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Studies of III-V Semiconductor Materials and Devices Using Different Analytical Technologies

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Surface analysis technologies are very important and had been widely used in semiconductor material and device analysis. In this presentation, several important studies of III-V semiconductor materials and devices using different surface analyses, including scanning electron microscopy, energy dispersive spectrometer (SEM+EDS), X-ray photoelectron spectroscopy (XPS), especially secondary ion mass spectrometry (SIMS), will be introduced. For example, the physical origin of the droop effect; different failure mechanism; etching mechanism of lateral porous GaN, and how to distinguish the dopant occupation in the semiconductor lattice, etc.

1. Introduction

For the III-V semiconductors, Gallium Nitride and Gallium Arsenide are the most outstanding semiconductor materials for optoelectronic devices as the direct band gap semiconductors. One of the main advantages to use semiconductors is that their structural properties can be controlled and engineered according to different electronics and optoelectronics application. Using surface analytical technologies can help to optimize the doping, understand the structural properties, and improve the reliability. In this presentation, several typical studies of III-V semiconductor materials and devices using different surface analyses will be introduced.

2. 1 Droop Effect of GaN-based LEDs

GaN and its related alloys have developed significantly in terms of both fundamental understanding as well as application. However, for these applications, LEDs need to operate at a relatively low current density because of droop effect and reliability issue. The external quantum efficiency (EQE) of LEDs increases initially but decreases after reaching the peak value with the drive current increasing. Different mechanisms have been suggested to explain the droop effect, such as polarization effect, electron overflow, carrier delocalization, carrier injection efficiency, Auger recombination and defects. But the essential physical mechanism was not clear. By changing the indium composition in the quantum barriers in the InGaN-based LEDs, we studied the influence of electron distribution, electron leakage and Auger recombination on the external quantum efficiency (EQE) and droop effect. The Indium composition were measured using SIMS combined with TEM. Experimental results as well as numerical simulations suggest that the electron distribution is the key factor to both influence the peak efficiency and droop effect. It is the electron concentration in the individual quantum well near the n-GaN that will stimulate the Auger recombination and lead to the droop effect instead of the total effective carrier concentration. If we modulate the indium composition in the quantum barriers of the InGaN-based LEDs, a uniform electron distribution can be achieved, which can not only enhance the EQE, but also avoid the Auger recombination and improve the droop effect.

2.2 Failure Analysis of GaN-based LEDs

Although LEDs has a long lifetime, different form microelectronics, the light intensity of LEDs may still change during the operation. Furthermore, reliability not only depends on the structures, materials and operate environments, but the dominant degradation mechanisms for the same LED can be different at different operation stage. Therefore, with the increase application of GaN-based LEDs, reliability issues of GaN-based LEDs have become critical. Previously, we investigated the reliability and failure modes of various GaN-based LEDs systematically using different analytical technologies. For blue LEDs, the decrease of the blue emission is due to the decrease of the reflectivity and degradation of the transparent silicone, and the browning in the silicone was due to the generation of S, Cl element and the increase of O elements. While for the white LEDs with green/red phosphors, the diffusion of [Ca]+ and [Sr]+ and the formation of corresponding hydroxide were detected to be one of the underlying origins, which reduce the light output and the conversion efficiency of phosphors. In addition, except for the generated microcracks and delamination of phosphor layer, which increase the blue light absorption, the decrease of the phosphor conversion efficiency is related to the oxidization of the phosphor's luminescence center Eu2+ ions instead of phosphor thermal quenching.

2. 3 Etching mechanism of lateral porous GaN

Recently, a new type of lateral porous GaN has generated increasing interests because of its excellent thermal, chemical and mechanical stability. However, the etching mechanism and devices based on laterally porous GaN was not explored. In our study, aligned porous arrays were fabricated in the GaN epilayer via a lateral anodic etching technique. Based on different structural and electrical analysis, the formation kinetics of porous GaN was investigated based on the etching current and the pore trajectories. It reveals that the two-stage characteristic of lateral etching, which is initially driven by the avalanche effect, then enter a steady state as a balance between the oxidation and dissolution of GaN at the pore tips. Furthermore, this new type of lateral porous structures have shown a strong potential in energy and optoelectronic applications.

2. 4 Distinguish the Mn occupation in the lattice

GaAs technology has already become a mainstream for integrated circuits. By doping magnetic ions such as Mn, paramagnetic or ferromagnetic semiconductors can also be achieved, which opens up the possibility of using a variety of magnetic spin dependent phenomena in the optoelectronic devices. However, it is very essential to have a proper understanding of the Mn content, compensating defects and hole concentration. In my previous study, the Mn compositions have been studied using different techniques. Furthermore, by combining the SIMs measurement with the Hall Effect measurements, we investigated the intrinsic and extrinsic contributions to the lattice constants of GaMnAs. The results show that Mn interstitial can increase the lattice constant of GaMnAs, and annealing did remove this kind of compensation and reduced the lattice constant, but the intrinsic lattice parameter of GaMnAs is significantly larger than that of GaAs, which is due to the Mn substitutional. This result helped to explain the origin of ferromagnetic and further improve the Curie temperature of GaMnAs ferromagnetic semiconductors.

3. References

[1] https://www.researchgate.net/profile/Lixia_Zhao2