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Invited

InGaAs Strained Quantum Wire Structures: Optical Properties and Laser Applications

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Pseudomorphic $In_{0.2}Ga_{0.8}As$/AlGaAs quantum wires (area=860nm^2) are grown as the active region in a laser structure on a V-grooved GaAs substrate. Spatially resolved cathodoluminescence unambiguously identifies the luminescence from the wire. A carrier lifetime of 1ns is measured almost identical to values found for comparable InGaAs quantum wells. Lasers grown on sub-μm pitch gratings are operated with waveguides oriented either parallel or perpendicular to the wires. Distributed feedback effects due to Bragg reflection off the periodic wire array are observed for the perpendicular configuration.

Single- and multiple-quantum wire (QWR) GaAs/AlGaAs diode lasers grown by organometallic chemical vapor deposition (OMCVD) on V-grooved substrates have been reported[1)-3)]. The *in situ* formation of crescent-shaped GaAs wires results in defect-free wire interfaces, leading to high quantum efficiency and sub-mA threshold currents at room temperature[2)]. Enhanced optical gain at the QWR subbands has been reported [1),2)].

This concept of fabricating QWRs *by self-organized growth* of quantum wells (QWLs) over nonplanar substrates is extended to the pseudomorphic system $In_{0.2}Ga_{0.8}As$/AlGaAs. The InGaAs QWR is grown as the active region in a laser structure between graded $Al_xGa_{1-x}As$ (*x=0.2-0.7*) cladding layers of a GRINSCH laser structure. As a substrate we used a (100) wafer *n*-GaAs with wet chemically etched V-grooves oriented in the [011] direction having various pitch.

For a systematic luminescence analysis, well separated (*pitch=3.5μm*) *single QWRs* were used. Details of sample structures and growth conditions are given elsewhere[4)]. The cross sectional transmission electron microscopy (TEM) image of the bottom of one V-groove (see Fig. 1) shows the crescent-shaped InGaAs QWR in the center. The InGaAs QWL layer grown on the {223} side wall exhibits quasi-periodic thickness modulation with a pitch of approximately 60nm, possibly due to strain accumulation resulting in 3D growth; similar periodic structures were reported on {111} [5)]. The thickness of the QWR is 22nm in the center, the lateral geometrical width 78nm.

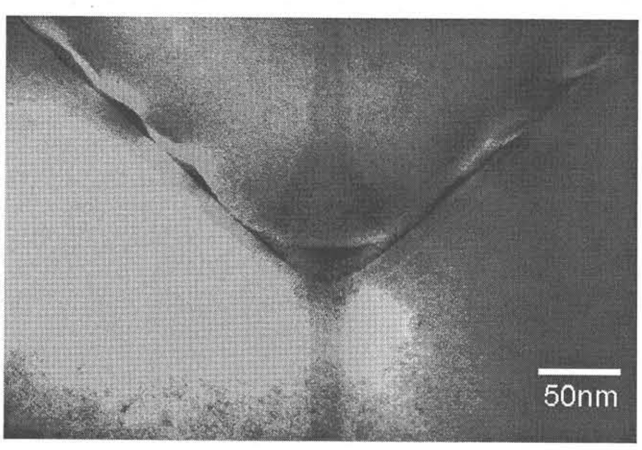


Fig. 1. TEM image of InGaAs single QWR in the GRINSCH at the bottom of V-groove.

The critical thickness for a $x = 0.20$ QWL is L_c = 15nm [6),7)]. Our QWLs are well below this value, whereas part of the QWR has a thickness above L_c. However, in TEM we could not find any defects due to the lattice mismatch. The strain energy stored in such a narrow QWR may not exceed the energy required to generate misfit dislocations. The electric field in the undoped GRINSCH and QWR region is about $4x10^4$V/cm, having only a minor effect of a few meV on the QWR energy levels[8].

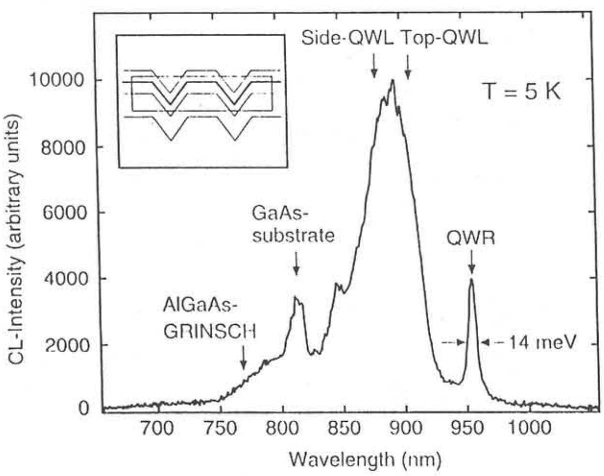


Fig. 2. Laterally averaged luminescence spectrum of QWR cross section (see inset).

The low temperature (*T=5K*) laterally averaged luminescence spectrum given in Fig. 2 of the cross sectional view consists of various peaks. The different spectral components of the luminescence stemming from the AlGaAs barriers, the top quantum well on the ridge in between the grooves (L_z = *7nm*, which is about half the critical thickness), the sidewalls and the InGaAs wire itself can be unambiguously attributed to the respective regions using spatially resolved cathodoluminescence (CL)[4)9)]. The $Al_yGa_{1-y}As$ GRINSCH emits at wavelengths 750-800nm, at 820nm the GaAs substrate dominates the spectrum, and the broad peak at 900nm consists of the emission from the sidewall QWL (higher energy side) and the top QWL (lower energy side). The wire emits at a peak wavelength of λ =*955nm* (1.298eV) with a full width at half maximum of 14meV. The absence of luminescence from the vertical QWL[10)] in the AlGaAs indicates a very fast depletion of the GRINSCH. Only in the very vicinity (Δz<*200nm*) of the QWR the vertical QWL has a direct bandgap and carriers which are generated there are most probably captured by the QWR on a sub-ps-timescale[11)] and/or separated by the *pn*-junction of the laser diode. Time-resolved CL experiments[9),12)] were performed on a reduced scan area (see inset of Fig. 3a) of 1μm^2 around the QWR center. For the decay of the QWR luminescence we find an initial recombination time constant of 1.0ns which compares well with carrier lifetimes found for InGaAs quantum wells of similar thickness and shows that the recombination is dominated by radiative processes. At longer delay times a much slower (τ=*30ns*) decay tail is observed. Time delayed spectra recorded in seven succeeding time windows (w0= pulse, w1=0.8ns, w2=2.4ns, w3=4.5ns, w4=10.4ns, w5=37ns, w6=95ns) as shown in Fig. 3b allow for an identification of the corresponding recombination process. After the initial decay of the QWR luminescence at 955nm within the first ns an extrinsic peak evolves at 958nm having a much slower decay.

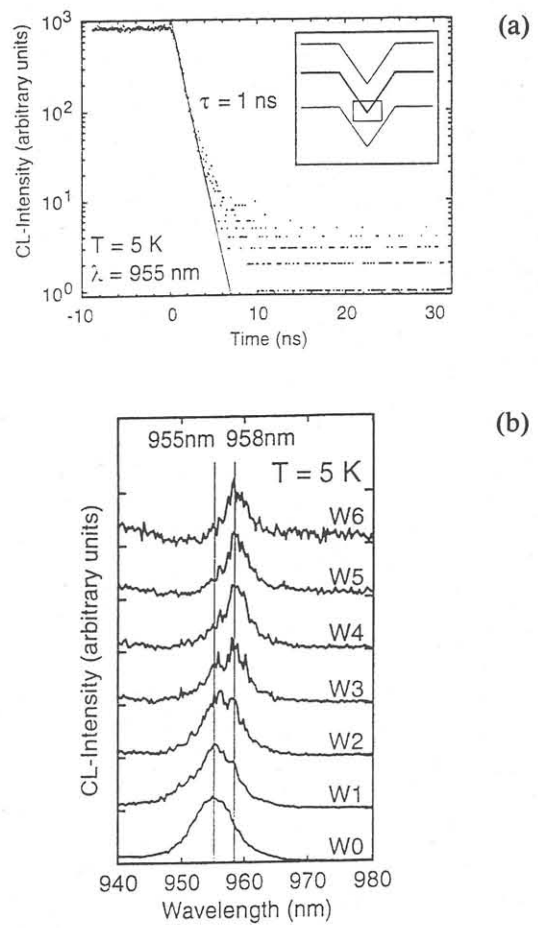


Fig. 3 Transient (a) and time delayed spectra (b) of QWR luminescence.

Strained InGaAs/GaAs QWR laser grown on sub-μm (250nm) pitch gratings were operated with waveguides oriented either parallel or perpendicular to the wires[13)] . (See Fig. 4 for the laser structure). Distributed feedback effects due to Bragg reflection off the periodic QWR array were observed for the perpendicular configuration[13)]. The lateral stack of crescent shaped InGaAs QWRs, 14-17nm thick and 70-80nm wide, located near the center of the optical waveguide are clearly visible in the cross sectional TEM in Fig. 4. The strain field produced by the lattice mismatch shows clearly up in form of darker contrast above and below the QWRs. A QWR subband separation of 8meV for electrons and 1.5meV for light holes is obtained in an adiabatic model calculation[1].

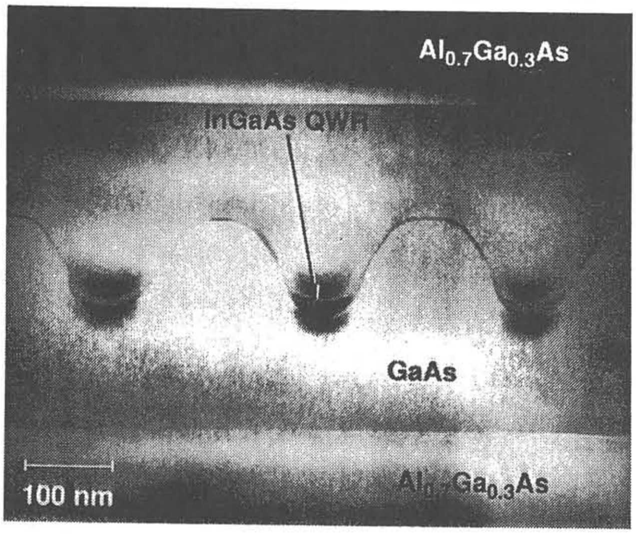
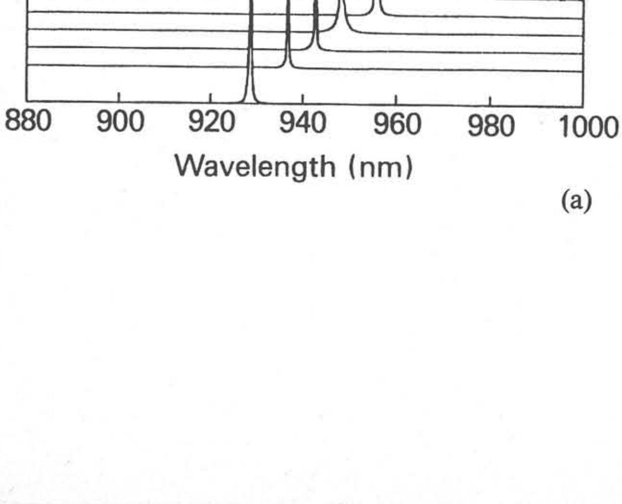


Fig. 4. Strained InGaAs/GaAs QWR laser on a sub-μm pitch grating.

Fig. 5 displays the emission spectra of uncoated lasers under pulsed condition. For the parallel configuration (a) the emission wavelength shifts monotonically to higher values with increasing temperature, following the band gap of the material. In contrast, for the perpendicular configuration (b) the lasing wavelength is locked near 920nm for T<150K, corresponding to the second order Bragg reflection of the QWR array. A tuning



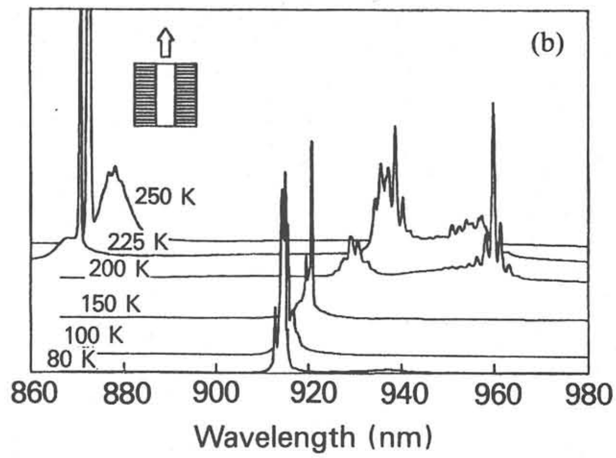


Fig. 5. Temperature dependence of the lasing spectra of the pseudomorphic InGaAs QWR-array lasers for cavity oriented parallel (a) and perpendicular (b) to the wires.

of 0.022nm/K is observable, consistent with the variation of the refractive index. Above 150K the laser wavelength is decoupled from the Bragg value as the peak of the gain spectrum shifts.

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