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Strain Relaxation of GaN_yAs_{1-y} Films on (100) GaAs Substrates Studied by Transmission Electron Microscopy

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GaN_yAs_{1-y} alloy semiconductors are of technological importance for optoelectronic devices. Recently, there has been considerable interest in using the dilute nitrides as the active materials in semiconductor lasers grown on GaAs substrates. The incorporation of very small amounts of nitrogen into GaAs leads to a dramatic decrease in the bandgap energy and has enabled the growth of GaAs-based laser diodes functioning in the 1.3-1.55 μm range. The growth of epitaxial GaN_yAs_{1-y} films on GaAs substrates presents a unique opportunity for studying growth mechanisms and strain relaxation in a highly-mismatched system.

In the growth of lattice-mismatched semiconductor materials, the most extensively studied strain relaxation mechanism is plastic flow - the development of misfit dislocations along the substrate film interface and the formation of microtwins [1, 2]. Alternatively, a purely elastic strain relaxation mechanism has been demonstrated, both theoretically and experimentally - the strain energy stored in the film can be relaxed by creating surface instabilities [3, 4]. A third strain relief mechanism in tensile strained layers is cracking [5, 6]. The occurrence of any strain relaxation during the epitaxial growth deteriorates the quality of the films making them unsuitable for device applications.

In this work, the strain relaxation behavior for a series of GaN_yAs_{1-y} films was studied by transmission electron microscopy (TEM), high-resolution x-ray diffraction (HRXRD) and atomic force microscopy (AFM). Samples consisting of 200 nm thick GaN_yAs_{1-y} epitaxial layers with $0.025 \leq y \leq 0.065$ (i.e. various misfit strain) were grown on (100) GaAs substrates by molecular beam epitaxy at 460°C. The $GaN_{0.025}As_{0.975}$ film shows no misfit dislocations and remains pseudomorphic well beyond the Matthews and Blakeslee's critical thickness, which can be explained by the high activation energy for a homogeneous dislocation nucleation at a smooth film surface. In samples with large N content ($y > 0.04$) relaxation of the built-in strain proceeds through morphological changes involving formation of surface cusps, followed by stacking faults and microtwins. The surface nucleation of 90° partial dislocations is shown to be feasible at the low growth temperature in the presence of cusps due to the stress concentration. The surface roughness is anisotropic between the two <011> directions in the low strained films, and this anisotropy of the surface morphology decreases with increase in N concentration.

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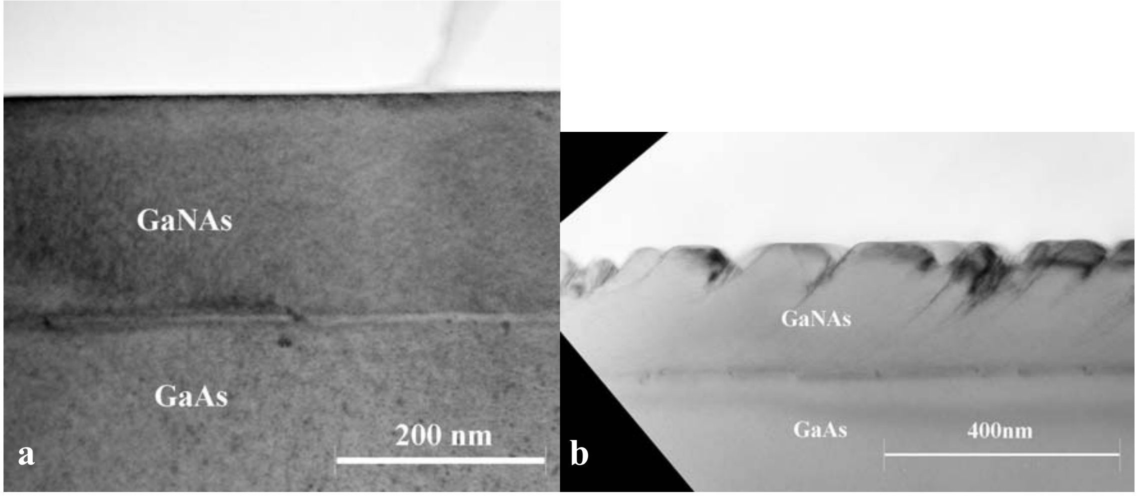

Fig. 1. $\left[0\bar{1}1\right]$ cross-section TEM image of the sample $GaN_{0.025}As_{0.975}$ showing the absence of structural defects in the film (a), and the cusps in the surface of the $GaN_{0.038}As_{0.962}$ film.

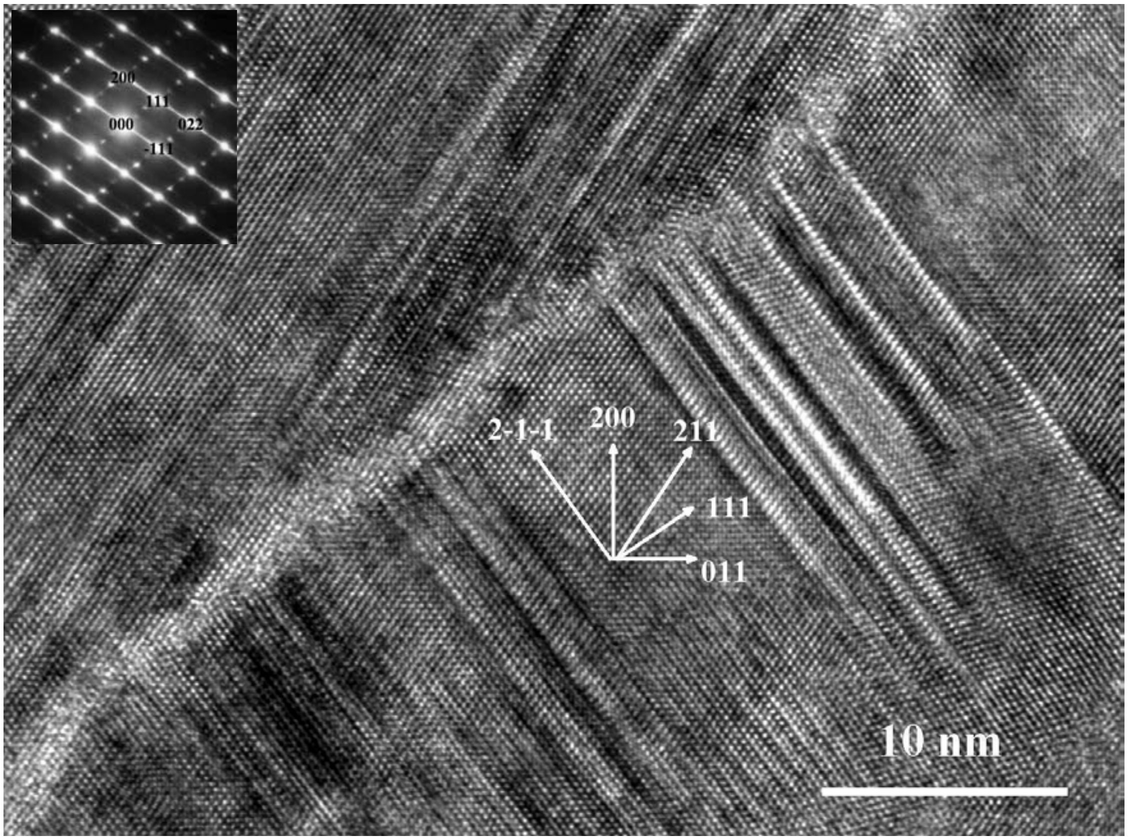

Fig. 2. $\left[0\bar{1}1\right]$ cross-section HRTEM images and corresponding $\left[0\bar{1}1\right]$ SAED patterns (inset) showing planar defects in the $GaN_{0.065}As_{0.935}$ film.