Epitaxy production technologies enabling next generation product roadmaps of wide band-gap semiconductor device industry

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Abstract

The paper reports on the progress of the MOVPE production technology for manufacturing of wide bandgap semiconductor power device stacks. High throughput processing built on wafer level automation, chamber cleaning technology for reliable chamber resetting and in-situ control of key process parameters are improving the robustness of the manufacturing process and ultimately lead to higher production yield and lower manufacturing cost. Basis for this development is the Planetary Reactor® allowing cost-effective multiwafer batch processes on 150 and 200 mm large area substrates with single wafer precision and uniformity.

INTRODUCTION

In recent years the focus of epitaxy production technology developments has been on productivity enhancements concepts like wafer level automation, in-situ metrology to acquire process data for smart system control and predictive maintenance concepts. The requirements for the process equipment are multifold, demanding utmost control of dopant and layer thickness uniformity and low defect density of the epitaxial layers. Besides layer quality, the ability to manufacture the device layer stacks reproducibly and economically is crucial to support the growing demand. Estimating a contribution of the SiC epitaxy to the cost structure of a 1200V MOSFET of approximately 30-40% (Fig. 1. Cost breakdown for a 1200V SiC MOSFET on 150 mm SiC substrate [AIXTRON estimates].), the need for further cost reduction motivates innovating epitaxial growth technologies to support the SiC device industry roadmaps of the future years.

For voltage applications in the range of 50 to 650V GaN on Si Power HEMTs have penetrated into first commercial applications.

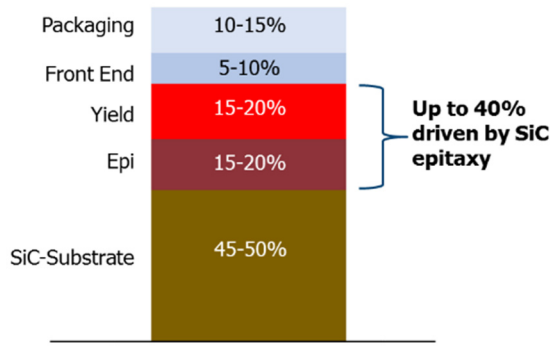

Fig. 1. Cost breakdown for a 1200V SiC MOSFET on 150 mm SiC substrate [AIXTRON estimates].

SIC EPI TECHNOLOGY REQUIREMENTS AND RESULTS

The epitaxy of SiC requires the precise control of the growth temperature and on-wafer uniformity at typical temperature level of 1600°C. For reproducibility of the growth conditions run to run and within a run for multiwafer batch reactors in-situ temperature measurement and correction for any deviations is mandatory. In the G5 WW Planetary Reactor® the individual wafer carriers (satellite) are floating on a gas cushion. By automatically adjusting the gas flows to each satellite (Autosat) the total temperature difference of the mean wafer temperature can be reduced to +/-1°C. The emissivity corrected average on wafer temperature for all satellites as a function of growth time is displayed in Fig. 2. After the onset of the Autosat correction modus the wafer to wafer temperature difference is drastically reduced.

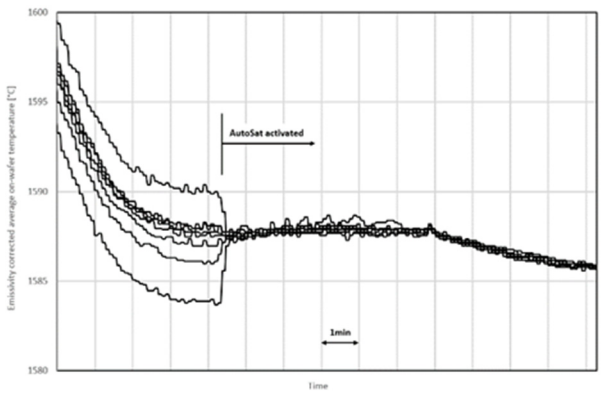

Fig. 2. Wafer to wafer mean temperature correction of mean temperature auto-correction of the gas flows to each of the 8x150mm wafer carriers (Autosat).

High growth rate processes have been demonstrated using SiH_4 at low growth pressure to reduce Si cluster formation at high Si supersaturation, HCl addition to the SiH_4 to form $SiCl_2$ molecules in the gas phase or chlorosilane precursors [1-3]. Besides uniformity of growth and low epi defectivity the parasitic growth in the reaction chamber is largely affected by the choice of the precursor type. We have shown a wide growth rate window enabled by Trichlorosilane (TCS) and C_3H_8 mixed into H_2 carrier gas. Fig. 3) shows the linear dependence of SiC growth rate on TCS partial pressure. Growth rates up to 50 µm/h could be achieved.

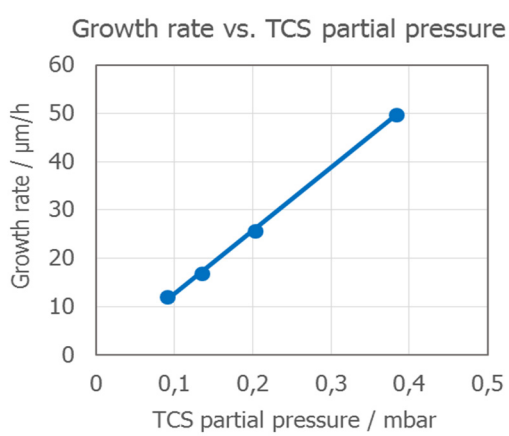

Fig. 3. Linear dependence of SiC growth rate on TCS partial pressure in an 8x150 mm Planetary Reactor®.

Uniformity of doping and thickness of the drift layer epi is critical in order to achieve uniform breakdown voltage of the device across the wafer. For the total on-wafer thickness uniformity (sigma/mean) of the layer stack of less than 1% is typically achieved. Intra and inter run mean thickness uniformity total variation are less than +/-1.3% (**Error! Reference source not found.**).

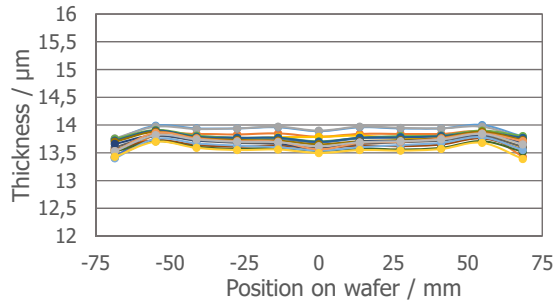

Fig. 4. Thickness uniformity of 16x150mm wafer measured by FTIR processed in four consecutive runs with four wafers each (5mm edge exclusion).

The on-wafer doping uniformity (sigma/mean) of a typical SiC drift layer measured by Hg-probe CV is less than 5%. Intra and inter run mean doping uniformity variation is less than +/-4.9%. The doping uniformity of 16x150 mm wafer measured by Hg-probe CV processed in four consecutive runs with four wafers each is shown in Fig. 5.

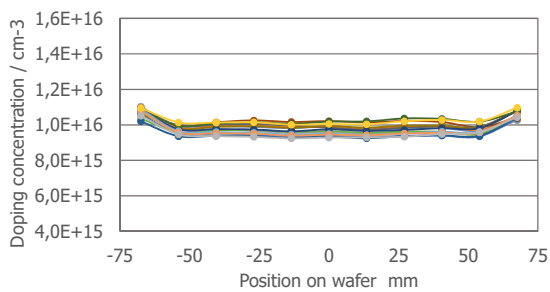

Fig. 5. Doping uniformity of 16x150 mm wafer measured by Hg-probe CV processed in four consecutive runs with four wafers each (5 mm edge exclusion).

Besides the epilayer quality and stability of the process the throughput of the epitaxial process is a critical metrics. High growth rate processes have been developed to minimize the actual growth time. The system overhead time (wafer loading/unloading, pump/purging of the chamber and thermal cycling of the susceptor), though can contributing to the same extend. Therefore, automation of the SiC epitaxial process has become a strong enabler for faster processing. Hot loading and unloading of wafer at 600-900°C preferably into standard wafer cassettes have been developed for different system platforms. In the Planetary Reactor® wafers are automatically loaded from standard cassettes cutting the typical process time for a 1200V layer stack grown at 25 µm/h into half by

heat cycle time savings. The throughput of the system can be doubled by our automation technology.

GaN EPI Technology requirements and results

GaN on Silicon for power and RF applications has demonstrated technological maturity. Rather the economical rational of how to improve cost efficiency in the material and device production is considered to be the obstacle for the faster adoption today. We present our recent work performed in a G5+ C2C Planetary Reactor® for high volume manufacturing of GaN based devices on 150 or 200 mm Silicon substrate [4]. To achieve high buffer breakdown voltages up to 1KV and low dispersion, suitable buffer technologies as well as carbon doping schemes were developed [5].

For the manufacturing of GaN HEMTs on Si challenges of integrating suitable AlGaN buffer schemes on standard thickness 150 and 200 mm Si substrates have been addressed recently with the development of suitable SL based buffer structures, Fig. 6. The high Al content in the SL structure and the use of extrinsic carbon doping during SL growth using hydrocarbon precursor [6] lead to improved buffer breakdown strength.

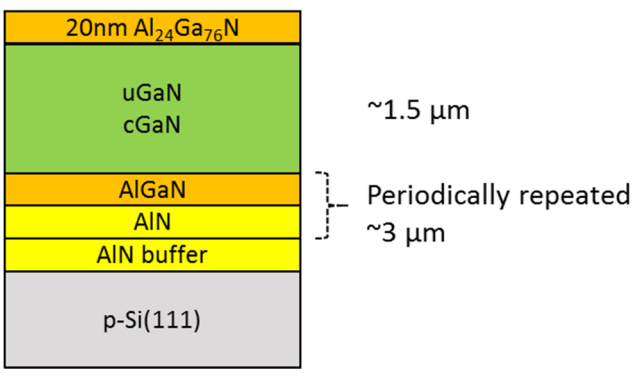

Fig. 6. Schematic representation of AlGaN/AlN SL structure targeting at 650V applications.

The static vertical breakdown characteristics of the 4.5 µm thick SL buffer stack exhibits a leakage current less than 1 µA/mm2 for a voltage exceeding 900V at room temperature. This corresponds to a very good critical electric field of the buffer stack of 2 MV/cm. The achieved uniformity

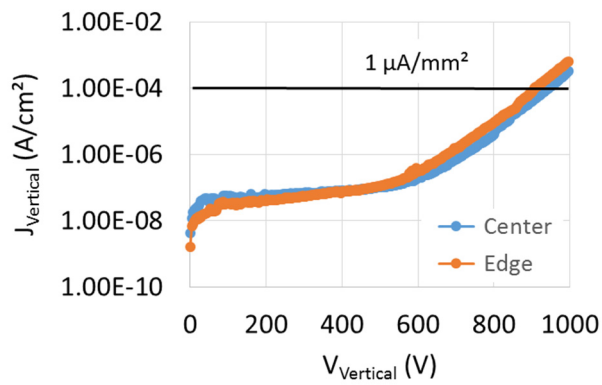

Fig. 7. Vertical breakdown measurements on extrinsic carbon doped SL buffer, comparing center and edge points for a 200 mm wafer [D. Fahle et al, this conference].

of the breakdown voltage is confirmed by two measurement points on center and edge of the 200 mm wafer in Fig. 7.

For the critical AlN seeding layer growth step on Si excellent reproducibility of the nucleation process is required. We have developed a Chlorine based reactor etch back process with high selectivity to Al and Ga metal deposits which is efficiently removing metal deposits from all chamber walls. This process results in a full restoring of the original reaction chamber hardware conditions and eliminates the risk of parasitic nucleation and metal etch back of the Si substrate.

Moreover, the reactor etch back technology enables fully automated processing with wafer load from cassettes which greatly improves the integration of MOCVD processing into standard Si fab environments and reduces particle contamination risks caused by manual handling of wafers or parts.

Conclusions

AIXTRON MOVPE Planetary Reactor® technology have been significantly advanced through innovations like wafer level automation, suitable reactor etch back processes and process improvements like higher growth rates and improved layer uniformities. These measures translate into higher throughput processing which is enabling cost benefits for the manufacturing of modern SiC and GaN based power devices.

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ACRONYMS

MOVPE:	Metal-organic vapor phase epitaxy
MOSFET:	Metal Oxide Field Effect Transistor
TCS:	Trichlorosilane
HEMT:	High Electron Mobility Transistor
SL:	Superlattice
Hg-CV:	Mercury probe capacitance voltage measurement
FTIR:	Fourier transform infrared spectroscopy