Strain studies on GaN−based structures on SiC

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Abstract:

The influence of AlGaN buffer on the strain in GaN grown on 6H−SiC is investigated. Composition, thickness and growth temperature of the buffer were varied. The grown structures were studied with x−ray diffraction and photoluminescence. The possibility to control strain from tensile to compressive state was shown. Relaxation of the GaN layer at the certain point was observed in many cases. Drastical reduction of GaN−based lasers' electrical series resistance was demonstrated.

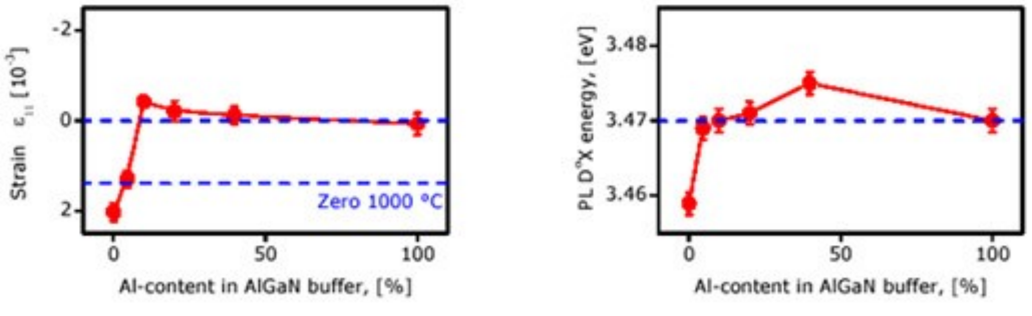
Introduction:

Using of non−native substrates to grow GaN and related layers requires the insertion of a specially optimized nucleation layer to the structure. The aim of such a layer is not only to provide 2D heteroepitaxial growth, but also to control the strain state of the whole structure because of the strong influence of the substrate quality and initial growth phase on the strain of single layers as well as sophisticated device structures. In particular, we have focused on the growth of laser structures grown on 6H−SiC by MOVPE. The epitaxy was performed in a horizontal RF−heated reactor at low pressure (100 mbar). The growth temperature for the bulk layers was set to 1000 °C. TEGa, TMAl and NH_3 have been used as gallium, aluminium and nitrogen precursors, respectively. As carrier gas we employed a H_2:N_2 mixture with the partial pressure ratio of about 1:1.

Experiments and discussions:

In the first stage of this work we have optimized the parameters of the nucleation process on 6H−SiC for single GaN layers. The grown samples were analysed by high resolution x−ray diffraction and low−temprature photoluminescence. The representative structure of these experiments is shown in Fig. 1. It is well known that it is impossible to grow high quality 2D layers of GaN directly on the SiC substrate [1, 2]. Nevertheless, we have varied the AlN−content in the buffer from 0 % to 100 % to study the strain in the GaN top layer which arised due to different compositions of the nucleation layer.

Fig. 1 Experimental structure



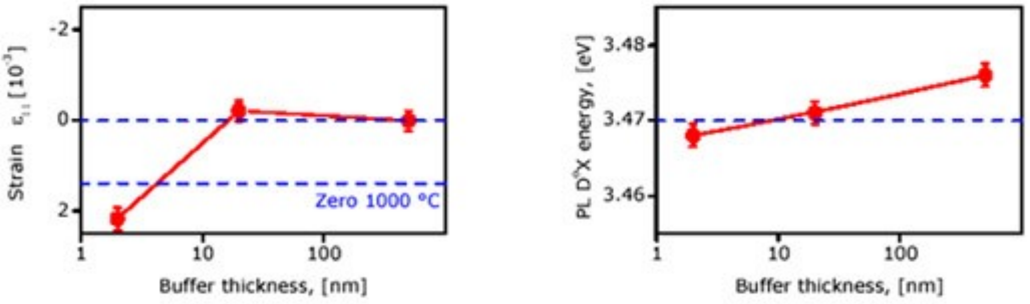
a) b)

Fig. 2 Influence of *Al-content* on the strain

a) measured by x-ray diffraction, b) measured by photoluminescence

The thickness of this layer, growth temperature and growth rates were kept constant in the first series. It should be mentioned here, that morphology of the grown structures changed from a rough, for low AlN−content, to a mirror−like surface with growing Al−flow. However, the strain did not change monotonically from sample to sample, as expected beforehand (Fig. 2). The layers with small AlN−content show strong tensile strain which arised mainly du to the difference of the thermal expansion coefficient between SiC (substrate) and GaN (layer). For more than 10% AlN in the buffer, we observed nearly perfect relaxation of the GaN layer at room temperature. For a small AlN−content where the number of nucleation centers is also small the required thickness to cover the substrate surface becomes larger. In this case an unstrained growth of GaN takes place at growth temperature, and after cooling, GaN becomes tensile strained. For a larger AlN−content coverage takes place faster and GaN grows under compressive strain, which decreases during cooling down at the end of the growth process. A small discrepancy between XRD and PL results can be explained by a partial relaxation of the GaN layer and the difference of penetration depth for x−rays and the 325nm laser light, respectively.

A comparable role plays the thickness of the buffer which we have studied in a second series. In these experiments we deposited an $Al_{.2}$ $Ga_{.8}$ N layer directly on SiC at 1000°C. The thickness of the buffer was varied from 2 to 500 nm (Fig. 3).

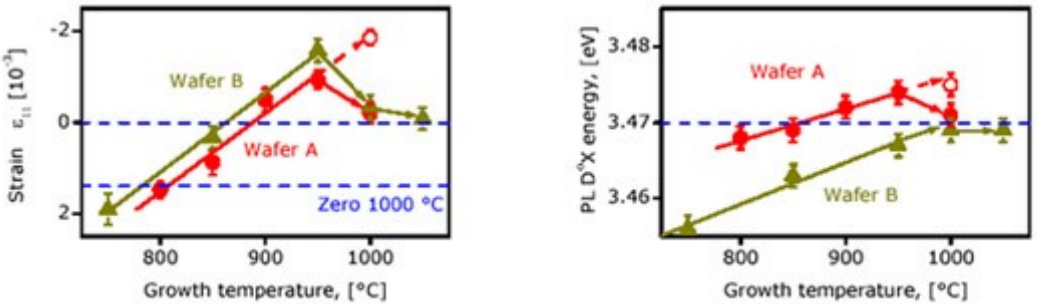


a) b)

Fig. 3 Influence of *the buffer thickness* on the strains

a) measured by x-ray diffraction, b) measured by photoluminescence

We suppose as main difference that the growth of GaN takes place on SiC either completely covered by a thick nucleation layer, but only partly covered by a thin layer. It provides to GaN to be strained or unstrained in the same way like it was explained before.



a) b)

Fig. 4 Influence of *the buffer growth temperature* on the strain

a) measured by x-ray diffraction, b) measured by photoluminescence

The dependence of the strain on the growth temperature of the buffer was studied in a third series, where we kept the Al content (20%) and the thickness (20nm) constant. It looks somewhat more complicated (Fig. 4). We see that in this case, the dependence has mainly linear character, but beginning from 950 °C a strong relaxation of the GaN layer takes place . It seems that this temperature depends on the composition of the AlGaN buffer and thickness of the GaN layer. In Figs. 4 a) and 4 b), the red open circles refer to 350nm GaN layers grown at the same condition as the other samples, which still follow the linear trend up to 1000°C.

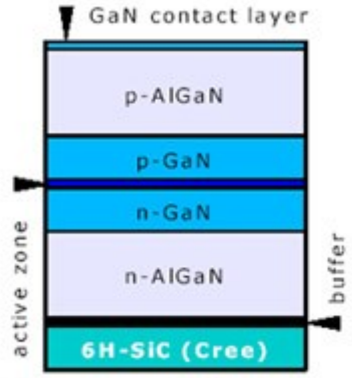
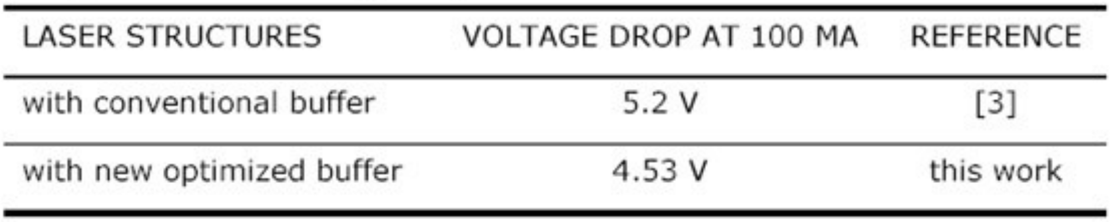


Fig. 5 Common GaN laser structure

The open question after this series is a big difference of the PL energy between 2 wafers which we utilized for our experiments. It seems that the quality of the SiC crystal and its surface plays a big role in the growth mechanism and the strain formation process as well.In the second stage of our work we have grown complete laser structures using these buffer layers. Due to the complexity of such laser structures (Fig. 5), the strain situation differs significantly from our test structures. Experiments have show that for our MOVPE machine optimal parameters for the buffer layer were as follows: 20 nm undoped−GaN buffer grown at 800 °C plus special in−situ treatment of SiC substrate before growth beginning [to be patented]. After a simple shadow mask device processing (details see [3]), we found a significant decrease of the series resistance (see Table).

Table: Comparison of the voltage drops for lasers with a conventional and new buffer



LASER STRUCTURES	VOLTAGE DROP AT 100 MA	REFERENCE
with conventional buffer	5.2 V	[3]
with new optimized buffer	4.53 V	this work

Conclusion:

We have investigated the influence of the AlGaN buffer growth conditions on the strain in GaN grown on 6H−SiC. It was shown that a small AlN−content in the buffer as well as a low buffer thickness led to tensile strained GaN at room temperature. Decreasing of the buffer growth temperature leads to the same effect. The variation of this parameter provides a good control of the strain state in GaN layers, whereas (AlN−content and thickness of the buffer layer) is less pronounceddue to the observed step−like changes. For most buffer layer parameters, the GaN layers were relaxed after cooling down to room temperature. These investigations are quite useful for a limitation of the AlGaN parameters space to grow high quality GaN layers. However, the optimum also depends from some particular substrate parameters.

When applying this approach to complete laser structures, we observed big differences as compared to single layers. Nevertheless, the optimization of the buffer layer parameters helped to reach a very low electrical series resistance on our standard GaN−based laser structure. However, it is also evident that further investigations of the buffer parameters are of big interest.

Acknowledgement:

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