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Nanoarchitecture Light Emitting Diode Microarrays Using Position-Controlled GaN/ZnO Coaxial Nanotube Heterostructures

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1. Introduction

Bottom-up approaches based on a nanometer-scale epitaxy have enabled the fabrication of high-quality materials without problems in material compatibility between the film and the substrate for the top-down approach [1]. In particular, one-dimensional nanomaterial heterostructures can provide the versatility and power of designing numerous quantum structures for optoelectronic nanodevice applications such as light emitting diodes (LEDs). Despite the successful demonstration of nanometer scale LEDs based on the bottom-up method, the practical use of individual nanowire LEDs has still remained out of reach because of difficulties in manipulating and positioning individual nanostructures [2]. To address this problem, a demand has arisen for precise controls of positions and dimensions during nanostructure growth.

Position-controlled nanoarchitecture arrays with numerous quantum structures can be very useful for many device applications, especially for LED microarrays. These nanoarchitecture arrays enable us to take advantage of accurately controlling positions, thicknesses, and compositions of quantum structures embedded in the nanoarchitectures, all of which may be useful for fabricating integrated optoelectronic devices and high-brightness LEDs. Here, we report the fabrication and describe the electroluminescent characteristics of nanoarchitecture LED microarrays using position-controlled and vertically-aligned GaN/ZnO coaxial nanotube heterostructure arrays.

2. Results and Discussions

As shown in Fig. 1(a), nanoarchitecture LED microarrays consist of GaN-based *p–n* homojunction heterostructures with GaN/$In_{1-x}Ga_xN$ multi-quantum well (MQW) structures, which are coaxially coated on the entire surface of ZnO nanotube arrays [3]. To fabricate nanoarchitecture LED microarrays, position-controlled ZnO nanotube arrays with good vertical alignment were first prepared by the catalyst-free metal-organic vapor phase epitaxy (MOVPE) method [4]. After the preparation of ZnO nanotubes, a Si-doped *n*-GaN thin layer was heteroepitaxially grown on the ZnO nanotube arrays. Following the *n*-GaN layer coating, three-period GaN/$In_{0.24}Ga_{0.76}N$ MQWs with a 2-nm-thick well and 13-nm-thick barrier layers were grown at 720°C and 820°C, respectively. Subsequently, an Mg-doped *p*-GaN layer with a thickness of 120 nm was deposited on top of the last GaN quantum barrier at 950°C using a commercial nitride MOVPE system. As shown in Fig. 1(b), then, LED devices were fabricated by making ohmic contacts on both the *p*-GaN surface and the heavily-doped *n*-GaN seed layer, where the gaps between individual nanoarchitectures were filled with a spin-on-glass layer to isolate two metal electrodes.

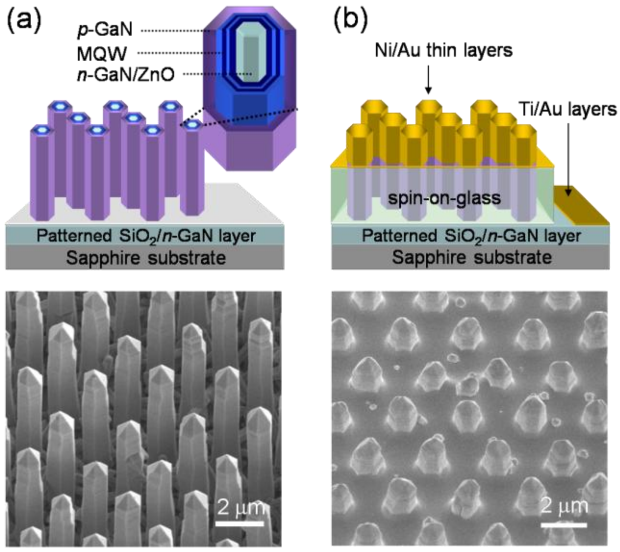

Fig. 1 Schematics and corresponding SEM images for (a) GaN/$In_{1-x}Ga_xN$/GaN/ZnO *p–n* homojunction coaxial nanoarchitecture heterostructure arrays and (b) nanoarchitecture LED microarrays.

As shown in Fig. 2, the nanoarchitecture LED microarrays exhibited strong green and blue emission from individual nanoarchitecture LEDs upon increasing the applied current. Although some local areas did not emit light, presumably due to failure of the contact layers, nearly the entire patterned area of the nanoarchitecture LED microarrays clearly emitted light. In addition, the light emission was so strong that it was clearly observed with the unaided eyes even under normal room-illumination.

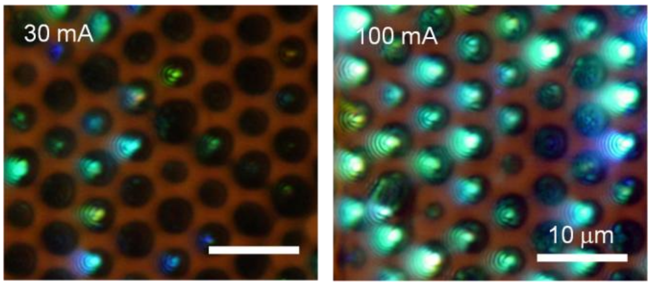

Fig. 2. Photographs of light emissions from nanoarchitecture LED microarrays at an applied current of 30 and 100 mA.

The origin of light emission was investigated by measuring the EL spectra at various applied current levels in Fig. 3(a). It clearly exhibited a dominant peak centered at 2.45 eV and a shoulder around 2.85 eV. Since we expected to observe the green emission from the MQW thickness and composition, the EL peak at 2.45 eV results from $In_{0.24}Ga_{0.76}N$/GaN MQWs. However, a broad shoulder observed at 2.8–2.9 eV results presumably from non-uniform thickness of the well layers deposited on the sidewalls of nanorods. In addition to the EL characteristics, the electrical characteristics of the nanoarchitecture LEDs were also measured as shown in Fig. 3(b). It showed typical rectifying behavior with a turn-on voltage of ~ 3 V and a leakage current of ~ 5×10^{-4} A at –4 V.

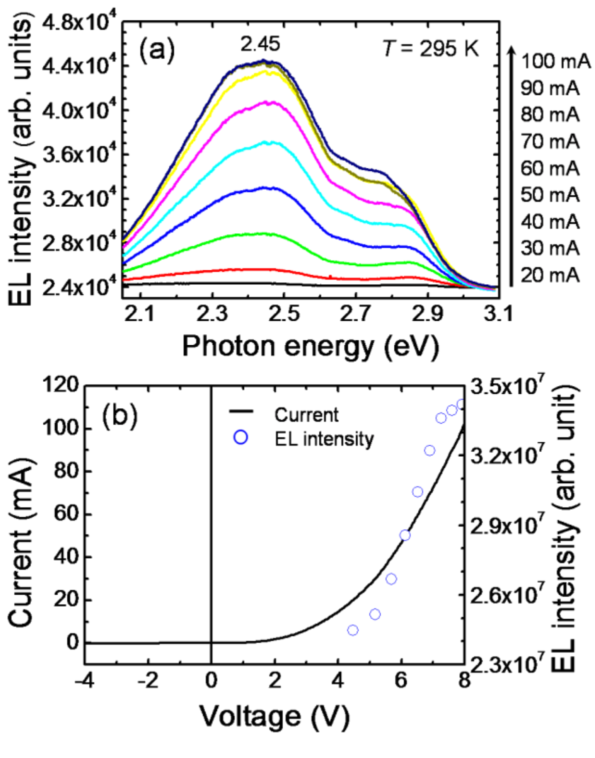

Fig. 3. (a) Electroluminescence spectra of nanoarchitecture LED microarrays at various applied current levels. (b) Current and integrated EL intensity as a function of applied voltage.

3. Conclusions

GaN-based nanoarchitecture LED microarrays were successfully demonstrated using position-controlled GaN/ZnO coaxial nanotube heterostructure arrays. The strong emissions from nanoarchitecture LED microarrays originated from individual nanoarchitectures in the green and blue visible range when a forward bias voltage was applied. Accordingly, from EL spectra, dominant emission peak were observed at 2.45 eV from GaN/$In_{1-x}Ga_xN$ MQWs. We believe that position-controlled nanoarchitecture heterostructures can be employed in the fabrication of many other optoelectronic devices, including laser diodes and solar cells.

Acknowledgements

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