MOCVD materials for electronic and optoelectronic applications

K. Christiansen, M. Luenenbuerger, Y. Dikme*, B. Schineller, M. Heuken
AIXTRON AG
Kackertstr. 15-17, D-52072 Aachen, Germany
phone: +49-241-8909-0, fax: +49-241-8909-40,
e-mail: info@aixtron.com

The recent years have seen a continuous transfer of exciting new technologies from basic research institutions to high yield mass production and into our everyday lives. Devices made from novel semiconductor compounds can be found in products ranging from consumer electronics to high speed backbone communication networks. This includes high power infrared laser diodes for glass fiber applications, ultra-high brightness light emitting diodes for display and lighting, high power blue and UV laser diodes for mass storage as well as all types of transistors made from silicon, III-V compounds and silicon-carbide. To facilitate the easy and straigtforward transfer from research scale experimental setups to large area substrates for mass production AIXTRON offers the whole scale of epitaxy solutions from single wafer systems to large scale production machines for up to 95 wafers. The easy configurability of the systems in terms of up-scaling of wafer sizes up to 7 × 6 inch for phosphides and arsenides and up to 8 × 4 inch for nitride materials in concurrence with easy maintenance, high reproducibility and high uniformity across the wafer and from wafer to wafer make the AIXTRON systems the ideal solution for mass production. The growth principle common to all AIXTRON MOCVD systems allows the easy up-scaling of established processes to larger configurations, even from single wafer AIX 200 systems to production type Planetary Reactors®.

Add-ons like in-situ monitoring of the growth process by reflectometry (*EpiTune® I* and *EpiTune® II*) or Reflectance Anisotropy Spectroscopy (Epi-RAS®) help in a considerable reduction of the development time and costs, hence improving innovation cycles and the time-to-market of novel devices since the growth of the material can be monitored in real time.

To assess the performance of the Planetary Reactor® for the growth of phosphide and arsenide based p-HEMT and HBT structures we have investigated the p- and n-type doping uniformities of GaAs, and the n-type doping of $Al_{0.3}GaAs$ and GaInP. On-wafer doping uniformities of GaAs on 6 inch of 1.24% and 1.1% standard deviation of the sheet resistance at carrier densities of 8×10^{17} cm^{-3} and 3×10^{19} cm^{-3} were achieved for n- and p-type, respectively. The corresponding wafer to wafer reproducibilites in the same run were of ±0.4% and ±0.7%, respectively. In analogous experiments n-type doping levels of 1×10^{17} cm^{-3} (σ_{onW} = 1.26%) and 1×10^{18} cm^{-3} (σ_{onW} = 3%) were achieved for $Al_{0.3}GaAs$ and GaInP, respectively. These values satisfy the demands of p-HEMT and HBT applications and insure excellent yield in mass production on large wafers.

Besides the need for excellent electrical data, the mass production of semiconductor devices demands the control of composition and thickness. A thickness uniformity of a 2 µm thick $Al_{0.3}GaAs$ layer on a 6 inch GaAs wafer was demonstrated. The standard deviation was determined to be 0.17%.

To assess the performance of the Planetary Reactor® for the growth of nitride based semiconductors in the 24x2 inch configuration we have chosen to investigate the properties of 5 period multi-quantum-well (MQW) structures emitting around 470 nm and 520 nm which are prominent wavelengths for blue and green LED applications. The entire quantum well stack was grown at constant temperature without temperature cycling between barrier and well. The mean wavelengths over all wafers were 472 nm and 522.3 nm with wafer to wafer standard deviations of 1.2 nm and 1.7 nm for blue and green emitting structures, respectively, which are excellent values fit for mass production requirements.

In-situ characterization, the ability to directly observe the growth of the semiconductor material in the reactor chamber, has been well known in molecular-beam-epitaxy (MBE) in the past. However, powerful methods of in-situ characterization have found their way into more production oriented growth methods like MOVPE. We developed different in-situ methods that both deliver valuable information on the growth of the layers and, therefore, speed up the optimization loops in the development of MOVPE processes. This allows for a diagnostic of the wafers even before the growth run is finished.

Reflection-anisotropy-spectroscopy (RAS, EpiRAS®) measures the difference between the normal-incidence optical reflectance of light polarized along the two principal axes in the surface as a function of photon energy. Therefore, the method is sensitive to the properties of the wafer's growth front and can give valuable information about the doping concentrations, the composition and the crystalline quality of the material. The different layers can clearly be identified in the time resolved false color plot. The growth specialist can now utilize his database to speed up the optimization process for the device fabrication.

Fabry-Perot like reflectance is utilized to determine the growth-rate and the crystalline quality of the growing wafers. These methods, *EpiTune® I* and *EpiTune® II*, can be applied in the case of nitride semiconductor structures where a step in refractive indices is present at the interface between the growing device structure and the sapphire wafer or in selected phosphorus and arsenic containing device structures.
In addition to the sole measurement of the reflectivity as a function of time, *EpiTune® II* offers the possibility to measure the emissivity corrected temperature for each wafer.

In summary these in-situ tools offer the possibility for efficient process development and monitoring, since the material can be observed directly during the growth process.