

Reducing dislocations in GaAs on silicon templates

Researchers optimize GaAs grown by molecular beam epitaxy using on-axis gallium phosphide on silicon substrates.

University of California Santa Barbara (UCSB) in the USA has been working to optimize gallium arsenide (GaAs) molecular beam epitaxy (MBE) on gallium phosphide on silicon (GaP/Si) [Daehwan Jung et al, J. Appl. Phys., vol122, p225703, 2017]. Normally, growth of GaAs on Si uses off-axis substrates in efforts to avoid anti-phase domains. On-axis silicon is preferred for compatibility with CMOS processing foundries. The lattice mismatch between GaAs and silicon is $\sim 4\%$, leading to dislocations.

The researchers managed to reduce threading dislocation densities (TDDs) to $7.2 \times 10^6/\text{cm}^2$, a factor of 40 lower than for an unoptimized process. They comment: "We believe that these high-quality GaAs buffer layers with low TDDs and smooth surfaces will serve as versatile templates for high-performance Si-based optoelectronic devices, including lasers and photodetectors as well as a myriad of photonic integrated circuits made from these devices."

The researchers used a commercial 300mm GaP/Si (001) template from NAsP III/V GmbH. The estimated unintentional miscut of the template was potentially only $0.1\text{--}0.2^\circ$. The silicon wafer was subjected to a special pre-epitaxial heat treatment designed to terminate anti-phase domains in the 45nm GaP layer.

The wafer was cut up into small pieces and put on molybdenum adapting plates in the Veeco MBE chamber. After oxide desorption, the growth began with 100nm GaAs at $400\text{--}550^\circ\text{C}$. The temperature was then raised to 600°C for $3\mu\text{m}$ GaAs layer growth.

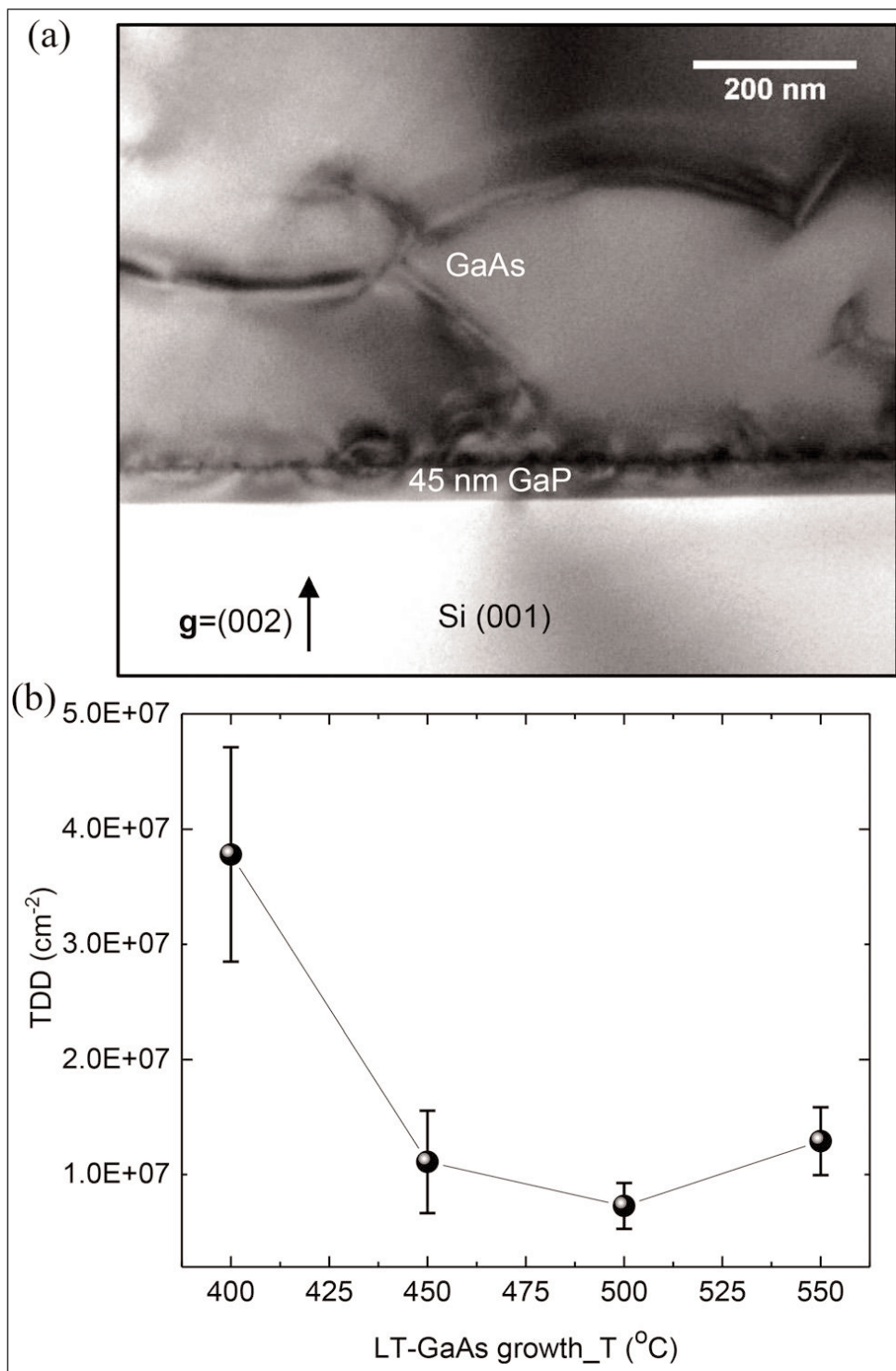


Figure 1, (a) Cross-sectional bright-field transmission electron micrograph of GaAs on GaP/Si. (b) TDD versus low-temperature-GaAs growth temperatures.

Electron channeling contrast imaging (ECCI) measurements gave a threading dislocation density (TDD) of $\sim 2.8 \times 10^8/\text{cm}^2$ averaged over a $1800 \mu\text{m}^2$ area on a reference unoptimized GaAs/GaP/Si sample, which was consistent with results from more traditional plan-view transmission electron microscopy (TEM). ECCI allows dislocation density assessments over larger areas, reducing uncertainties. Root-mean-square (RMS) roughness of the reference was 7.8nm, according to atomic force microscopy (AFM) on $10 \mu\text{m} \times 10 \mu\text{m}$ fields.

Various optimizations were applied to the growth process: in-situ thermal cycle annealing, dislocation filter layers, and altering the growth temperature of the low-temperature GaAs layer.

The annealing consisted of 500°C low-temperature GaAs, $1.5 \mu\text{m}$ high-temperature GaAs, 4x thermal cycling between 700°C and 320°C , and $1.5 \mu\text{m}$ more high-temperature GaAs. ECCI measurements gave a TDD of $5.5 \times 10^7/\text{cm}^2$. RMS roughness was 4.8nm. The team believes that the dislocations are removed by gliding and misfits fusing or annihilating.

A variety of dislocation filter layers were tested. The best involved 10 periods of 10nm indium gallium arsenide ($\text{In}_{0.1}\text{Ga}_{0.9}\text{As}$) and 10nm GaAs applied after thermal cycle annealing, giving $7.2 \times 10^6/\text{cm}^2$ TDD and 2.9nm RMS roughness. The 200nm filter was capped with $1.3 \mu\text{m}$ GaAs. The InGaAs was applied at 500°C . Somewhat lower TDDs of $1.2\text{--}1.4 \times 10^6/\text{cm}^2$ have been achieved with metal-organic chemical vapor deposition (MOCVD) on $4\text{--}6^\circ$ offcut substrates. Also, higher annealing temperatures can be reached in MOCVD chambers.

Variation of the low-temperature GaAs nucleation layer found that 500°C was optimal for a structure grown with thermal cycle annealing and InGaAs/GaAs dislocation filtering (Figure 1). Also adding extra dislocation filter layers (DFLs) increased the TDD level, while paradoxically decreasing roughness. The team explains: "We believe that adding more sets of DFLs nucleated more dislocations to relax the upper InGaAs/GaAs DFLs rather than recycling the pre-existing TDs."

Photoluminescence (PL) measurements were made on GaAs in aluminium gallium arsenide (AlGaAs)

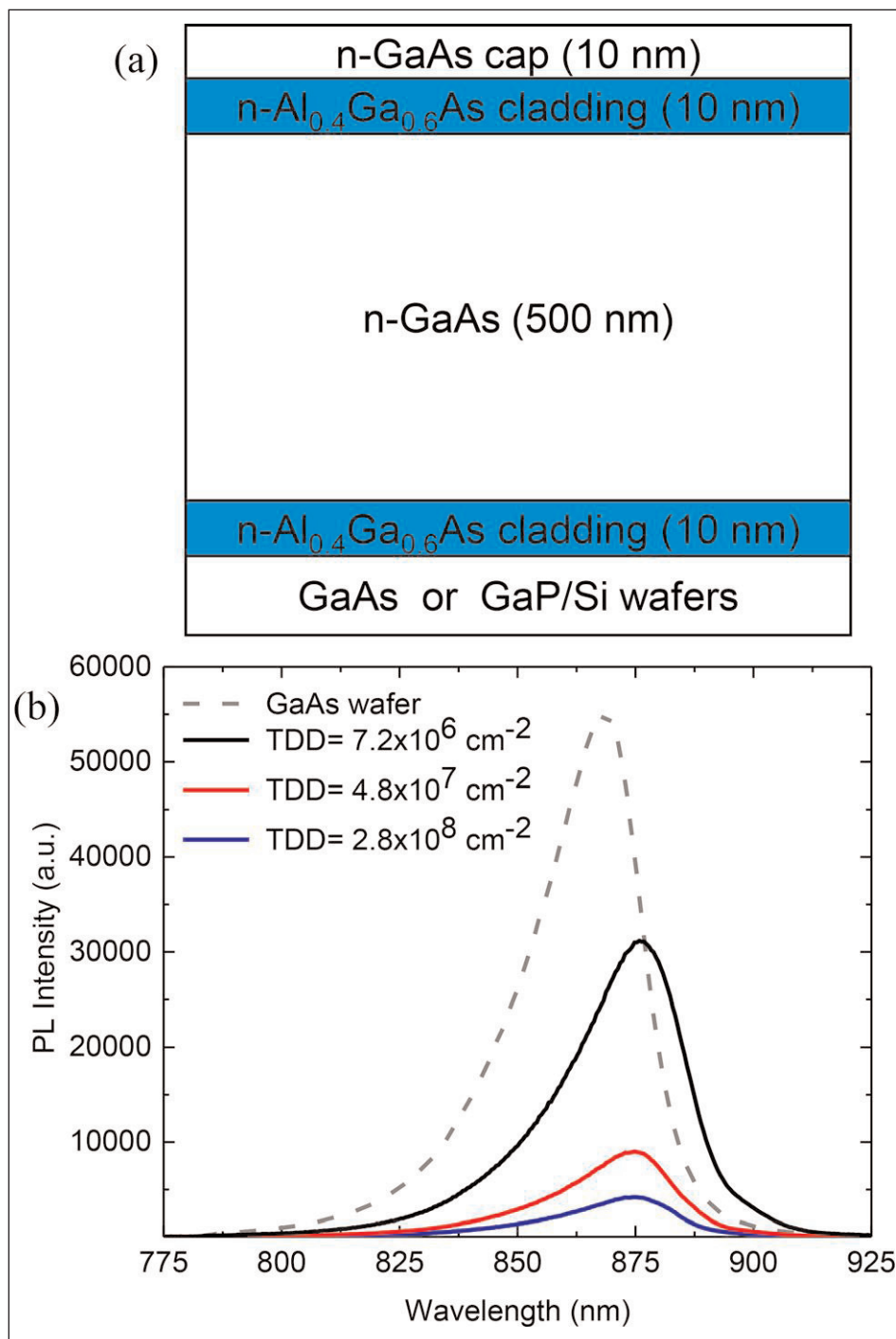


Figure 2. (a) Schematic of GaAs/AlGaAs PL structure. (b) Room-temperature PL spectra of GaAs PL samples grown on native GaAs, and three different GaAs/GaP/Si templates.

cladding structures grown on three GaAs/GaP/Si templates with TDDs varying between $2.8 \times 10^8/\text{cm}^2$ and $7.2 \times 10^6/\text{cm}^2$ (Figure 2). The researchers report: "It is noted that the integrated PL intensity from the optimized GaAs buffer layer is 7 times larger than the reference sample (TDD = $2.8 \times 10^8/\text{cm}^2$). Compared with the GaAs layer grown on a native GaAs wafer, the optimized sample shows only $\sim 40\%$ reduction in the PL intensity at room temperature." ■

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