

Response to "Comment on 'Shallow donors in GaN studied by electronic Raman scattering in resonance with yellow luminescence transitions' "

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M. Ramsteiner, J. Menniger, O. Brandt, H. Yang, and K. H. Ploog
Paul-Drude-Institut für Festkörperelektronik, D-10117 Berlin, Germany

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In their comment, Siegle *et al.*¹ present Raman and photoluminescence (PL) data from samples grown either on GaAs by molecular beam epitaxy (MBE) or on sapphire by metal organic vapor phase epitaxy and hydride vapor phase epitaxy. They observe electronic Raman scattering (ERS) peaks like those reported in Ref. 2 and claim, however, our assignments to be incorrect.

Siegle *et al.*¹ report peaks at 60 (α), 95 (β), 102.5 (γ), 125 (δ), and 250 cm^{-1} (ϵ) in addition to the ERS peaks at 151 (A^*), 189 (A), 218 (B^*), and 237 cm^{-1} (B) discussed in Ref. 2 and assert that all these peaks have the same origin. In fact, we also observe peaks β and δ in the spectra of our GaN samples. According to our model,² we expect a very similar Raman resonance behavior for different donor species with sufficiently low binding energy. Therefore, the argument based on the resonance behavior is invalid in attributing all the observed peaks to the same origin.¹ If the same origin is assumed for all peaks, their relative intensities should be nearly constant for different samples. This is by far not the case as shown, e.g., in Fig. 1 of Ref. 2 for peaks A and B vs A^* and B^* as well as for peaks β vs δ in Fig. 1 (compare also Figs. 1 and 2 in Ref. 1). In contrast to the ERS peaks discussed in Ref. 2, peak δ has been observed also in p -type GaN and shows a weak temperature dependence. Therefore, it is not even clear whether peak δ is due to ERS.

Siegle *et al.*¹ further claim as a main statement that the ERS peaks are only observable for GaN grown on GaAs. However, we observe the ERS peaks reported in Ref. 2 also in GaN layers after removal of the GaAs substrate [Fig. 1(c)] demonstrating that they do not originate from GaAs. It is furthermore known that N impurities in GaAs introduce a resonant energy level in the conduction band which is not occupied under normal conditions.³ Moreover, peak B^* was observed previously by absorption spectroscopy⁴ and, more recently, peaks A^* and B^* by Raman scattering⁵ from hexagonal GaN grown on sapphire. These findings completely rule out any connection with GaAs and therefore refute the statement of Ref. 1. The observability of the ERS peaks rather depends on the donor concentration and the Fermi level in the GaN layer. For too small donor concentrations, the intensity of the corresponding Raman excitations vanishes below the detection limit. At very large concentrations, a pronounced formation of impurity level bands is expected to destroy the observability of individual electronic transitions. In addition, the resonance enhancement² should be only observable for sufficiently high concentrations of the involved deep level defect. In this respect, arguments based

on the comparison of samples grown under different conditions¹ are not conclusive.

Comparing PL spectra from different samples, Siegle *et al.*¹ question the direct link between yellow PL transitions and the observed enhancement of the ERS intensities. However, PL intensities are known to depend on carrier relaxation processes including nonradiative recombination channels and are hence no measure for the concentration of the defects involved. Consequently, in contrast to the arguments of Ref. 1, the observation of the ERS peaks is not necessarily connected with the appearance of a strong yellow PL band. Due to carrier relaxation processes, also the PL excitation spectra of the yellow luminescence might differ substantially from the Raman resonance profile.

Finally, Siegle *et al.*¹ claim that peaks A^* and B^* , which we assign to hexagonal GaN, can also be observed from purely cubic samples. Here, we note that our assignment is consistent with measurements from hexagonal GaN on sapphire where ERS peaks A^{*5} and $B^{*4,5}$ dominate. Concerning the Raman spectrum of MBE grown GaN in Fig. 1 of Ref. 1, a more careful examination clearly reveals a hex-

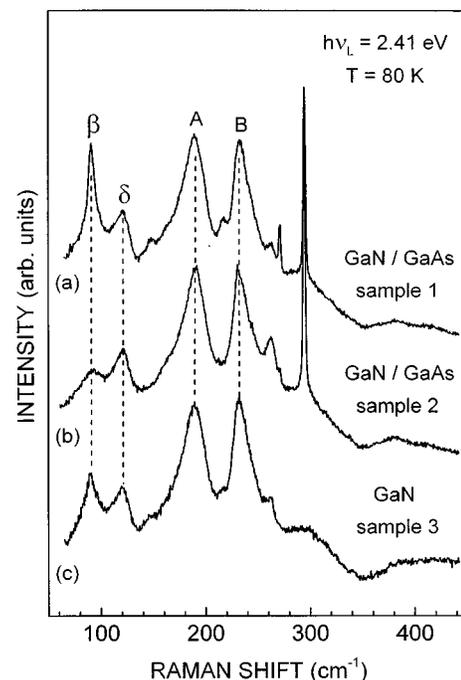


FIG. 1. Low-temperature Raman spectra of predominantly cubic GaN layers grown by MBE on GaAs. Samples 1(a) and 2(b) were measured as-grown and sample 3(c) after removal of the GaAs substrate by wet chemical etching in a $\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$ solution.

agonal contribution via the E_2 phonon line at 569 cm^{-1} even though not well resolved. Therefore, the observation of lines A^* and B^* from their sample is in accordance with our assignment. Of course, the intensity of the ERS peaks relative to the E_2 phonon line depends on the defect concentration, the orientation of the hexagonal GaN portion, and the scattering geometry used.

In summary, we presented in Ref. 2 an explanation for specific ERS peaks from cubic and hexagonal GaN layers. Additional low-frequency peaks can, consistently, be attributed to other origins. The assignment of the ERS peaks as

well as our Raman resonance model are not in contradiction to the experimental results of Ref. 1.

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