Introduction

For about thirty years researches have been able to monolithically grow GaAs quantum well structures on top of silicon substrates however, they were never able to create the high crystal quality that is needed for the structures to work efficiently. Following a patterned substrate growth method, a series of experiments to determine whether or not one-step growth on the patterned substrates or two-step growth would be more optimal were conducted. After the experiments were complete the samples went through the series of characterization tests, those of which are mentioned in the abstract. From that we were able to determine that the two-step growth method produced the smoothest surface and eliminated nearly all of the mismatches created between the quantum well structures and the silicon substrate. The two-step growth allows for the most optimized growth method meaning that the photonics industry is one step closer to the integration of photonics in more practical consumer electronics.

Materials & Methods

SEM images for arrays of patterned holes with 1 μm diameter formed by stepper lithography, where the dark circular holes are exposed Si surface. Schematics of tilted and cross-section views for patterned Si substrates with a 200-nm-thick SiO₂ mask used in our experiments.

Results

Figure 1. (a) shows the schematic of a single-step growth and its surface morphology. (b) displays a SEM photo of GaAs on top of a Si(111) substrate. (c) shows the schematic of a two-step growth and a much smoother surface morphology. (d) and (e).

Figure 3. (a) HAADF XTEM image of GaAs/Si(111) grown by the two-step growth scheme. (b) Close-up view of BF XTEM image of GaAs/Si(111), (c) HREM image of GaAs/Si(111), indicating that the misfit dislocations (d) GaAs/Si covalent bond diagram. (e) and (f) SAED patterns taken in GaAs epilayer and Si.

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Sponsors

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Future Work

High Speed Fiber Optics Communications

Integration in Satellite Communications

Conclusion:

We have successfully grown high structural and crystalline quality GaAs on patterned Si(111) substrates through our two-step growth scheme. Utilizing the finite size growth and lower surface energy of Si(111), we make it possible to obtain high quality GaAs atop Si with ultra-thin (~175 nm) and ultra-smooth epilayers through the two-step growth scheme. The defect-free GaAs epilayer is a potential candidate substrate for planar optoelectronic devices. The fabricated InGaAs/GaAs quantum well structures represent the first step forward of silicon integration.

Scientific Question

How to efficiently and inexpensively produce 1.3 μm InGaAs/GaAs quantum well light emitters grown on Silicon substrates.

Abstract

We used the Molecular Beam Epitaxy system (MBE) to grow InGaAs/GaAs quantum well structures on top of patterned silicon substrates. After the structures have been grown, we perform a series of characterizations including: scanning electron microscopy, atomic force microscopy, transmission electron microscopy, X-Ray diffraction, Raman spectroscopy and photoluminescence. From the characterizations we determined that the two-step growth method produced high-quality defect free quantum well structures along with the preferred single crystalline structure. This discovery could lead researches closer to the integration of InGaAs/GaAs lasers to silicon substrates for consumer electronics.

Schematics

(a) Thickness dependent experiments for high temperature grown GaAs buffer layer.
(b) Material dependent experiments for low temperature grown nucleation layer.

(c) Optically pumped InGaAs/GaAs quantum well structure based on the optimized buffer layer on top of patterned silicon substrates.

Figure 6. Photoluminescence spectra for the InGaAs/GaAs quantum structure before and after post growth ex-situ thermal annealing.

Figure 2. The growth model for (a) the two-step growth and (b) the one-step growth.