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Quantum wires obtained by dislocation slipping

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ABSTRACT

Dislocation slipping is used as an atomic scale tool to cut a 5 nm GaAs single quantum well (QW) grown by MBE on a (001) GaAs substrate into quantum wires (QWW). Three point deformation bending is used to control dislocation slipping. The minimum value of the QWW widths is evaluated to 25 nm. PL studies after deformation show intense peak, shifted in regard to the undeformed SQW in good agreement with theory. Raman scattering results confirm the additional lateral confinement.

1. INTRODUCTION

QWW have received intense interest over the past few years but for experimental studies the most important step is the fabrication and control of nanostructured semiconductors. Two major ways can be distinguished : the direct growth of wires (on vicinal or V-grooved substrates) [1] and the patterning of existing two dimensionnal (2D) structures by nanometer scale lithography followed by etching [2] or by selective ion implantation [3] but these techniques have to deal with either surface recombination or smooth potential barriers; in both cases the size dispertion is small but a lot of active material is lost during the processes.
Recently, we showed that dislocation could be an ideal tool to cut an existing 2D structure in 1D or even 0D. The method we propose leaves the entire active region free of damage and thus keeps the optical and transport properties of the system unaltered except for the consequences of the lateral confinement; it is also applicable to any crystalline material but we tested it on the well known $GaAs/Al_xGa_{1-x}As$ system.

2. PRINCIPLE

The basic principle can be simply described as follow : a GaAs crystal, submitted to a stress higher than its elastic limit, deforms plastically if the temperature is sufficient to allow motion of the dislocations in their slip planes. A source emits a dislocation loop which increases in size until it reaches the free

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surface of the crystal : at this point, one part of the crystal is shifted with respect to the other by an amount equal to the Burgers vector $\vec{b}$ of the dislocation.

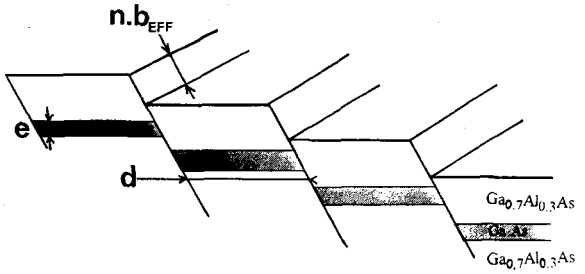

figure 1 : schematic view : different sources have been considered to obtain QWW.

It should be pointed out that, in the volume, the crystalline perfection is fully restored. So, if a GaAs layer of thickness e is sandwitched between two AlGaAs barriers it will be completly cut when a source has emitted n dislocation loops with n satisfying $n.b_{eff} \geq e$, where b_{eff} is the component of the Burgers vector along the growth direction

So, the control of the slip by choosing the crystal orientation, stress conditions, temperature and sources density, will provide a perfectly adapted tool to pattern a 2D stucture in 1D (or even 0D).

3. DEFORMATION CONDITIONS

GaAs plasticity in simple slip configuration has been widely used [4], but since M.B.E. grown AlGaAs/GaAs systems are available only on (001) substrates, we choose to use a three point bending test in order to demonstrate the efficiency of the method for the following reasons : a bending test is a simple way to apply a tensile stress, no cutting stress being involved ; in addition, from the (001) surface to the $(00\bar{1})$ one, the stress varies linearly from tension to compression and the neutral plane at the center acts as a barrier for dislocation slipping; and finally we can obtain in only one sample different deformation conditions with a curvature radius varying from 3 mm to infinity. The major disadvantage of being bended for our samples lies in the fact that this configuration causes a major problem for photoluminescence (PL) measurements and most important, polarisation studies. But it should be emphasized that other configurations can be used on different substates.

The stress orientation along $[1\bar{1}0]$ favours the development of 60°α dislocations sources from the surface on which the active layer is grown. The choosen temperature 673K is much lower than the growth temperature to prevent any degradation of the sample. The surface strain rate is about $10^{-5}s^{-1}$ in order to favour slipping deformation mechanisms.

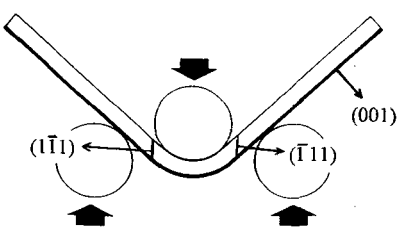

figure 2 :three point bending test

4. RAMAN AND PL MEASUREMENTS

Raman and PL spectra are recorded at room and liquid nitrogen temperatures using several Ar^+ laser lines as excitation. The laser beam is focussed on the most deformed part of the sample. The signal is dispersed trough a triple spectrometer and collected by a low noise photo-counting system. Three samples grown by M.B.E. on (001) GaAs Substrates are analysed within the same experimental conditions: an homoepitaxial GaAs layer (A), a 5nm QW embedded in $Al_xGa_{1-x}As$ before (B) and after(C) deformation. In order to enhance the QW signal versus the substrate one the thickness of the top barrier is limited to 20 nm whereas that of the bottom barrier (between the QW and the substrate) is

fixed at 200 nm. Taking into account the value of the absorption coefficient of GaAs,α_1 =(46nm)$^{-1}$ and of $Al_{0.36}Ga_{0.64}As$,α_2 =(81nm)$^{-1}$ for λ=454.5nm, 97% of the GaAs signal originate from the QW. As a matter of fact no substrate luminescence is detected, so only barriers and QW are analysed.

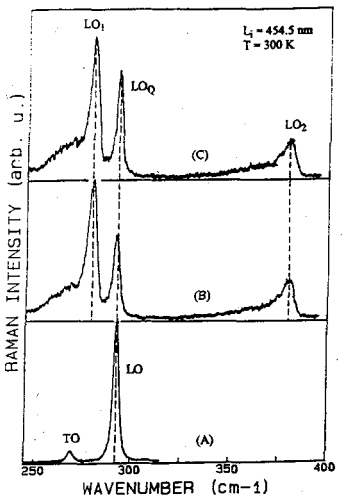

figure 3 : Raman spectra

Three structrures are easily identified on Raman spectra recorded at 300 K : the GaAs-like (LO_1) and AlAs-like (LO_2) modes of the barriers and confined mode of the QW (LO_Q). The frequency separation (110cm^{-1}) between LO_2 and LO_1 allows to determine the composition [5]: x=0.36± 0.01. The frequency shift on spectrum B (-1cm^{-1}) of the LO_Q versus bulk GaAs LO manifests itself as a 2D confinement effect [6].The comparison between B and C spectra shows negligible modification of the barrier. Deformation leads to a small braodening, an intensity increase and a shift towards higher frequency of the LO_Q feature. Neither chemical intermixing nor structural degradation is observed. On the contrary, the increase of the LO_Q signal shows a selective enhancement of the electron-LO phonon interaction. This may originate in and additive lateral confinement. Polarisation measurements (not reported here) show that the in-plane isotropy of the GaAs layer is effectively lost: the LO_Q signal is only modified for incident and scattered field polarisation parallel to the expected wire direction.

The PL spectra from the QW and from the barrier are recorded at 77K using the highly absorbed 454.5nm line.

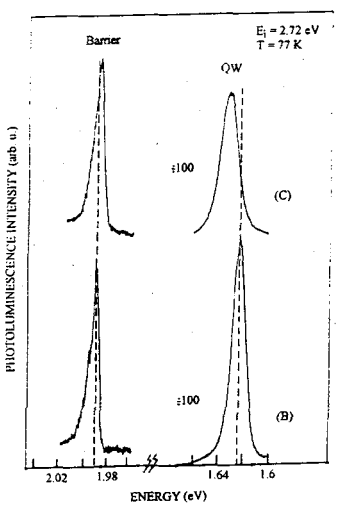

figure 4 : PL spectra

The energy position of the peaks (1.623 and 1.989 eV) in the undeformed sample (B) is in good agreement with the alloy composition and QW width. After deformation (C) no lineshape change is observed on the signal assigned to the barriers, testifying that their chemical and structural characteristics are preserved during the deformation process. Only a sligth energy red-shift (-2.5meV) is detected. It may originate from (a) a tensile residual stress, (b) a lowering of the x composition and/or (c) a local heating by the exciting beam. However deformation leads to a blue shift (+9.3meV) of the QW PL signal. It should be pointed out that the PL signal intensity is only sligthly reduced. Hence, the energy shift is of opposite sign for the QW and the barriers: the (a) and (c) hypothesis can be ruled out. Moreover, the constant value of the LO_2-LO_1 Raman frequency and the positive shift of the LO_Q frequency are already in contradiction with hypothesis (b). Therefore, only the effect of and additional confinement is relevant.

In addition, the exciton energy shift value (10meV) is in good agrement with an average wire width of 25nm [7]. The broadening of the line observed on the deformed sample can be reasonably attributed to fluctuations on the wire width.

5. CONCLUSION

The dislocation is used here as an interatomic tool which does not degrade the 2D crystalline structure. The results reported here, either Raman spectroscopy or PL, give evidence that additional lateral confinement is obtained in a controlled deformation process. This method presents the advantage of producing wires on the whole MBE grown surface and is particularly well suited for GaAs/AlGaAs systems were mechanical properties of both compounds are very close. In addition, due to its principle, the obtained wires have the same length (as large as few mm) as the starting sample itself.

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