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Optical and Electronic Properties of Ga(N,As,P) Quantum Wells on Silicon for Laser Application

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Abstract

The interplay of N-induced disorder and optical and structural properties of Ga(N,As,P) multi quantum wells on silicon has been investigated. Important optimal parameters have been revealed for the synthesis of monolithically integrated light sources for optoelectronic devices on silicon.

Introduction

The monolithic integration of suitable light sources on silicon is an important goal in today's optoelectronics. Realizing such a device enables one to combine the advantages of silicon microelectronics and optical data transmission. The quaternary material Ga(N,As,P) is a promising candidate for the realization of such a device and successful laser operation on Si substrate has already been demonstrated [1].

On the one hand, N is a crucial part of the luminescent Ga(N,As,P) quantum wells, as it enables lattice matched growth on silicon. On the other hand, N introduces a huge disorder that can influence the device performance negatively.

Here, we present a comprehensive analysis of monolithically integrated Ga(N,As,P) quantum wells on silicon substrate, in order to improve the device performance and understand the interplay of N-induced disorder and optical and structural properties.

1. Experimental

The sample structures under investigation were grown in a horizontal reactor using metal-organic vapor phase epitaxy (MOVPE). The substrate for growth was a GaP/Si template consisting of a 100 nm thick GaP nucleation layer on exactly oriented Si substrate [2,3]. On this substrate a multi-quantum well (MQW) was grown. It consists of three units of Ga(N,As,P) quantum wells separated by barriers of 5.6 nm GaP and 33 nm (B,Ga)P. The boron containing layers are introduced to reduce the strain in the sample, while the GaP interlayer prevents the formation of B-N center, which are a non-radiative recombination center. The MQW region is embedded in an optical confinement region of (B,Ga)(As,P).

To analyze the influence of N on optical and structural properties two different sample series were prepared. In the first series the samples were grown at $T_{gr.} = 575°C$ and annealed via rapid thermal annealing (RTA) at temperatures between $T_{a.} = 850°C$ and $T_{a.} = 1000°C$. The second samples series was grown at varying temperatures between $T_{gr.} = 525°C$ and $T_{gr.} = 700°C$ and the annealing temperature for the RTA process was kept constant at $T_{a.} = 925°C$.

In both sample series the N-content in the Ga(N,As,P) QW was kept constant at $x_N = 7\%$.

2. Results

Figure 1 depicts the room temperature photoluminescence of the samples with varying annealing temperature.

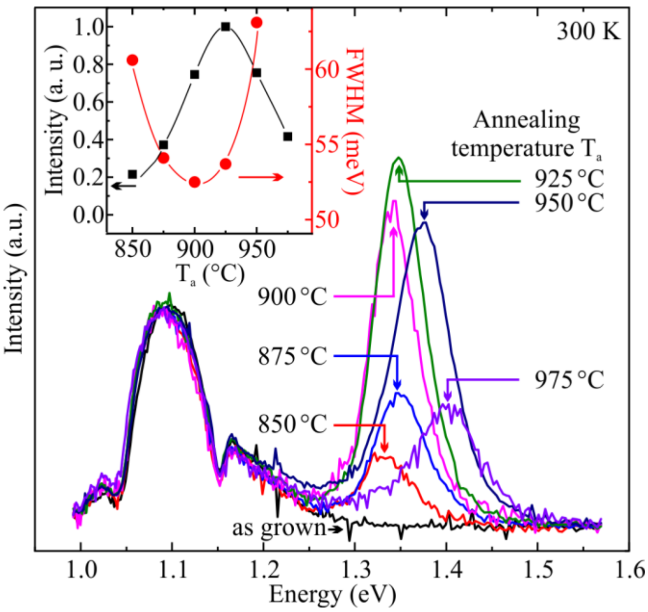

Fig. 1 PL spectra of the Ga(N,As,P) MQWs measured at room temperature. The spectra are labeled according to the annealing temperature $T_{a.}$ during the RTA process. The inset shows the integrated intensity of the Ga(N,As,P) luminescence (squares) and the full width at half maximum (circles) as a function of the annealing temperature $T_{a.}$. The solid line is a guide to the eyes only.

The room temperature PL in Fig. 1 is normalized to the silicon emission at 1.09 eV. The Si emission vanishes at low temperatures and the Ga(N,As,P) PL gains intensity by more than an order of magnitude. Already in the PL behavior one can see the complex interplay between structural and optical properties. On the one hand, the emission properties such as full width at half maximum (FWHM) and integrated intensity (c.f. inset of Fig.1) have are optimal around $T_{a.}$ = 925°C. On the other hand, there is a monotonous blueshift of the Ga(N,As,P) emission with increasing $T_{a.}$ indicating severe structural changes. A similar behavior is found for varying the growth temperature.

To further study this behavior, the disorder in the samples is investigated using temperature dependent PL. A two scaled disorder, typical for the Ga(N,As,P) material system [4-7], is found and quantized. To connect the disorder parameters to the structural properties of the samples X-ray diffraction (XRD) and high angle annular dark field transmission electron microscopy (HAADF-TEM) is employed. This allows to precisely determine the composition of the quantum wells and their morphology. Here, we find that the long ranged disorder, is caused by fluctuations in the quantum well width. Furthermore, the analysis of the intensity profiles of the TEM images allows to reveal changes in the composition and complements the XRD analysis. Furthermore, confocal Raman spectroscopy is employed to reveal changes in the samples composition. The GaAs-LO_{Γ} is especially sensitive to changes in the Ga(N,As,P) QWs, as these are the only arsenic-rich layer [7].

Photoluminescence excitation spectroscopy (PLE) and photomodulation reflectance spectroscopy (PR) is employed to analyze the electronic structure of the samples. These methods reveal ground and excited states of the Ga(N,As,P) QWs. The interconnection between Stokes shift and disorder is discussed. Additionally, the experimentally determined energetic position of these states are used as input parameters for a QW model, taking strain and the band anticrossing between the N-impurities and the Ga(As,P) conduction band into account. This allows us to determine the hetero-offets between the quaternary Ga(N,As,P) and the barriers.

3. Conclusions

The complex interplay between N-induced disorder and optical and structural properties of Ga(N,As,P) MQWs on silicon substrates will be discussed. Utilizing PL, PLE and PR the optical properties of the MQWs are revealed and connected to the structure of the samples. Therefore, a better understanding of the Ga(N,As,P) material system is achieved, allowing to find optimized parameters for the manufacturing of monolithically integrated light sources for optoelectronic integration on silicon.

Acknowledgements

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