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Si Doping of GaN in Hydride Vapor-Phase Epitaxy

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Growth of GaN boules by hydride vapor-phase epitaxy (HVPE) is very attractive for fabrication of GaN substrates. Use of dichlorosilane as a source for Si doping of bulk GaN is investigated. It is shown that no tensile strain is incorporated into mm-thick, Si-doped GaN layers on sapphire substrates if the threading dislocation density is previously reduced to 2.5×10^{7} cm^{-2} or below. High-quality GaN layers with electron densities up to 1.5×10^{19} cm^{-3} have been achieved, and an upper limit of about 4×10^{19} cm^{-3} for Si doping of GaN boules was deduced considering the evolution of dislocations with thickness. A 2-inch, Si-doped GaN crystal with length exceeding 6 mm and targeted Si doping of about 1×10^{18} cm^{-3} is demonstrated.

Key words: HVPE, GaN, bulk, Si doping, defects, strain

INTRODUCTION

There is a great need for suitable substrates for fabrication of current group III nitride devices such as violet–blue laser diodes (LDs) and white light-emitting diodes (LEDs) as well as for realization of, e.g., green LDs and high-brightness LEDs with high performance or other future device concepts.[1] Such substrates should allow for epitaxial growth of differently oriented device layer structures with low defect densities, i.e., threading dislocation density (TDD) below 10^{6} cm^{-2} and negligible stacking fault density (SFD). It has been shown that appropriate native GaN substrates with high quality can be obtained by cutting and subsequent polishing of slices from thick GaN crystals grown by hydride vapor-phase epitaxy (HVPE).[2,3] For optoelectronic applications, a sufficiently high *n*-type conductivity and high transparency of the substrates are also desired. The most commonly used donor dopant in epitaxy of III–V compounds is silicon. However, it has been observed that use of Si for doping is accompanied by incorporation of tensile strain and hence reduced critical layer thickness for crack formation during epitaxial growth of GaN layers.[4–6] Early explanations suggested point defects[4,7] or coalescence of crystallites at the growth front[6] as the reason for the observed tensile strain, because the size difference between dopant and host atoms was found to be small. A breakthrough was achieved in terms of a quantitative model that explained the reduction of compressive strain in Si-doped $Al_xGa_{1-x}N$ layers by inclination of edge dislocations, referred to as an "effective climb" mechanism.[8] However, the underlying mechanism at the growing surface, i.e., either silicon nitride micromasking of dislocation cores[9] or Fermi-level-induced formation of vacancy jogs attached to dislocation cores,[10] is still under controversial debate. Even recently, focusing on GaN layers with high TDD, contradicting statements have been published which propose Ge as a beneficial *n*-type dopant to circumvent tensile strain[11] or not.[12] However, avoiding incorporation of tensile strain and the resulting crack formation is essential for boule-like growth of GaN in HVPE. Use of elemental silicon,[13] dichlorosilane (DCS),[14–16] and more recently $GeCl_4$[16] has been reported for successful *n*-type doping of GaN layers grown by HVPE. The aim of this study is to determine whether Si is a suitable dopant for boule-like HVPE growth of GaN of several mm length at high growth rates exceeding 300 μm/h starting on GaN/sapphire templates.[17] Taking into account that the amount of tensile strain increases with the Si concentration as well as with the TDD,[8–10] the idea

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