Measurement and control of semiconductor-insulator interface state density in AlGaN/GaN MIS-HEMTs

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Doctoral Dissertation Abstract

Major Advanced Interdisciplinary Science and Technology

Course Electrical and Electronics Engineering

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1. Dissertation Title (If in English, add the Japanese translation.)

Measurement and control of semiconductor-insulator interface state density in AlGaN/GaN MIS-HEMTs

（AlGaN/GaN MIS-HEMT の半導体・絶縁体界面状態密度の評価と制御）

2. Abstract (Roughly 2,000 Japanese characters or 800 English words)

In the dawn of integrated circuits, the famous prediction by Gordon E. Moore was made: "The complexity for minimum component costs has in-creased at a rate of roughly a factor of two per year". By popular interpretation it means doubling of the transistor count every year. Originally even the author believed it to be only short term advancement, that would continue for a decade and possibly decrease afterwards. Yet we are now, almost 6 decades later, referring to this prediction as a Moore's law and with minor changes added in 1975 it still applies. Field of semiconductors and microelectronics since then was advancing exponentially, quickly approached theoretical limits of germanium and replaced it with silicon. Utilizing clever design techniques, process control and advancements in photolithography allowed us to push well into nanometer feature size with extraordinary yields. But for high power and high frequency applications theoretical limits imposed by silicon are already a significant problem.

One promising solution to this problem is the use of high band gap semiconductors and Gallium Nitride based semiconductors specifically. Low ON resistance, extremely high breakdown voltage and possibility for high frequency operation makes them the strong candidate for low loss high frequency amplifiers and high density power conversion applications. AlGaN/GaN heterostructure based high electron mobility transistors (HEMTs) have been on the market for a while, but the race to improve performance characteristics is still going. First, Schottky-Gate HEMTs – without gate insulator were

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reported. While simplified structure was beneficial for development speed and overall stability reasons, it suffered from multitude of problems like gate leakage current and excessive electron injection into access regions. This serious roadblock on the way to approaching theoretical limits of the material can be cleared by adding gate insulator, turning it into Metal Insulator Semiconductor (MIS) HEMT. However, more complicated structure leads to undesired effects like Insulator-Semiconductor interface electronic states, which impact device performance in a multitude of ways. Creation of these states depends heavily on materials and processes used for device processing during production. Production process includes multiple steps, any of which could potentially impact the result, so in this research we have focused on most hear intensive treatments as higher energy input has higher chance of physically altering the surface.

First method of interface state reduction we have explored addresses the first step in creating a heterostructure on a wafer – epitaxial growth with Metal Organic Chemical Vapor Deposition. We have used commercially available epitaxially grown AlGaN/GaN structure on SiC semi-insulating substrate to perform ex-situ regrowth of 3nm AlGaN layer. MIS HEMTs and Capacitors were fabricated from treated samples as well as reference samples from the same original wafer. After that we have rigorously studied the effects of ex-situ regrown layer with direct current characteristics of HEMTs as well as Capacitance-Voltage (CV) and Photo-assisted CV curve measurements. Obtained data that treated samples were performing better in terms of saturation current, hysteresis and transconductance, which was conclusively explained with lower interface state density. Physics behind this effect was suggested to be more optimized thermal regime of MOCVD regrowth, with lower temperature compared to industrial growth methods as well as effective removal of native surface oxides and nitrogen vacancies.

Second proposed method addresses the second highest thermal budget treatment in the device production process – Rapid Thermal Annealing (RTA) during ohmic contact formation. Conventionally the Titanium based metal stack is used which requires annealing at almost 900 degrees Centigrade for successful ohmic contact formation. Alternative metal stacks with RTA temperatures of around 650 degrees were reported previously, but the impact of RTA itself on surface state density was never investigated. We have utilized Vanadium based metal stack to obtain ohmic contact with similar to conventional approach contact resistance and linearity, but only with 660 degree annealing. Devices were yet again rigorously analyzed and showed consistently better characteristics when compared with conventional devices. Interface state density was also proven to be the main contributing factor to this effect.

Our methods were developed with existing technologies and production approaches in mind, so implementation into existing production is possible with minimal impact to upstream and downstream treatments and equipment. Finally, further development for this research was discussed in the conclusion of this dissertation. It includes further optimization efforts of individual methods proposed as well as combinatory approach, which most probably would require more elaborate evaluation techniques.