We report on the growth of GaNAs and GaInNAs layers with Gas Source Molecular Beam Epitaxy (GSMBE) using the alternative nitrogen precursors NH$_3$ and DMHy. Emission wavelengths up to 1260 nm in the quaternary alloy semiconductor GaInNAs are demonstrated.

1. Introduction

For fiber communication laser diodes with emission wavelengths of 1.3 and 1.55 μm are of great interest. The material system InGaAsP on InP substrate is suited for this wavelength range. Preferable would be a system which is compatible to the well-known GaAs technology. Combining GaInNAs with wide gap materials such as AlGaAs that can be formed on GaAs substrate provides better electron confinement so that the characteristic temperature ($T_0$) of long wavelength laser diodes can be improved in comparison to devices based on InGaAsP/InP [1].

This becomes more evident if one considers the relationship between lattice constant and bandgap energy in III-V semiconductors (Fig. 1). Adding of In to GaAs increases the lattice constant while incorporation of N decreases it. By appropriate choice of In to N content GaInNAs can be grown lattice-matched to GaAs. The observed reduction of bandgap energy through adding In and N is an untypical behaviour for quarternary III-V alloy semiconductors.

Fig. 1. Relationship between lattice constant and bandgap energy [1].
2. Nitrogen Sources

The growth of N containing layers requires efficient sources of reactive nitrogen. Usually plasma-assisted nitrogen sources are used [1]. The generation of reactive nitrogen is done by RF, ECR or DC discharge. However, the creation of high energetic ions can lead to damages of the crystal during growth. This results in a degradation of optical quality.

Therefore, we investigate the alternative nitrogen precursors NH$_3$ and DMHy. DMHy is a particularly attractive source because it decomposes at relative low temperatures on GaAs substrate [2].

3. Epitaxial Growth

Epitaxial growth is carried out in a modified Riber 32P GSMBE. The injection of DMHy is made through a Low (LTI) and the injection of NH$_3$ through a High Temperature Injector (HTI). The Group-III-Elements In and Ga are provided as elements in effusion cells. The hydride arsine (AsH$_3$) serves as Group-V-precursor. As substrate semi-insulating (100) GaAs of epi-ready quality is used.

4. Material Characterization

Detection of nitrogen incorporation and its consequences on material quality and emission wavelength is measured by X-ray diffraction (XRD) and photoluminescence (PL).

A) Nitrogen Incorporation in GaNAs

The investigated samples are all of the same structure. After a 230 nm thick GaAs buffer follows a GaNAs layer of 100 nm.

With ammonia as nitrogen precursor one can recognize from the PL spectra that an increasing injector temperature leads to higher wavelengths (Fig. 2). For DMHy a reduction of substrate temperature results in longer emission wavelengths (Fig. 3).

From the corresponding X-ray measurements it is difficult to see a clear link between nitrogen incorporation and injector temperature for ammonia because of the relatively low nitrogen content (Fig. 4).
However, for DMHy as nitrogen precursor the relationship between substrate temperature and nitrogen incorporation is confirmed (Fig. 5). The redshift of the PL peaks from the bandgap of GaAs is consistent with the nitrogen concentration determined by XRD. Moreover the appearance of thickness fringes is an indicator for good interface quality.

![Fig. 4. XRD rocking curves of GaNAs/GaAs layers grown with NH₃.](image1)

![Fig. 5. XRD rocking curves of GaNAs/GaAs layers grown with DMHy.](image2)

Table 2 shows the comparison between the calculated nitrogen contents by PL and XRD measurements. The values obtained from photoluminescence were estimated using the following empiric equation [3]

\[
E_g(x) = 1.42 - 20x + 280x^2 \quad eV \quad ([N] < 3\%)
\]

Tab. 2. Comparison of nitrogen content as determined by XRD and PL for different nitrogen precursors.

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<thead>
<tr>
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<th>NH₃</th>
<th>DMHy</th>
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<tbody>
<tr>
<td>Sample</td>
<td>[N]</td>
<td>Sample</td>
</tr>
<tr>
<td>(T_{HT1})</td>
<td>PL XRD</td>
<td>(T_{substrate})</td>
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<tr>
<td>X450</td>
<td>0.40</td>
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<td>X470</td>
<td>0.64 0.2</td>
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With DMHy as nitrogen source a higher nitrogen incorporation in GaNAs is achieved. Latest results show an emission wavelength shift of 200 nm which corresponds to a nitrogen content of about 2%.

B) Nitrogen Incorporation in GaInNAs

To verify nitrogen incorporation in the quaternary semiconductor GaInNAs samples containing two quantum wells are grown. The first pure InGaAs quantum well in the layer structure, shown as inset in Fig. 6, serves as a built-in reference for the second GaInNAs quantum well grown under identical conditions. Fig. 6 and 7 show the low- and room-temperature PL spectrum of a sample with the second quantum well grown under NH₃ injection. A peak wavelength shift of 40 nm of the GaInNAs quantum well compared to the reference InGaAs quantum well is observed.
Up to now wavelengths close to 1200 nm are demonstrated with NH$_3$. Employing DMHy emission wavelengths up to 1260 nm are obtained at room-temperature (Fig. 8).

5. Summary

GaNAs is successfully grown by GSMBE using alternative nitrogen precursors. With DMHy a maximum wavelength shift of about 200 nm, being equivalent to a nitrogen content of about 2%, is achieved. In the material system GaInNAs wavelengths up to 1260 nm are reached. Further investigations will focus on device structures.

References
