ZnCdSe/ZnSe Quantum Wires by Epitaxy on Prepatterned GaAs Substrates

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The growth rate of ZnSe depends sensitively on the crystalline orientation. This anisotropic growth enables us to obtain lateral confinement in quantum wells grown on prepatterned GaAs substrates. We obtain blue light emitting ridge quantum wires and demonstrate the feasibility to fabricate V-groove quantum wires in II-VI compounds. The lateral confinement is studied by low temperature luminescence experiments.

1. Introduction

$Zn_{1-x}Cd_xSe$/ZnSe quantum wells can be utilized for the fabrication of laser diodes emitting in the blue-green spectral range. For III-V semiconductors it has been demonstrated that the spike-like density of states in reduced dimensions yields much narrower and higher gain peak values as compared to quantum well lasers [1]. Up to now, ZnCdSe/ZnSe nanostructures were fabricated by post molecular beam epitaxy (MBE) structuring and etching techniques [2]. However, these nanostructures suffer from damage induced by the etching process, and the optical properties are dominated by nonradiative recombination and strain relaxation processes [2]. For that reason, we investigate the possibility to realize quantum wires by MBE on patterned GaAs substrates, to achieve "V-groove" or "ridge" quantum wires.

2. Selectivity of the MBE Growth

As substrates we prepare (100) oriented GaAs gratings with a period of 800 nm by laser holography and subsequent preferential wet chemical etching. The etching gives trapezoidal shaped ridges, with (111) and (1-1-1) planes as side walls, embedded between grooves with various widths and depths. The substrates were dipped in HCl/H_2O before they were transferred into the MBE chamber. As reference, an unpatterned GaAs substrate was mounted on the same sample holder. The growth was performed at a substrate temperature of 350 °C in an anion enriched growth regime using elementary Zn, Cd, and Se effusion cells. To investigate the anisotropy of the growth, a sample was fabricated consisting of a stack of nominally 50 nm thick ZnSe and $Zn_{0.8}Cd_{0.2}Se$ layers. The transmission electron micrograph in Fig. 1 shows the cross section of this sample. It clearly demonstrates that the growth rate of both alloys, the ZnSe and the ZnCdSe, is smaller on the (111) side walls of the substrate grooves as compared to the (100) oriented substrate regions on the bottom of grooves and on top of the ridges.

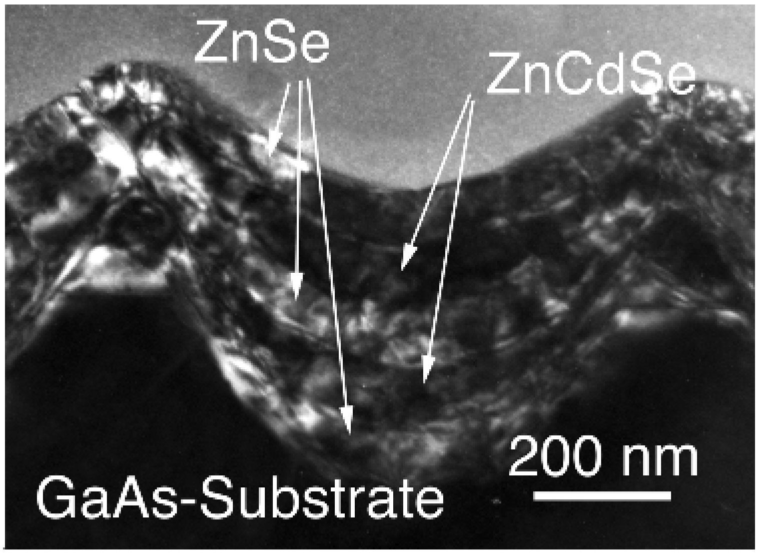

Fig. 1: Transmission electron micrograph of a stack of nominally 50 nm thick ZnSe/ZnCdSe layers grown on a patterned GaAs substrate.

According to these different growth rates, a quantum well grown on such a patterned substrate will be thinner at the sidewalls of the grooves also. Carriers in the quantum well will be confined in lateral direction by those thinner parts. The carriers will be localized in the potential minima of the well at the bottom of the grooves and on top of the ridges. Thus, quantum wires can be realized by the choice of the width of the (100) surfaces of the patterned GaAs substrates and by the choice of the buffer thickness under the quantum well.

3. Fabrication of Quantum Wires

In order to obtain quantum wires the following layer sequence was chosen: a 5 nm wide $Zn_{0.8}Cd_{0.2}Se$ quantum well was grown on top of a 150 nm thick ZnSe buffer layer and was capped by 120 nm ZnSe. This layer sequence was grown on two differently patterned substrates simultaneously. For both substrates the depth of the grooves was 160 nm. In sample no. 1 the width of the (100) planes on top of the ridges was 340 nm while for sample no. 2 this width was reduced below 20 nm. Fig. 2 (a, b) shows scanning electron micrographs of the sample cross sections. The surface height profiles are measured with an atomic force microscope (AFM). The results presented in Fig. 2 (c) and (d) demonstrate quantitatively the differences between these two samples. For sample no. 1, the surface shows narrow ridges with steep side walls restoring the initial (111) planes of the GaAs substrate. The ridges are separated by flat parts in the grooves. From the surface profile and the cross section (Fig. 2) it can be concluded that in this particular sample a quantum wire could be formed on top of the ridge while the lateral dimensions of the quantum well in the groove are to large to yield quantum confinement effects.

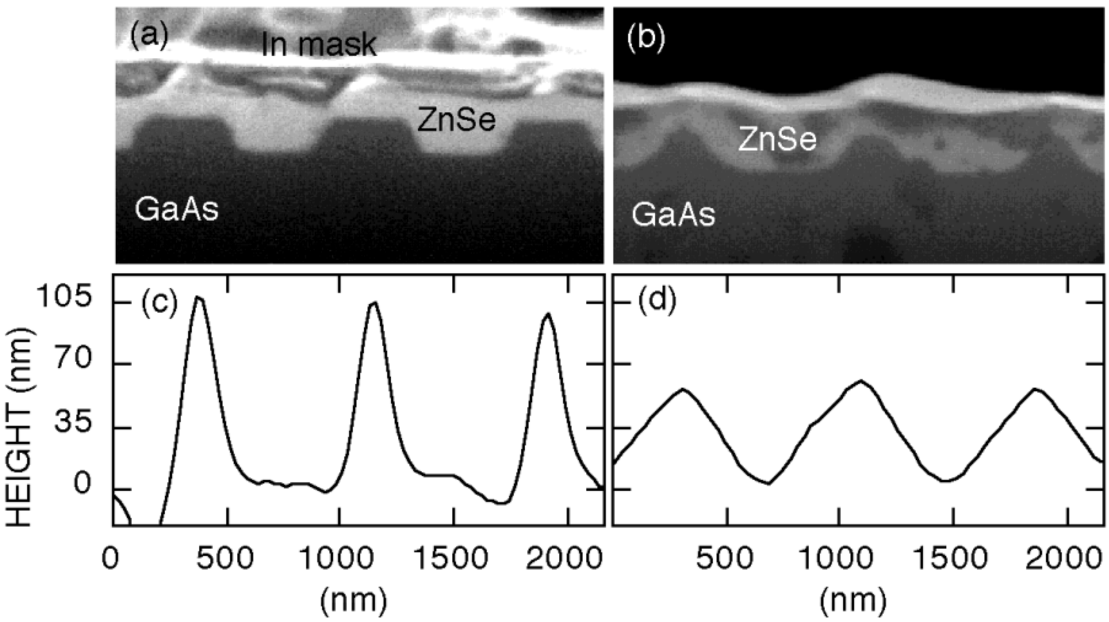

Fig. 2: Cross section of sample no. 1 (a) and no. 2 (b) together with AFM-height profiles of the surface in (c) and (d).

However, in sample no. 2 the situation is completely changed. This sample shows a zig-zag surface profile with a slope of the side walls much smaller than that of the substrate. This flattened surface indicates that the ZnSe grows slowest on top of the ridges. So, on such substrates quantum wires could be formed only in the grooves.

4. Optical Properties

At low temperatures the ZnSe/ZnCdSe quantum wire structures show bright luminescence in the blue-green spectral range. The two-dimensional reference sample shows a single, excitonic emission line at 2.60 eV with a width of 11 meV. However, the spectra of the quantum wire samples are much broader and exhibit a more complex shape. Sample no. 1 shows an emission maximum at 2.59 eV with a shoulder in the blue (Fig. 3 (a)). In the spectrum of sample no. 2 two distinct emission maxima are resolved. These emission spectra are a result of the anisotropic quantum well width. However, the luminescence is also affected by lateral carrier confinement [3] and strain relaxation [4]. An assignment of the photoluminescence spectra can be done only with the help of spatial resolved low temperature cathodoluminescence experiments. A detailed study will be presented elsewhere. However, for sample no. 1 the red edge of the luminescence is located on top of the ridge while in sample no. 2, in contrast, the origin of the red luminescence peak is on the bottom of the groove. So, the luminescence experiments confirm the suggestions presented above: sample no. 1 indeed represents a “ridge” quantum wire while sample no. 2 demonstrates the possibility to achieve blue light emitting “V-groove” quantum wires.

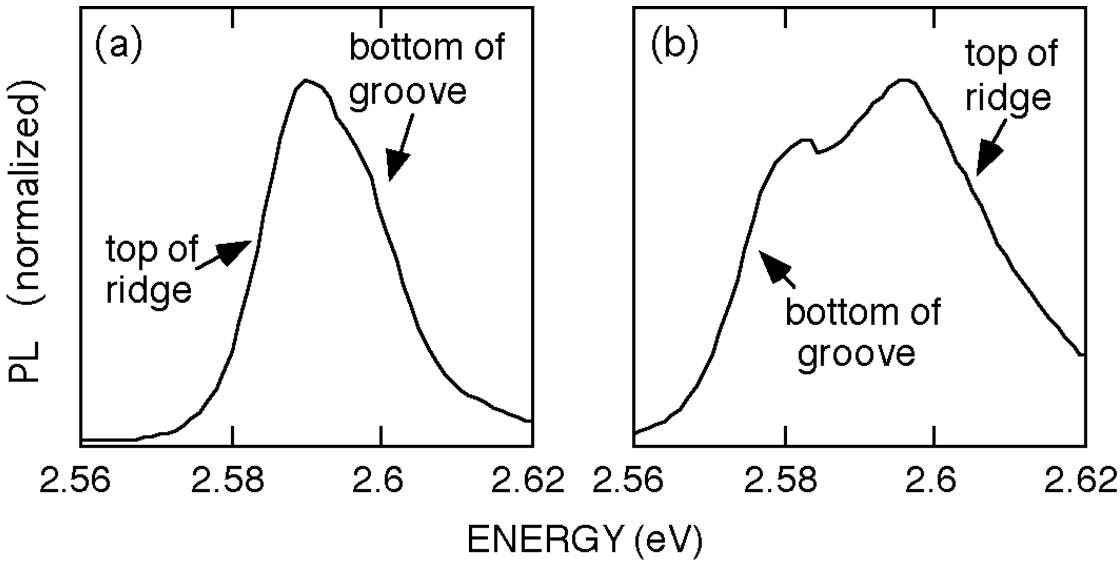

Fig. 3: Low temperature luminescence spectra of sample no. 1 (a) and no. 2 (b) excited by the 458 nm line of an Ar laser.

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References

[1] S. Tiwari, J. M. Woodall: "Experimental comparison of strained quantum-wire and quantum-well laser characteristics", *Appl. Phys. Lett.*, Vol. 64, 1994, pp. 2211 – 2213.

[2] T. Kümmel, G. Bacher, A. Forchel, G. Lermann, W. Kiefer, B. Jobst, D. Hommel, G. Landwehr: "Size dependence of strain relaxation and lateral quantization in deep etched $Cd_xZn_{1-x}Se/ZnSe$ quantum wires", *Phys. Rev. B,* Vol. 57, 1998, pp. 15439 – 15447.

[3] W. Heiss, D. Stifter, G. Prechtl, A. Bonanni, H. Sitter, J. Liu, L. Toth, A. Barna: "Lateral confinement in ZnSe/ZnCdSe quantum wells grown on patterned substrates", *Appl. Phys. Lett.*, Vol. 72, 1998, pp. 575 – 577.

[4] D. Stifter, W. Heiß, A. Bonanni, G. Prechtl, M. Schmid, K. Hingerl, H. Seyringer, H. Sitter, J. Liu, E. Gornik, L. Toth, A. Barna: "Molecular beam epitaxy of ZnCdSe/ZnSe wires on patterned GaAs substrates", *J. of Crystal Growth*, Vol. 184/185, 1998, pp. 347 – 351