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Observation of the Potential Distribution in GaN-Based Devices by a Scanning Electron Microscope

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For semiconducting devices, the precise control of their electro-static potential distributions is very important for device operations. For GaN-based light emitting diodes (LEDs), quantum wells (QWs) are usually used in the active region, and the wells are under strained state generating piezoelectric fields. These piezoelectric fields isolate electron-hole pairs, and this leads to a reduction of the luminescence efficiency. Therefore, understanding of the potential distribution is essential for the development of LEDs with improved emission efficiency. Electron holography has been used for this purpose [1-4], however, sample preparations are not easy. In recent years, mapping of the potential distribution using a scanning electron microscope (SEM) has been reported [5][6] for semiconductors such as Si, GaAs and InP. Sample preparation for SEM is easy and quick. But, there are no such studies on GaN-based devices, to our knowledge. In this study, we observed two types of GaN-based devices by SEM to see if there is a condition that the contrast matches the potential distribution of the devices.

The first device we studied is GaN p-n junction (p, n ~5×10^{17} cm^{-3}) grown on c-sapphire by metal organic vapor phase epitaxy (MOVPE). The device was cut, and polished from the cross-section to a flat surface. The cross-section was observed by SEM. Figure 1(a) shows an SEM image taken at 3 kV. The p-region appears bright and the n-region appears dark. The image intensity changes at the position of p-n junction, for which we used electron beam induced current (EBIC) technique to determine the p-n junction position. Figures 1(b) - 1(d) compare SEM line profiles across the p-n junction (shown in red) with calculated potential distributions (black) for three different values of p and n concentrations. In the calculation, p and n concentrations are assumed to be the same. Flat parts of SEM line profile in p and n regions were fitted with the potential profile, and the change at the junction is compared. It can be seen that the intensity profile across the p-n junction matches the potential distribution with p, n ~8×10^{17} cm^{-3} very well. The SEM observations were carried out for several accelerating voltages. But, best result was obtained at 3 kV. For lower accelerating voltages, the image seemed to reflect the surface potential. On the other hand, higher accelerating voltages resulted in blurred images.

The second sample is a green light emitting diode with a multiple quantum well (MQW) structure in the active region. The MQW structure consists of five 2.5-nm-thick InGaN wells separated by 10-nm-thick GaN barriers and is sandwiched by p- and n-GaN. These layers were grown on c-sapphire by MOVPE. The sample was obliquely polished from the surface (~10°) to improve the lateral resolution. Figure 2(a) shows an SEM image of the MQW structure taken at 3 kV. The wells appear as dark bands. Figure 2(b) shows a line profile across the p-n junction. We think the difference of the SEM signal intensity between p and n region corresponds to the built-in potential, and we assume the SEM signal intensity from each barrier layer varies with the piezoelectric field of the neighboring well. Based on these assumptions, piezoelectric fields of each well are calculated and the result is shown in Figure 3. Overall direction of the piezoelectric field is from the surface side to the substrate side. The strength decreases from the surface side to the substrate side. These features match with our previous analysis using electron holography [4]. But, the absolute strength is smaller than the previous one. This may be due to a possible relaxation of the strain in wells because of the oblique structure of the sample.

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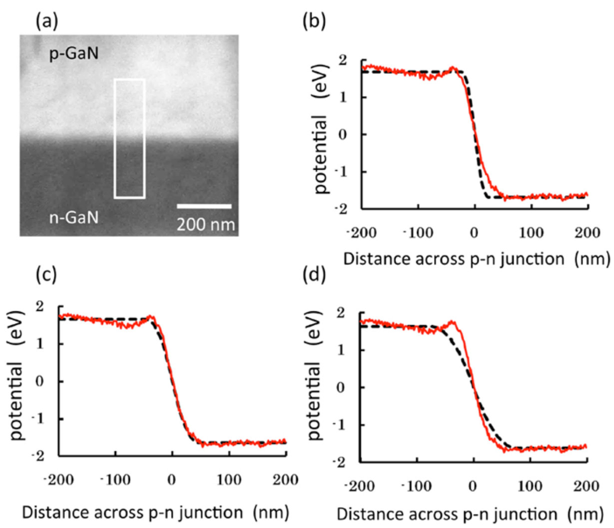

Fig.1 SEM image (a) and comparison of intensity profile across the junction with calculated potential profiles. The line profile was measured at the boxed region in (a). Dopant concentration: (b) 3×10^{17} cm^{-3}, (c) 8×10^{17} cm^{-3}, (d) 3×10^{18} cm^{-3}.

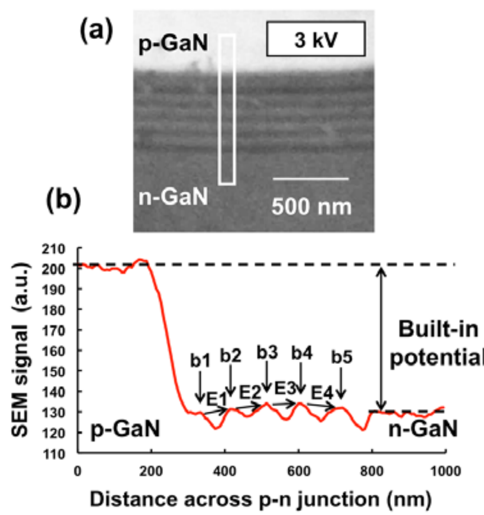

Fig.2 SEM image (a) and intensity profile across the junction (b). b1 to b5 indicates the position of barriers.

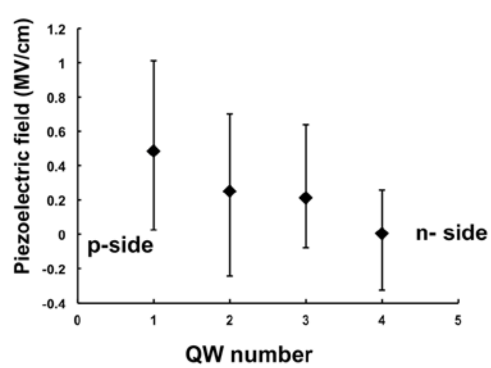

Fig.3 Estimated piezoelectric field strength. QWs are numbered from the p-side (surface side).

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