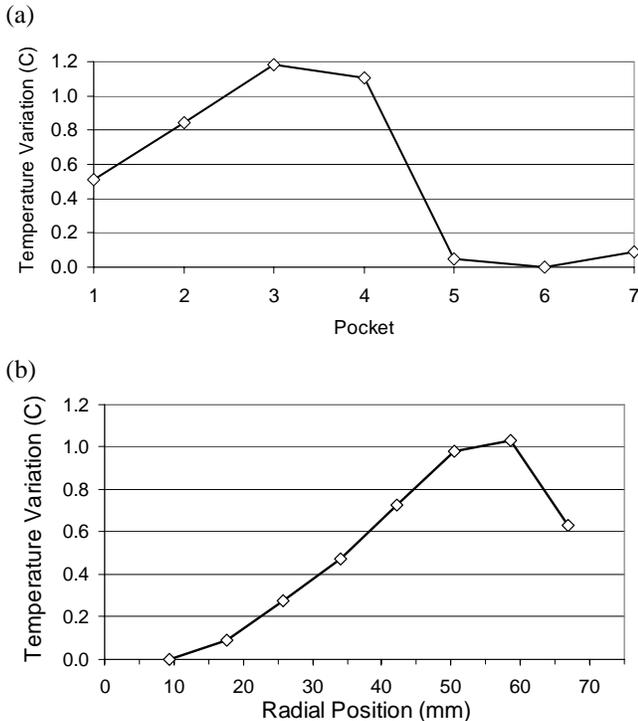


Figure 5. Here are two plots of the surface wafer temperature data available. In (a) the temperature difference between each wafer is plotted, while in (b) the temperature change across a wafer is plotted. These signatures allow the temperature profiles of a system to be directly and rapidly measured.

analysis. The reflectance oscillations from the thin layers begin to resemble gently curving lines. This challenge is often the case for real device structures.

The key capability of Kopin's data system is the generic ability to define structures, define the individual measurement of each layer in the structure, and to automatically populate a database with this information that is ready to be charted, controlled, and verified. These structures can be bulk layers, HBT, PHEMT, etc. In the case where the layers are thick, as in Fig. 1, conventional data fitting routines can be used, in other cases a library of routines are available to extract information from limited datasets, as in Fig. 2, 3, and 4.

In addition to production benefits *in situ* monitoring is able to reduce the time to return a growth system to production following maintenance. One example of this is the temperature data in Fig. 5. Growth system temperatures are generally controlled by either a pyrometer or a thermocouple measuring the temperature of a block of graphite removed from the growth surface. The ability to directly measure the wafer surface temperature is a fundamental change. The quality and integrity of the reactor components determine these temperature variations, which go on to influence the devices. Acceptable temperature

variations can now be rapidly measured and verified directly.

The ability to measure real time composition and growth rates is widely known. This capability is particularly valuable as a tool to measure uniformity. This can also serve to rapidly verify proper operation of a machine after maintenance. A more powerful capability is to use this capability to develop new growth conditions for uniform film growth. To conventionally investigate 10 different growth conditions would require 10 runs lasting most of a day followed by 10 measurements, which may take 1 or 2 days longer. With *in situ* monitoring this series of 10 layers could be ran sequentially in a single run. What used to take 2 or 3 days could now be completed in 3 hours with much lower cost.

CONCLUSIONS

The power of this analysis tool is immediately obvious. Prior to beginning production *in situ* monitoring greatly accelerates returning to production. System components and operation can be immediately verified following maintenance by direct measurement of wafer surface temperature. Development set of runs that previously took days to complete can be finished in hours. When moving to production *in situ* monitoring gives non-destructive and real-time measurements for each product wafer of significantly more material parameters critical for HBT growth than has historically been possible. Epitaxial wafers are inserted into expensive device fabrication processes. This measurement will translate into higher quality and yields throughout the HBT device supply chain.

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