Increasing the dot density in quantum dot infrared photodetectors via antimony-mediated dot formation

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Abstract— We report on the use of antimony for increasing the quantum dot (QD) density, and hence improving the performance of MBE-grown QD infrared photodetectors (QDIPs). We have achieved an increase in QD density from ~4x10^{10}cm^{-2} for conventional InAs QDs to ~7x10^{10}cm^{-2} by depositing a thin layer of GaSb just prior to the InAs QD growth. Intraband spectroscopic measurements demonstrate an increase in absorption strength associated with the higher QD density. We also present InAs/$In_{0.15}Ga_{0.85}As$ dots-in-a-well infrared photodetectors incorporating GaSb which exhibit responsivity values up to ~ 0.3A/W at 90K.

***Index Terms*—antimony, enhanced absorption, dots-in-a-well, quantum dot infrared photodetectors**

I. Introduction

One of the key factors limiting the performance levels of QDIPs relative to quantum well infrared photodetectors (QWIPs) is the ~10x lower intraband absorption strength for a single layer of QDs compared to a single QW. The main reason for the lower absorption is that the in-plane QD density limits the number of absorbing electrons to a few 10^{10}cm^{-2} in a QDIP, compared with a few 10^{11}cm^{-2} in a typical QWIP. It is therefore essential to address this issue if the potential benefits of QDIPs, including longer excited lifetimes (higher responsivity) and normal incidence operation, are to be realized.

The QD density can be increased by decreasing In surface diffusion of adatoms, via the use of a low-growth temperature and/or a high-growth rate [1]. However, the increase of density in this case leads to the formation of coalesced giant islands, which deteriorate the QD optical properties. Other methods of increasing the dot density using InP substrates [2] also often lead to coalesced dots or dashes. One very promising method [1], [3] for increasing the QD density that we have recently investigated is to deposit a thin layer of GaSb just prior to the InAs QD growth. Although the exact mechanism of Sb-mediated growth is yet to be fully understood, the density enhancement and suppression of QD coalescence are generally attributed to surface and interface energy changes [4].

Manuscript received March 15, 2007. (This work was supported by the Engineering and Physical Sciences Research Council (EPSRC), grant number GR/T2 1158/01

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II. Results

Using this approach we have found an increase in QD density from ~3x10^{10}cm^{-2} for conventional InAs QDs to ~7x10^{10}cm^{-2} for Sb-mediated growth, which was observed with atomic force microscopy (Fig 1). From detailed interband and intraband absorption studies, we find no significant differences in the conduction band structure for QDs formed using the two approaches, whilst observing an increase in the absorption strength for the Sb-mediated grown structures (Fig 2). This is an important point for intraband devices, since in most other high QD density approaches (which result in the formation of coalesced QDs or quantum dashes) the intraband oscillator strength is exhausted by the many low energy transitions which do not contribute to the photoresponse. We have extended this approach to grow InAs/$In_{0.15}Ga_{0.85}As$ dots-in-a-well infrared photodetectors incorporating GaSb and have found the very good performance levels of these preliminary devices, with responsivity values of 0.3A/W at -2.5V and 77K, showing no reduction up to 90K, and still maintaining 0.1A/W at 110K, whilst exhibiting low dark currents, and narrow spectral characteristics at ~8µm. Our results are also highly relevant for other QD-based devices, such as interband lasers, in which the QD density is a critical parameter affecting device performance.

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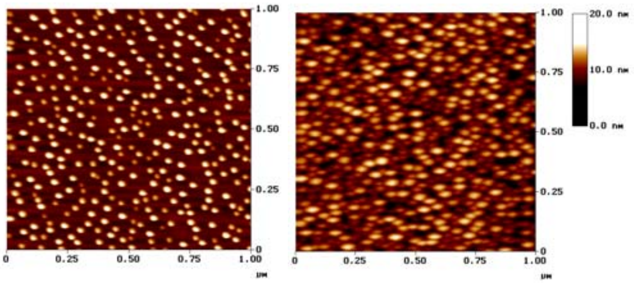

Fig.1. Atomic force microscopy images for conventional InAs /GaAs QDs (QD density ~$4x10^{10}cm^{-2}$) and InAs/GaAs QDs with Sb (QD density ~$7x10^{10}cm^{-2}$)

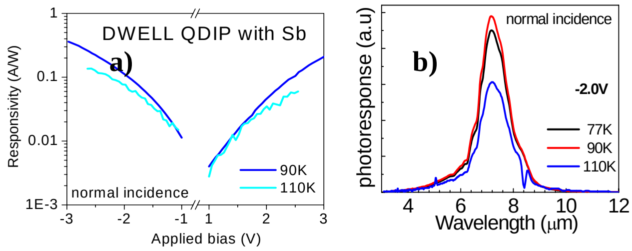

Fig.3. a) Peak Responsivity of DWELL QDIP with Sb at 90K(blue) and 110K(cyan) and b) Spectral photoresponse for DWELL QDIP with antimony at 77K(black), 90K(red) and 110K(blue) at normal incidence

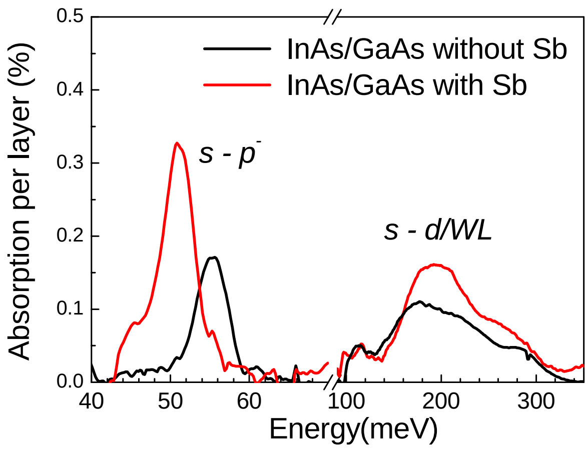

Fig.2. Absorption spectra for conventional InAs /GaAs QDs and InAs/GaAs QDs with Sb for samples with ~1 electron per dot