## Recent Progress in MOCVD Technology: III-Nitrides and 2D Nanomaterials

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Today nanostructures play a crucial role in electronic and optoelectronic devices, circuits and systems. Modern devices such as transistors, optical emitters of various wavelength and sensors rely on quantum effects based on semiconductor nanostructures. These components achieve outstanding performance and are utilized in commercially available advanced MOCVD production systems.

This talk describes trends and our developments in high yield mass production of compound semiconductor based device structures using <u>Metal</u> <u>Organic Chemical Vapour Deposition (MOCVD)</u>. Developments in the simulation of reactor technology, in thermal on wafer uniformity and insitu control contribute to higher production yield.

Recent progress in the technology including productivity (cycle time, automation, MOCVD 4.0 principles) will be discussed selecting AlGaN/GaN HEMT and blue LED structures as prominent examples. All HEMT samples were grown in a stateof-the-art high throughput Planetary® Metal-Organic Chemical Vapor Deposition (MOCVD) reactor (AIXTRON<sup>TM</sup> G5+C), utilizing in-situ Cl<sub>2</sub> cleaning (see Fig. 1 and 2). Uniformities of total thickness and AlGaN barrier Al composition are well below 1% (sigm/mean) for all samples. Devices with breakdown voltages as high as 900 V exhibit low onresistances of 5.7 ohm.mm ±0.19 ohm.mm across the entire 200 mm wafer. Physical principles and numerical simulation results on MOCVD equipment improvements as well as process optimizations for advanced nanostructures and devices will be reported and discussed.

On the other hand GaN based LED manufacturing for Solid State Lighting (SSL) requires also high performance high yield MOCVD production tools. The manufacturing yield is predominantly determined by the uniformity and reproducibility of the active layer of the LED device structure, the InGaN multi quantum well (MQW). Therefore the understanding and optimisation of the MOCVD tool uniformity and reproducibility for InGaN growth is developed and presented here. The dependencies of InGaN MQW emission wavelength and growth rate on surface temperature, ammonia flow, group III molar flows, total flow, chamber height and total pressure were experimentally determined for a state of the art production reactor and will be discussed. A number of parameters have an impact on wavelength with the growth temperature being the strongest. These data serve as input to simulate, understand and improve the MOCVD tool uniformity and performance of LED produced.

Looking at future challenges the international road map of semiconductors (ITRS) lists 2D materials as possible new materials for electronic devices. Among them, the semiconducting transition metal dichalcogenides (TMDC) like MoS<sub>2</sub> or WS<sub>2</sub> are the most promising ones. Large-scale fabrication of TMDC is still a challenge to be overcome. The experiments reported here are carried out in a horizontal hot-wall MOCVD reactor in a 10×2 inch configuration. The developed process leads to a uniform; wafer-scale deposition of MoS<sub>2</sub> on various substrate types. The deposited films mainly consists of MoS<sub>2</sub> bilayers and exhibit a very high initial nucleation density. With optimization of growth parameters, a crystal growth process closer to thermodynamical equilibrium can be achieved. A set of experiments are conducted to investigate the nucleation of the films and to further tune nucleation density and lateral growth rate. The samples are characterized via Raman spectroscopy (cf. Fig. 3), photoluminescence (PL) spectroscopy (Fig. 4), atomic force microscopy (AFM) and scanning electron microscopy (SEM) to investigate their optical and structural properties. To reduce and control the nucleation density and to promote a layer-by-layer growth mode, the growth parameters such as DTBS and MCO precursor flows are optimized and temperature treatment was adjusted. The target is to deposit coherent wafer-scale monolayer MoS<sub>2</sub> films for future electronic and optoelectronic applications.



Fig. 1: Schematic principle of the Planetary ® Reactor to achieve outstanding wafer uniformity in composition, doping and layer thickness.



Fig. 3: Raman measurement of  $MoS_2$  showing the influenz of growth temperature and growth atmosphere.



Fig. 2: Overview of a state of the art production MOCVD system with cassette to cassette module and vacuum robot to achieve low production cost and high yield.



Fig.4: PL measurement of  $MoS_2$  demonstrating the effect of prebake conditions on film quality.