1. Introduction

Since the activation of magnesium (Mg) in p-type gallium nitride (GaN) [1,2], striking progress has been made in III-nitride materials in terms of properties, growth, and applications [3]. Nowadays, aluminum nitride (AlN) epitaxially grown on nano-patterned AlN/sapphire template has a lower dislocation density as low as $3.3 \times 10^4 \text{ cm}^{-2}$ [4–6]. The behavior of impurities such as carbon in GaN has also been thoroughly investigated [7]. Recently, methods for characterizing the edge dislocation density of a thin film [8] or the interface roughness of multiple quantum wells (MQWs) or superlattice structures have also been further developed [9]. In addition, the light emission mechanisms of InGaN have also been investigated through the clarification of localized states [10] and the direct observation of carrier transportation between different localized states [11,12]. Some mechanisms still need to be unveiled, such as the abnormal enhancement of photoluminescence (PL) intensity in the mid-temperature range of InGaN materials during the temperature-dependent photoluminescence (TDPL) measurement [13–18].

Due to their high luminous efficiency and widely tunable bandgap, InGaN light-emitting diodes (LEDs) have permeated our daily lives. The properties of InGaN LEDs are still being improved, such as the light-output power, the lower leakage current, the efficiency of green, yellow, orange, red, and ultraviolet LEDs, etc. [19–27]. The external quantum efficiency (EQE) of InGaN blue LEDs is over 80% [28], while that of green ones surpasses 50% [29,30]. Great breakthroughs are also made in the “green gap” range [31]. Novel treatments of the quantum barrier have also rendered thrilling properties [32–35]. Single-chip white light has also been investigated [36]. In recent years, with their merits of high brightness, fast response, and high resolution, microLEDs have played an important role in next-generation displays such as augmented reality, full-color matrix automotive lamps, pico-projectors, etc. [30,37–42]. The EQE of InGaN red microLEDs has already reached 7.4%, demonstrating promise for application soon [43,44]. Blue and green InGaN lasers have also achieved inspiring performances [45,46]. Photonic integrated circuits with lower power consumption may alleviate the heat dissipation problem in computers. Microdisk lasers are promising light sources in photonic integrated circuits [47]. The threshold, quality, and other properties are gradually being improved [47–52].

Owing to the polarization effect, two-dimensional electron gas (2DEG) can be generated adjacent to the AlGaN/GaN interface, thus facilitating the development of high-electron-mobility transistors (HEMTs) [53]. The enhancement-mode (i.e., normally off) GaN HEMT has been demonstrated by fluoride-based plasma treatment for the first time [54]. Nowadays, the p-GaN gate is more commonly used to obtain enhancement-mode GaN HEMTs [55]. At present, p-channel GaN field effect transistors (FETs) are attracting attention, with potential in fabricating GaN-based complementary integrated circuits [56–59].

Benefiting from the inverted polarization field, N-polar GaN may surmount the bottlenecks faced by their incumbent Ga-polar counterparts [60,61]. Achievements have been made in the metal–organic chemical vapor deposition (MOCVD) growth of N-polar GaN [62–66]. Additionally, HEMTs based on N-polar GaN have exhibited transcendental performance in some aspects [67–69].
This Special Issue has collected recent research focused on the properties, growth, and applications of III-nitride materials. It contains ten articles and two reviews, which will be briefly described in the following paragraphs.

2. An Overview of Published Articles

Li et al.’s article (contribution 1) used an intelligent algorithm to investigate the light extraction surface structure for deep-ultraviolet LEDs (DUV-LEDs). As a result, compared to conventional structures, the optimized truncated pyramid array (TPA) and truncated cone array (TCA) structures enhanced the light extraction efficiency (LEE) of the DUV LED with an emission wavelength of 280 nm by 221% and 257%, respectively.

Chen et al. (contribution 2) investigated the surface evolution and emission properties of InGaN/GaN MQWs with different ammonia flow rates by MOCVD. Different ammonia flow rates led to different temperature-dependent photoluminescence (TDPL) behaviors. Combined with atomic force microscopy (AFM), the underlying mechanisms were investigated in detail.

The third article (contribution 3) was composed by Tian et al., who investigated GaN/MoS\(_2\) heterostructures by first-principles calculations. The heterojunctions of N-polarity GaN/MoS\(_2\) and Ga-polarity GaN/MoS\(_2\) are compared from the binding energy. A type-II energy band alignment occurs between both the Ga-polarity and N-polarity GaN/MoS\(_2\) polar heterojunctions, although the directions of the built-in electric field are opposite. Moreover, the energy band alignment could change from type II to type I by exerting in-plane biaxial strains on GaN/MoS\(_2\) heterostructures.

The fourth article (contribution 4) by N’Dohi et al. investigated the physical and electrical properties of vertical GaN Schottky diodes. The correlation between the reverse leakage current and doping, as well as dislocations, was investigated.

Zhang et al. (contribution 5) fabricated a normally off p-GaN gate HEMT with an air-bridge source connection. The as-fabricated HEMT exhibited an on-resistance as low as 36 \(\Omega\) \(\cdot\) m, a threshold voltage of 1.8 V, a maximum drain current of 240 mA/mm, and a breakdown voltage of 715 V.

In the sixth article (contribution 6), Guo et al. quantitatively analyzed the relationship between carrier energy and the potential height to be surmounted in the GaAs/InGaAs MQW structure by considering the Heisenberg uncertainty principle. Pump–probe technology is adopted to determine the lifetime of the photo-generated carriers under short circuit (SC) and open circuit (OC) conditions.

Liu et al. (contribution 7) employed plasma-enhanced atomic layer deposition (PEALD) to grow aluminum nitride (AlN) thin films on Si (100), Si (111), and c-plane sapphire substrates at a low temperature of 250 °C. The as-grown polycrystalline AlN thin films had a hexagonal wurtzite structure with a preferred c-axis orientation regardless of the substrate. The surface morphology and refractive index were compared between the three samples and the mechanisms behind it were discussed.

Mukhopadhyay et al. (contribution 8) reported a crack-free AlGaN/AlN/GaN HEMT structure with a high aluminum composition (>35%) and thick barrier (>30 nm) grown on sapphire substrate. It exhibited ultra-low sheet resistivity (<250 \(\Omega/\square\)). The optimized growth conditions were detailed. The density of 2DEG was as high as \(1.46 \times 10^{13}\) cm\(^{-2}\) and the mobility reached 1710 cm\(^2\)/V\(\cdot\)s at room temperature.

The ninth article (contribution 9) also comes from Mukhopadhyay et al., who prepared carbon-doped semi-insulating N-polar GaN on a sapphire substrate through a propane precursor. As N-polar GaN usually contains more oxygen than its Ga-polar counterparts, thus resulting in a high unintentionally doped electron concentration, this work provides a feasible method to grow semi-insulating N-polar GaN.

In Zhang et al.’s article (contribution 10), InGaN-based red microLEDs (\(\mu\)LEDs) of different sizes were prepared. The KOH wet treatment was investigated to alleviate the surface damage to sidewalls after dry etching. It could significantly inhibit the surface non-
radiative recombination processes, thus enhancing the optical and electrical performances of the 5 µm µLEDs.

Han et al. (contribution 10) reviewed the research progress and development prospects of enhanced GaN HEMTs. The importance and merits of Si-based GaN HEMTs were illustrated. The MOCVD growth technology, HEMT structures, reliability, and CMOS compatibility were delineated and compared. Future development directions were also envisioned.

The twelfth text is also a review by Jafar et al. (contribution 12) on the growth conditions and EQEs of InGaN LEDs. The challenges of InGaN growth were reviewed. The mechanisms behind the efficiency droop were analyzed. Furthermore, novel approaches to improve the EQE were also discussed.

3. Conclusions

This compilation of articles is devoted to the growth, device fabrication, and theoretical calculations of III-nitride materials and structures. DUV LEDs, green lasers, red microLEDs, HEMTs, the low-temperature growth of III-nitride by PEALD, N-polar GaN, the heterostructure of GaN/MoS$_2$, vertical GaN Schottky diodes, and the mechanism of carrier transportation in multiple quantum wells are investigated by researchers globally. All the studies are important issues in the realm of III-nitride materials and applications. We hope the methods and results in this Special Issue will promote the exploration of III-nitride materials and applications, which keep providing discoveries that will change our daily lives.

Conflicts of Interest: The author declares no conflicts of interest.

List of Contributions


29. Lv, Q.; Liu, J.; Mo, C.; Zhang, J.; Wu, X.; Wu, Q.; Jiang, F. Realization of Highly Efficient InGaN Green LEDs with Sandwich-like Multiple Quantum Well Structure: Role of Enhanced Interverrrier Carrier Transport. ACS Photonics 2018, 6, 130–138. [CrossRef]


