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Molecular Beam Epitaxy of Graded-Composition InGaN Nanowires

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We report the growth of graded InGaN nanowires by plasma-assisted molecular beam epitaxy. Wire composition is linearly graded from InN to GaN along the length of each wire. The large lattice mismatch between GaN and InN (11%) introduces tensile strain in the graded region, which results in cracking of the wires. Growing with reverse grading (i.e., GaN to InN) results in crack-free nanowires. The composition is measured by energy-dispersive x-ray spectroscopy of individual nanowires performed in a scanning transmission electron microscope, and strain is measured by high-resolution x-ray diffraction.

Key words: InGaN, nanowires, composition gradient, strain relaxation, nitrides, molecular beam epitaxy

INTRODUCTION

Within the family of group III nitrides, $In_xGa_{1-x}N$ is an attractive alloy for its direct and tunable bandgap from 3.4 eV (GaN) to 0.65 eV (InN). Since it covers most of the solar spectrum, InGaN is a promising candidate for high-efficiency solar cells and green emitter applications.[1–5] To maximize solar cell or photodetector performance, light must be absorbed in the active region of the device and then photogenerated carriers in the active region should be collected efficiently before they recombine. A typical active region consists of a single-composition semiconductor, which absorbs light above its bandgap energy. An active region of compositionally graded InGaN (i.e., varying In composition from 100% to 0%) will have a varying direct bandgap and therefore will strongly absorb photons over a broadband region from 1700 nm to 365 nm. Additionally, band-structure calculations for a graded active region show that the changing bandgap gives rise to a large quasi-electric field ($\sim 10^5$ V/cm) that can separate and drift photogenerated electrons and holes faster than their recombination lifetime.[6] However, the large lattice mismatch between GaN and InN (11%) prohibits compositionally graded thin films of InGaN without incorporating strain-related extended defects such as misfit and threading dislocations. To avoid this problem graded InGaN nanowires can be used due to strain relaxation by surface compliance.[7–9] To the best of our knowledge, there are no reports of intentionally graded-composition InGaN nanowire structures. Here we describe the growth and structural characterization of compositionally graded InGaN nanowires over the entire alloy range.

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EXPERIMENTAL PROCEDURES

All samples were grown by plasma-assisted molecular beam epitaxy (PAMBE) using a Veeco 930 system with background pressure of 10^{-11} Torr. Nanowires grew vertically from the substrate and along the [0001] direction of the wurtzite crystal axis in a self-assembled, catalyst-free growth mechanism.[10–16] Details concerning growth conditions and how system parameters were calibrated can be found in previously published work.[17] All nanowires were grown on Si(111) substrates. The native oxide was