

High-Efficiency Ultraviolet Emission from AlInN/GaN Nanowires Grown by Molecular Beam Epitaxy

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Abstract: The epitaxial growth and characterization of AlInN/GaN core-shell nanowire structures with highly stable emission and high internal quantum efficiency of ~52% in the ultraviolet wavelength range are presented.

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1. Introduction

III-nitride based ultraviolet (UV) emitters have been intensively studied for applications in biological, medical and communication. Until recently, fundamental and applied research approaches for light-emitters, have essentially focused on the use of InGaN and AlGaN alloys in the active region for near UV [1,2] and UV photonic devices working in the spectrum below 350nm, respectively. However, the approach of using different III-nitride compounds for UV emission is relatively unexplored. Moreover, the performance of conventional AlGaN-based planar deep UV LEDs suffers severely from the presence of large dislocation densities and polarization fields. Identifying and developing the potential of alternative UV materials will be critical to make further progress in deep UV emitters. In this regard, $\text{Al}_x\text{In}_{1-x}\text{N}$ alloy has not been widely studied even though it holds high potential application in UV and visible light-emitting devices. The AlInN growth difficulties have resulted from: (1) extremely large differences in optimal growth temperatures for InN (~ 450°C) and AlN (~ 800°C), and (2) remarkable differences in pressures required to stabilize the crystal surface against decomposition. Additionally, large difference in lattice parameters and covalent bond strengths between InN and AlN lead to phase separation and composition inhomogeneity [3]. Additionally, inefficient *p*-type doping in AlInN also strongly affects the electrical properties of the related devices. Such difficulties result in the low crystalline quality and low device performances. In this context, we have performed a detailed investigation of the growth mechanism, structural and optical properties of catalyst-free $\text{Al}_x\text{In}_{1-x}\text{N}$ nanowires grown on Si (111) substrate by plasma-assisted molecular beam epitaxy (PAMBE). An AlN shell is spontaneously formed during the growth of AlInN epi-layer which can lead to drastically reduced nonradiative surface recombination. By controlling the Al/In compositions in the AlInN active region, the emission wavelength can be varied from 290 nm to 350 nm.

2. Epitaxial Growth and Characterization of AlInN Nanowires

Vertically aligned self-organized AlInN/GaN heterostructures were grown on Si(111) substrates by PAMBE. Illustrated in Figure 1(a), GaN template was first grown on Si substrate to facilitate the formation of AlInN segment. The growth conditions of GaN nanowires include a growth temperature of 770 °C, with a nitrogen flow rate of 1.0 sccm, a forward plasma power of 400 W, and Ga beam equivalent pressure of 6×10^{-8} Torr. To achieve

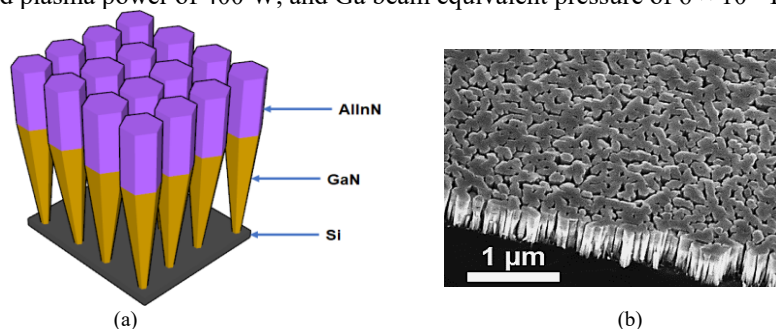


Fig.1. (a) Schematic diagram of AlInN nanowires on GaN template. (b) 45° tilted scanning electron microscope (SEM) image of AlInN nanowire LED sample grown on Si(111) substrate.

UV light emission, self-organized AlInN segments were subsequently grown on top of GaN nanowires. The In composition in the active region can be well controlled by varying the In and Al beam flux and/or the substrate temperature. The growth temperature of AlInN active regions was varied to enhance the In incorporation which is controlled in between 680 °C to 720 °C. During the epitaxial growth of AlInN segments, the nitrogen flow rate and plasma power were kept of 3.0 sccm and 400 W, respectively. Structural properties of the AlInN nanowires were characterized by scanning electron microscopy (SEM). Shown in Fig. 1(b), nanowires are relatively uniform and vertically aligned to the substrates. The wire diameter increases from GaN segment to AlInN portion and remains constant at the top of nanowire which is similar to our reported studies on InGa_N, and AlGa_N nanowires [4,5]. Moreover, it is also suggested that a core-shell AlInN/GaN structure is spontaneously formed during the epitaxial growth of AlInN layer.

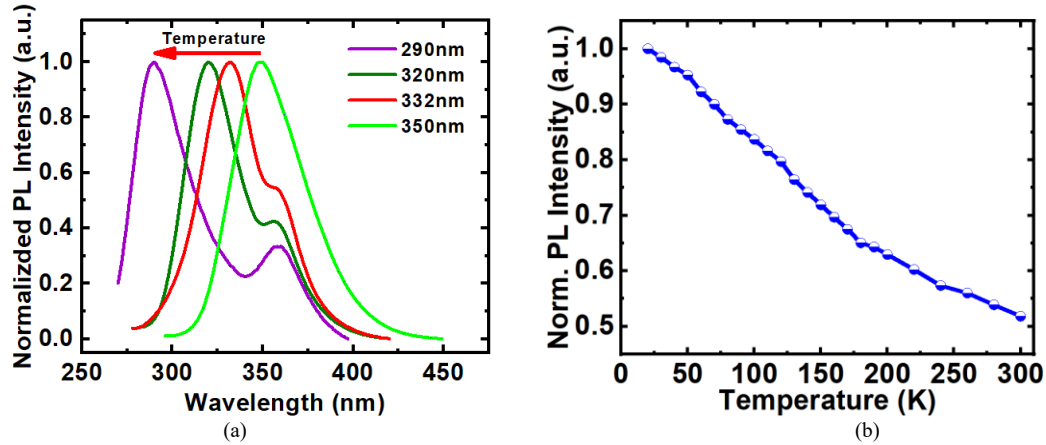


Fig.2. (a) Normalized PL spectra. (b) Temperature dependent photoluminescence intensity of AlInN/GaN nanowires on Si(111) substrate.

Photoluminescence (PL) spectra of AlInN nanowire on GaN templates were measured using a 266 nm diode-pumped solid-state laser as the excitation source at room-temperature. The PL emission was spectrally resolved by a high-resolution spectrometer and detected by a photomultiplier tube. Fig. 2(a) shows the PL spectra of different AlInN/GaN nanowire structures which were grown at different growth conditions. It is clearly shown that the peak emissions vary from 290nm to 350nm by varying the Al composition in the AlInN layers. The peak emission is shifted to shorter wavelength when the substrate temperature gets increase which is attributed to the increased In adatom desorption at higher growth temperature, resulted in the reduced In composition in the AlInN segment. The optical properties of those AlInN/GaN nanowires were further characterized at different temperatures varying from 20K to 300K using liquid Helium to estimate their internal quantum efficiency (IQE). Shown in Fig. 2(b), the AlInN/GaN nanowire exhibits relatively high IQE which is estimated of ~ 52% at room temperature. The IQE is calculated by comparing the PL intensity at room temperature and 20K, assuming the IQE at 20K is near unity.

3. Conclusion

In summary, we have successfully grown high efficiency AlInN/GaN core-shell nanowire structures with strong emission from 290 nm to 350 nm. The UV nanowire emitters exhibit relatively high IQE of ~ 52% at room temperature. Such high-quality nanowires are suitable for fabricating high performance UV LEDs operating in the deep UV regime. The achievement of high efficiency AlInN/GaN nanowires and their related device applications are being developed and will be presented.

4. References

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