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Performance Enhancement of AlGaN/GaN based High Electron Mobility Transistor (HEMT) with Structural Reconfiguration and Thermal Engineering for High Power Applications

Soumen Mazumder, Yeong-Her Wang*

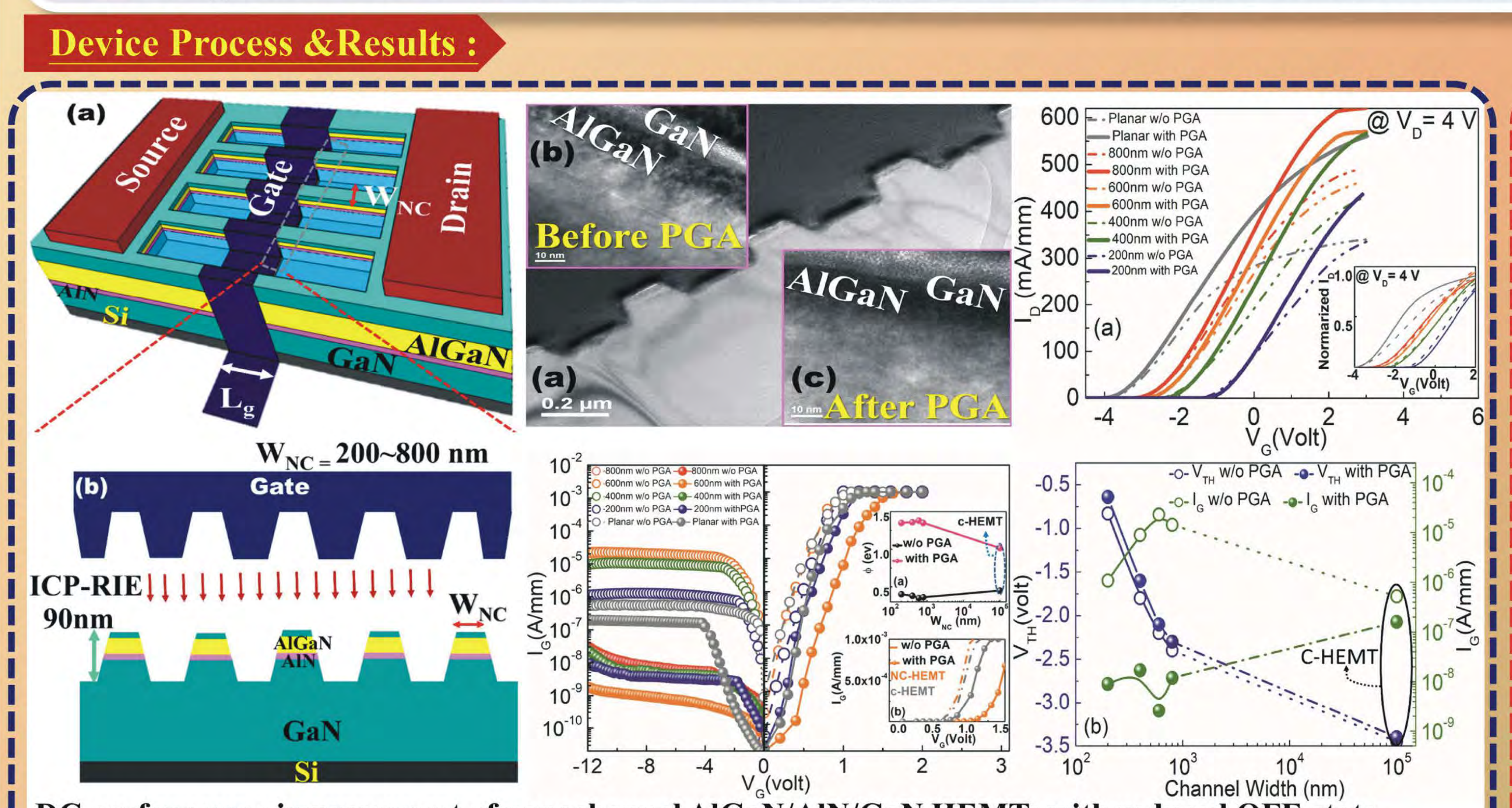
4th year PhD student, Advisor

Institute of Microelectronics, College of Electrical Engineering & Computer Science, National Cheng Kung University, Tainan- 701, Taiwan

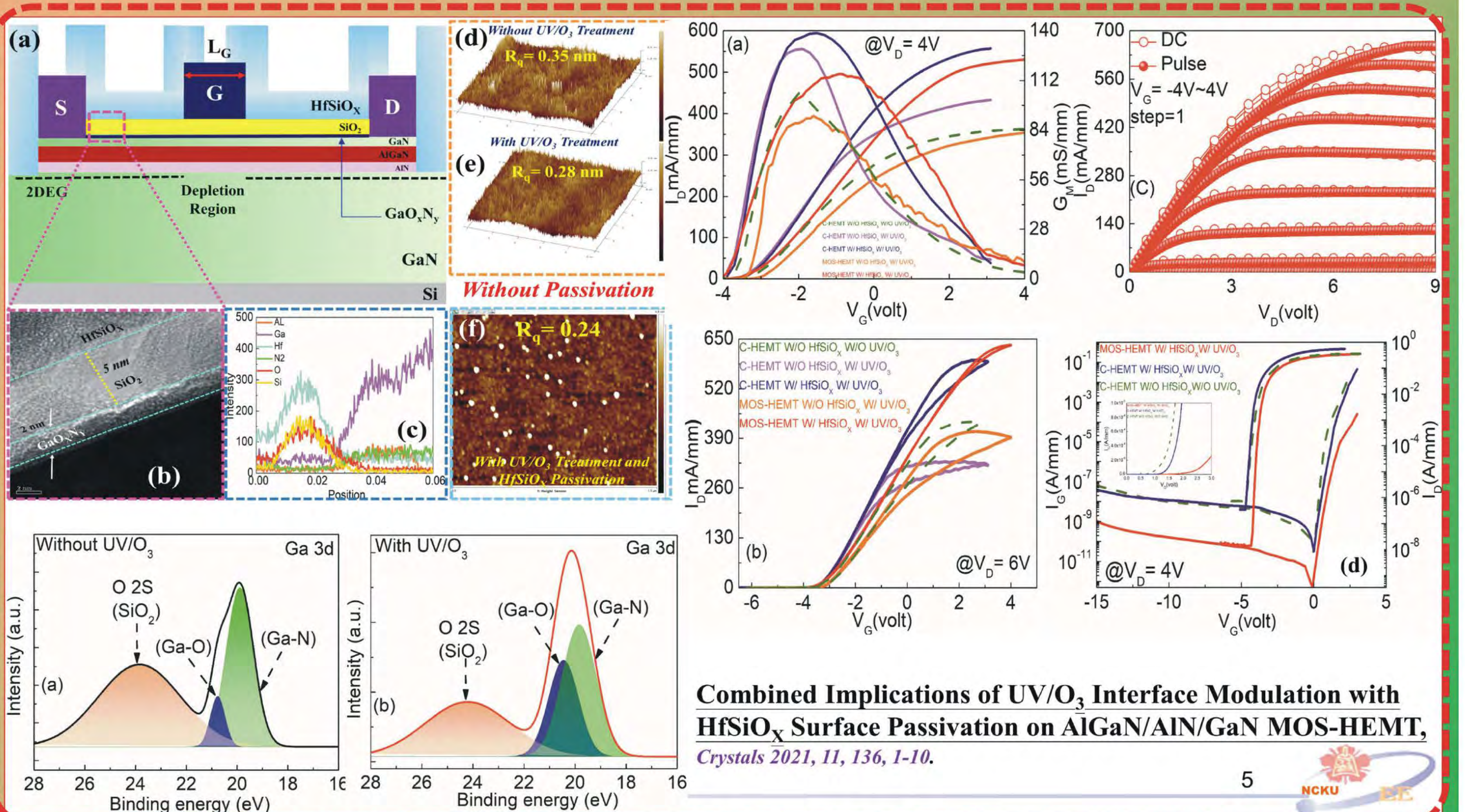
Abstract:

The performance of the AlGaN/GaN based High Electron Mobility Transistors (HEMTs) is enhanced by the different structural reconfiguration and thermal engineering approach. At first, the effects of a post-gate annealing (PGA) treatment on the DC performance of AlGaN/AlN/GaN nanochannel (NC)-HEMTs were analyzed, with channel widths of 200, 400, 600, and 800 nm for a constant fill factor of 0.45. A systematic improvement in the DC parameters was observed in the NC-HEMTs after PGA treatment at 400 ºC for 10 min. Then, a flash like Al_2O_3/SiO_2 stacked layer AlGaN/GaN MIS-HEMT was fabricated using trap assisted technique. The MIS-HEMT showed a large positive shifting of threshold voltage (ΔV_{TH}) of 4.6 V after applying a low program voltage (V_P) of 3 V, resulting in a very low V_{TH} of -0.3 V with a I_{DMAX} of 575 mA/mm, due to the ultraviolet-ozone (UV/O_3) surface treatment prior to gate dielectric deposition. Next, we demonstrate the surface passivation effects in AlGaN/AlN/GaN-based MOS-HEMTs using UV/O_3 plasma treatment prior to SiO_2 -gate dielectric deposition. Due to combined effects of the UV/O_3 plasma treatment and $HfSiO_X$ surface passivation, the magnitude of the D_{it} was effectively reduced, which further improved the current collapse to 0.6% from 10%. Finally, the optimized device performance in the Γ-shaped gate AlGaN/AlN/GaN MOS-HEMT was demonstrated by incorporating aluminum into HfO_2 and comparing it with the commonly used HfO_2 gate dielectric with the N_2 surface plasma treatment. I_G was significantly reduced with the increasing post deposition annealing (PDA) temperature from 300 to 600 °C in $HfAlO_X$-based MOS-HEMT, compared to the HfO_2-based device. In comparison with HfO_2 gate dielectric, D_{it} can be reduced significantly using $HfAlO_X$ due to the effective passivation of the dangling bond.

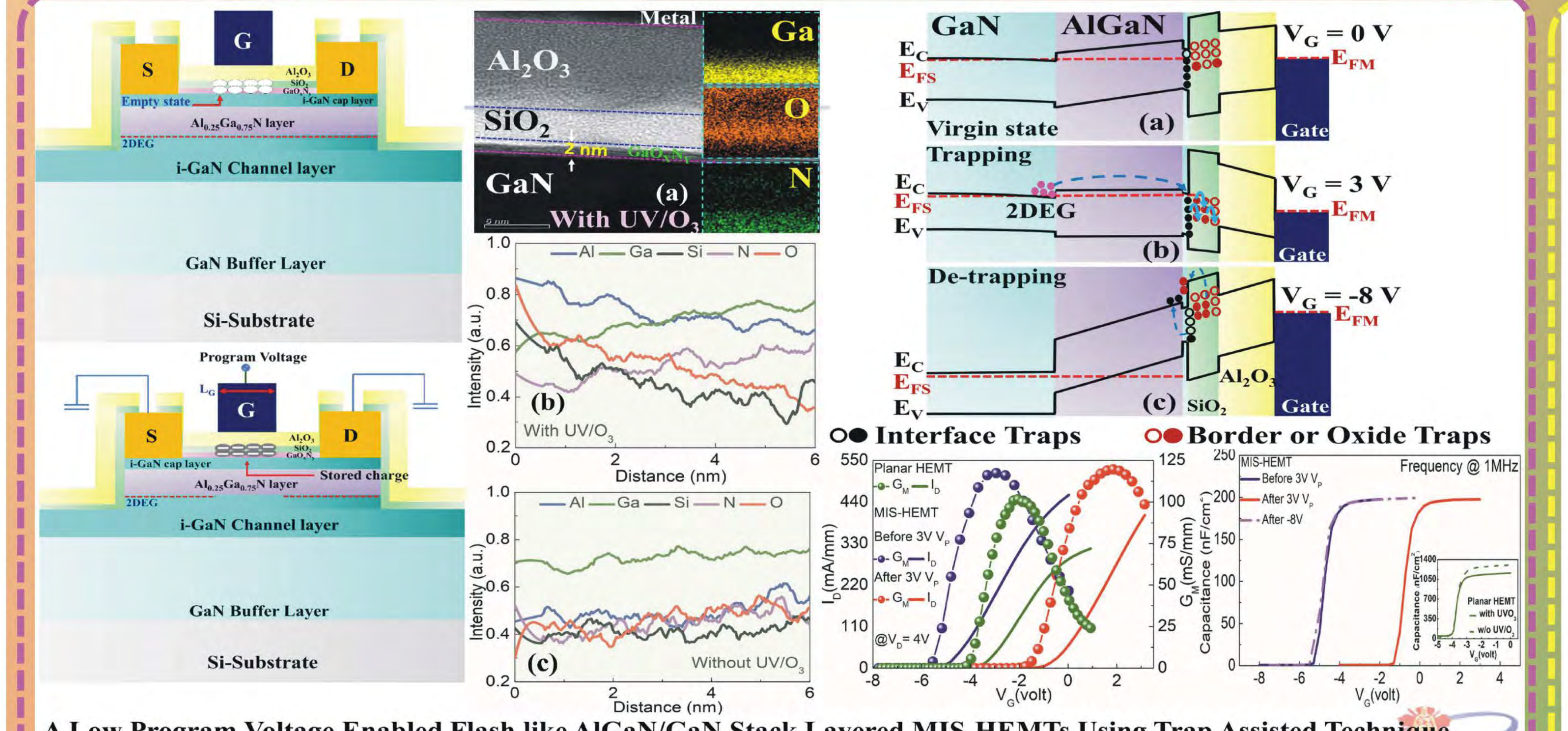
Device Process &Results :



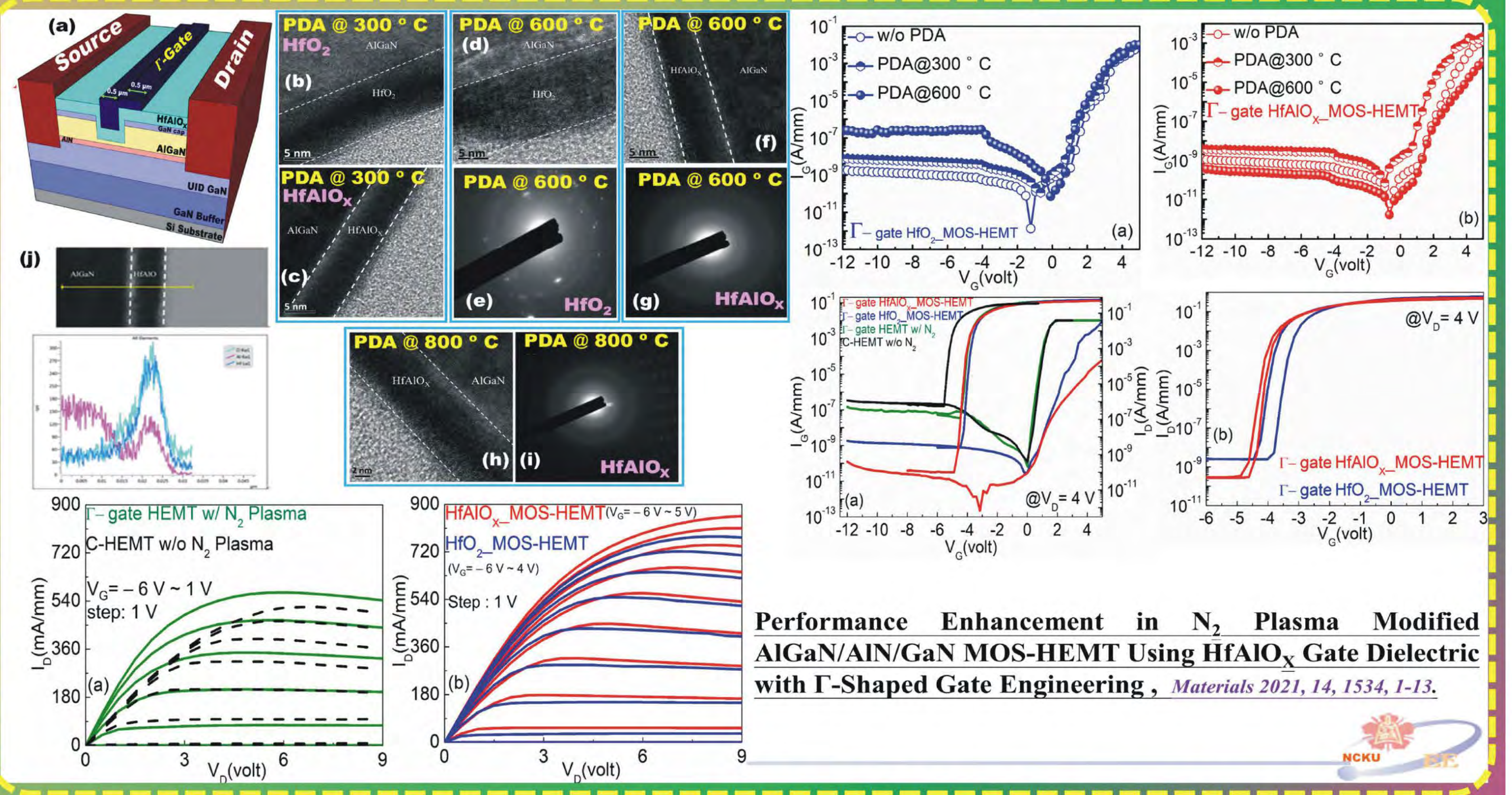
DC performance improvement of nanochannel AlGaN/AlN/GaN HEMTs with reduced OFF-state leakage current by post-gate annealing modulation, *Semicond. Sc. Technol., 2021, 36, 095003,1-11.*



Combined Implications of UV/O_3 Interface Modulation with $HfSiO_X$ Surface Passivation on AlGaN/AlN/GaN MOS-HEMT, *Crystals 2021, 11, 136, 1-10.*



A Low Program Voltage Enabled Flash like AlGaN/GaN Stack Layered MIS-HEMTs Using Trap Assisted Technique, *ECS, J. Solid State Sc. Technol., 2021, 10, 055019.*



Performance Enhancement in N_2 Plasma Modified AlGaN/AlN/GaN MOS-HEMT Using $HfAlO_X$ Gate Dielectric with Γ-Shaped Gate Engineering , *Materials 2021, 14, 1534, 1-13.*

Conclusions:

◆*In summary, the effects of a PGA treatment on DC performance were compared in AlGaN/AlN/GaN NC-HEMTs for a constant FF (0.45) with conventional HEMT. A significant improvement in the electrical characteristics of the devices was observed after gate annealing treatment at 400 ◦C for 10 min. Next, a high-quality $HfSiO_X$ passivation with UV/O_3 surface treatment, significantly reduced the current degradation from 10% to 0.6% in MOS-HEMT compared to C-HEMT by decreasing the trapping phenomenon originating from the surface states. The trap assisted technique by low V_P (3V) along with a stack layer Al_2O_3/SiO_2 dielectrics were utilized to implement the positive shifting of V_{TH} to a great extent of AlGaN/GaN MIS-HEMT. The I_G was significantly reduced with the increasing PDA temperature from 300 to 600 ◦C in the $HfAlO_X$-based MOS-HEMT compared to the HfO_2- based devices. Due to the inclusion of Al into HfO_2, the crystallization temperature was significantly improved to ~1000 ◦C of $HfAlO_X$. The D_{it}'s in the $HfAlO_X$-based MOS-HEMT was effectively reduced compared to the HfO_2 device, due to the effective passivation of the dangling bonds, which subsequently improved the hysteresis and current collapse characteristics.*

References :

1. S. Mazumder et. al, "Combined Implications of UV/O_3 Interface Modulation With $HfSiO_X$ Surface Passivation On AlGaN/AlN/GaN MOS-HEMT", *MDPI Crystals 2021, 11, 136.*
2. S. K. Yang† et. al, "Performance Enhancement in N2 plasma Modified AlGaN/AlN/GaN MOS-HEMT using $HfAlO_X$ Gate dielectric with Γ-Shaped Gate Engineering", *MDPI materials 2021, 14, 1534.*
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4. S. Mazumder et. al, "DC Performance Improvement of Nanochannel AlGaN/AlN/GaN HEMTs with Reduced off-state leakage Current by Post-Gate Annealing Modulation", *Semicond. Sci. Technol. , 2021, 36*, 095003.

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