High confinement energies of strained GaAs/InAlAs single quantum wire structures

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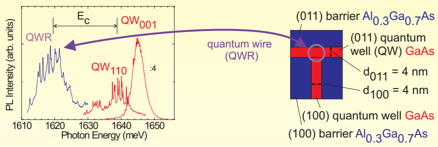
Motivation

Quantum wires, which form at the T-shaped intersection of two quantum wells, offer many advantages of 1D structures:

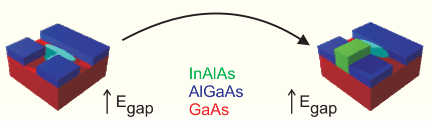
- modified density of states
- enhanced exciton binding energies
- concentration of the oscillator strength

→ low threshold currents in laser devices

In order to realize room temperature devices, large confinement energies are necessary. Using the symmetric structure shown below, a confinement energy E_c of 20 meV has been achieved.

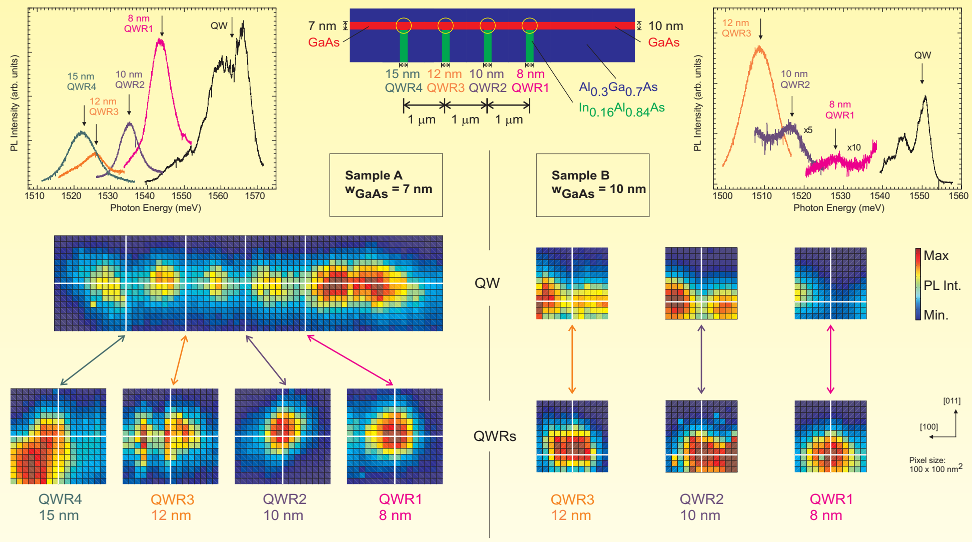


Although the structure can be optimized by varying the layer composition and widths, a new concept is needed to substantially improve E_c. For a structure proposed by Regelman et al. [1] calculations of Grundmann et al. [2] predict confinement energies of up to 90 meV. Whereas in conventional samples the wires form by the wave function spreading into the adjacent wells, the quantum wire is purely strain induced, if the (100) well is replaced by an InAlAs layer.



The large lattice constant of InAlAs (compared to GaAs) leads to biaxial strain during the first growth step, which is transmitted to the (011) GaAs QW, finally resulting in the QWR formation.

Identification of strain induced T-shaped quantum wires

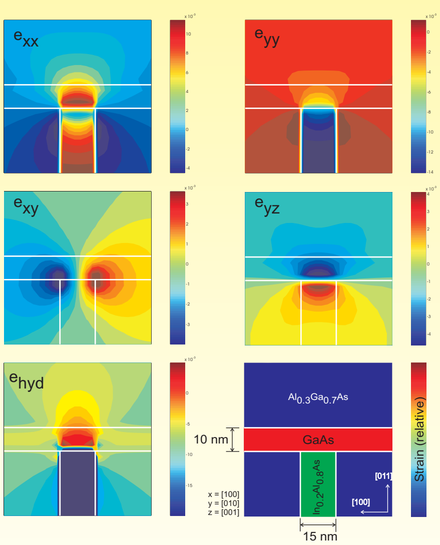


PL spectra of the GaAs QW and of QWR1 to QWR4 of sample A (left) and QWR1 to QWR3 of sample B (right) taken at the positions marked in the mappings below.
The mappings of the PL intensity at the photon energies marked in the spectra show clearly that the minima of the QW intensity coincide with the maxima of the QWR emission.

	Sample A	Sample B
	w_{GaAs} = 7 nm	w_{GaAs} = 10 nm
w_{InAlAs} (nm)	E_c (meV)	E_c (meV)
8	19	22
10	28	33
12	37	41
15	40	-

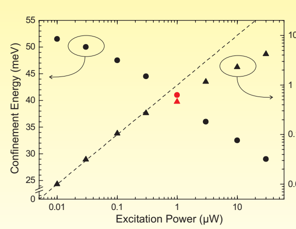
The lateral size (FWHM = 800 nm) is given by the spatial resolution of the confocal microscope. The mappings for QWR3 and QWR4 in sample A are smeared, requiring further investigations (see below).
The confinement energy E_C, which is defined as the difference between the transition energy of the QW and the QWR, varies systematically with the layer widths.

Simulation



Components of the strain tensor calculated with 'nextnano' [3]. This two-dimensional simulation results in positive values for the hydrostatic strain (e_{hyd}) at the T-shaped intersection. Here, purely strain induced QWRs are expected.

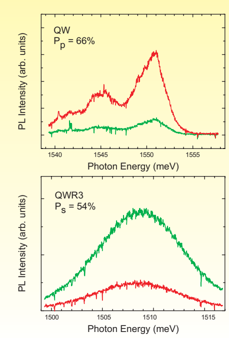
Power and Polarization dependence



Sample B (QWR3)
w_{GaAs} = 10 nm
w_{InAlAs} = 12 nm

The graph above shows that the confinement energy rises with decreasing excitation power (up to 51.5 meV). Even for 0.01 µW the line shapes of the QWR peaks remain smooth, which can only be interpreted as sub-exciton diameter scale interface roughness fluctuations along the wire.

The spectra on the right show the PL light detected with polarization parallel and perpendicular to the GaAs QW. Although the light emitted from the QW is polarized in plane, the QWR signals are preferably polarized perpendicular. This reflects the fact that tensile strain is the basis for the QWR creation.



p $P_p=(I_p-I_s)/(I_p+I_s)$
s $P_s=(I_s-I_p)/(I_s+I_p)$

AFM pictures of the (0$\bar{1}$1) surface

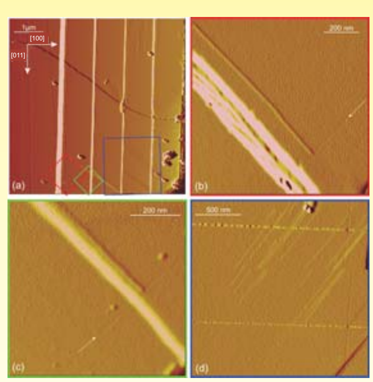


Figure (a) shows 6 x 6 μm^2 of the (0$\bar{1}$1) surface of sample A. The picture is dominated by four (white) steps with heights ranging from 7 to 67 nm. The InAlAs layers of QWR1 (b) and QWR2 (c) are located close to the steps (the arrows mark the (110) GaAs QW). However, for QWR3 and QWR4 the stressor layer lies within the step, giving a possible explanation for the smeared mappings above.

References

[1] D. V. Regelman and D. Gershoni, Proceedings of the 24th International Conference on the Physics of Semiconductors, 1111 (1999).
[2] M. Grundmann et al., Phys. Rev. B **61**, 1744 (2000).
[3] www.nextnano.de

Support and Acknowledgement

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Sample growth and characterization

All samples were grown by molecular beam epitaxy using the cleaved edge overgrowth technique resulting in precisely defined quantum structures.
Spectrally and spatially resolved information is obtained with the help of a micro-photoluminescence setup. The excitation light is focused on the sample in the cryostat, which is mounted on a piezo translation stage. A pinhole selects the PL light from the excitation spot and a double monochromator in combination with a CCD is used to obtain the spectra.

Summary and Outlook

- Realization of novel cleaved edge overgrowth QWRs.
- Structures exhibit large confinement energies (up to 51.5 meV), systematically depending on the layer width. PL signals indicate smooth uniform wires (no natural quantum dots).
- Transfer to zero dimensional quantum dots:
  High confinement energies in 'artificial atoms'