Stimulated Emission and Optical Gain of InGaN Heterostructures grown by MOVPE production scale reactors

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Abstract

Heterostructures of compound semiconductors are of great importance for the rapidly increasing market of optoelectronical devices and high speed, high temperature electronics. This demandes very flexible large scale production systems that offer the growth of high-quality group III-nitride devices. The purpose of this paper is to show that by using production scale AIXTRON MOCVD systems it is possible to grow highly efficient GaInN heterostructures for device applications. The most important properties of these heterostructures are the efficieny of the stimulated emission and value of optical gain. These properties were increased by controlling and optimising the growth process.

Introduction

Due to an increased interest in the large scale production of GaN-based devices we have used AIXTRON single wafer horizontal tube and multiwafer planetary MOVPE systems for the fabrication of InGaN/GaN heterostructures, multi-quantum well structures and LED's. The drastic changes during the growth of these epitaxial films require a close inspection and controlling of the process conditions. The growth of III-nitrides, especially the InGaN/GaN system poses a challenge as temperature have to be changed by several hundred °C, molar flows differ by an order of magnitude and even total pressure may have to be altered. Therefore, carefully adapted designs of the reactor chambers have to be employed to guarantee the optimized growth of highly uniform layers with excellent physical properties. The quality of the ternary layers grown with the AIXTRON MOVPE system are described in [1]. The focus of this paper is to show the properties of stimulated emission and optical gain of these heterostructures and to demonstrate the ability to grow highly efficient device structures with production scale AIXTRON reactors.

Experimental

The samples presented here were grown in AIX 200RF horizontal tube and AIX 2000 HT planetary reactors, using TEG/TMGa, TMIn, NH_3 and SiH_4 as precursors. All samples contain a GaN buffer layer, grown with a nucleation layer on c-plane sapphire wafers. Statistical evaluations usually take the entire 2'' wafer area into account. The low-excitation measurements were performed using a He-Cd laser with an excitation wavelength of 325nm. To obtain the high excitation density necessary for our investigations we used an excimer laser, providing pulses with a duration of 15 ns at a rate of 30 Hz and a total energy of up to 20 μJ at 308 nm. The samples were mounted in a bath cryostat at 1.8 K. Gain measurements were performed using the stripe length method [e.g., 2].

Results

The low temperature photoluminescence measurements are displayed in Fig.1. The In-content of the heterostructures was determined by the splitting of the Θ/2Θ mode of X-ray diffraction measurements. With increasing In-content, ranging from 5 to 14%, a shift of the peak position from 3.1 eV for the 7 % InGaN sample to 2.9 eV for the 14% InGaN sample can be seen. The full with at half maximum (FWHM) increases with increasing In-content from 25 meV (5 % In) to 420 meV (14%In). This broadening can be explained by a strong increase of In fluctuations into the sample. The important In compositions are clustered in island like regions where the In-content is higher than those of neighboring regions. The local distribution of In clusters is revealed by EDX and CL measurements for the InGaN material system by several goups[3][4]. From the PL spectra it can be seen that samples with an In-content up to 13% do not change the lineshape drastically indicating the homogenous incorporation of In into the DH structures. This is confirmed by mappings of the entire wafer showing a standard deviation of less than 1.1 nm.[5]

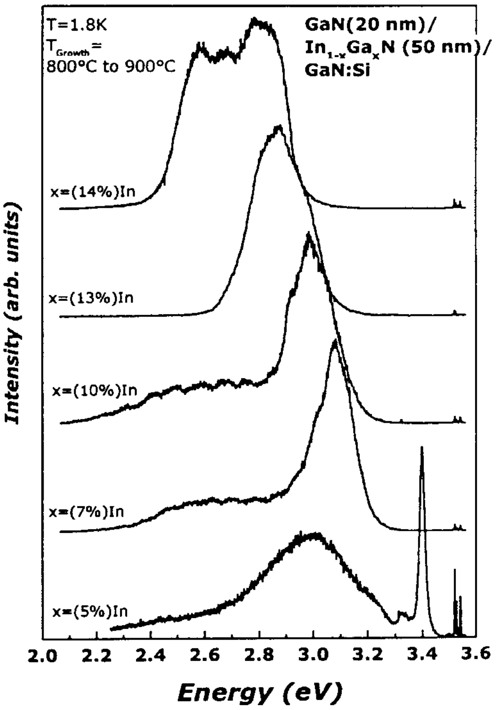

Fig. 1: *Low temperature PL spectra for various InGaN DH structures*

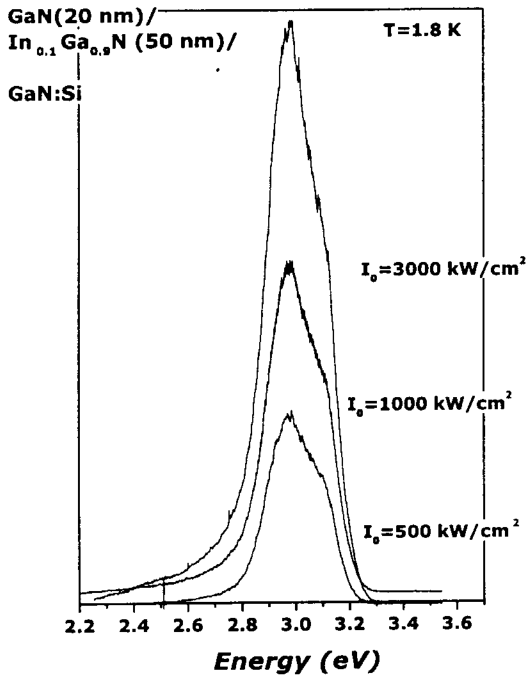

Fig.2 : *Intensity-dependent stimulated emission of a DH structure with an In-content of 10%*

With increasing excitation density the stimulated emission of the samples increases with increasing In content. The intensity-dependent stimulated emission of an 10% In-content sample is displayed in Fig. 2.

The peak position shifts to higher energies with increasing excitation density. This can be explained by the influence of piezoelectric fields in this material system. The strong piezoelectric fields in the samples are screened by photogenerated carriers. Therefore, the transition energy is increased by the weakend piezoelectric fields which leads to the observed blue shift.

The same effect can be seen in the gain spectra displayed in Fig. 3. With increasing excitation density the gain peak shifts to higher energies reaching again value of 70 cm^{-1} at an excitation density of 2 MW/cm^{2}. From the lineshape of the gain spectra an electron-hole-plasma is likely to be the dominating gain process.

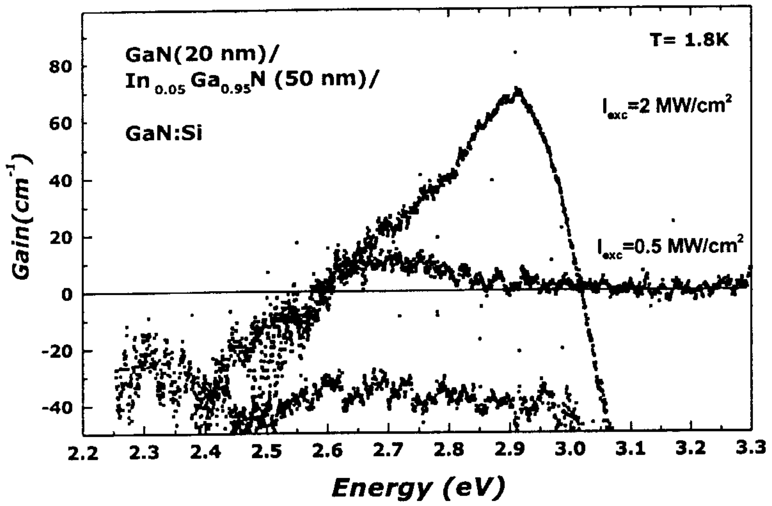

Fig. 3: *Intensity-dependent gain spectra for a DH structure with an In-content of 5%*

The cw-PL of the LED at 2 K is dominated by emission from the GaN:Mg layer. At a treshold excitation density of 500 kW/cm^{2} optical gain is observed. The peak gain values achieve 170 cm^{-1} at 5 MW/cm^{2}. These high gain values can be explained by an increased optical confinement in these heterostructures.

The best values of optical gain and stimulated emision exhibit the GaInN multi-quantum well structure. Here a threshold value for optical amplification of 200 kW/cm^{2} and gain values up to 140 cm^{-1} are observed at room temperature. These values are comparable to reported values [6],[7]. The stimulated emission at 3.23 eV appears strongly blue shifted with respect to the

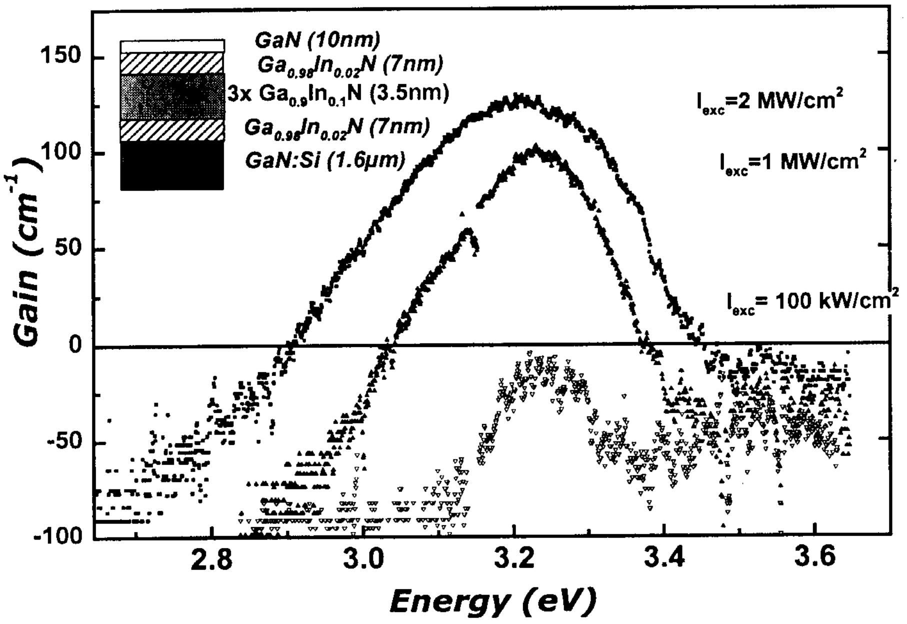

Fig. 4: *Room temperature gain spectra for a InGaN multi-quantum well structure*

spontaneous emission, which can be explained by the strongly screeend piezoelectric fields in the quantum well. As possible gain process a band-to-band transition is proposed from the lineshape of the gain spectra. The gain structure broadens with increasing photoinduced carrier density which can be estimated from the lineshape to be in the 10^{19} cm^{-3} range.

Conclusion

In conclusion various GaInN heterostructures were grown in MOVPE production reactors. The investigations of the optical properties clearly indicate the increased sample quality by optimizing the growth procedure. Double-heterostructures of device quality have been demonstrated, resulting in samples with state of the art composition uniformity across full 2 inch wafer. High gain values at the low threshold densities indicate the high-quality of the multi-quantum well samples grown by the large scale MOVPE reactors. These results resemble the high efficiency of the multi-quantum well device structures which are very promissing for optoelectronical applications.

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