III-Nitrides Growth with Plasma-Assisted Molecular Beam Epitaxy for High Electron Mobility Transistors

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INTRODUCTION: Metal Organic Chemical Vapor Deposition (MOCVD) has become the standard method of growing epi-layers of III-Nitride semiconductor. However, MBE (Fig. 1 shows our EPI-930) possesses some interesting characteristics that may complement MOCVD in this context, e.g. (1) In-situ monitoring techniques resulting in excellent control of the growth process, (2) Good control of interface abruptness, (4) Ultra-high vacuum and high purity materials leads to lower levels of contaminants, (5) p-GaN does not need a high-temperature activation anneal to become electrically conductive, due to the low hydrogen levels, (6) doping profiles do not suffer from memory effects, (7) lower growth temperatures facilitate high indium content materials.

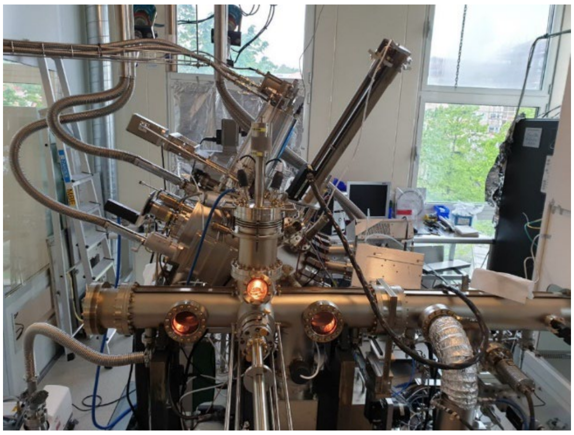
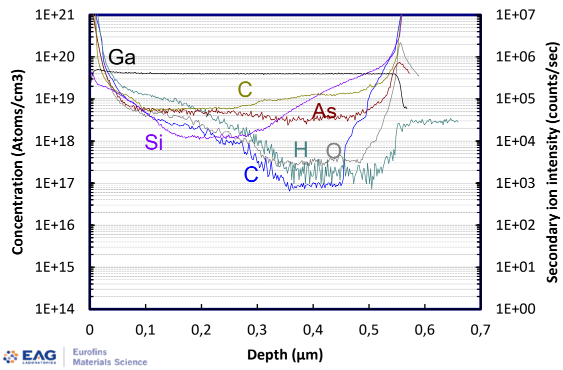


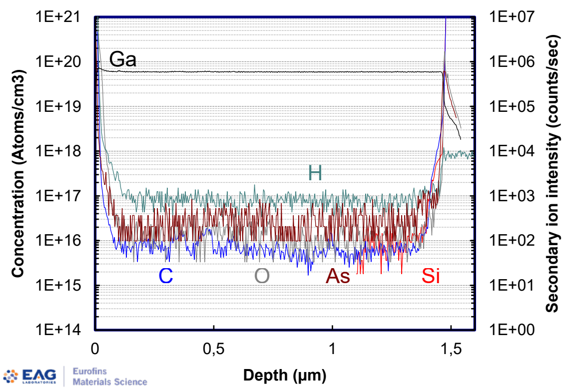
Fig. 1: The EPI-930 Plasma Assisted Molecular Beam System equipped with ultra-pure (Ga,Al,In)(Si, Mg) and two N-plasma sources.

METHODS: We are currently growing epitaxial layers in an EPI-930 III-nitride MBE equipped with (In,Ga,Al)(Si,Mg) solid effusion cells and two Nitrogen plasma sources. Until now we have grown GaN-layers, AlN/GaN heterostructures, AlN/GaN-Multi-Quantum Wells, GaN:Si-doped layers and initial HEMT-structures. 4H-SiC(0001)-substrates and MOCVD-grown GaN/AlN/4H-SiC(0001) semi-insulating-templates have been used so far. Direct growth on more expensive AlN-substrates will be done when we have better process control and device measurements performed.

RESULTS: Our growth chamber exhibits a very low background impurity levels assessed with Residual Gas Analysis (RGA). This is also reflected in a low impurity incorporation in grown GaN-layers measured with Secondary Ion Mass Spectroscopy (SIMS) shown in Fig.1 in GaN-layers grown before (a) and after (b) our refurbishment of the growth chamber.



(a)



(b)

Fig. 2: Impurity levels (C, O, H, Si, As) in GaN layers grown before (a) and after (b) refurbishment of the MBE-system at Chalmers (only unintentional Si-level shown).

DISCUSSION & CONCLUSIONS: The aim of our work is to grow more complex heterostructures suitable for High Electron Mobility Transistors (HEMT:s) operating well beyond 100 GHz as shown in Fig.3. We are aiming at HEMT:s with regrown (GaN:Si) contacts and In-containing channels since this is expected to give a high electron velocity. Pure

InN-layers is predicted to have a very high electron velocity (10^7cm/s). The EPI-930 is located inside MC2 Nanofabrication Laboratory which is a fully equipped cleanroom with state-of-the-art processing equipment which will be used to fabricate the HEMT-structures.

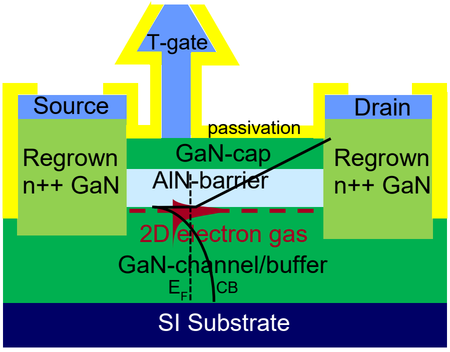


Fig. 3: A schematic of a HEMT with re-grown contacts.

Material characterization is currently being performed with High Resolution X-Ray Diffraction (HRXRD), Scanning Electron Microscope (SEM) and Atomic Force Microscope (AFM). Transmission Electron Microscope (TEM) characterization will be used for detailed imaging of interfaces at the atomic level. It is also possible to perform advanced Ellipsometry end Photoluminescence in cooperation with Linköping University. We will also use advanced electrical measurements both at room temperature and cryogenic temperatures with the equipment operational at the Microwave Electronics Laboratory, MC2, Chalmers.

ACKNOWLEDGEMENTS: This template was modified with kind permission from eCM conferences Open Access online periodical & eCM annual conferences. This project is funded by a Vinnova competence center, C3NiT, a joint-venture research center on III-N development for RF & high-power applications in collaborations with industrial partners (Ericsson, Saab, Hitachi, UMS, SweGaN, Gotmic, Hexagem, Epiluvac, ON semi, Volvo Cars). This center also includes Lund University as academic partner and FMV).