2.6 Optically induced strain relaxation in anisotropically strained *M*-plane GaN films

It has been previously demonstrated that strained M-plane GaN films, where the c axis lies in the film plane, exhibit a very large in-plane polarization anisotropy [S. Ghosh *et al.*, Phys. Rev. B **65**, 075202 (2002)]. In particular, for a certain range of in-plane strain values, the wave function of the highest and the second highest valence band (VB) becomes completely $|x\rangle$-like and $|z\rangle$-like, respectively. Therefore, the absorption coefficient $\alpha_\perp$ is enhanced for the electric field component perpendicular to the c axis ($\boldsymbol{E}\perp\boldsymbol{c}$) as compared to $\alpha_\|$ for the electric field component parallel to the c axis ($\boldsymbol{E}\|\boldsymbol{c}$). As a result, the component $\boldsymbol{E}\perp\boldsymbol{c}$ of a linearly polarized incident light beam is filtered after transmission through the film, appearing in the experiment as a rotation of the polarization vector toward the c axis. Recently, we have demonstrated that this effect of polarization filtering can be dynamically controlled by additional optical pumping, if a linearly polarized pulsed pump beam bleaches the absorption by creating carriers in one or two of the uppermost VBs. Furthermore, the time behavior is influenced by coherent effects [T. Flissikowski *et al.*, Phys. Rev. B **74**, 085323 (2006)]. Since the change in the absorption is connected to the carrier density generated in a certain state, this modulation is a reversible effect on the time scale of the life time of these carriers.

In Fig. 15, we show that after strong optical pumping also a permanent change in the absorption is observed. Two partly overlapping rectangular areas of about (100×100) μm^2 were exposed by the pump laser focused to a 1 μm spot and with a power density of 5 mJ/cm^2 by moving step by step across the sample. Probing the transmission T for $\boldsymbol{E}\|\boldsymbol{c}$ and $\boldsymbol{E}\perp\boldsymbol{c}$ showed that $T_\|$ is reduced in the exposed areas [Fig. 15 (a)] while $T_\perp$ remains unchanged [Fig. 15 (b)]. Quantitatively, the scan along a line through the exposed area compared with a one through an unexposed area of the sample [Fig. 15 (c)] reveals that the exposure reduced $T_\|$ by about 10%.

Our explanation is based on the idea that the focused pump laser locally induced a relaxation of the strained film. While the out-of-plane strain can be directly measured by x-ray diffraction, the two components of the in-plane strain ε_{xx} and ε_{zz} can be determined only indirectly.

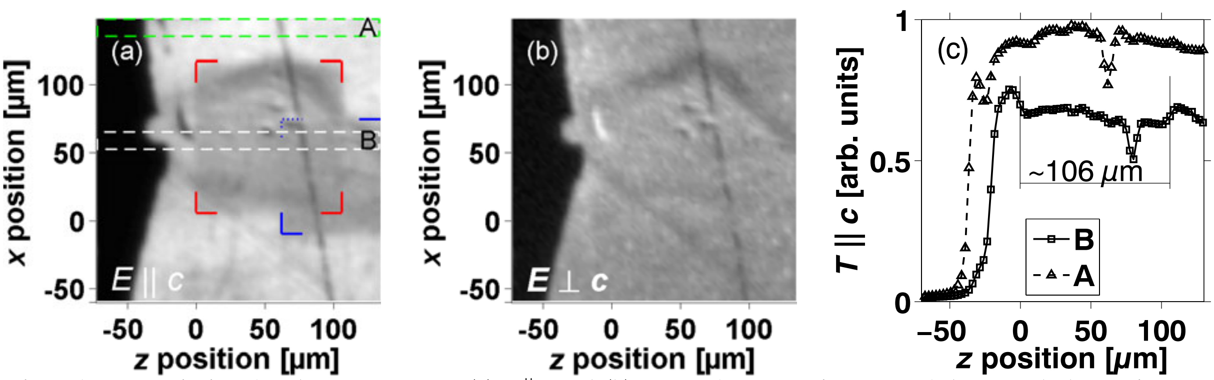

Fig. 15. Transmission for the components (a) $\boldsymbol{E}\|\boldsymbol{c}$ and (b) $\boldsymbol{E}\perp\boldsymbol{c}$ after exposing part of the sample by an intense pulsed laser beam. (c) A line scan through the exposed area (squares) in comparison with a line scan through a non-exposed area (triangles) both extracted from (a).

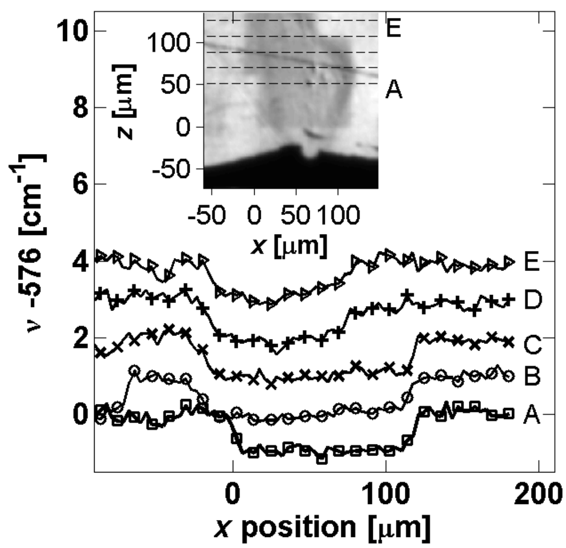

Fig. 16. Frequency of the E_2-phonon mode at different sample positions with respect to the exposed area as indicated by the lines in the inset.

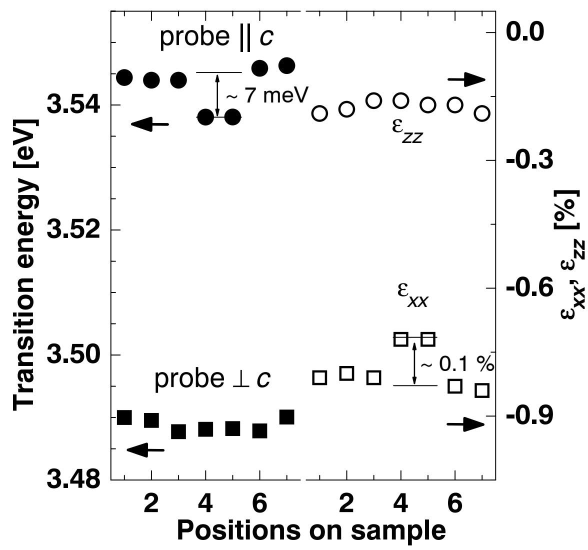

Fig. 17. Transition energies from the highest (filled squares) and second highest (filled circles) VB as measured by PR at different sample positions and the corresponding in-plane strain values (open symbols).

By measuring the phonon frequency ν of the E_2-Raman line inside and outside the exposed area, different in-plane strains can be detected. Figure 16 shows ν as measured along five different lines (A to E) indicated in the inset. At the edges of the exposed area, ν drops abruptly by $\Delta\nu = 0.8$ cm^{-1}. A smaller ν inside the exposed area indicates a smaller strain. With the deformation potential approximation $\Delta\nu = 2a\varepsilon_{xx} + b\varepsilon_{zz}$, where a and b are constants, one can estimate the maximum change as $\Delta\varepsilon_{xx,\max} \approx -0.05\%$ and $\Delta\varepsilon_{zz,\max} \approx -0.09\%$. Here, it is assumed that the relaxation takes place only along one of the two directions x or z.

By following Ghosh *et al.*, the variation of the strain can be determined more accurately. After the transition energies from the two uppermost VBs had been determined by photoreflectance (PR) spectroscopy, a $\mathbf{k}\cdot\mathbf{p}$-perturbation approach was employed to find the corresponding value of ε_{xx} and ε_{zz}). In Fig. 17 (left-hand side), the transition energies measured at different sample positions along a line parallel to the x-axis are presented. On the right-hand side of Fig. 17, the corresponding pairs of ε_{xx} and ε_{zz} are summarized. The energies measured at the exposed area (positions #4 and #5) correspond to a strain value of $\varepsilon_{xx} = -0.72\%$ instead of $\varepsilon_{xx} = -0.82\%$ for the non-exposed area, while $\varepsilon_{zz} = -0.18\%$ remains unchanged.

In summary, it was found that, after exposure with intensive pulsed light, the highly strained M-plane GaN film relaxes only along the x-direction by about 10%. Preliminary photoluminescence data indicate that the stress relaxation is accompanied by the formation of defects, which can act as non-radiative recombination centers. However, the actual defect type is still under investigation.

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