High Quality AlN and GaN Grown on Compliant Si/SiC Substrates by Gas Source Molecular Beam Epitaxy

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Epitaxial layers of AlN and GaN were grown by gas source molecular-beam epitaxy on a composite substrate consisting of a thin (250 nm) layer of silicon (111) bonded to a polycrystalline SiC substrate. Two dimensional growth modes of AlN and GaN were observed. We show that the plastic deformation of the thin Si layer results in initial relaxation of the AlN buffer layer and thus eliminates cracking of the epitaxial layer of GaN. Raman, x-ray diffraction, and cathodoluminescence measurements confirm the wurtzite structure of the GaN epilayer and the c-axis crystal growth orientation. The average stress in the GaN layer is estimated at 320 MPa. This is a factor of two less than the stress reported for HVPE growth on 6H-SiC(0001).

Key words: Si/SiC, substrate, composite, AlN, GaN

INTRODUCTION

One of the problems in the epitaxy of nitrides is the lack of a suitable substrate material on which lattice-matched group III-nitride films can be grown. The large lattice mismatch of most of the available substrates leads to high interfacial strain between the substrate and the epitaxial layer, resulting in three-dimensional (3D) growth and formation of misfit dislocations.1 Growth on compliant substrates offers a way of minimizing such interfacial strain.1–6 The idea is to produce a free-standing thin layer by placing the layer on a bulk substrate with frictionless glide on each other.7 There are additional advantages of bonding the compliant layer to a polycrystalline substrate. More specifically, polycrystalline SiC substrate offers an excellent match of thermal expansion coefficient to GaN. Low cost, large diameter polycrystalline SiC substrates are commercially available, offer high thermal conductivity (300 W/m·K), and can be made electrically conducting or insulating (>5000 ohm-cm), an important feature for optical devices and microwave power applications. The concept of a strain-relaxed compliant substrate and the behavior of epitaxial films grown on such substrates are well known.2 However, the influence of the free-standing layer thickness and its plasticity on the subsequent growth of AlN and GaN are still under study.

This work describes preparation of AlN and GaN on a thin (250 nm) Si(111) film that is wafer bonded to a 100 mm diameter polycrystalline SiC substrate. We also discuss the investigation of growth mechanisms, stress relaxation, and optical properties of epitaxial AlN and GaN layers.

EXPERIMENTAL DETAILS

AlN and GaN films were grown by gas source molecular beam epitaxy (GSMBE) with ammonia on a thin (250 nm), chemically-mechanically polished (CMP) silicon (111) layer that was bonded to a polycrystalline SiC substrate. The poly-SiC substrates were polished using the technology developed previously for SiC mirrors, which makes wafer bonding possible.4 Atomic force microscopy (AFM) of the top Si layer shows a RMS roughness of 0.2 nm.

The influence of growth conditions on the structure and homogeneity of the epitaxial layers of AlN and GaN was studied using 10 kV reflection high energy electron diffraction (RHEED), x-ray diffraction (XRD), Raman spectroscopy, and cathodoluminescence (CL).

Ammonia was introduced into the growth chamber through a mass-flow controller operating in the range of 30 sccm. The substrate temperature was measured by a pyrometer, corrected for the emissivity of the
substrate. To increase the substrate heating efficiency Ti and Ni were used to coat the backside of the Si/poly-SiC. Layers of AlN were grown in the temperature range of 860±30°C.9 Layers of GaN were grown at 780±20°C.10

RESULTS AND DISCUSSION

Epitaxial growth of AlN and GaN was performed using growth conditions similar to those described previously for bulk Si(111).9,10–12 Formation of a thin film of AlN was monitored by RHEED. The growth process was carried out at a high temperature (>830°C), where formation of the Al-Si γ-phase is not possible due to the short residence time of Al atoms on Si. The growth was initiated by a brief exposure to NH3. At this point, RHEED showed the presence of an ordered periodic structure on (111)Si, attributed to a strongly bound layer of chemisorbed N. Once the ordered structure was formed, the surface was exposed to the flux of Al. This resulted in the formation of Si-N-Al islands. This step was followed by alternating exposure to Al and ammonia, carried out several times, until a complete surface coverage with the Si-N-Al phase was obtained. After this step, the growth surface was free of amorphous SiNx and epitaxial growth of AlN could be started. The surface periodic order examined by RHEED suggests that the nucleation of AlN occurs in a 2D mode. A typical 1×1 RHEED pattern due to the formation of AlN ordered surface structure is shown in Fig. 1a.

The best growth results were achieved for a NH3/Al flux ratio near unity, in agreement with previous results obtained on bulk Si(111).11 Thin (40 nm) AlN was used as a buffer layer for the subsequent growth of GaN. The initial formation of GaN on AlN layer showed 3D character. This could be explained by the large (~3%) lattice mismatch between GaN and AlN. The transition to 2D growth mode was observed after the growth of at most 10 nm of GaN. Once the 2D growth was reached GaN layers showed 2×2 surface reconstruction, presented in Fig. 1b.

In our experience on bulk Si (111), the strain energy of GaN can be reduced by a defect-blocking superlattice (SL) consisting of two to four pairs of AlxGa1−xN (x = 0.1–0.4) with GaN spacers.10,13 The SL tends to accommodate the strain due to a large difference in thermal expansion coefficients between group-III nitride layers and Si. This strain is responsible for the formation of cracks in thick nitride layers (>0.1 μm). The use of the SL results in complete elimination of cracking in nitride layers thicker than 0.2 μm (see for details Ref. 10). However, in our growth experiments on Si(111)/poly-SiC substrates, the AlGaN/GaN superlattice was not needed. Formation of cracks was not observed for 0.5 μm thick layers of GaN grown on 40 nm thick AlN buffer layers. Such an outcome can be explained by