Electrostatic potential distribution on pn junction GaN-semiconductor

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Nowadays, group III-Nitride semiconductor are important because of the possibility to produce light emitting devices in the whole visible spectrum. However, even the growth of GaN-based light emitting devices causes several obstacles, which hinder the luminescence efficiency of these devices [1].

We measured the electrostatic potential at the pn junction of GaN by means of off-axis electron holography. This modern transmission electron microscopy method allows the acquisition of the complete information (amplitude, phase) of the electron wave. Under kinematical condition and in the absence of magnetic fields, the phase of the electron wave is modulated by the electrostatic potential [2]. The total phase modulation is described as $\varphi_{tot} = \sigma \cdot (V_{GaN} + V_{pn}) \cdot t$, where σ is the interaction constant, t the thickness of the specimen, V_{GaN} the mean inner potential of GaN, and V_{pn} the built-in potential. Because the dopant does not change V_{GaN} significantly, it can be assumed as constant over the specimen. Thus, a phase shift will occur at the pn junction due to V_{pn}.

The cross-section prepared specimen was mechanically grinded, polished and followed by both side dimpling. The final thinning process was accomplished by Ar-ion-milling under cooling with liquid nitrogen.

Figure 1a), 1b) show the reconstructed amplitude and phase of the electron wave. A strong thickness variation leads to several phase wraps in the reconstructed phase. After unwrapping the phase, a phase shift across the pn junction is clearly observable as depicted in Figure 1c).

In order to measure the potential at the pn junction from the phase modulation, the thickness must be known. The thickness is obtained from the attenuation of the amplitude by inelastic scattering. With the mean free path for inelastic scattering of electrons $\lambda_{inel.}$, the thickness can be expressed as, $t / \lambda_{inel.} = -2 \ln (A/A_r)$ [3]. A/A_r is the normalized amplitude of the hologram, where A and A_r is the amplitude of the electron wave and reference wave, respectively. Due to strong noise in the normalized amplitude, it is low pass filtered and approximated by a smooth simple analytical function. Instead of the measured amplitude this function is used for further analysis (Figure 2a)). Unfortunately, in the literature $\lambda_{inel.}$ varies in its value and makes the determination of the exact thickness difficult. Thus, we approximate $\lambda_{inel.} \approx 84$ nm from the slopes of the normalized amplitude and phase in a region far from the pn junction by assuming a linear variation of the thickness. As V_{GaN} is known from the literature, $\lambda_{inel.}$ can be calculated from the ratio of this slopes [4].

Actually, the absolute phase is not correct because of the lack of a vacuum region in hologram. Since we determined the thickness above, the absolute phase can be deduced from the phase modulation formula.

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The measured value of the built-in potential is about 0.6 V, which is much less than expected (Figure 2b)). Therefore, further investigations are under way.

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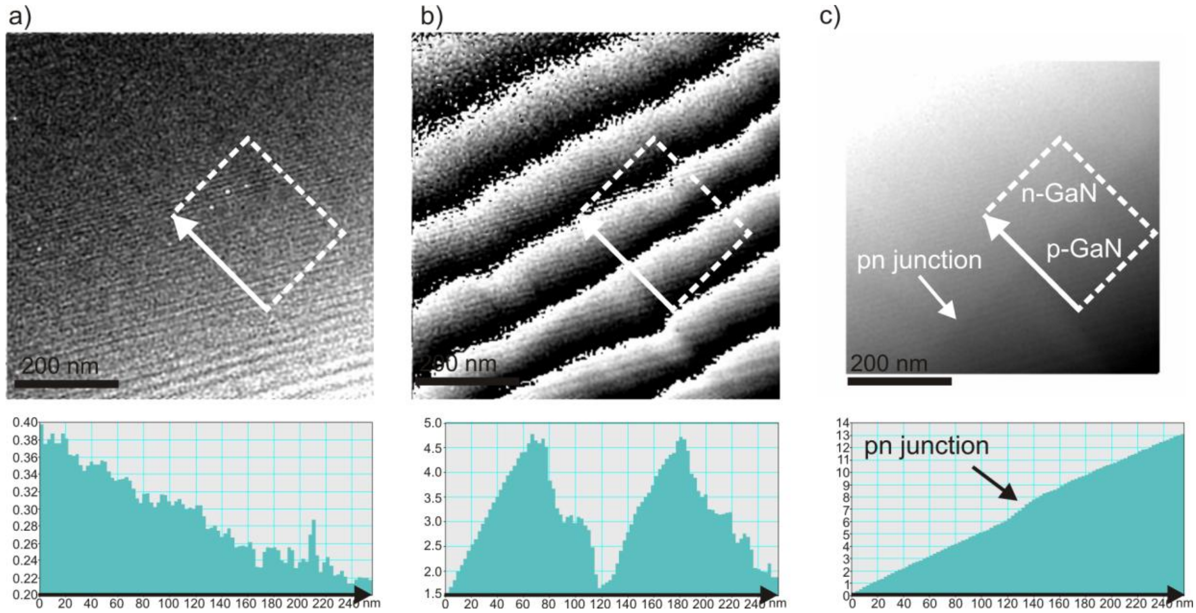

Figure 1. Reconstructed electron wave from off-axis hologram in the region of the pn junction. a) Normalized amplitude and b) phase with its profile. c) The unwrapped phase, particularly, the phase shift due to pn junction is clearly visible.

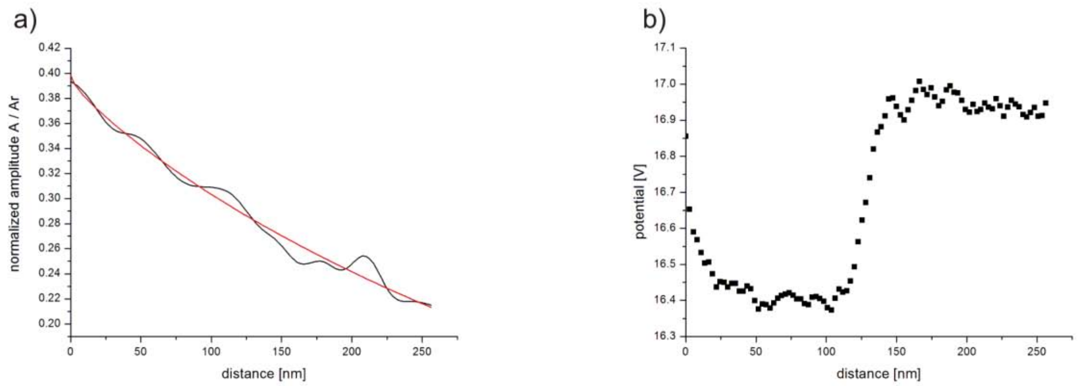

Figure 2. a) Shows the normalized amplitude from reconstructed amplitude after utilizing a low pass filter. The red line represents the smooth analytical approximated function. b) potential shift across the pn junction obtained by adjusting the absolute phase and then dividing the phase by the thickness.

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