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Comparative study of metamorphic InAs layers grown on GaAs and Si for mid-infrared photodetectors

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ABSTRACT

We report a comparative study of metamorphic InAs p-i-n photodetectors epitaxially grown on GaAs and Si by molecular beam epitaxy. Linearly graded InAlAs buffers were employed to bridge the high lattice mismatch between InAs and Si. Quantitative measurement for threading dislocation density (TDD) in the InAs layers grown on GaAs and Si has been performed using transmission electron microscopy and electron channeling contrast imaging, both of which revealed that the TDD of InAs/Si sample is ~35% higher than that of GaAs sample. Comparison of fabricated InAs p-i-n photodetectors indicated that reduction of threading dislocation density is crucial for low dark current and high responsivity mid-infrared photodetectors on Si.

1. Introduction

Mid-infrared (mid-IR) spectral region is important for various applications such as molecular spectroscopy, gas detection, military counter measures and medicine since the majority of chemical elements possess strong vibrational absorption bands [1,2]. Different types of photodetectors have been developed in the wavelength regime using diverse material systems [3,4]. Cryogenic-cooled HgCdTe (MCT) detectors have long been the main choice for industry applications since its invention. However, MCT detectors require use of liquid nitrogen for its sufficient performance, which makes MCT very bulky and expensive [5].

GaAs-based quantum well and quantum dot infrared photodetectors (QWIP and QDIP) [6] and InAs(Sb) type-II-based superlattice detectors [7] have been extensively studied as an alternative material choice over MCT. They have achieved significant strides in increasing operation temperature and specific detectivity [8]. Recently, direct epitaxy of III-V materials on Si for mid-IR photodetectors has drawn much attention due to their potential for high throughput manufacturing, low-cost, and easy integration of III-V opto-electronics to the silicon photonics platform. Jiang Wu *et al.* have demonstrated epitaxially integrated GaAs-based QD infrared photodetectors on Si for 5 – 8 μm detection [9] and Sengupta *et al.* have reported QWIPs monolithically integrated on Si for 6 – 12 μm detection [10]. While InAs is a suitable material for 2 – 3.5 μm spectral wavelength, direct epitaxy of InAs on Si wafer and its material characterizations for mid-IR photodetectors has relatively been unexplored [11,12].

Major challenges of InAs epitaxy on Si arise from the high lattice mismatch (11.6%) and polar (III-V)/non-polar (IV) growth. The polarity disparity which induces electrically active anti-phase domains (APDs) can be resolved by growing III-V materials on 4–6 degree offcut Si substrates or by growing APD-free GaP/Si wafers [13,14]. The large lattice mismatch has yet been completely solved for high performance mid-IR InAs photodetectors on Si [15]. Especially, threading dislocations (TDs) in the metamorphic InAs layer result in high dark current density and low responsivity for the photodetectors [16,17]. Therefore, it is crucial to quantitatively investigate the density of TDs in the InAs metamorphic layer monolithically grown on Si and correlate that to the InAs photodetector performance.

Here, we compare the crystalline quality of InAs buffer layers epitaxially grown on GaAs over Si and analyze the p-i-n photodetectors grown on the templates. Low growth temperature for InAlAs linearly graded buffers enabled smooth InAs layers on the substrates. Atomic force microscopy and high-resolution x-ray diffraction showed that the InAs layer grown on Si possesses similar structural quality compared to the one grown on GaAs. Fabricated InAs p-i-n photodetectors grown on GaAs showed a slightly higher peak responsivity of 0.092 A/W than the

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