Reduction in Production pHEMT Process Variation Due to MBE Rotational Effects

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Minimizing both within wafer and wafer-to-wafer variation is an area of continuous improvement in MBE. These variations include doping, thickness, compositions, beta in HBTs, and pinch-off voltage in pHEMTs. The geometries of MBE sources and substrates are designed to minimize variation while the substrate is rotated[1]. Continuous azimuthal rotation is necessary to improve uniformity both within wafer and wafer-to-wafer for multi-wafer production systems. Finding the optimal substrate rotation speed which minimizes variation while not over-stressing the tool can be challenging. Manipulator rotation is not always necessary in small research-oriented MBE systems but rotation effects may be amplified as tools grow larger. Manipulator rotation has been found to be very important at RFMD which runs 7x6" MBE systems for both HBT and pHEMT production.

Compositional oscillations in the growth direction as a function of substrate rotation speed have been studied in depth[2,3]. For thick layer devices, this effect is averaged out by the large number of rotations that take place during growth. Thin layer devices grown by MBE such as AlGaAs/InGaAs QW for IR detectors, VCSELs, QCLs, spatial light modulators (SLM) and, in the case of this work pHEMTs, need precise control of layer thickness and compositions. Here, we look at the effect of rotation speed on pHEMT characterization data, specifically sheet resistance.

All pHEMT wafers grown at RFMD are characterized by the non-contact Lehighton Model 1510ERS sheet resistance measurement and mapping system. For pHEMT wafers grown with a rotation speed of 25RPM, a sinusoidal pattern to the pHEMT average sheet resistance across the outer wafers of the platen was observed (see figure 1). There was also a phase shift in the pattern when the length of the recipe was changed in such a way that the rotational position of the platen at a specific part of the recipe was different. These effects are identical to those seen by Svensson and Towner in their work on QW devices[4]. Their findings indicated that thicknesses were not centered about the wafer centers on a single wafer system due to a combination of incomplete rotation averaging and mole fraction oscillations in the growth direction.

To determine which layers contributed most to the sinusoidal sheet resistance pattern, the pHEMT was split into four groups (see figure 2). The wafer-to-wafer variation decreased significantly when the thin, short duration layers from the lower charge to the upper charge were grown at 50RPM. When the rotation speed for the five short duration layers of the pHEMT recipe from the lower charge layer to the upper charge layer was increased from 25RPM to 50RPM, the within-run wafer-to-wafer variation decreased by over 40% (see figure 3). Also after implementation of the 50RPM change, the overall Rs StDev% decreased from 0.93% to 0.76% and Cp and Cpk increased by 24% and 22% respectively. These results show that there can be within-run rotational effects on pHEMT growths and these effects can be significantly reduced with increased rotation rate.

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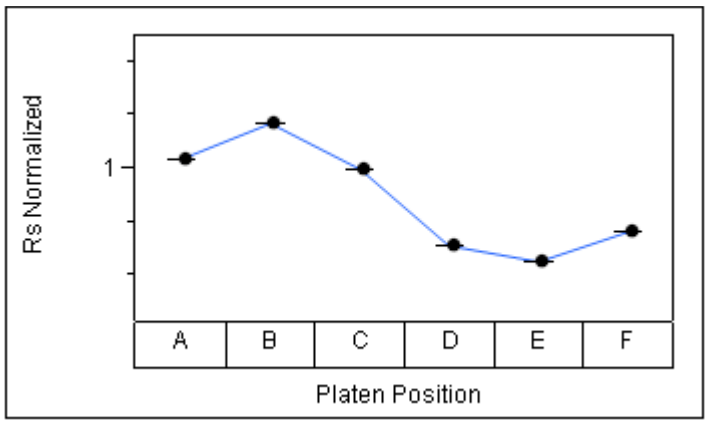

Figure 1: Sinusoidal sheet resistance pattern created by rotation effects on pHEMT structure at standard low RPM.

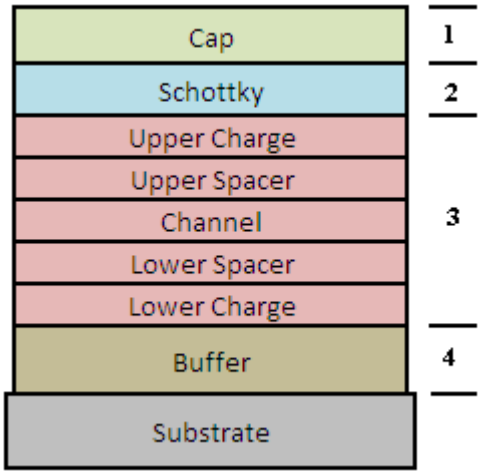

Figure 2: Schematic of a typical pHEMT structure. The five short duration layers from the lower charge to the upper charge (group 3) were found to be the contributors to the sheet resistance variation.

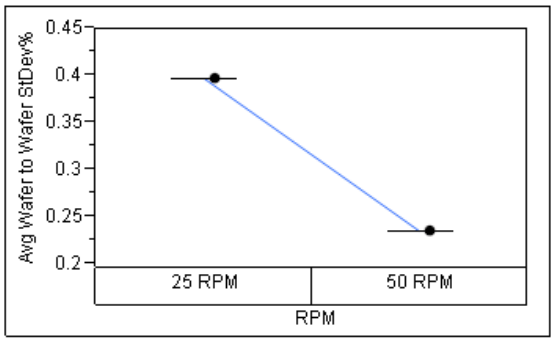

Figure 3: Over 40% improvement in wafer to wafer sheet resistance StDev% after increasing the rotation speed in the short duration layers to 50RPM.