Title: Investigation of the properties of polycrystalline gallium nitride films prepared by ion beam assisted deposition on flexible polyimide substrates

Abstract

The present work describes the growth and characterization of thin gallium nitride (GaN) layers on thin polyimide substrates in an Ion Beam Assisted Deposition process (IBAD), using nitrogen ions with hyperthermal energies. For that purpose, initially the material systems GaN and polyimide are illuminated, followed by a theoretical introduction to the basic principles of thin film formation. Here, the thermodynamic basics and the kinetic growth model are described as well as the different growth modes and the characteristics of the film formation on polyimide surfaces. In the following, the IBAD process is explained and compared to other common used deposition techniques for GaN layers like Metal Organic Vapour Phase Epitaxy (MOVPE) or conventional Molecular Beam Epitaxy (MBE). Likewise, the experimental setup is illuminated, followed by descriptions of the applied analysis methods Auger Electron Spectrometry (AES), Reflection High Energy Electron Diffraction (RHEED), X-Ray Diffraction (XRD), X-ray Photoelectron Spectrometry (XPS), Energy-Dispersive X-ray Spectroscopy (EDX), Scanning Electron Microscopy (SEM), and Atomic Force Microscopy (AFM).

GaN layers are deposited on thin (25µm) *Kapton* substrates in an IBAD process, under the same conditions as during the deposition on single crystalline substrates (SiC or Si). Only the effusion cell temperature is varied during the deposition. The results investigated with the various analysis methods described before. It shows up that *Kapton* is an appropriate substrate to successfully deposit GaN layers at 350°C substrate temperature. During the deposition *in situ* RHEED measurements are performed. The examination of diffraction patterns allows first statements according growth modes. The GaN films are growing polycrystalline on the PI substrate and have a preferred orientation. Still *in vacuo*, the chemical composition of the GaN surfaces is analysed with AES. The results indicate contaminations on the surface, typical for deposition of thin films in vacuum. Following, EDX investigations are performed to compare the chemical composition of the GaN film surfaces *in situ* and *ex situ*, but show no additional contaminations with foreign elements and a very homogenous distribution of the elements on the surface. In a next step XRD measurements are performed. The results confirm the statement made before. GaN grows in a preferred (0002) orientation in its hexagonal wurtzitic modification. With the FWHM of the (0002) peak the average crystallite size of ca. 30 nm are calculated. The following SEM investigations show a relatively homogeneous and dense GaN film. The layer consists of columnar grown GaN crystallites; this confirms the preferred growth orientation parallel to the hexagonal c-axis. AFM measurements show single GaN crystallites with nearly the same shape and size. With AFM data RMS roughness are calculated and with profile measurements over the surface the calculated crystallite size could be confirmed. To verify if the GaN film is fully closed (without holes or cracks) XPS spectra are used to compare the C 1s signal from Kapton with the C 1s signal from the carbon contaminations on the GaN surface. The investigations show, that the C 1s signal on the surface of the coated samples is only descended from the carbon contaminations and not the substrate. Therefore the GaN forms a closed film on the PI substrate. Finally mechanical properties are quantitatively investigated. At first the thermal induced residual stress caused by different thermal

expansion of GaN and PI is calculated. Afterwards the adhesion of the GaN film on the PI is tested through an adhesive tape. There was no delamination of GaN observed. To investigate the flexibility of the GaN film the samples are bended over a sharp edge. SEM images ahve clearly shown cracks all over the stressed surface. EDX line scans and mappings are taken over the fractured areas to demonstrate that the GaN layer is fully broken.

The results of the characterization show, that PI is an appropriate substrate for growing GaN under the same conditions as on single crystalline substrates. The films are preferred orientated along the (0002) direction and have a relatively smooth surface. The crystallites show columnar growth with nearly the same size and shape. The dense and closed film with low defect density was not delaminated from the substrate, but is heavily fractured, after high mechanical stress was applied.