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# Cracks in GaN/AlN multiple quantum well structures grown by MBE

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**Abstract**. Due to the large lattice constant mismatch and thermal expansion coefficient difference between GaN and AlN, large strain is generated inside the GaN/AlN multiple quantum wells, which causes cracks in the structure. We investigated such cracks by optical microscopy and AFM. The crack density was studied with buffer and cap layer thickness, the number of quantum well periods, and the temperature reduction rate after growth as parameters. It was found that the crack density increased exponentially, with the number of periods above 4. Besides, a very thin, 100 nm, GaN buffer layer and ~ 300 nm GaN cap layer greatly reduced the crack density.

## 1. Introduction

Among the rapid growth in application for III-nitride materials, there is a partial interest in GaN/AlN multiple quantum wells for intersubband transitions. Because of the large conduction band offset (~ 2 eV) and the very short relaxation time (140-370 fs) [1, 2], GaN/AlN multiple quantum wells (MQWs) are promising candidates for developing ultrafast all-optical switches operating at Tbit/s [3]. However, due to the large lattice constant mismatch (~ 2.5 % along the a-axis) and the thermal expansion coefficient difference (~ 30 % at room temperature) between GaN and AlN, large strain is generated inside the GaN/AlN multiple quantum wells. This is strong enough to cause defects in the sample which may be harmful for devices. In this work the defect (called cracks) density was studied with the GaN buffer layer thickness, the GaN cap layer thickness, the number of quantum wells and the rate of temperature reduction after growth as parameters.

## 2. Experimental details

All samples were grown on 2.5 μm MOVPE-grown GaN templates [4]. The MBE growth was carried out in a Varian Gen II Modular system. Gallium and aluminum were supplied from solid effusion cells, while the active nitrogen atoms were generated in a radio-frequency plasma source (model SVTA RF-4.5). The GaN/AlN multiple quantum well structures, with different parameters, were grown on top of the templates. The schematic structure is shown in Fig. 1. The GaN well and AlN barrier widths were ~ 2.7 nm and 3 nm, respectively. Samples were all grown at the substrate temperature of 700 °C. The values of the Ga and Al beam equivalent pressure, nitrogen flow rate and plasma power were kept constant at $P_{Ga}$=1.1x$10^{-6}$ Torr, $P_{Al}$= 5x$10^{-7}$ Torr, $\Phi_{N2}$ = 1.5 sccm and P = 300 W, respectively. This provided GaN and AlN growth rates 280 and 270 nm/h, respectively. A bright thin, streaky RHEED pattern throughout the growth indicated a two-dimensional growth mode. After growth, the surfaces were studied by tapping mode atomic force microscopy (AFM) and standard optical microscopy.

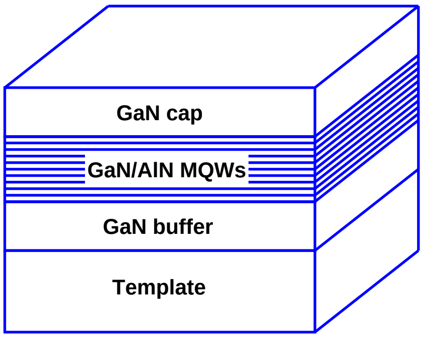


**Figure 1.** Schematic multiple quantum well structure grown on a GaN template.

## 3. Results and discussion

After the growth of 10 periods GaN/AlN MQWs, line features were observed on the surface, see Fig. 2. Typical width of these lines is 200 nm, which is best described as cracks. We believe these are cracks formed due to the large strain generated in the AlN barrier layers. MQWs grown on sapphire had no such cracks even for 20 MQW periods [5]. On the template a very thick GaN buffer layer (2.5 µm) was grown by MOVPE. The largest force is induced when the GaN layers were fully relaxed and the AlN barrier layers fully strained to the GaN. However, it is known that the AlN layers in the MQWs grown on sapphire had certain degrees of relaxation (15 – 50 %) [5]. This reduces the force which causes the cracks. To avoid such a large strain generated in the AlN barrier layers, a thick AlN buffer layers (typically 1 µm) or a thin GaN buffer layer can be used [6, 7]. In this work we found that the crack density was strongly influenced by the number of quantum wells, the buffer and cap layer thickness, but less affected by the temperature reduction rate.

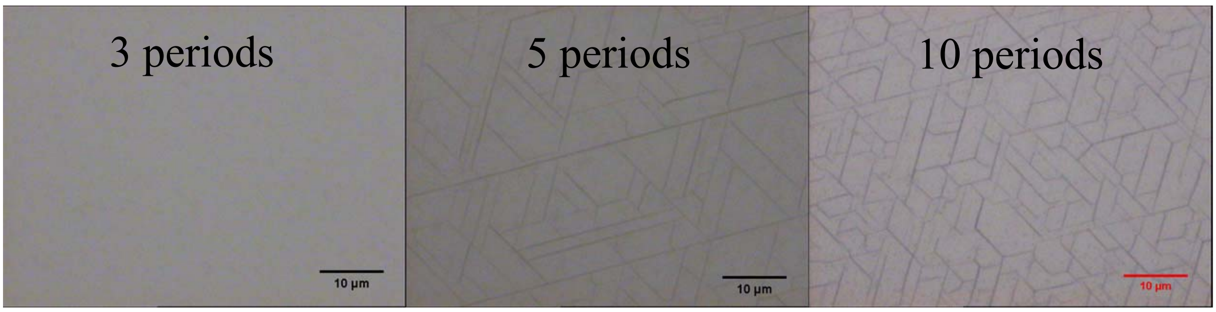


**Figure 2.** Optical microscope images of different periods of MQWs grown on templates.

Figure 2 shows optical images with typical cracks on the surface (5 and 10 period samples). The crack lines cross each other with 60 or 120 degrees form a triangular or hexagonal pattern. To investigate the crack density, MQWs with different periods were grown on top of a 100 nm thick MBE-grown GaN buffer layer grown directly on a template. No cap layers were grown and the quantum well layer thicknesses were kept same for all MQWs. We used the inverse average distance between cracks to identify the crack density. Figure 3 shows that the cracks are formed above 3 periods. After this the crack density increased exponentially with the number of periods. The corresponding optical microscope images are shown in Fig. 2. The average distance between cracks saturates at 2 - 3 μm for 10 QWs.

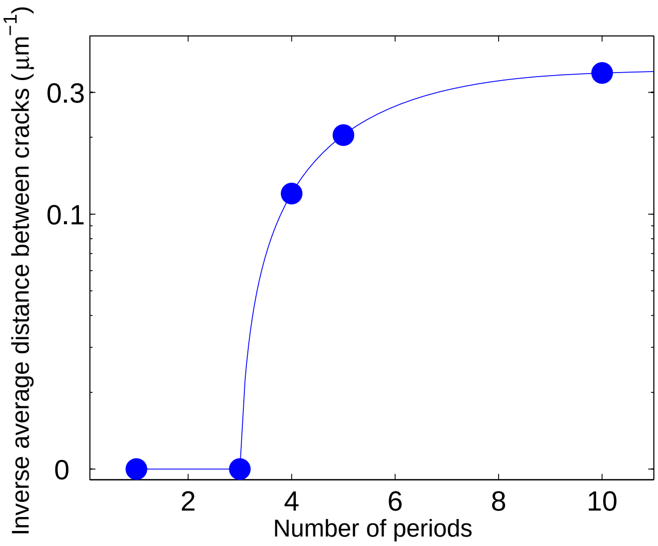


**Figure 3.** The inverse average distance between cracks as a function of number of periods. The solid line indicates the trend.

In order to study any effect of the substrate temperature reduction rate to the crack formation, different reduction rates, 10 and 60 °C/min, were used after growth of 5 periods MQWs. Optical microscope images on these surfaces show they had similar crack density, which indicated that the temperature reduction rate only had a small effect on the crack formation.

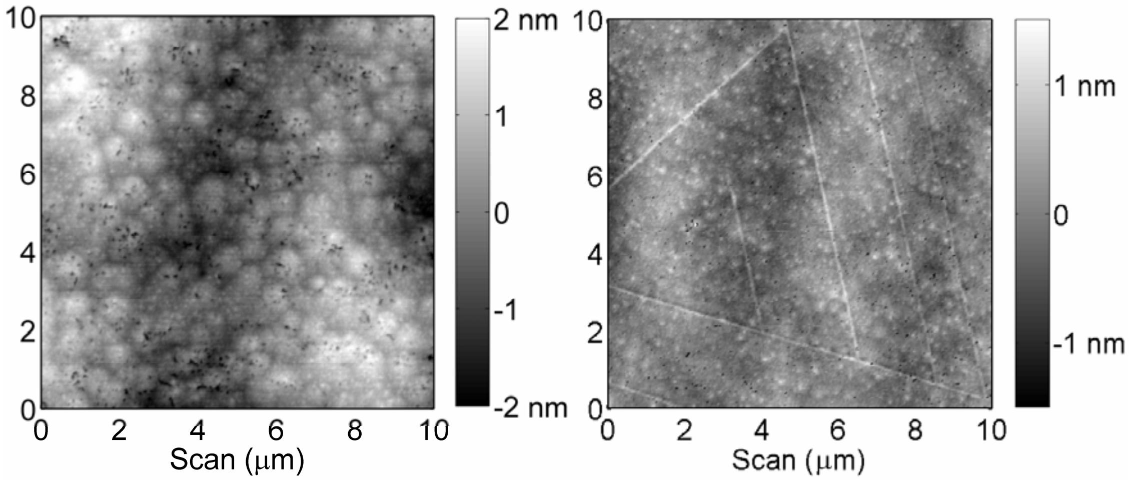


**Figure 4.** Tapping mode AFM images of two 3 periods MQW samples. The left one, grown on a 100 nm thick GaN buffer layer, exhibits no crack. The right one, grown directly on a template, showed long crack lines on the surface.

The influence of the GaN buffer layer on the cracks was investigated. The results showed that 3-period MQWs grown on a 100 nm thick GaN buffer layer on a template exhibited no cracks on the surface, c.f. Fig. 4 (left), whereas, the MQWs grown directly on the template appeared clear crack lines, c.f. Fig. 4 (right). Clearly the MBE-grown GaN buffer layer reduced the strain generated in the QWs.

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The relation between the GaN cap layer and the cracks was also studied. Different cap layer thicknesses were grown on top of MQWs, grown directly on the template. The results for 3 and 5 periods QWs are plotted in Fig. 5. These two groups of data show a similar trend. The crack density had a minimum for a cap layer thickness of ~ 300 nm. Thus the cap layer can reduce the MQW strain to a certain degree. For a too thick cap layer, the crack density increased again. The reason for this is unclear at this point and need further investigation.

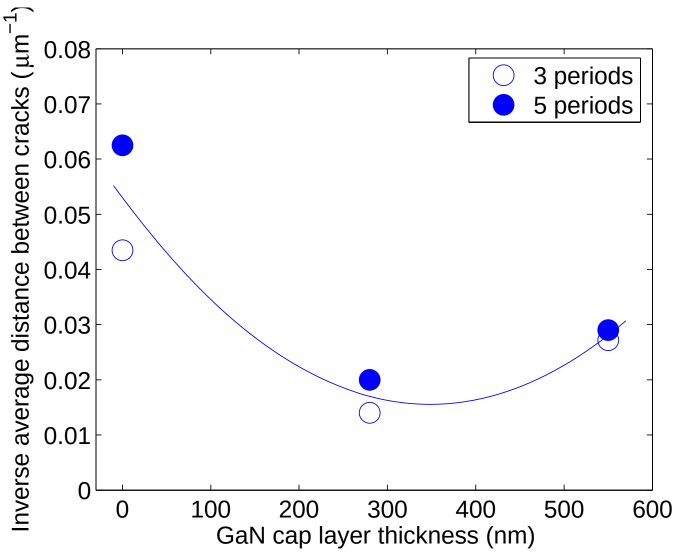


**Figure 5.** The crack density as a function of cap layer thickness. The symbols represent 3 and 5 periods MQWs grown directly on the template with different GaN cap layer thickness. The solid line is data fitting.

## 4. Summary
GaN/AlN multiple quantum well structures were grown on template substrate by MBE. Cracks were observed on the sample surfaces and the relation with the number of quantum well periods, the GaN buffer and cap layer thickness and the rate of growth temperature reduction were studied. It was found that the crack density increased exponentially above 4 periods. An MQW structure grown on a 100 nm thick GaN buffer and/or with ~ 300 nm GaN cap layer showed greatly reduction of crack density.

## References
[1] C.Gmachl, S.V. Frolov, H.M. Ng, S.-N.G. Chu and A.Y. Cho, *Electron. Lett.* **37** 378 (2001)
[2] J. Hamazaki, S. Matsui, H. Kunugita, K. Ema, H. Kanazawa, T. Tachibana, A. Kikuchi, and K.Kishino, *Appl. Phys. Lett.* **84** 1102 (2004)
[3] N. Suzuki and N. Iizuka, *Proc. Int. Conf. Physics and Simulation of Optoelectronic Devices VI,* SPIE Vol. **3283**, 614 (1998)
[4] T. Aggerstam, T.G. Andersson, P. Holmström, P. Jänes, X.Y. Liu, S. Lourdudoss and L. Thylén *Proc. Int. Cof. Quantum Sensing and Nanophotonic Devices IV,* SPIE **6479** 64791E (2007)
[5] X.Y.Liu, P. Holmström, P. Jänes, L. Thylén, and T.G. Andersson, *Phys. Stat. Sol. (a)*, (2007)
[6] A.Helman, M.Tchernycheva, A.Lusson, E.Warde, F.H.Julien, K.Moumanis, G.Fishman, E.Monroy, B.Daudin, D.L.S.Dang, E.B.Amalric, and D.Jalabert, *Appl. Phys. Lett.* **83** 5196 (2003)
[7] H.M.Ng, C.Gmachl, T.Siegrist, S.N.G.Chu, and A.Y.Cho, *Phys. Stat. Sol. (a)* **188** 825 (2001)