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Strain Induced Carrier Confinement in a Buried Stressor Structure

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A buried stressor structure was proposed and fabricated using *in situ* focused ion beam sputter etching and molecular beam epitaxy for the first time. Strain induced band gap modulation and the consequent carrier confinement were demonstrated by cathodoluminescence spectra. Theoretical calculation was performed to optimize structural parameters. A potential well up to 12 meV was formed. The experimental results are in good agreement with the theoretical prediction.

1. INTRODUCTION

Advances in the growth and processing of semiconductor materials have led to ultra small structures in which quantum effects are dominant. Several methods have been proposed to obtain quantum confinement in more than one dimension. These include electron beam lithography[1)], ion implantation induced interdiffusion[2)], tilted superlattice (TSL)[3-5)], and growth on patterned substrates[6)]. Some 1-D effects have been observed, such as blue shift in the photo luminescence spectra[7)], splitting of the sub-bands[8,9)], and periodic conductance oscillations as a function of density[10)]. However, these methods either introduce damage to materials in processing, or difficulties in controlling the growth. Recently, damage free lateral confinement has been demonstrated by means of strain induced confinement[11,12]], this method allow the lateral modulation of band gap, manifesting the potential to form quantum confinements without any damage.

In this paper, we proposed and fabricated a buried stressor structure. Theoretical calculation using continuum elasticity and a strain hamiltonian were performed to optimize the structural parameters. *In situ* process techniques using focused ion beam etching and molecular beam epitaxy were used to realize this structure. Cathodoluminesence measurement was employed for the structure characterization.

2. EXPERIMENTAL

Fig. 1 shows a schematic diagram of the buried stressor structure and conduction and valence band. This structure was fabricated by *in situ* sputtering of an InGaAs pseudomorphic layer using focused ion beam (FIB) and regrowth using molecular beam epitaxy (MBE). The structure consists of a strained $In_{0.30}Ga_{0.70}As$ layer and a regrown $GaAs/Al_{0.3}Ga_{0.7}As$ QW. The biaxially strained InGaAs layer is separated from carrier confining GaAs QW by a thin AlGaAs layer. The thickness and barrier height of this thin layer are designed so as to prohibit carrier tunneling effect from the QW to the InGaAs layer. The parameters of the InGaAs layer (hardness, growth temperature) are chosen to gain maximum strain without breaking pseudomorphic growth regime. After patterning of the InGaAs layer and regrowth, the compressed InGaAs layer is allowed to relax partially, producing a pattern of inhomogeneous strain in the upper regrown QW. The spatial modulation of band gap in the QW is related to the strain of the material at each point by the hydrostatic and shear deformation potential. Thus a potential well should be created in the GaAs QW.

The detailed structure and the processing scheme are shown in Fig.2. A UHV shuttle chamber ($<1\times10^{-9}$ torr) is used as a sample carrier between the MBE and the FIB. The pre-growth started with semi-insulating GaAs (100) wafer. After growing smoothing superlattice and 500 nm buffer layer, the growth temperature was cooled down to 520 ^{o}C for InGaAs growth. RHEED oscillations were used to monitor the pseudomorphic growth of InGaAs layer and the thickness of InGaAs was 6 nm. A 1.5 nm GaAs was grown on the InGaAs layer to prevent the oxidation of InGaAs. The sample was then transfered to the FIB chamber for ion beam sputter etching. The sputter etching was carried out with 50 keV Ga^+ beam. The beam current was 40 pA and beam diameter (FWHM) 150 nm for 50 keV Ga^+ ion. InGaAs gratings with periodicities ranging from 100 nm to 2000 nm were fabricated. Following the sputter etching the sample was transfered into MBE chamber and annealed at 540 ^{o}C for 60 min under an As_4 flux before starting regrowth. The regrowth temperature was kept at 520 ^{o}C

to suppress indium diffusion. Five GaAs quantum wells with well widths 15nm, 8nm, 6nm, 3nm and 2nm were grown on the InGaAs. The distances from the regrown interface were 20nm, 100nm, 300nm, 500nm and 700nm. The aluminum composition for barrier AlGaAs was 0.3. After regrowth the sample was annealed at 900 °C for 20 sec with a GaAs to anneal out FIB induced damage.

3. RESULTS AND DISCUSSION

Low temperature cathodoluminescence provides both high spatial and high spectral resolution, which gives us an effective tool to characterize the strain induced band gap modification. Fig. 3 shows the CL spectra of the GaAs QW structure regrown on the InGaAs gratings. The GaAs QW had a well width of 8 nm, and was 100 nm away from the InGaAs layer. The width of the InGaAs grating stressor was 0.8 um, and the thickness 6 nm. As evidenced on the spectra, only one peak was observed for the QW on the uniform InGaAs layer. Two pronounced peaks can be resolved for the QW region regrown on the InGaAs grating, one at 789 nm, and the other at 782.4 nm, corresponding to a 6 meV red shift and a 6.6 meV blue shift. This was caused by the band gap modulation in the QW.

In order to obtain the information on the lateral modulation of the band gap, spatially resolved photon counting line scan were performed by scanning the electron beam cross the strained quantum well and measuring the photon counts at a fixed wave length, as shown in Fig. 4. At λ = 789 nm, the peak appeared at the center of each grating, indicating most photon came from center of the grating at this wave length, which is consistent with the strain induced band gap shrinkage predicted by the continuum elasticity theory[13]. At λ = 782.4 nm, the peak existed at the edges of the grating, suggesting a thinner QW was formed. The regrowth on a FIB implanted layer is generating point defects that are migrating during RTA. This causes Ga-Al interdiffusion at AlGaAs/GaAs interface[14], and Consequently, a blue shifted peak was observed.

The strain tends to disappear as the distance to the stressor increases, hence the red shift is dependent on the distance between InGaAs stressor and QWs. Fig. 5 shows the red shift as a function of the distance between stressor and QW. The open circle is the theoretically value calculated value using continuum elasticity theory and a strain Hamiltonian. The black circle indicates experimental data. It is clear that experiment and calculation are in good agreement.

In this experiment the strain induced band gap modulation was not very large, this was primarily due to the very wide stressor (800 nm). From the calculation using continuum elasticity theory we found that the strain induced band gap shrinkage can succeed 25 meV if the width of the stressor is 60 nm. Therefore, high resolution and low damage etching are desirable to obtain high band gap modulation.

4. SUMMARY

We proposed and fabricated a buried stressor structure to achieve in-plane band gap modulation. Theoretical calculation were performed using strain Hamiltonian to optimize structural parameters. A unique UHV *in situ* focused ion beam processing and MBE regrowth techniques were then developed to realize the structures. Cathodoluminescence measurement were used to characterize this structure. A 12 meV potential well for exiton was formed. The experimental results are in good agreement with theory. The stressor approach is the only available technique today for inducing a red shift in a QW. This provides an feasible method for damageless quantum wire formation.

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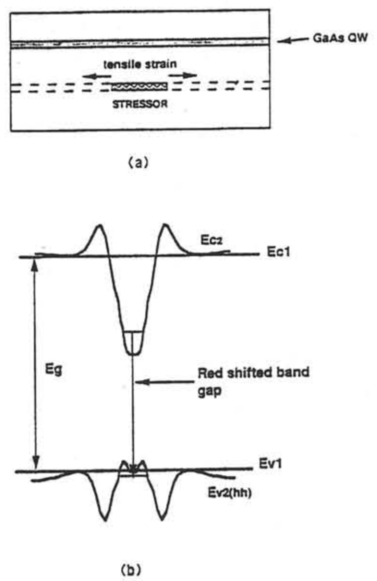

Fig. 1 Schematic diagram of the buried stressor structure and conduction and valence band.

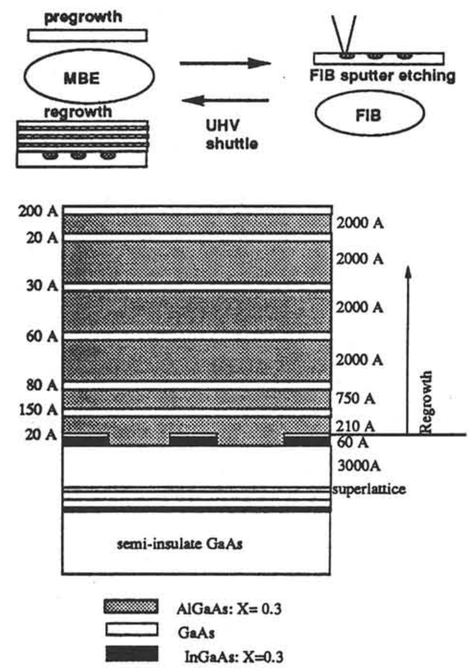

Fig. 2 The processing scheme for this structure.

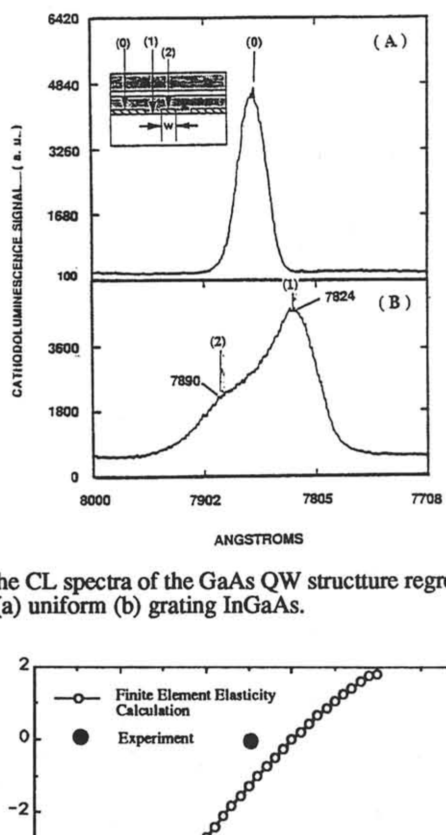

Fig. 3 The CL spectra of the GaAs QW structture regrown on (a) uniform (b) grating InGaAs.

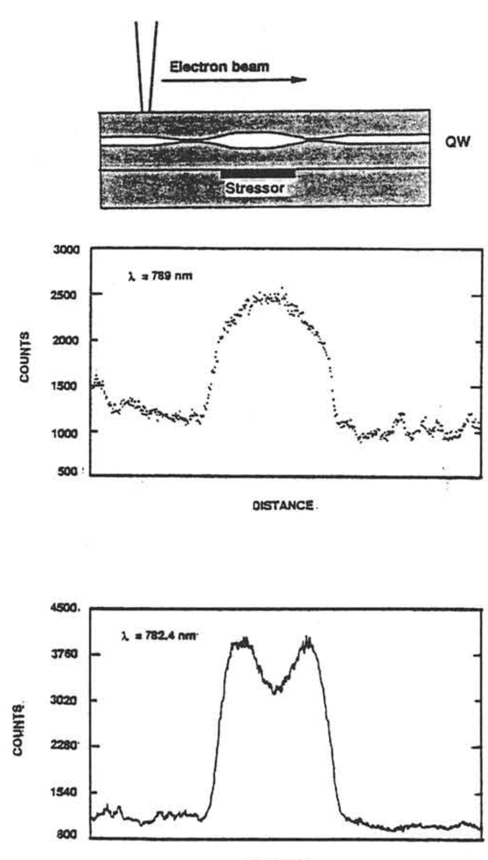

Fig. 4 CL line scan across a stressor at fixed wave length.

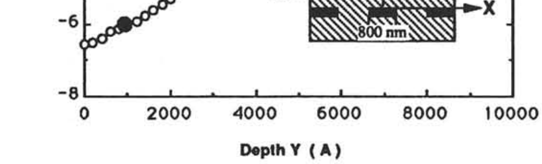

Fig. 5 Red shift as a function of the distance between stressor and QW.