A4.2 Raman and IR studies of InN

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February 1998

A INTRODUCTION

Absorption and reflection in the near infrared spectral region have been employed to study the fundamental bandgap, phonons and the free carrier absorption in wurtzite InN films [1-7]. Raman spectroscopy has been used to identify the phonon modes [8,9].

B PHONON MODES

The first investigation of the phonon modes in binary InN was an extrapolation of the Ga$_{1-x}$In$_x$N ($0 \leq x \leq 1$) alloy modes in reflection towards the binary compound [1]. A typically high free carrier concentration in the mid $10^{20}$ cm$^{-3}$ controls the absorption (Drude absorption) in the infrared and must also be accounted for the broadened Reststrahlen band in pure InN films (e.g. in [1]). In this case infrared active phonons couple to the plasma of the free electrons forming phonon-plasmon coupled modes [10,11]. However, layers of low carrier concentration have been achieved and pure LO phonon energies have been derived in Raman spectroscopy. Resonant Raman spectroscopy at 514 nm has been performed assigning five of the six Raman allowed zone center phonon modes [8,9] (Table 1):

<table>
<thead>
<tr>
<th>Symmetry</th>
<th>active in</th>
<th>Raman (cm$^{-1}$)</th>
<th>Reflection (cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>[9]</td>
<td>[8]</td>
</tr>
<tr>
<td>$E_2$ low</td>
<td>$\Gamma_6$</td>
<td>Raman</td>
<td></td>
</tr>
<tr>
<td>$A_1$(TO)</td>
<td>$\Gamma_1$</td>
<td>Raman, IR</td>
<td>436</td>
</tr>
<tr>
<td>$E_1$(TO)</td>
<td>$\Gamma_5$</td>
<td>Raman, IR</td>
<td>471</td>
</tr>
<tr>
<td>$E_2$ high</td>
<td>$\Gamma_6$</td>
<td>Raman</td>
<td>488</td>
</tr>
<tr>
<td>$E_1$(LO)</td>
<td>$\Gamma_5$</td>
<td>Raman, IR</td>
<td>572</td>
</tr>
<tr>
<td>$A_1$(LO)</td>
<td>$\Gamma_1$</td>
<td>Raman, IR</td>
<td>593</td>
</tr>
<tr>
<td>$B_1$ low</td>
<td>$\Gamma_3$</td>
<td>(silent)</td>
<td></td>
</tr>
<tr>
<td>$B_1$ high</td>
<td>$\Gamma_3$</td>
<td>(silent)</td>
<td></td>
</tr>
</tbody>
</table>

* attributed to phonon-plasmon coupled mode by the present authors

An additional set of Raman lines in resonant scattering were reported and tentatively assigned: 190 cm$^{-1}$ ($E_2$), 400 cm$^{-1}$ ($A_1$), 490 cm$^{-1}$ ($E_1$), 590 cm$^{-1}$ ($E_2$) [6].

Despite resonant excitations conditions ($E_{\text{gap}}$(InN) = 1.9 eV) the Raman spectrum of InN strongly resembles that of GaN although shifted to softer modes. Note however, that the sequence of $E_1$(LO) and $A_1$(LO) appears to be inverted compared to GaN. The $E_1$ symmetry assignment of the reflection modes [2] was performed in Ref. 7 and by the present author after a reevaluation of the data. In addition, the large value of 694 cm$^{-1}$ indicates an $E_1$(LO)-plasmon coupled mode. It may be assumed that phonon frequencies in heteroepitaxial InN are subject to stress conditions in a similar way as in heteroepitaxial GaN.
CONCLUSION

Raman spectroscopy in InN is expected to become an important tool for the characterization of doping and stress conditions in heteroepitaxial material and device structures.

ACKNOWLEDGMENT

The authors have the pleasure to thank Prof. H. Amano for good collaboration and fruitful discussion. C.W. thanks Prof. E.E. Haller and Dr. J.W. Ager for previous collaborations. This work was partly supported by the Ministry of Education, Science, Sports and Culture of Japan (contract nos. 09450133 and 09875083, and High-Tech Research Center Project) and JSPS Research for the Future Program in the Area of Atomic Scale Surface and Interface Dynamics under the project of Dynamic Process and Control of Buffer Layer at the Interface in Highly-Mismatched Systems.

REFERENCES