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Progress in Nonpolar and Semipolar GaN-base Materials and Devices

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1. Introduction

Devices grown on *c*-plane GaN suffer from large internal electric fields due to discontinuities in spontaneous and piezoelectric polarization effects which cause charge separation between holes and electrons in quantum wells and limits the radiative recombination efficiency. Nonpolar GaN devices, such as in the nonpolar (NP) *m*-plane $(1\underline{1}00)$, are free from polarization related electric fields since the polar *c*-axis is parallel to any heterointerfaces. Semipolar (SP) GaN-based devices have reduced electric fields and in some cases, such as $(11\underline{2}2)$, show a high propensity for Indium update for InGaN quantum wells. New SP orientations such as $(20\underline{2}1)$ show remarkable promise for long wavelength LEDs and laser diodes.

In this presentation, we review progress in nonpolar and semipolar emitters and highlight recent work on high polarization ratios in long wavelength m-plane LEDs; progress in light preserving polarized emission with embedded photonic crystals; strain relaxation in SP structures; and new promising results on new semipolar orientations.

2. Overview

In this talk, we present work on outstanding materials issues in nonpolar and semipolar growth and device technology. The work is the result of nearly a decade of highly collaborative research at UCSB between the Speck, DenBaars, Nakamura, Mishra and Weisbuch groups that ranges from fundamental materials studies to solid state physics to device design, growth, and process development.

Materials

NP and SP nitride-based materials offer a remarkable range of opportunities and challenges – many are unique from the materials issues encountered in c-plane structures. As an example, substrate miscut is an important parameter to control growth mode and morphology. Through systematic studies, we have shown that m-plane growth morphology, and concomitant device performance, can be controlled by intentional miscut [1,2].

In planar c-plane heterostructures, the most likely planes for dislocation glide, namely the (0001) basal plane and the $\{1\underline{1}00\}$ prism plane have no resolved shear stress. In contrast, in SP heterostructures, the basal plane can have significant shear stresses. We show new results for dislocation-related strain relaxation in semipolar GaN-based heterostructures [3,4,5] and discuss the implications on growth of fully coherent SP device structures and the potential for the development of metamorphic SP buffer layers.

Solid State Physics

By symmetry, the maximum polarization discontinuity should be for c-plane heterostructures and zero for NP heterostructures. In SP heterostructures, based on fundamental solid mechanics calculations with the best available elastic, polarization, and piezoelectric constants, we predicted a cross-over in the polarization discontinuity for SP samples oriented ~45° for the c-plane [6]. Our collaborators at the Army Research Laboratory have shown unambiguous determination of the polarization cross-over in specially-designed and grown single quantum well semipolar InGaN/GaN LEDs and determined the magnitude of the polarization-related electric field in the QW [7]. Atom probe tomography on the same samples show no evidence of indium clustering [8].

Devices

InGaN QWs, when grown in NP and SP orientations have a significantly modified valence band (VB) structure. In c-plane InGaN QWs the top two nearly degenerate VBs have |X> and |Y> symmetry at the Γ-point and a split off band with |Z> symmetry. The reduced symmetry of NP and SP orientations, combined with biaxial stress in the QWs causes a re-ordering of the VBs such that the top VB has |X> symmetry, the middle VB has |Z> symmetry, and the bottom VB has |Y> symmetry. The conduction band (CB), which corresponds to metal s-like states, has isotropic symmetry. Thus, radiative interband transitions near the Γ-point can be treated as emission from classic dipoles with the symmetry of the VB. For NP and SP orientations, this gives rise to the potential for polarized emission. We review our work on polarized emission from planar m-plane LEDs and demonstrate polarized light emission ratios as high as 96% at 520 nm [9]. Recently, we have developed embedded photonic crystal (PhC) technology for our m-plane LEDs and shown that the embedded PhCs are high effective internal diffraction gratings that preserve the polarized nature of the light emission [10].

Finally, we update progress on NP and SP LEDs and LDs including the achievement of high performance true blue (λ >450 nm) and true green (λ >515 nm) lasers on m-plane and semipolar (namely, $(20\underline{2}1)$) GaN substrates [11,12]. Finally, we will present recent work on promising new SP planes that show low droop, narrow emission widths, and highly polarized emission [13].

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Appendix

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