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IT-11-P-3140 Electron Beam induced Currents in GaN p-n Junctions

Park J. B.[1], Niermann T.[1], Lehmann M.[1]

[1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, D-10623 Berlin, Germany

Email of the presenting author: park@physik.tu-berlin.de

Off-axis electron holography (EH) is a unique approach for analyzing potential variation down to nanometer scale. In absence of magnetic fields and in kinematical diffraction condition, the phase modulation is proportional to the potential (sum of mean inner potential and built-in potential V_{pn}) and the specimen thickness. However, quantitative measurement of V_{pn} in GaN shows a huge deviation with the theoretical value. Additionally, it seems that the hypothetical "dead layer" on both surfaces affected by focused ion beam (FIB) preparation is not the only reason for the discrepancy since the measured V_{pn} from the bulk (n-GaN)/shell (p-GaN) geometry of the GaN p-n junction is not affected by the FIB preparation [1].
In this study, we assess the influence of the electron beam on the measured V_{pn} at GaN p-n junctions. Two GaN p-n junctions of comparable dopant concentration were prepared by FIB. Thereby, a needle-like shape geometry is deliberately chosen to ensure that the whole specimen is illuminated during the experiment [2]. Moreover, a defined path of the induced current arising from electron-hole pair generation and secondary electron emission is provided. Low voltage (5 kV) is applied for the final polishing step to mitigate the surface damaging by FIB.
Fig. 1 shows the FIB milled needle with a sketch of the layer structure. In order to enhance the signal to noise ratio of the phase, series of holograms separately for each illumination intensity were recorded and subsequently averaged. The reconstructed phase depicts a clear phase jump at the p-n junction (Fig. 1 (c)).
Two electron beam induced effects are observed. Firstly, in Fig. 2 the measured V_{pn} increases with reducing the electron dose rate. This illumination dependency of V_{pn} can be quantitatively explained by a solar-cell model. Hence, $V_{pn} = V_{pn, expected} - V_{bias}$ is fitted on the data set, where $V_{pn, expected}$ is determined by the doping concentration (sample A: 3.41 V, sample B: 3.43 V), V_{bias} is the voltage drop across the p-n junction, which is affected by illumination induced currents owing to secondary electron emission and e-h pair generation [3]. Additionally, fluctuation of V_{pn} is depicted by two needles, which are prepared from a same wafer and with the same FIB preparation steps. However, both needles (I and II) show the same behaviour of V_{pn} over the electron dose rate. Secondly, beam damage of the specimen is observed in Fig. 3. The V_{pn} diminishes over a period of time and might converge to a constant value, which is about the half of the initially measured V_{pn}.

1. S. Yazdi et al., journal of physics: Conf. Ser. 471 (2013), p.012041.
2. A. Lenk, Dissertation, Dresden (2008).
3. S.M. Sze in "Physics of Semiconductor Devices", 2. Edition, John Wiley & Sons (1981).
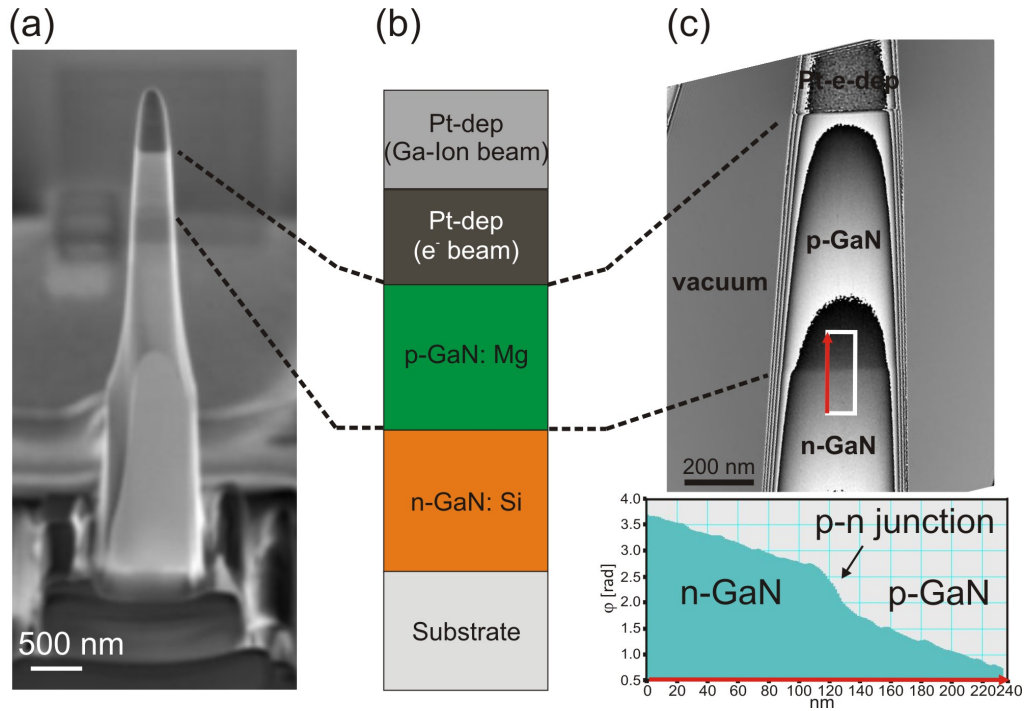
Fig. 1: (a) SEM image of the needle-like shape specimen after FIB preparation. (b) The layer structure of the specimen. (c) The reconstructed phase of (a). The phase jump at the p-n junction due to different doping type is clearly visible. The large-area undulation of the phase change along the specimen is caused by thickness variation.
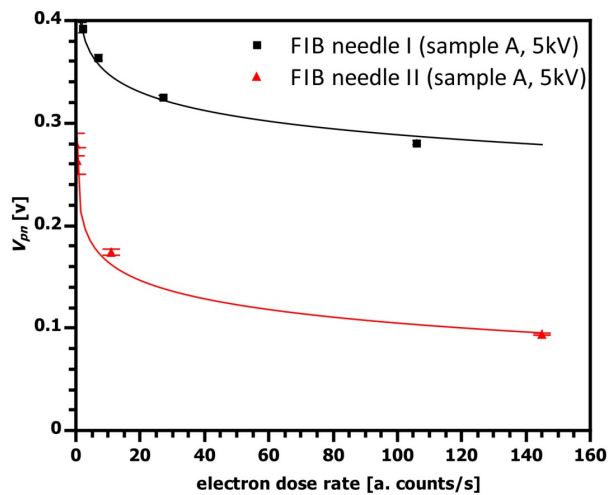

Fig. 2: The measured built-in potential V_{pn} over the electron dose rate for two needle specimens of sample A (FIB needle I and II). The V_{pn} is enhanced over roughly 30% by reducing the electron dose rate by a magnitude of 2.
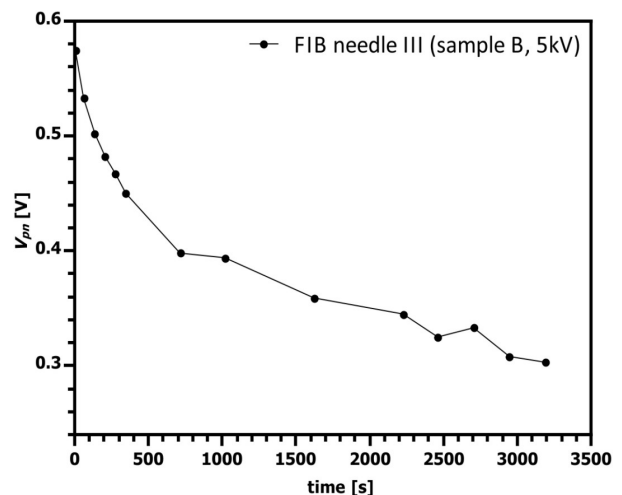

Fig. 3: The V_{pn} is measured directly after FIB preparation over a period of time (about 1 hour) at sample B. We observe a decrease of V_{pn} by a factor 2 over time.