Near-UV Pyrometry for Group-III Nitride MOCVD

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Motivation—Temperature measurement during InGaN MOCVD is particularly difficult due to the transparency of the substrates (e.g., sapphire) and epilayers at the near-IR wavelengths (e.g. 900-1000 nm) normally used for pyrometry. In fact, with the exception of our technology, there is currently no readily available method that measures the true wafer surface temperature during deposition. The problem is particularly severe because the InGaN composition (and therefore emission wavelength) is extremely sensitive to temperature in the 700-800°C range. Due to errors in existing temperature measurement techniques, drifts of 10-20°C are common, leading to InGaN devices that emit outside the target wavelength window.

Accomplishment—This work extends our previous development of a near ultraviolet-violet emissivity-correcting pyrometer (NUV-ECP) that we installed and tested on our single-wafer research reactor, CVD1. We have now extended this method to our multiwafer Veeco D-125 MOCVD reactors, which required additional technology development, mostly requiring signal synchronization to the actual wafer position. The optics also required a redesign to optimize signal in a more constrained environment. The collection/injection optics installed on one of our D-125 reactors (DNZ) is shown in Fig. 1. This NUV pyrometry approach relies on the opacity of the GaN epilayer at wavelengths above the bandgap. Fortunately, the GaN bandgap red-shifts substantially with temperature: from ~350 nm at room temperature to ~ 430 nm at 1000°C. The shift in bandgap is essential for success. For example, at 800°C there is ~$10^{6\text{-}7}$ less signal at 400 nm compared to the typical pyrometer detection wavelength (~1000 nm). The very weak thermal emission signal near 400 nm requires a number of substantial modifications to the typical pyrometer design. The payoff has been the first true surface temperature measurements during GaN and InGaN MOCVD. All other techniques have directly or indirectly measured the temperature of the wafer holder, which is **never** equal to the actual wafer temperature. Measurement of the true surface temperature will result in better control of the desired InGaN composition, and therefore better control of the emission wavelength. This will result in higher yield of the epitaxial process, and lower cost of the final LED product. Two examples of the true surface temperature during InGaN multiquantum well growth are shown in Fig. 2. The 8°C temperature drift that occurred during the "bad" example will cause a quantum well emission wavelength shift of ~12 nm.

Significance—This research will impact the DOE SSL Mission/Goal, because precise temperature measurements in production-class multiwafer group-III MOCVD reactors will substantially increase the InGaN yield and lower the final LED cost. Lumileds Lighting is currently using a variation of this technology on a large number of their production MOCVD systems. We also expect this technology to significantly impact and accelerate InGaN epitaxy research earlier in the R&D cycle due to improved reproducibility of the GaN and InGaN epitaxial growth processes. A major cause of the irreproducibility is the lack of a true wafer temperature measurement method, which has now been addressed.

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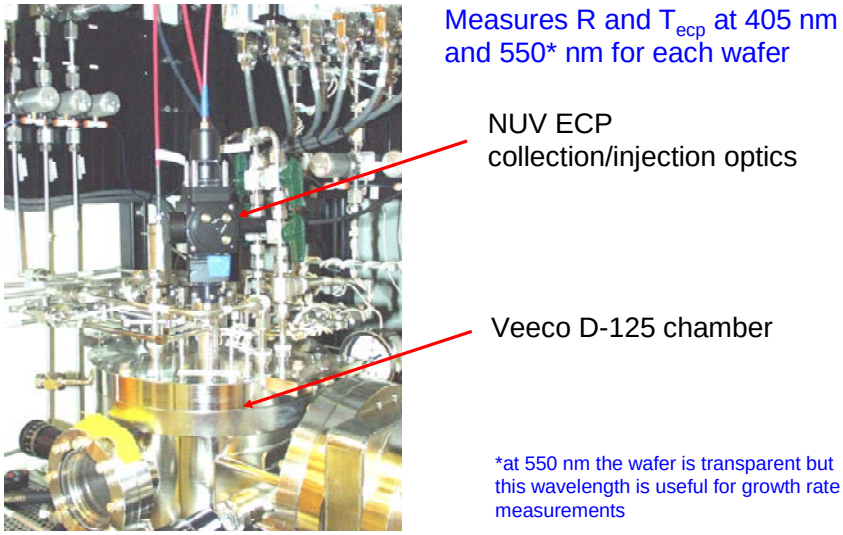

Figure 1. Photo showing installation of NUV-ECP collection/injection optics on a Veeco D-125 MOCVD system used to grown AlGaInN thin films.

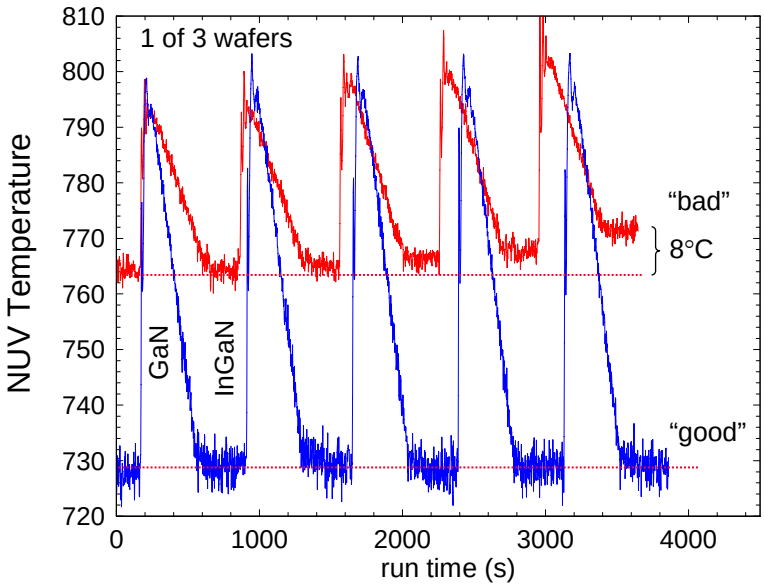

Figure 2. Two examples of the NUV-ECP temperature measured during InGaN multiquantum well deposition. In one case the temperature stayed constant during the InGaN step (good), while in the other example a substantial temperature drift occurred (bad). For reference, an 8°C drift will shift the quantum well emission wavelength by ~12 nm.