Both symmetric and asymmetric $\omega$–2$\theta$ scans are taken with a Bruker D8 triple-axis diffractometer using Cu K$_{\alpha1}$ radiation ($\lambda = 0.15406$ nm).

Fig. 7 shows the XRD $\omega$-2$\theta$ scans of samples A and B. The GaN (002), (004) and (102), (204) diffraction peak positions were used to calculate the lattice constants $c$ and $a$ by using the following equations:\(^1\)

$$d_{hkl} = \frac{\lambda}{2\sin(\theta_{hkl} + \Delta\theta)} = \frac{2\lambda}{2\sin(\theta_{2h2k2l} + \Delta\theta)}$$  \hspace{1cm} (1)

$$d_{hkl} = \frac{1}{\sqrt{\left(\frac{4}{a}k^2 + \frac{4}{c}h^2 + \frac{4}{b}h^2k^2\right)}}$$  \hspace{1cm} (2)

where $(h k l)$ are the indices of the diffraction plane, $\theta_{hkl}$ is the measured angular position of the $(h k l)$ reflection, $\lambda$ is the X-ray wavelength (0.154 nm for Cu K$_{\alpha1}$ radiation), and $\Delta\theta$ is the zero error of the instrument.

The in-plane strain was obtained by using the formula:

$$\varepsilon_{//} = \frac{a - a_0}{a_0}$$

Hence, the residual stress in the films can be roughly estimated by using the formula:
\[ \sigma = M \times \varepsilon_{//} \]

where \( \sigma \) is the in-plane stress, \( M (M_{\text{GaN}} = 202 \text{ GPa}) \) is the biaxial elastic modulus, and \( \varepsilon \) is the in-plane strain. The lattice constants of strain-free GaN are \( a_0 = 0.31892 \text{ nm} \) and \( c_0 = 0.51850 \text{ nm} \).\(^1\)

The calculated lattice constants, strains and stresses are listed in Table I:

<table>
<thead>
<tr>
<th></th>
<th>Sample A</th>
<th>Sample B</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c ) (nm)</td>
<td>0.51898</td>
<td>0.51907</td>
</tr>
<tr>
<td>( a ) (nm)</td>
<td>0.31836</td>
<td>0.31839</td>
</tr>
<tr>
<td>( \varepsilon_{//} )</td>
<td>-0.18%</td>
<td>-0.17%</td>
</tr>
<tr>
<td>( \sigma ) (GPa)</td>
<td>-0.35</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

According to the calculated results, it can be concluded that the in-plane stress in both samples are compressive stress in nature. Moreover, the calculated in-plane stress in sample A is almost same as that of sample B. There seems a discrepancy between the stress values from XRD results and Raman measurements. This discrepancy may come from the domain size characteristic of each technique.\(^3\) According to ref.3, the X-ray beam is scattered by the crystalline and the effect of lattice distortion is averaged over a large sample area through the whole depth for XRD characterization. In contrast, micro-Raman spectroscopy is a local technique that probes only the spot-size area with a shallow depth. Another source of error in the stress evaluation may come from the variation of the elastic modulus with film quality, which may be a significant source of error resulting in the discrepancy between the values obtained by these two techniques. However, it is a topic of ongoing investigation.

Reference