



Optical and microstructural properties of InGaN/GaN multiple quantum wells with embedded graphene coating



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ABSTRACT

We investigate the effects of embedded graphene coating on the optical and microstructural properties of ultrathin InGaN/GaN multiple quantum wells (MQWs). The InGaN/GaN MQWs grown on graphene-buffered GaN templates displayed enhanced internal quantum efficiency compared to conventional ones and showed the internal electric field effect-free characteristic, desirable for general lighting applications. These phenomena were attributed to the enhancement of potential fluctuation with increased indium content and negligible piezoelectric polarization in ultrathin InGaN QWs, respectively. It was found that the atomically rough surface of GaN induced by embedded graphene coating efficiently relieved the biaxial compressive strain in the ultrathin InGaN/GaN QWs and enhanced the In incorporation efficiency during the InGaN growth, suggesting the potential use of atomic-thick carbon layer in niche optoelectronic applications.

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1. Introduction

For the last decades, full color light sources based on III-N semiconductor light-emitting diodes (LEDs) have attracted great interest as highly energy-efficient and environmentally stable lighting technologies [1–3]. Although the development of epitaxial growth techniques such as molecular beam epitaxy and metal-organic chemical vapor deposition (MOCVD) has enabled the growth of single-crystalline III-N thin-films with excellent performance for optoelectronic device applications; however, the applications of III-N LEDs toward general lighting requires even higher brightness and efficiency [4,5]. Currently, state-of-the-art III-Ns technology has been focused on the III-N thin-film growth on a c-

plane sapphire (c-sapphire) substrate using a conventional two-step growth method in a MOCVD reactor, which employs about 20-to-30-nm-thick, low-temperature (LT)-grown (Ga,Al)N buffer layers before the growth of GaN epitaxial layers at high temperatures [2,3]. It is well known that the nitride buffer growth condition has a deterministic effect on the structural and optoelectronic properties of the subsequent GaN epitaxial layers as well as active InGaN/GaN quantum wells (QWs). Generally, the heteroepitaxy of III-Ns on c-sapphire leads to strained epilayers originating from considerable differences in in-plane lattice and thermal mismatches between III-Ns and c-sapphire. This biaxial stress is responsible for the generation of high density threading dislocation or piezoelectric polarization in the subsequent InGaN/GaN QWs [6–8]. This polarization-induced, built-in piezoelectric field causes the spatial separation of electron and hole wave-functions within QWs, resulting in a red-shift of emission wavelength as well as a significant diminution of radiative recombination efficiency [8–11]. Therefore, the control of strain/stress relaxation in III-N epilayers is one of the effective approaches to obtain efficient solid-state light emitters with reduced defect density. To overcome this issue, many

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approaches such as lateral epitaxial overgrowth, introduction of nanoporous or patterned substrate, and so forth were proposed [12–15]; however, those approaches resulted in process complexity as well as cost increases owing to the compulsory photolithography and subsequent complicated processes. Thus, one promising method to overcome this problem would be to develop an alternative buffer layer with a high functionality that could enable the growth of high-quality III-Ns epilayers and simplify the subsequent growth/fabrication process.

Graphene (Gr) - a two-dimensional (2D) atomic crystal of carbon - has excellent physical and chemical properties such as mechanical strength, chemical and thermal stabilities, large surface area, and is inherently impermeable to almost all atoms and molecules [16–24]. Furthermore, a single layer of graphene exhibits approximately 2.3% light absorption [25] and offers excellent electrical and thermal conductivities due to its 2D electron gas properties at room temperature (RT) [17,22,26]. These functional attributes synergistically allow Gr-based heterostructures to exhibit unique and enhanced properties and are expected to have numerous niche applications in high-growth markets including semiconductors, photovoltaics, and LEDs in the near future [18,20–22]. In these industries, there has been increasing

demand for carbon with greater stability and enhanced, uniform properties. Thus graphene can serve as a key functional coating for III-Ns. In our earlier study [18], we reported that the use of graphene as a coating layer allows one-step growth of heteroepitaxial GaN films on c-sapphire in a MOCVD reactor, simplifying the GaN growth process. To modify the surface morphology and enhance the wetting property of graphene for GaN nucleation, we employed diffusion-assisted synthesis (DAS) method to grow nanocrystalline graphene [27,28]. We found that the wetting between GaN and c-sapphire can be greatly altered by graphene coating and the overgrown GaN layer on c-sapphire becomes continuous and flat, with as little as ~0.6 nm of graphene coating. Under optimized growth condition, one-step GaN films showed highly desirable structural and optical properties, suitable for 'pseudo-substrates' in III-N LED epilayer structure [18].

In this article, we systemically investigated the effects of embedded graphene coating on the optical and microstructural properties of III-N LED epilayer structure including ultrathin InGaN/GaN multiple QWs (MQWs). The InGaN/GaN MQW structures grown on a Gr-buffered GaN template exhibited improved internal quantum efficiency (~55%) compared to conventional ones (~30%) and internal electric field effect-free characteristic from

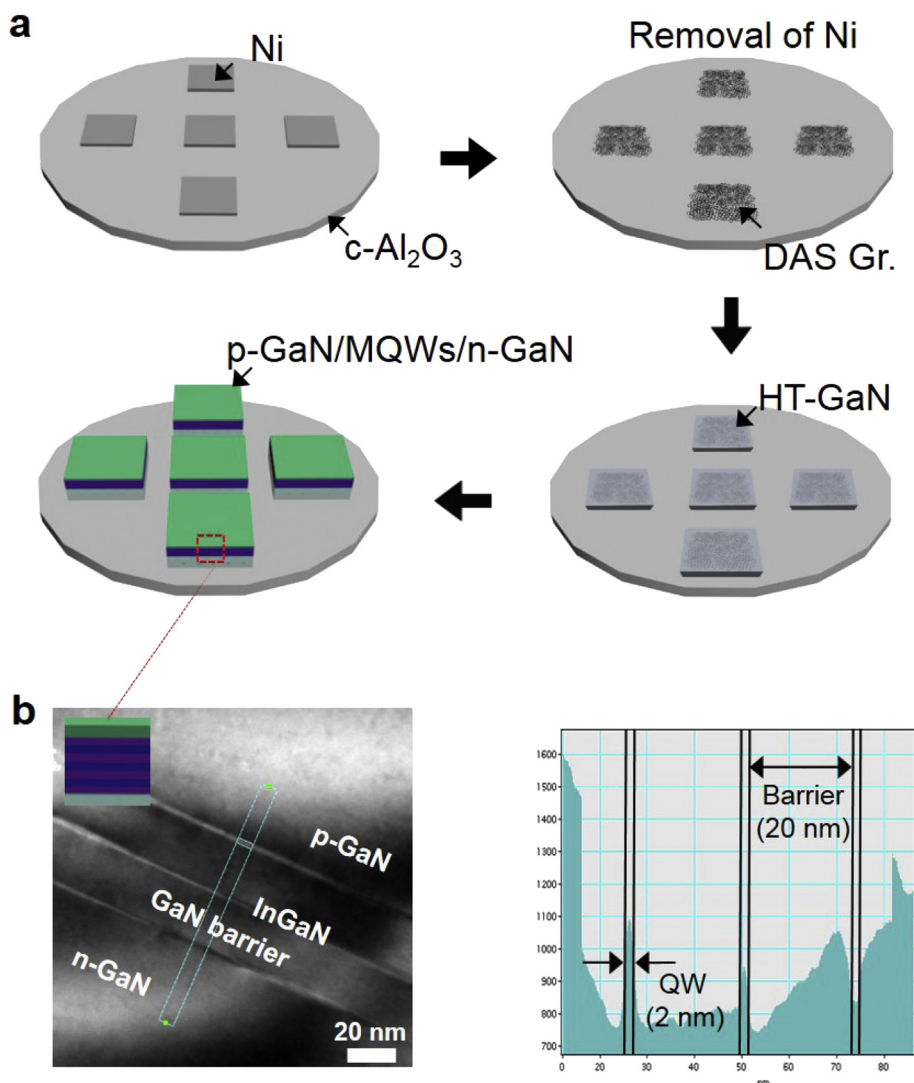


Fig. 1. (a) Scheme of patterned growth of III-N LED epilayer structure with embedded graphene coating layer, (b) Cross-sectional, bright-field HRTEM image of III-N LED epilayer structure (p-GaN/InGaN MQWs/n-GaN) and its corresponding depth profile in InGaN/GaN MQW region.

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