Plasma Science and Technology
Room 124 - Session PS2-WeA

Plasma Processes for Emerging Device Technologies

Moderators: Phillipe Bezard, IMEC Belgium, **Catherine Labelle**, Intel Corporation

4:15pm **PS2-WeA-9 Low Damaged GaN Surface Through Passivating Plasma Etching and Post-Etch Treatments for Improved GaN-MOS Capacitor Performance**, ***David Cascales,*** CEA-LETI & LTM, France; *P. Pimenta-Barros, E. Martinez,* CEA-LETI, France; *B. Salem,* LTM - MINATEC - CEA/LETI, France

The power electronics industry is facing new challenges to meet the increasing needs of electrical power in modern devices[1]. These needs require an efficiency rise of power converters, also accompanied by higher operating voltages, currents and frequencies. Wide bandgap materials such as GaN are then investigated and preferred to Si-IGBT converters due to silicon limits being reached[2]. Lateral and vertical GaN-based power devices have emerged such as the vertical MOSFET or the lateral MOS-channel High Electron Mobility Transistor (MOSc-HEMT). With both technologies, normally OFF properties are needed and can be achieved with a gate recess, while a MOS gate controls the channel operation.

Plasma processing is crucial for channel and gate performance[3]. For instance, the recess shape can directly affect channel conducting properties and gate leakage, while the damaged GaN layer can influence the gate's behavior by deteriorating the flat band voltage. Indeed, flat band voltage is driven by charge generation that is caused by lattice amorphization, nitrogen depletion, element implantation or etching by-products deposition[4].

This study aims to investigate negative charge generation at the GaN/dielectric interface in order to shift threshold voltages towards greater values. Plasma etchings and post etch treatments (PET) were performed in an ICP chamber, together with pre-deposition treatments in the ALD chamber prior to dielectric deposition to limit nitrogen depletion and lattice amorphization.

First, thanks to X-ray Photoelectron Spectroscopy measurements, we will discuss the chemical modifications induced by silicon introduction ($SiCl_4$) in a Cl_2 plasma etching chemistry. A Si-based layer protecting GaN from ion bombardment is present at the Al_2O_3/GaN interface. The Si-layer and GaN evolution through the MOS capacitor fabrication steps will then be analyzed, including the O_2 PET, and the Al_2O_3 ALD preceded by an HCl gallium oxide removal. $SiCl_4$ addition shows a significant flat band voltage improvement with C-V measurements. As well, HCl replacement by a dry *in situ* N_2/H_2 pre-deposition treatment for high $SiCl_4$ etching ratios will also be examined.

Finally, we will explore the impact of PET chemistry variations after $SiCl_4/Cl_2$ etching with addition of N_2 to the O_2 chemistry, giving a better understanding of the plasma interactions with GaN, the SiN holder and chamber walls. The goal is to restore the N/Ga ratio with nitrogen supply.

[1]International Energy Agency (IEA), World Energy Outlook (2022)
[2]E. A. Jones et al., *IEEE WiPDA* (2014)
[3]S. Ruel *et al.*, *J. Vac. Sci. Technol. A*, 39(2), p. 022601
[4]P. Fernandes Paes Pinto Rocha, *Energies*, 16(7), p. 2978

4:30pm **PS2-WeA-10 Anisotropic and Sub-Micrometric InGaP Plasma Etching for High Efficiency Photovoltaics**, ***Alison Clarke***, *M. de Lafontaine,* University of Ottawa, Canada; *R. King, C. Honsberg,* Arizona State University; *K. Hinzer,* University of Ottawa, Canada

Nanoscale III-V semiconductor etching enhances light trapping, enabling low cost and efficient photovoltaic devices [1]. Mitigating sidewall erosion and chlorine-based defects is crucial for increased device performance. However, anisotropic III-V patterning with sub-micrometric definition has many challenges, such as sidewall erosion and surface damage [2]. Room-temperature InGaP plasma etching is challenging due to non-volatile $InCl_x$ subproducts. Chlorine-based plasmas lead to defects which can be passivated by introducing hydrogen-based plasma chemistries [3].

InGaP nanotextures with vertical sidewalls were patterned using electron-beam lithography and inductively coupled plasma etching. Circular nanotextures with 850 nm diameter and 150 nm minimum spacing were patterned in a hexagonal array. The etch was performed at room temperature to limit sidewall erosion [3], using the resist as a mask. To assess the impact of chlorine and hydrogen, four plasma chemistries were investigated: Cl_2/Ar, Cl_2/H_2, Cl_2/Ar/H_2, and Ar/H_2. The etched InGaP was investigated with atomic force microscopy. The Cl_2/H_2 plasma produced the fastest average etch rate (150 nm/min), with aspect ratio of 0.66. The Ar/H_2 plasma had the slowest average etch rate (75nm/min) due to the absence of Cl-based chemical etching. All etch rates were low due to the high (~25%) In content in the InGaP which creates poor volatility byproducts. Hydrogen improved the etching process, suppressing chlorine-based defects and decreasing the line edge roughness by up to 48% compared to the plasma without hydrogen.

These results show that hydrogen-based plasma chemistries improve pattern transfer for photovoltaics applications, where precise control of critical dimensions is required to improve conversion efficiencies. Ongoing work on top view and cross-sectional scanning electron microscopy will also be presented along with device performance measurements to confirm light-trapping properties. Complimentary characterizations such as energy-dispersive X-ray spectroscopy will be performed to benchmark the passivation properties of hydrogen plasmas.

[1] N.P. Irvin et al., "Monochromatic Light Trapping in Photonic Power Converters," *49th IEEE Photovoltaics Specialists Conference,* 0143 (2022).

[2] M. Bizouerne et al., "Low damage patterning of In0.53Ga0.47As film for its integration as n-channel in a fin metal oxide semiconductor field effect transistor architecture," *J. Vac. Sci. Technol.*, 36(6):061305 (2018).

[3] M. de Lafontaine et al., "Anisotropic and low damage III-V/Ge heterostructure etching for multijunction solar cell fabrication with passivated sidewalls." *Micro Nano Eng.*, 11:100083 (2021).

4:45pm **PS2-WeA-11 On the Plasma Etching Mechanisms of Patterned Aluminum Nitride Nanowires with High Aspect Ratio**, *S. Sales de Mello,* ***Lucas Jaloustre,*** University Grenoble Alpes, CNRS, LTM, France; *S. Labau, C. Petit-Etienne,* University Grenoble Alpes, CNRS,LTM, France; *G. Jacopin,* University Grenoble Alpes, CNRS, Institut Néel, France; *E. Pargon,* University Grenoble Alpes, CNRS, LTM, France

III-nitride (III-N) semiconductor light-emitting diodes (LEDs) are a particularly promising alternative to mercury vapor lamps as ultra violet (UV) sources [1]. However, the external quantum efficiency (EQE) of current planar Al_xGa_yN well-based UV LEDs is extremely low (<1% for wavelengths below 250 nm)[2]. Three-dimensional (3D) core−shell architecture offers some promising solutions to increase UV LED efficiency up to 50%.This approach consists in radially growing emissive quantum wells on predefined aluminum nitride (AlN) nanowires (Fig.1) [3]. The top-down combining lithography and plasma etching transfer is the only viable approach to fabricate the well-organized arrays of high Aspect Ratio (AR) AlN nanowires required.

This study aims to develop a chlorine (Cl_2) plasma etching process in a Inductively Coupled Plasma (ICP) reactor dedicated to high AR AlN nanowires (AR>10, i.e. sub-500nm diameters, 4µm-high) fabrication, based on a fundamental understanding of the etching mechanisms involved. The samples are AlN (4µm) grown on sapphire substrate with a silicon oxide (SiO_2) 1.4µm thick hard mask on top. Electron beam lithography is used to design dots with several diameters, densities and shape. We investigate the impact of the plasma parameters (source, bias and pressure) on the AlN etch rates, AlN/SiO_2 etch selectivity, pattern profiles and sidewalls roughness. We observe that the carrier wafer (CW) chemical nature (Si or Si_3N_4) affects the nanowire profile. Under the same plasma conditions, the use of Si_3N_4 CW always leads to passivation layer formation on the AlN sidewalls, which creates more tapered AlN pillars than using Si CW (Fig. 2). In both cases SiClx etch by products coming from the CW are present in the plasma and are likely to redeposit on AlN sidewalls [4]. However, with Si_3N_4 CW, the presence of N helps to fix the SiClx and to form a SiNCl passivation layer.

Ion flux, ion angular distribution and ion energy measurements show that, the plasma conditions that favor high ion flux over radical flux (higher source power, lower pressure, higher bias) enhance the AlN etching, suggesting an ion-enhanced chemical etching mechanism. In addition, conditions for which the physical component of the plasma dominates lead to tapered profiles, while anisotropic ones can be obtained when the chemical component dominates. Fig. 3 shows the source power impact on the profiles. Charging and ion angular distribution effects also affect the pattern profiles. Finally, we also observe a crystal orientation preferential etching phenomenon. Cl_2 plasma etching tends to reveal nonpolar a-planes, suggesting that they are the most stable in this process.

5:00pm **PS2-WeA-12 Development of a New Underlayer to Improve the Adhesion of Photoresist for EUV**, ***Wafae Halim,*** KU Leuven and Imec, Belgium; *P. Bezard,* Imec, Belgium; *S. De Gendt,* KU Leuven and Imec, Belgium

Metal Oxide Resist (MOR) is a promising resist candidate for Extreme ultraviolet lithographyexhibiting a sufficient etch contrast with carbon-based hard masks to no longer impose a particular etch resistance to the EUV underlayer. The main objective of this study is removing spin on glass from the conventional stack to avoid using the high Global Warming Potential gases used for its patterning (Fig.1). Thus, MOR should be coated on the top of a carbon hard-mask.One of the ways to achieve this objective is by treating the surface of amorphous carbon (aC) to promote adhesion between MOR and aC.

In this work, PECVD processes have been developed and their impact on the surface energy of amorphous carbon has been investigated. The MOR spin-coated on the differently treated carbon hard-masks has then been exposed to EUV light, and developed, so that the impact of the surface treatment on pattern collapse could be studied.

Figure 1 An approach to remove the SOG from the standard flow in order to have a good adhesion between MOR and aC

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