Nondestructive Characterization of Epitaxial Structure for High Electron Mobility Transistors

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Abstract

A nondestructive technique for screening of pHEMT epi in order to comply with electrical specification criteria is discussed. The 300K PL spectra deconvolution and the spectra differences were used to track the sheet charge Ns in the InGaAs channel. The PR aproach to AlGaAs Schottky layer composition and charge is applied for production wafer screening. The correlation with PCM device results was used to create a pass/fail filter for pHEMT epi.

Introduction

HEMT manufacturing requires a high quality multi layer epitaxial structure. The active area of the device has high sheet charge concentration close to the channel/barrier interface with very high mobility and a capability to produce high output power [1,2,3]. To select the epitaxial wafers that will yield satisfactory device performance one needs to implement in-line, nondestructive characterization techniques.

Nondestructive characterization of High Electron Mobility Transistors **(**HEMT) aims to reveal the material parameters of the active layers of the epitaxial structure, such as: the (In%) mole fraction in the channel, the thickness, the quantum well shape and asymmetry, the total sheet charge (Ns) in the channel, the (Al%) mole fraction and the quality of the barrier (Schottky and carrier-providing layer), and indirectly, the degree of perfection of the channel/barrier interface [4].

Nondestructive optical characterization of a pHEMT device using photoluminescence (PL) [5] and photoreflectance (PR) [6] can provide the information on the epitaxial material parameters, which define the final device performance. The PL spectra thermal broadening, the spectral shape and symmetry changes show the probability and energies of the important Quantum Well (QW) transitions. PR reveals Franz-Keldysh oscillations (FKO) [6] and relates to the built-in field at the interfaces between different films (layers) of the structure. It can be used to determine the Al% and the build in field in the AlGaAs epitaxial layers of pseudomorphic High Electron Mobility Transistors (pHEMT) [2], which are difficult to be distinguished by other techniques. The optical techniques have a short cycle time.

Results

The nondestructive technique for screening of pHEMT epi was implemented in order for epi to comply with electrical specification criteria. The 300K PL spectrum and its deconvolutionat two Ns values of 2.2 and 2.7 is shown in Fig.1. The curve fitting is done using Levenberg-Marquardt nonlinear curve fitting procedure realized by WaveMetrics in IgorPro mathematical software.The physical model is explained in [5].

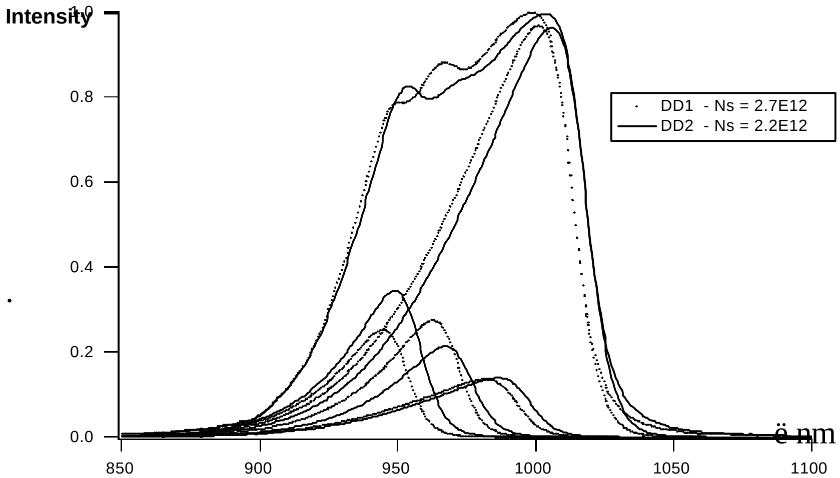


Fig.1 PL spectrum deconvolution of MBE grown pHEMT with variation in the sheet charge Ns.

We wrote a software Macro for Igor to deconvolve the PL spectra, when implementing a set of constrains for the fitting parameters. The initial parameters were chosen based on an analytical calculation for the particular HEMT structure (pHEMT, Emode etc.).

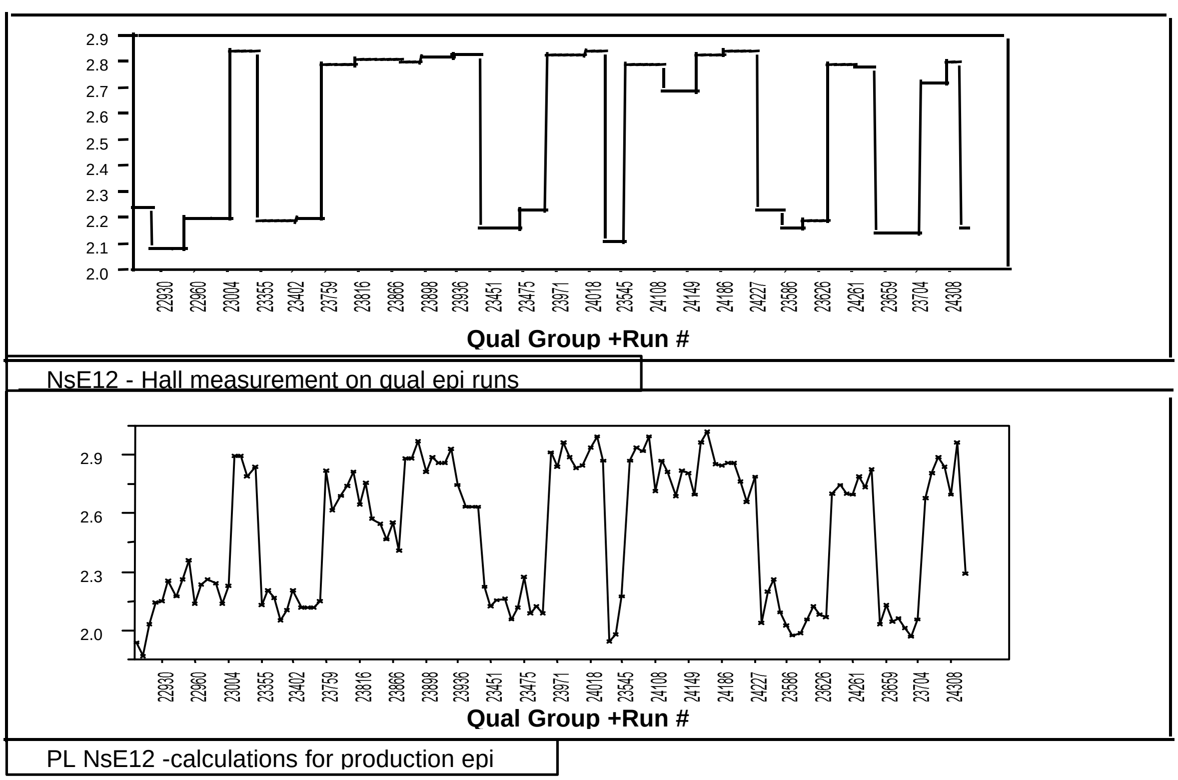


Fig.2 Correlation between Hall Ns readings for MOCVD epi reactor qualification for growing the pHEMT epi and the corresponding PL spectral data from the production epi runs .

The correlation was established with Ns measured by Hall on calibration runs, and PL response from the production epi structures grown after the epi reactor is calibrated. It can be seen as a time-chart in Fig.2, where the Hall Ns results are assigned as a constant to each production epi run after particular reactor qualification. There we can seen that the calculated Ns from PL parameters can track the Hall destructive measurement and also during the production cycles (between the calibration runs) the trend of Ns can be tracked.

The PR determination of AlGaAs composition of Schottky layer is shown in Fig.3 as a position of the first zero of the harmonic[2]. The shift in AlGaAs FKO is indication for build in field changes, which is related to charge in the layer. More charge in to the layer contribute to the shift to the side of the higher energy (firs maximum). This information is important when tracking the gate leakage and gate-drain breakdown issues.

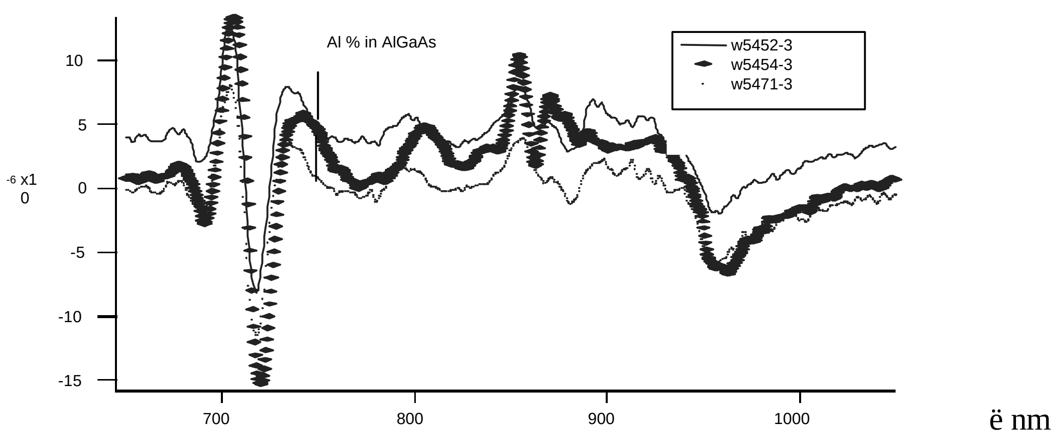
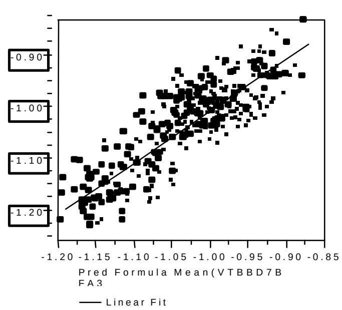


Fig.3 PR spectra on MBE grown pHEMT - AlGaAs mole fraction determination by energy bandgap.



Linear Fit

Mean(VTBBD7B FA2000S5D9____2000 = 2.27e-8 + 1 Pred Formula Mean(VTBBD7B FA3

Summary of Fit

RSquare	0.726152
RSquare Adj	0.725416
Root Mean Square Error	0.043756
Mean of Response	-1.02129
Observations (or Sum Wgts)	374

Fig.4 PL calculated PVth correlation with process control monitoring data for Vth. The Y axis represents the PCM Vth. The X axis represents the calculated values PVth when using deconvolution (fitting) parameters in multivariable regression correlation formula.

The changes in the AlGaAs Schottky by PR or InGaAs channel charge by PL generate the corrective actions. The destructive measurements (TEM,SEM etc) have to be performed to verify the details of particular material issue.

After spectra quantification, we were able to establish a correlation with Process Control Monitoring (PCM) device results, shown in Fig.4. The PL calculated PVth was correlated with PCM data for Vth. The Y axis represents the PCM Vth. The X axis represents the calculated values PVth when using deconvolution (fitting) parameters in multivariable regression correlation formula. These correlation results were used to create a pass/fail filter for CS1 pHEMT epi. It helped to improve with 20% the yield in pHEMT production line.

Conclusions

The nondestructive characterization of modulation doped quantum well pHEMT was presented. The microparameters of the structure can be extracted from PL or PR optical measurements. The influence of epitaxial structure on the device was obtained in more details by a semi- empirical approach. The obtained values have been correlated with device parameters from PCM (I_{DSS}, V_{th}) The results were used to create the pass/fail criteria for epi flows production screening.

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