Surface self-organization and structure of highly doped n-InGaAs ultra-shallow junctions *

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Compound semiconductors having high electron mobility and high injection velocity such as InGaAs are being profusely studied as possible candidates to replace Si as the channel material in highly scaled MOSFETs. One of the most critical challenges of III-V MOSFET miniaturisation lies in achieving low resistance source/drain access regions suitable for high performance logic beyond the 10 nm technology node. A strong need exists to develop III-V n-type doping strategies that are capable of delivering low resistivity and low-defect ultra shallow source/drain regions with dopant concentrations above $10^{19}\,\mathrm{cm}^{-3}$ and junction depths of $X_j = 5 - 10\,\mathrm{nm}$ for future devices.

In this work we study the Si doping characteristics of MBE grown $In_xGa_{1-x}As$ ($x = 0.17 - 0.33$) ultra-shallow junctions ($X_j \sim 8\,\mathrm{nm}$) deposited on GaAs(001) substrates under different substrate and Si effusion cell temperatures and V:III flux ratios. To this aim three in-situ doping strategies have been explored, namely homogeneous co-deposition, continuous δ-doping and pulsed δ-doping. The resulting Si-doping levels , determined by time-of-flight secondary ion mass spectrometry (ToF-SIMS) analysis, were found to lie between $2.7 \cdot 10^{18}\,\mathrm{cm}^{-3}$ and $5.8 \cdot 10^{19}\,\mathrm{cm}^{-3}$, the highest values corresponding to InGaAs junctions with triple Si δ-layers. Elemental profiles evidence In segregation to the surface even in those samples grown at the lowest substrate temperature studied (375°C), for which the highest Si solubility is observed. Atomic force microscopy (AFM) imaging and high-resolution transmission electron microscopy (HR-TEM) indicate an improvement in the crystal quality of the InGaAs USJs for growth temperatures above 400°C. A characteristic self-organization of the surface into a cross hatch pattern is observed up to Si concentrations of ca. $3 \cdot 10^{19}\,\mathrm{cm}^{-3}$. Above this value the InGaAs crystalline quality is degraded and the surface roughness increases significantly.

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