Electron Mobility Studies of Device Quality InAs/GaAs Short Period Superlattices Grown by Dynamic Stoichiometry Control and Bloating In Flash-off Methods†

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The strained layer InGaAs/GaAs system has been the subject of substantial work emphasizing both growth studies and device applications. Relatively few studies have successfully explored the binary InAs on GaAs system because of the difficulties of maintaining a specular growth front and the apparently small value of the critical thickness. The surface phase diagram which describes the MBE growth of InAs on GaAs, and GaAs on InAs on the (100) surface has a complex dependence on temperature, component flux ratios, surface reconstruction and substrate topography. In our previous work, we have demonstrated that the quality of the growth front, the dislocation density and the electronic properties of pseudomorphic InAs on GaAs is strongly dependent on the temperature and growth front stoichiometry. Unfortunately, these experimental conditions are often difficult to achieve over a large area, and TEM and RHEED studies are not simply related to the electronically active defect density of such materials. Recently, Brandt, Ploog and coworkers,[1] have published a series of careful studies of this system, and have introduced a novel growth method to realize high quality heterointerfaces. This method requires substrate temperature modulation, growing InAs at 420°C, and GaAs at 540°C with a 3 ml capping layer of GaAs on InAs at 420°C. After GaAs cap layer growth, the substrate is heated to 540° C to desorb a floating submonolayer film of In before resuming GaAs growth. In this work, we have used a Quantum Well HEMT structure to experimentally compare the channel electron mobility of pseudomorphic InGaAs random alloys to that of short period $InAs_n/GaAs_m$ strained layer superlattices in which the average In content and the pseudomorphic InAs layer thicknesses were both varied. The pseudomorphic InAs samples were grown using our dynamic stoichiometry control method and the floating In flash-off technique for direct comparison. All samples wei e grown on Ga As <]()()> substrates, witl ı n = 1 , 2 ()1 4, and m varying from 2 to 8. The specific sti uctui e studied consisted of a GaAs buffei layei grown at 580 "C, the short pei iod strained-layei superlattice g rown at 420 °C (using, the stoichiometi y control method), a 30 Å undoped $Al_{0.25}Ga_{0.75}As$ spacer layei , a planer delta doped layer (6×10^{12} cm^{-2}), a 300 Å undoped $Al_{0.25}Ga_{0.75}As$ layei and a ?00 Å Si-doped (2. $\times 10^{18}$ cm^{-3}) GaAs cap layer. All $Al_{0.25}Ga_{0.75}As$ layers were grown at a substrate temperatures o f 540°C. The 1 lall mobility and carrier concentration of these films were measured at both 77 and 298 K using geometi ies which permitted an alysis of anisotropic scattering propei ties. During growth, the ill/V ratio was individually adjusted for the In, Ga and Al containing, layers, and a systematic suits of process interrupts were inserted bet ween depositions of In, As and Ga monolayers using values published for both methods. Fluxes of In, Ga, Al and As were calibrated using RHEED oscillation techniques. Instantaneous surface stoichiometi y and systematic variations of the surface latt ice constant were also determined by analysis of video RHEED data. Photoluminescence (1'1 .), cathodoluminescence (CL) and transmission electi on microscopy (TEM) st udies were also performed.

We found that small deviations from optimum growth conditions produced poor material, with room temperature mobilities of 500" to 2000 cm^2/V-sec at room temperature with little. change at 77 K. Larger deviations produced roughened gi owth interfaces as indicated by 1<111 :ED, and substantial 10ss of carriers in the. Quantum WC]] channel. For optimized growth conditions for the stoichiometry control method, we obtained room temperature mobilities of 4500" to 6400," and 77K mobilit ies of 150(X) to 37000 cm^2/V-sec as a function of effective InAs mole fi act ion. For example at 5 0 mole percent (n = m = 2 monolayers), tile observed mobility for a 6 0 Å thick quantum well was 5300 at 298 K and 27000 at 77 K with a measured carrier density of 1.2 - 1.4 $\times 10^{12}/cm^2$. For effective in mole flat.tions of up to 35% the mobility of the. strained layei super lat tices were no le ss than the 1 andom alloy cont rol samples and were generally ?()% greater for any give.n carriei concentration. Samples grown by the floating in flash-off technique gave considerably highei mobilities (?() to 80%) than those. grown by the stoichiometry control method when samples of equilivant in composition and carriei concent rat ion were compared.

Mobility, carrier concentration, 1'1, and (3. spectra all showed measurable variations outside, an area 20 mm. in diameter, aligned with the center of the substrate.. TEM analysis of the Quantum Well structures show atomically abrupt interfaces free of dislocations, and discrete InAs/GaAs superlattices but suggest a terrace structure between 150 and 300" Å in length in the chemically modulated images. The stoichiometry controlled samples gave continuous InAs layers, with a roughened InAs/GaAs interface as compared to the GaAs/InAs interface. Micro x-ray analysis of the TEM specimens show an outward diffusion of Indium in the growth direction from the InAs/GaAs interface. The In-Flash-off method gave extremely sharp structures for both the GaAs/InAs and InAs/GaAs interfaces. No In out-diffusion was observe.d for this latter case, however, in al] in-l~ltish-off samples we observed discontinuous InAs layers with 80 to 175 Å wide GaAs segments inserted in 800" to 2600" Å long InAs layers. Only the 4 ml. InAs In-Flash-off samples showed any evidence of dislocations. In this case, defects were only observed in the outermost InAs layer. in this paper we will detail the complex growth procedures needed to prepare these structures, present PL and cathodoluminescence images to analyze lateral reproducibility of the growth front, compare these data with 1 .6Å resolution TEM cress- sectional and plane view micrographs (taken with an ABT ()()2]1 200" keV microscope), analyze the systematics of growth-induced variations in mobility and carrier density of these highly strained superlattices, and describe the growth dynamics in terms of the surface and interface free energies.

1.) o. Brandt, K. Ploog, 1,. Tapfer, M. Hohenstein, R. Bierwolf, and F. Phillip, Phys Rev. 1145,3443 (1992)

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