Influence of the Growth Conditions on the Performance of InAs Sub-Monolayer Quantum Dot Infrared Photodetectors

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Semiconductor devices that can efficiently emit or detect infrared radiation (IR) are in ever increasing demand for applications in fields as diverse as medicine, agriculture, astronomy and national security. A common type of IR detector is the quantum well infrared photodetector (QWIP), which relies on intraband carrier transitions between the confined states of the quantum wells. Although QWIPs perform well under certain conditions, these devices are not sensitive to normal incident radiation, have high values of dark current and require cryogenic temperature to operate, making them bulky and expensive. In contrast, quantum dot infrared photodetectors (QDIPs) offer higher sensitivity to normal incidence light, longer photoexcited carrier lifetime, and lower dark current values [1,2]. Quantum dots for QDIP devices are often grown via the Stranski-Krastanov growth mode, but this self-assembly process places limits on how closely we can control QD size and composition. However, sub-monolayer quantum dots (SML-QDs) offer enhanced height and composition uniformity, higher surface density of nanostructures, the absence of a wetting layer and improved 3-dimensional confinement [3].

The nucleation of InAs islands on GaAs(001) is influenced by our choice of MBE growth parameters, leading to SML-QDs with different shapes, sizes and compositions that can impact QDIP performance. In the present work, we have explored the effects of growth rate and arsenic flux on the growth and performance of InAs/GaAs SML-QD structures for QDIPs. We consider the influence of these variables on the formation and stacking of the small 2D InAs islands, verifying their structure with x-ray diffraction (Fig. 1). We tested the QDIP devices optically and electrically at 10 K (Fig. 2), measuring specific detectivities in the 10^{11} cm Hz$^{1/2}$ W^{-1} range. We will discuss differences in QDIP performance as a function of the MBE conditions used.

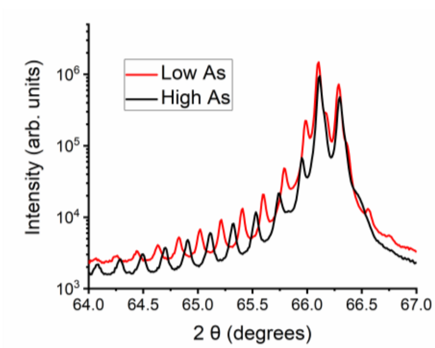

Figure 1: X-ray diffraction spectra from two superlattice samples of InAs/GaAs SMLQDs grown with high and low arsenic fluxes.

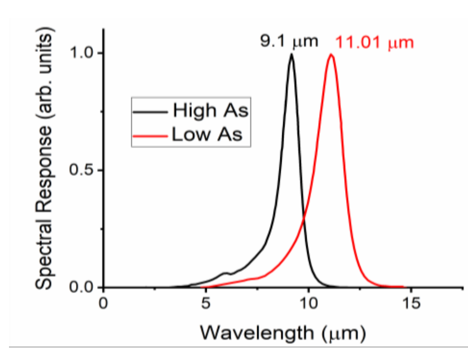

Figure 2: Spectral response at 10 K of two SML-QD superlattice samples grown with high and low As fluxes.

[1] Liu, Opto-Electronics Rev. **11**, 1 (2003). [2] Wu, *et al. Appl. Phys. Lett. 112*, *111103 (2018)* [3] Sengupta *et al.* Appl. Phys. Lett. **100**, 191111 (2012)

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Supplementary Information

The lower dark current values presented by QDIPs allows them to operate at higher temperature than QWIPs. InAs/GaAs SML-QDs are grown by the alternate deposition of a fraction of a ML (30-50%) of InAs material and a few MLs of GaAs, forming 2-dimensional (2D) islands. Due to the internal strain field, the small 2D InAs islands from adjacent layers will align vertically and form stacks (the so-called SML-QDs) with the desired height and average composition.

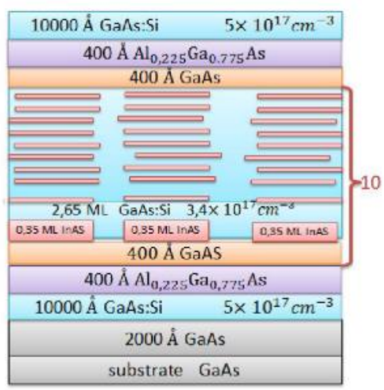

Figure 3: Schematic of QDIPs sample growth. The 10-period superlattice of SML-QD enhances the emission from strain aligned InAs islands.

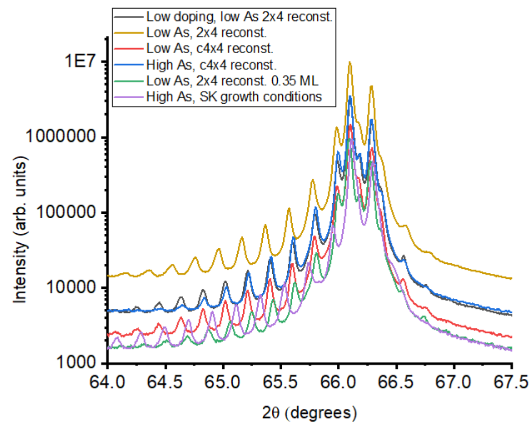

Figure 4: XRD pattern of a battery of samples studied with varying As pressure conditions. After the initial screening we selected the biggest varying conditions to study.

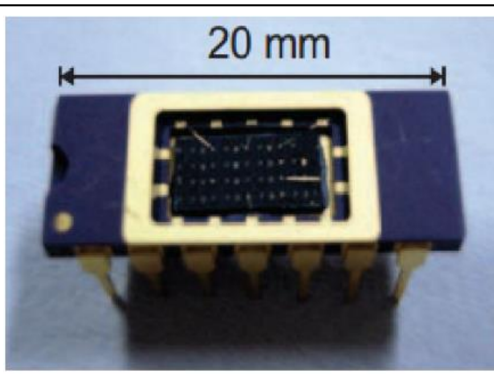

Figure 5: Chip containing the processed QDIPs devices. We fabricated the epitaxially grown samples using standard photolithographic techniques, wet etching and metallization.

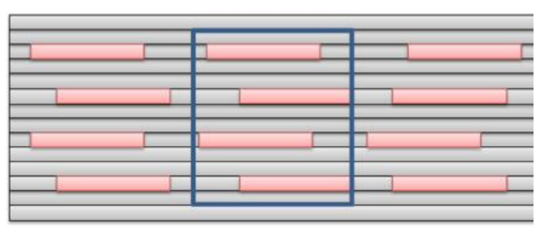

Figure 6: Schematic of the strain alignment presented in the growth of InAs islands. Vertically stacked grown SML-QD nanostructures increase QDIP detection efficiency.