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Metamorphic InAs/InGaAs QWs with electron mobilities exceeding $7\times10^5\mathrm{cm}^2/\mathrm{Vs}$

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ABSTRACT. We present a study on the influence of strain-relieving InAlAs buffer layers (BL) on metamorphic InAs/InGaAs quantum wells (QW) grown by MBE on GaAs. Residual strain in the BL, InGaAs barrier and InAs QW were assessed by X-Ray diffraction and high-resolution TEM. By carefully choosing the composition profile and thicknesses of the BL, virtually unstrained InGaAs barriers embedding an InAs QW with thickness up to 7nm can be grown. This allowed to reach low-T electron mobilities much higher than previously reported for metamorphic growth on GaAs, and comparable to the values achieved on InP.

Keywords: 2DEG, InAs, GaAs, metamorphic growth, strain, electron mobility.

InAs-based 2D electron gases (2DEGs) are potential platforms for a class of low-temperature applications taking advantage of strong spin-orbit coupling, large g-factor, and interface transparency to superconductors. Unfortunately, the difficulty in finding lattice-matched substrates limits the flexibility of heterostructure engineering. While almost lattice-matched GaSb substrates allow growth of InAs quantum wells (QW) with thickness up to 24nm and low-T electron mobilities $\mu \sim 2\times10^6\mathrm{cm}^2/\mathrm{Vs}$ [1], growth on the more technologically relevant and resistive InP and GaAs wafers limits the maximum InAs thickness to the sub-10nm range due to strain, with μ up to $\sim 10^6\mathrm{cm}^2/\mathrm{Vs}$ and $\sim 5\times10^5\mathrm{cm}^2/\mathrm{Vs}$ on InP and GaAs, respectively [2, 3]. In this paper, we show that metamorphic InAs/InGaAs QWs can be achieved on GaAs substrates with similar quality to InP substrates. With respect to our previous work [3], a careful optimization of strain relief allowed us to increase the InAs QW thickness from 4 to 7nm, thus decreasing interface and alloy scattering.

InAs/$\mathrm{In}_{0.81}\mathrm{Ga}_{0.19}\mathrm{As}$ QWs were grown by solid source MBE on GaAs (001) substrates (Fig. 1). An $\mathrm{In}_x\mathrm{Al}_{1-x}\mathrm{As}$ step-graded buffer layer (BL) with x increasing up to 0.84 allows for gradual relaxation of the lattice parameter. By varying the thickness *t* of the $\mathrm{In}_{0.84}\mathrm{Al}_{0.16}\mathrm{As}$ layer from 50 to 400 nm we were able to tune the strain in the x=0.81 barrier regions. Figs. 1b and c show (004) XRD rocking curves and the residual strain in the 0.84 and 0.81 regions, respectively. For *t* above 200nm the 0.81 region becomes virtually strain-free, while in the 0.84 region the strain switches from compressive to tensile. We estimated the strain in the InAs QWs with cross-sectional TEM. Figs. 2a and b show high-resolution cross-sectional images of the QW regions for *t* = 300 nm and 50 nm, respectively. Corresponding out-of-plane strain maps calculated using geometric phase analysis with <111> reflections are shown in Figs. 2c and d, respectively. Strain profiles in the QWs relative to the 0.84 regions (Fig. 2e) show that the mean residual strain is about 0.9±0.5% and 2.2±1.1% for 300 nm and 50 nm, respectively.

Van Der Pauw measurements at 4.2K indicate that μ increases up to 7.1×10^5 cm²/Vs at *t*=300nm, after which it saturates (Fig. 3a), consistently with the saturation of residual strain in the barriers, with *n* in the 3-3.5×10^{11} cm²/Vs range, largely independent on *t*. Shubnikov-de Haas oscillations for *t*=300nm confirm the formation of a 2DEG without parasitic conduction channels, and the onset of integer quantum Hall plateaus (Fig. 3b). Our samples are thus competitive with state-of-the-art equivalent systems grown on InP substrates in terms of electron mobility for similar electron densities [2].

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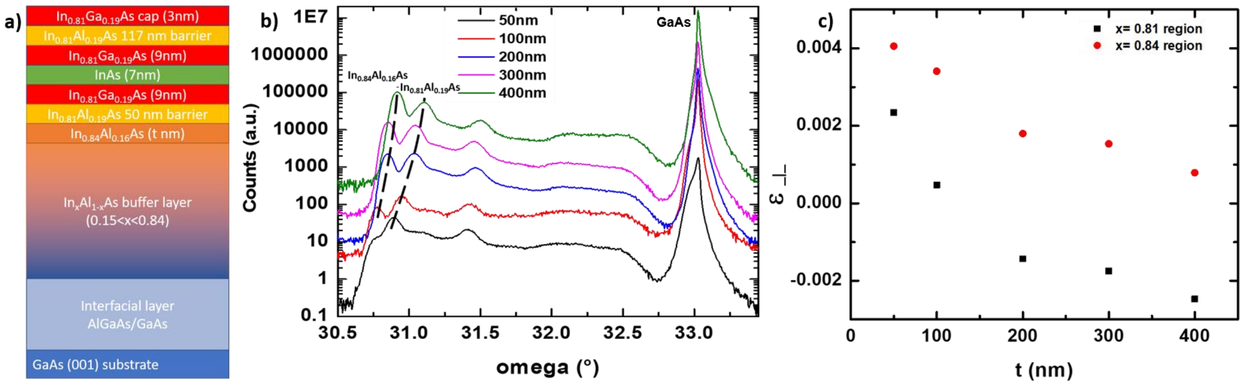

Figure 1. (a) Schematics of the growth sequence. Different samples with thickness *t* of the topmost $In_xAl_{1-x}As$ graded buffer layer step (*x*=0.84) ranging from 50 to 400 nm were grown. (b) (004) XRD rocking curves showing GaAs and $In_xAl_{1-x}As$ Bragg peaks for different *t*. Spectra were taken at the MCX beamline, Elettra, Trieste, with a photon energy of 8keV. Dashed lines indicate the $In_{0.81}Ga_{0.19}As$ and $In_{0.84}Ga_{0.16}As$ peak shifts. (c) Residual perpendicular strain in the *x*=0.81 and 0.84 regions as a function of *t*.

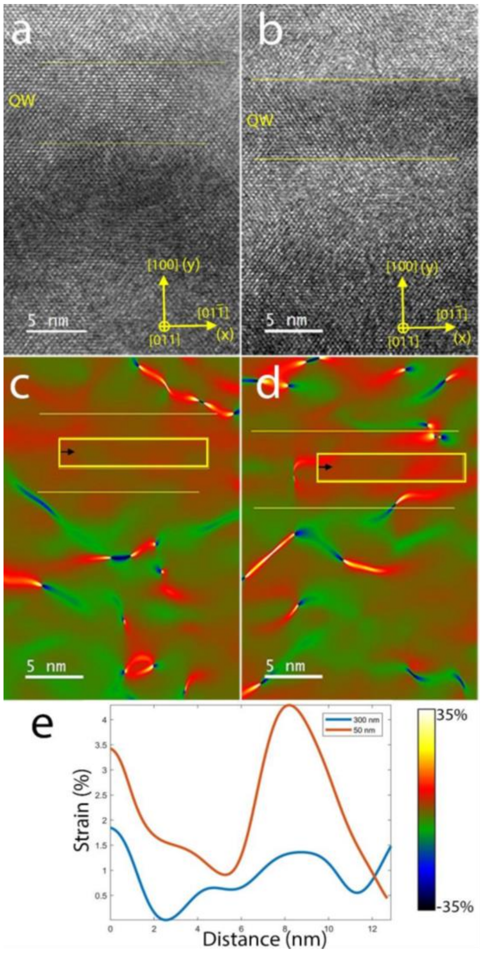

Figure 2. High-resolution [011] cross-sectional TEM images of the QW region for (a) *t* = 300 and (b) 50 nm. Out-of-plane strain maps calculated using geometric phase analysis (GPA) with <111> reflections for (c) *t* = 300 and (d) 50 nm. (e) Strain profiles from the yellow rectangular boxes in (c) and (d). The spatial resolution of the strain maps is 5 nm.

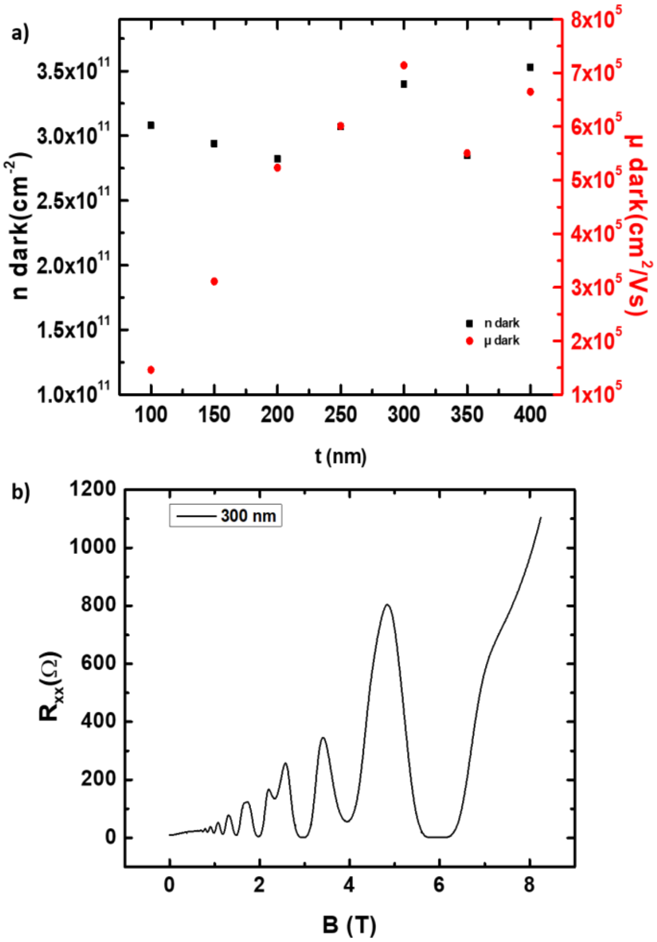

Figure 3. (a) Low-temperature (T=4.2 K) electron charge density and mobility in the InAs/$In_{0.81}Ga_{0.19}As$ 2DEG as a function of *t*. (b) Longitudinal resistance R_{xx} as a function of magnetic field *B* for *t* = 300nm.