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Selective area epitaxy of gallium phosphide-based nanostructures on microsphere lithography-patterned Si wafers for visible light optoelectronics

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ABSTRACT

In this study, we present the selective area plasma-assisted molecular beam epitaxial growth of GaP-based nanoheterostructures (nanostubs), incorporating direct bandgap GaAsP or GaPN segments, on patterned SiO_2/Si(001) wafers. A microsphere optical lithography and anisotropic Si wet-etching techniques were employed for wafer-scale surface patterning through SiO_2 growth mask, allowing to obtain either planar or pyramidal pit nucleation site morphologies. X-ray diffraction reciprocal space mapping and Raman microspectroscopy studies confirm compositional homogeneity of the nanostub arrays. The dilute nitride nanostubs display the narrowest and most intense visible red photoluminescence response at room temperature, which is an order of magnitude higher compared to the GaAsP ones. The formation of the nitrogen sub-band in GaPN alloy was confirmed in the framework of density functional theory, providing insights for interpreting the experimental results. These findings demonstrate the feasibility of the proposed approach for fabricating the ordered arrays of nanoscale visible light emitters on silicon.

1. Introduction

Monolithic integration of direct bandgap III-V compound semiconductors on silicon offers new pathways for fabricating energy-efficient micro/nanoscale light emitters for optoelectronic integrated circuits, optical sensors, optical data transmission, optobiology, microdisplay and imaging technologies [1–3]. However, the inherent mismatching in crystal symmetry, lattice parameters, and thermal expansion coefficients between silicon and most III-V materials cause challenges for direct heteroepitaxial growth of III-Vs on Si [4]. Consequently, achieving the high crystalline perfection, required for optoelectronic applications, commonly suggests the use of complex epitaxial growth techniques [5,6].

One of the promising strategies for integrating III-V materials on silicon is selective area growth (SAG) technique [7]. The use of a patterned growth mask during heteroepitaxial growth restricts the interface area, reducing mismatch strain energy and localizing structural defects. SAG facilitates the formation of epitaxially aligned and size-uniform arrays and networks [8] of III-V nanostructures with a high surface to volume ratio, such as nanoridges [9], nanowires and nanopillars [10], nanosheets [11,12] or nanostubs [13]. The large specific surface area facilitates elastic strain relaxation, enabling the integration of lattice-mismatched III-V materials within a single nanoheterostructures [14]. Moreover, the morphology and orientation of nucleation sites within mask openings can effectively reduce the defect formation during III-V/Si epitaxy [9,15] while tailor nanostructure morphology and growth direction [16,17].

The tailored morphology of nanostructures enhances light scattering,

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