MOCVD Carrier Emissivity and Temperature Uniformity Characterization

Carrier emissivity and temperature maps reveal carrier micro cracks and emissivity variation that can directly affect thin-film deposition and device performance

Introduction and Motivation

MOCVD wafer carriers (sometimes called platens) are typically baked in an oven for many hours, even days, after every growth run. This bake is crucial for removing deposited material from the carrier, as well as removing contamination from the carrier. The ultimate goal of this bake is to clean the carrier and return its emissivity to its original value, so that the same recipe will yield the same layer thickness and composition. Run-to-run and tool-to-tool repeatability are heavily dependent on this process.

Figure 1: kSA Emissometer with lid open and a standard K465i carrier loaded.

Over many growth runs and subsequent bakes, the carrier emissivity and the uniformity of its emissivity will change. Currently the production MOCVD community does not have a quantitative method for monitoring these carrier changes. Many MOCVD Fabs deal with emissivity changes by making small temperature set point adjustments, based on the growth run utilization of a particular carrier. This process can help account for changes in emissivity, but cannot address non-uniformities.

Determination of the end-of-life point for each carrier is another important process for MOCVD Fabs. Some carriers are retired if visual inspection via the human eye shows significant defects or blemishes on the carrier. In other instances, the carriers are retired based on the characterization of the material grown on them. These carrier end-of-life characterization methods can result in wasted growth runs and yield reduction and provide little quality control data to improve the end-of-life determination process. For example, SiC coatings on MOCVD carriers can develop micro cracks, eventually rendering the carrier unusable. These small cracks, typically invisible to the naked eye, are due to the small mismatch of the coefficient of thermal expansion of the graphite (the bulk material of the carrier) and the SiC coating. They are the result of frequent and large-scale temperature swings that occur during the MOCVD deposition process and the subsequent carrier bakes. In time, the SiC coating of the carrier, typically ~ 100 µm in thickness, cracks, exposing the bulk graphite of the carrier. Exposed graphite promotes carbon doping, significantly changes the surface emissivity, and ultimately can cause implosion of the carrier inside the MOCVD reactor. Hence, wafer carriers are given a typical “lifetime” in terms of number of growth runs allowed. After this number is reached, the carrier is retired. The “real” lifetime of a particular carrier frequently remains unknown.

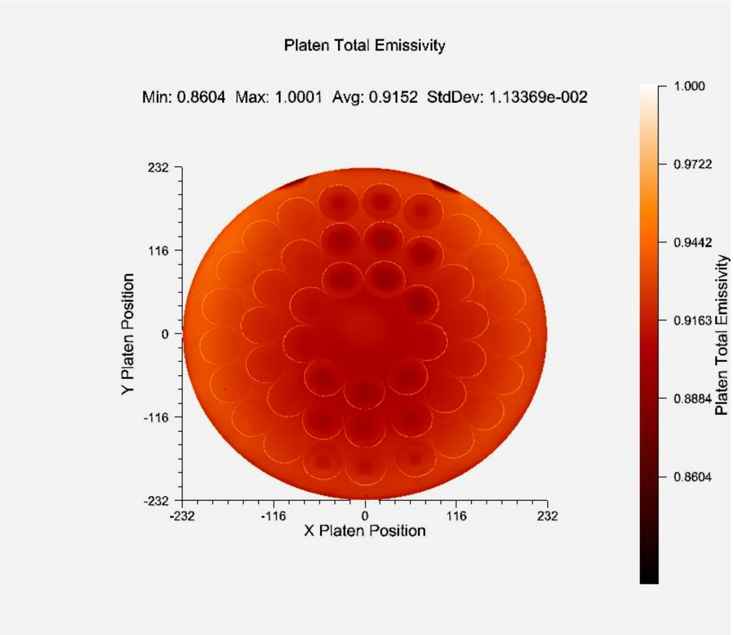

Figure 2: Total emissivity map acquired on an MOCVD carrier using the kSA Scanning Emissometer.

Carrier Inspection with the kSA Emissometer

To address the carrier issues described above, k-Space has developed the kSA Emissometer, shown in Figure 1. This tool measures the absolute diffuse and specular reflectance over the entire carrier. The total reflectance (diffuse and specular) determined is then used to calculate the total emissivity over the entire carrier, with typical spatial resolution of 1mm. Figure 2 shows an emissivity map acquired from the kSA Emissometer. Note the non-uniform pocket emissivities in this figure: the darker pockets have lower emissivity values. In this scan the difference in pocket emissivity values resulted from partial loading of this carrier during process development. Pockets loaded with wafers were protected from MOCVD deposition and therefore retained more of the original surface properties of the new carrier.

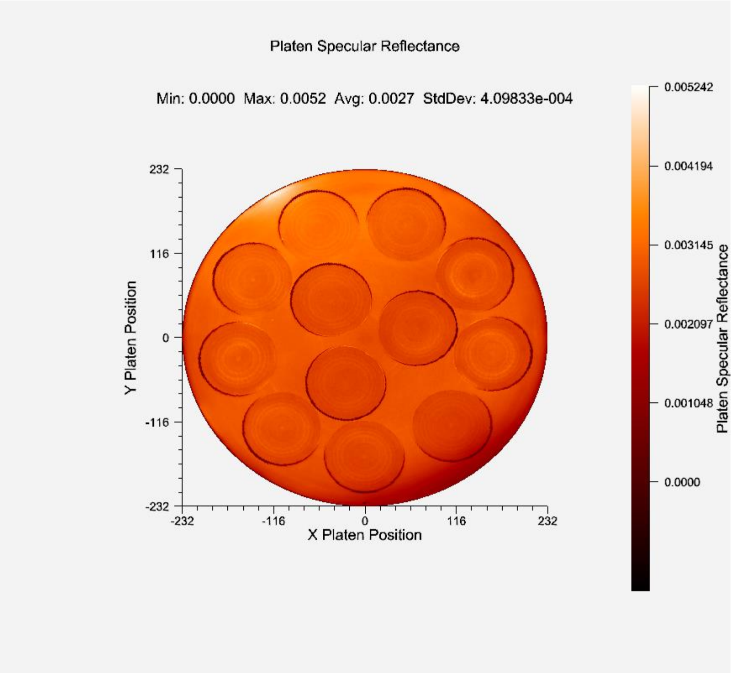

Figure 3: Specular reflectance of an MOCVD carrier, showing pocket machining marks. The specular reflectance measurement is very sensitive to surface imperfections.

On a typical, properly baked wafer carrier, the diffuse reflectance component should be the main contributor to the total emissivity, while the specular component should remain at or close to zero over the entire surface. However, if there is residual MOCVD deposition on the carrier, the specular reflectance signal will spike over those areas. The specular map is also particularly useful to pinpoint small irregularities on the carrier surface. For example, specular signal can reveal the machining marks underlying the SiC coating, as seen in Figure 3. Using the kSA Emissometer, the total emissivity measurements can be averaged over certain radii, corresponding to the location of optical pyrometers (such as RealTemp™). These values can then be used to adjust the temperature set points for the production run on the particular carrier, yielding more accurate results than previous "estimation" methodologies.

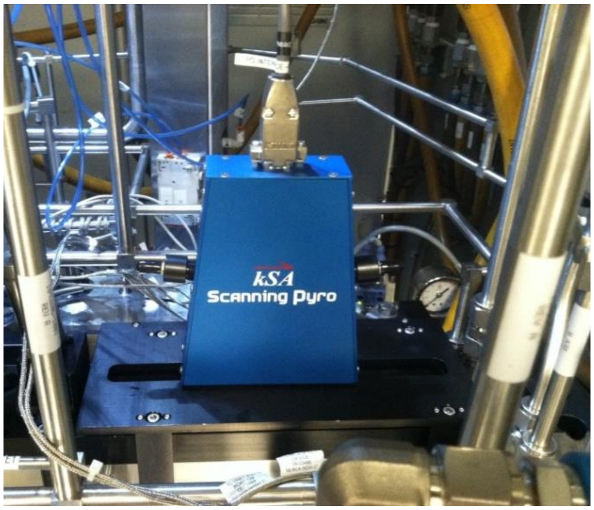

Figure 4: kSA Scanning Pyro in use on K465i MOCVD reactor.

Emissivity and Temperature Comparison

In order to demonstrate the power of *ex situ* emissivity characterization, the correlation between carrier emissivity and the actual carrier temperature in an MOCVD reactor must be studied. This requires both carrier emissivity mapping by the kSA Emissometer and carrier temperature mapping using the kSA ScanningPyro (shown in Figure 4). First, an in-production carrier was selected by a production customer. The carrier was visually inspected and is shown in Figure 5 (only the central portion of the carrier is shown here). Next, the carrier was scanned with the kSA Emissometer. The absolute, total emissivity from the Emissometer scan is shown in Figure 6a. Note the clear micro cracks on the carrier that are not visible to the naked eye. These cracks clearly have a different emissivity, and should result in temperature non-uniformity on the heated carrier.

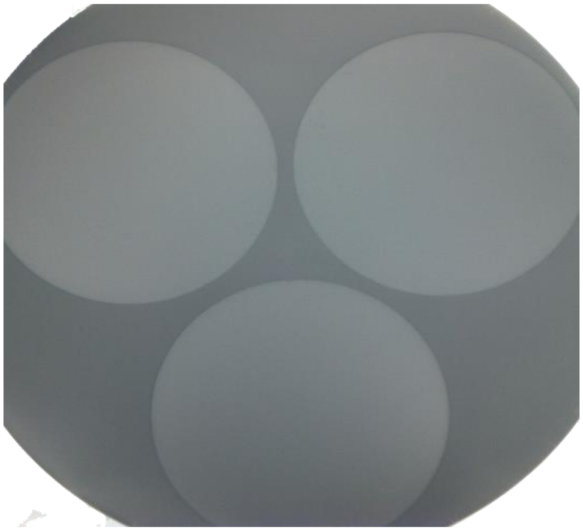

Figure 5: Photograph of the in-production wafer carrier used in testing. This is what the human eye and digital camera can see on inspection of the carrier.

To test this assumption, the same in-production carrier was then loaded into a K465i reactor and heated up to a nominal temperature of 1000°C (as measured by the middle Veeco RealTemp™ pyrometer). Next, the kSA ScanningPyro *in situ* temperature measurement tool shown in Figure 4 was used. The kSA ScanningPyro is a dual-detector pyrometer with full scanning capability, yielding full carrier temperature maps and thus the temperature uniformity of the carrier. The central portion of the temperature map is shown in Figure 6b. The micro cracks are clearly visible. Note that when the carrier is in the reactor at temperature, the center of the carrier is significantly cooler, as seen by the darker central spot in Figure 6b. This is a typical effect of the spindle underneath the carrier. Temperature affects aside, the micro cracks will likely result in Carbon doping of the deposited MOCVD films.

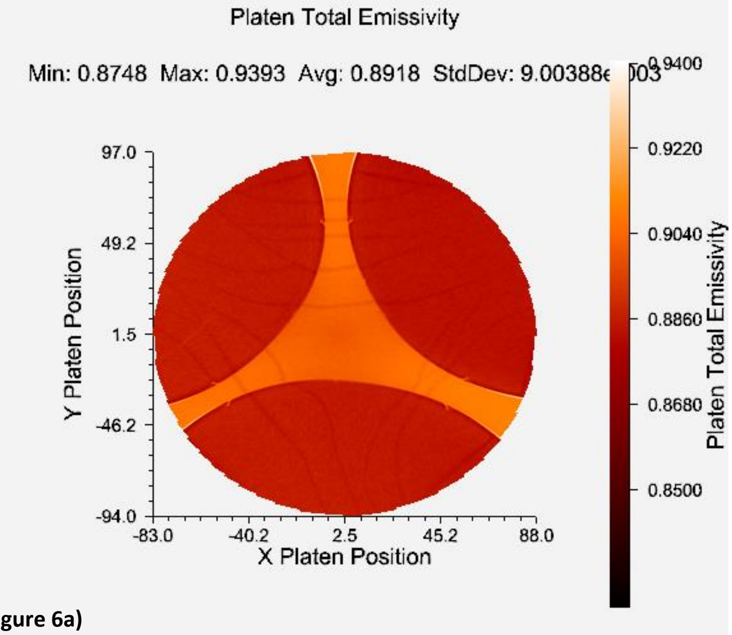

Figure 6a)

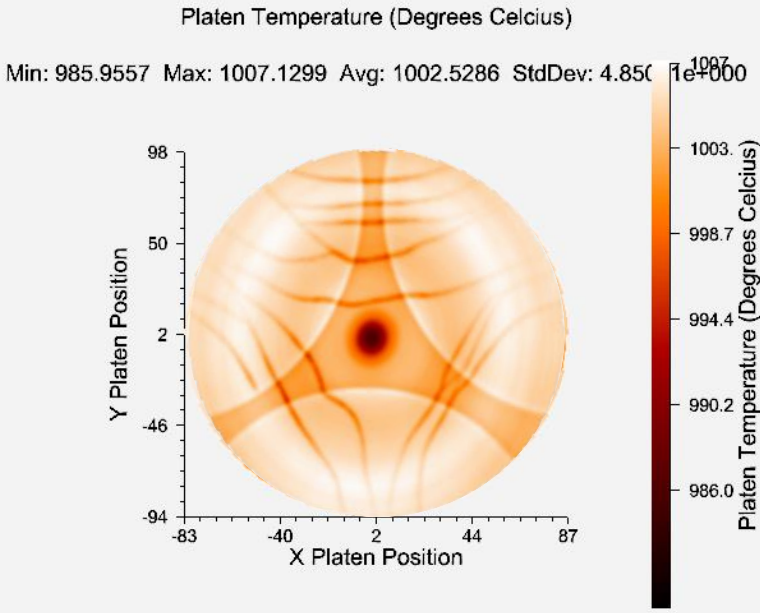

Figure 6b)

Figure 6: a) kSA Emissometer scan of K465i carrier, showing total emissivity. Micro cracks are clearly visible. b) kSA Scanning Pyro i*n situ* temperature map of the same carrier scanned in Figure 6a.

Conclusions

The kSA Emissometer and kSA Scanning Pyro have been utilized to characterize a production MOCVD carrier, both *ex situ* (at room temperature) and *in situ* (at nominally 1000°C). The kSA Emissometer measures the total emissivity of the carrier, while the kSA Scanning Pyro measures the carrier temperature. The data presented here shows that the two techniques complement each other, and that the micro cracks seen in the emissivity measurement translate directly to locations of lower temperature in the temperature scan. Micro cracks (which typically cannot be seen by the naked eye) can be detrimental to thin-film deposition, as they result in temperature non-uniformity, carbon outgassing, and ultimately lead to the implosion of the carrier at high temperatures typical of MOCVD growth.

The kSA Emissometer opens the door to a scientifically based, quantitative approach to wafer carrier characterization in the production environment. It will become indispensable for:

- Determination of the quality of the carrier bake after the deposition run. Yields a “Go-no-go” decision on the suitability of a particular carrier for the next production run.
- Quantitative determination of real surface emissivity and the necessary temperature set-point adjustments for a particular wafer carrier post-bake.
- Presence and severity of the micro cracks in the SiC coating. Decision to retire the wafer carrier at the end of its useful lifetime.
- Qualification of the wafer carrier vendors, via examination of the emissivity uniformity over the carrier and within the batch of carriers. Incoming quality control (QC) of the new wafer carriers.
- Prevention of wasted MOCVD growth runs.