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Post-growth thermal annealing of high N-content GaAsN by MOVPE and its effect on strain relaxation

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Abstract

We report on the further investigation of the effect of post-growth thermal annealing on optical and structural properties of the high N-content $GaAs_{0.949}N_{0.051}$ layer grown on a GaAs(0 0 1) substrate by metalorganic vapor phase epitaxy (MOVPE). Photoluminescence (PL) spectroscopy was performed to measure the energy positions of the near band edge excitonic emission. The high-resolution X-ray diffraction and Raman spectroscopy were conducted to examine the lattice parameters, also the N concentration of the layers annealed at 650 °C with different annealing times. The layer subjected to thermal anneals exhibits an increasing of N incorporation, a strain relaxation and a blue shift of the PL peak energy. For such high N-containing layer, the interstitial N atoms generated in the growth process may replace the As atoms/vacancies on the lattice sites to become more stable substitutional N atoms through the thermal annealing process, which will produce the strain relaxation, in addition to an improvement of the alloy uniformity. Our results suggest the two major effects: (i) the reorganization of N and (ii) the strain relaxation in the GaAsN layer that can be explained the blue shift in the PL peak energy after annealing.

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1. Introduction

Great efforts have recently been devoted to the preparation of high-quality GaAsN films with high N incorporation, the characterization of GaAsN films, the development of devices using GaAsN-based materials. Low-bandgap Ga(In)AsN-based heterostructures are expected as useful for optoelectronic devices such as laser diodes emitting at 1.3 and 1.55 μm for optical communication systems [1–3]. The GaAsN films with N contents up to 5–8% were grown on a GaAs(0 0 1) substrate by metalorganic vapor phase epitaxy (MOVPE) [4–6]. However, the optical quality of GaAsN has been found to degrade with higher N incorporation. This may be due to comparatively to the lower growth temperature commonly used for the III–V nitrides, compared to that for GaAs. Post-growth thermal annealing can improve the luminescence properties significantly, but leads to a blue shift of the photoluminescence (PL) peak energy [7–9]. The structural origin of the effects of post-growth annealing treatments has been an issue. However, there are presently few reports on the effect of post-growth thermal annealing on the high N-containing GaAsN films [4,10,11].

Previously, we reported the results on the MOVPE growth of the high N-content GaAsN films with N content range of 0–5.1% using 1,1-dimethylhydrazine (DMHy), and tertiarybutylarsine (TBAs) as the source materials for N and As, respectively [11]. In this work, we have investigated the influence of the post-growth thermal annealing on structural and optical properties of the high N-content $GaAs_{0.949}N_{0.051}$ film.

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2. Experiments

The GaAsN layer with N content of 5.1% was grown on a GaAs(0 0 1) substrate at 500 °C by MOVPE using trimethylgallium (TMGa), DMHy, and TBAs as the source materials for Ga, N, and As, respectively. The thickness of the GaAsN layer was examined by high-resolution X-ray diffraction (HRXRD) to be about 200 nm. The N content in an as-grown layer was determined from a symmetrical (0 0 4) and an asymmetrical (1 1 5) reflections using HRXRD [6,7], by assuming a linear dependence of lattice constant (a_0) on the N content [12].

The post-growth thermal annealing was performed in the growth reactor under TBAs environment at 650 °C for 2 and 5 min. To investigate the influences of the annealing on structural and optical qualities, HRXRD, PL, and Raman scattering measurements were performed. In order to evaluate the strain relaxation precisely, reciprocal lattice mapping of asymmetrical (1 1 5) reflection was carried out for all annealed samples.

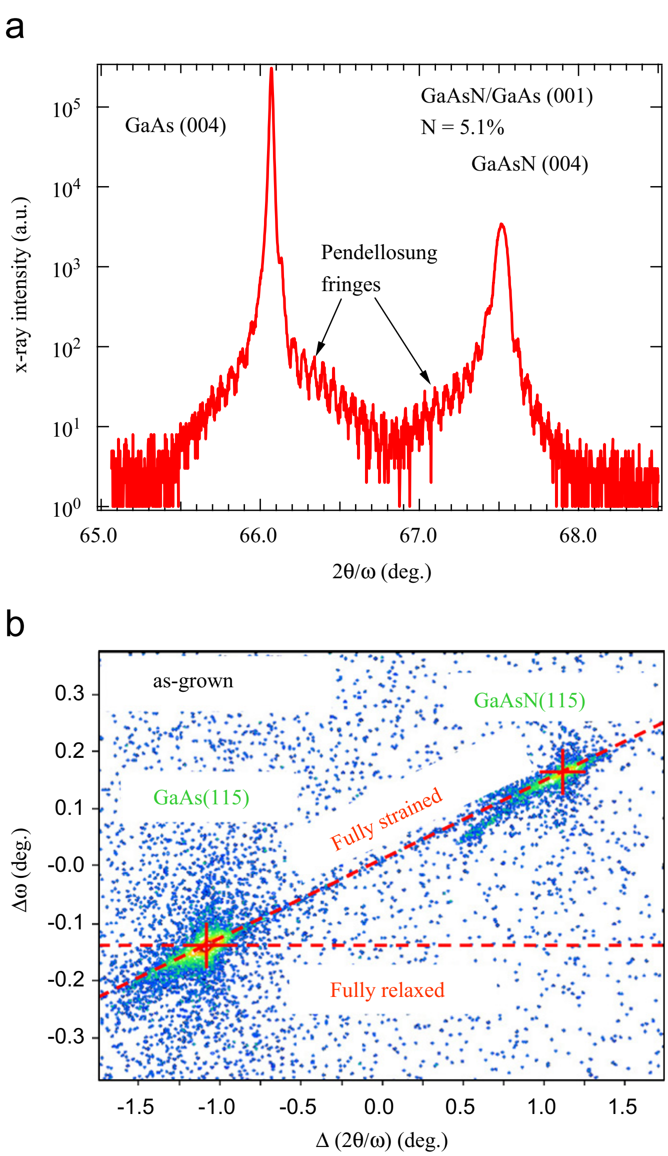

Fig. 1. (a) Symmetrical (0 0 4) HRXRD $2\theta/\omega$ curve and (b) asymmetric (1 1 5) reciprocal lattice map of the as-grown $GaAs_{0.949}N_{0.051}$ layer.

3. Results and discussion

To evaluate the N concentration in the GaAsN grown layer on a GaAs(0 0 1) substrate, it is required to know the lattice parameters of the epilayer perpendicular ($a_{\perp}$) and parallel ($a_{\parallel}$) to the GaAs(0 0 1) surface, which are generally calculated from a symmetric (0 0 4) and an asymmetric (1 1 5) HRXRD, respectively. Fig. 1a shows a (0 0 4) HRXRD $2\theta/\omega$ scan of the GaAsN layer on GaAs(0 0 1) substrate. From the separation between the GaAs and GaAsN reflection peaks, the $a_{\perp}$ was determined to be 5.544 Å. In addition, Pendellösung fringes are clearly visible due to a finite thickness and high structural quality of the grown layer. It is also shown that the spacing between the nearest fringes corresponds to a layer thickness of 200 nm. Fig. 1b shows a reciprocal space map of the (1 1 5) reflection. It is clearly seen that the GaAsN layer is coherently strained and exhibits a good epitaxial quality. By using both the (0 0 4) $2\theta/\omega$ scan and the (1 1 5) reciprocal space mapping measurements [7], the in-plane lattice parameter, $a_{\parallel}$, was determined to be 5.653 Å. Note that this value is in an excellent agreement with the lattice constant of GaAs. Thus, the N concentration, which can be estimated from the lattice parameters using Vegard's law [7], was determined to be 5.1%. HRXRD results demonstrate that a high epitaxial quality and coherently strained GaAsN layer with N content as high as 5.1% was successfully grown. However, it is found that the lumines-

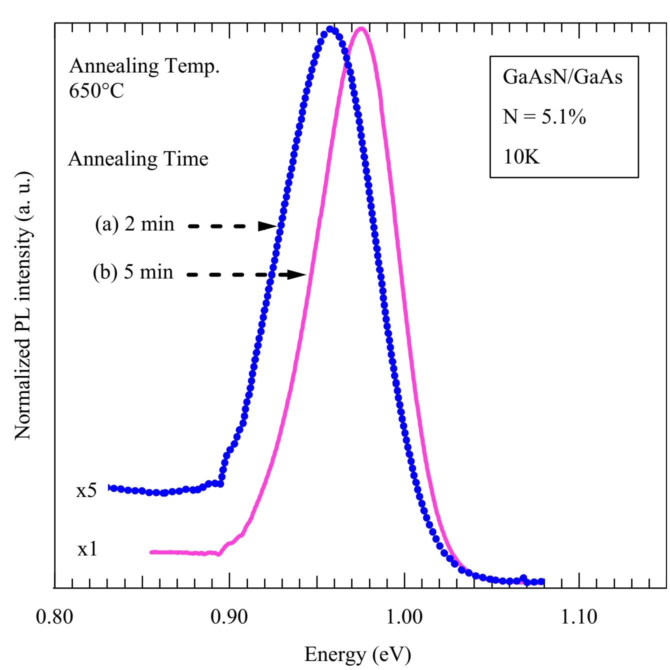

Fig. 2. Low-temperature (10 K) PL spectra of the annealed $GaAs_{0.949}N_{0.051}$ layers at 650 °C for different annealing times: (a) 2 min and (b) 5 min.