Intersubband Absorption in p-type Ge Multiple Quantum Wells for Mid-IR Sensing Applications

Andrea Barzaghi[1*], Virginia Falcone[1], Stefano Calcaterra[1], Raffaele Giani[1], Andrea Ballabio[1], Daniel Chrastina[1], Giovanni Isella[1] and Jacopo Frigerio[1]

[1] L-NESS, Dipartimento di Fisica, Politecnico di Milano, Polo Territoriale di Como, Via Anzani 42, Como, 22100, Italy
[*] andrea.barzaghi@polimi.it

High-quality p-type Ge multiple quantum wells structures were grown, and mid-IR absorption spectra have been measured by FTIR spectrometry. Clear absorption peaks were observed for different values of the quantum well thickness and were attributed to intersubband transitions by k·p simulations backed by XRD measurements.
Keywords: *Ge MQW, QWIP, intersubband*

INTRODUCTION

Detection in the mid-IR wavelength range is of great interest to enable gas sensing and biological spectroscopic detectors, which require an absorbing material in the 3-5 and 8-13 µm windows [1]. Commercial detectors employ either mercury-cadmium-telluride (MCT) or InSb as sensing material, but they're fragile, difficult to process and integrate on silicon, resulting in a very high cost [2, 3].

Cost effective mid-IR detectors may be fabricated by exploiting intersubband transitions in high-quality Ge multiple quantum wells nanostructures, thanks to the possibility of integration in standard CMOS processes. Moreover, the absorption of such quantum well infrared photodetectors (QWIP) can be tuned by varying the quantum well width and strain level, therefore shifting the transition energy to the desired value.

n- and p-type SiGe QWIPs, which present a weaker absorption compared to pure Ge MQW structures, have already been demonstrated in the past [4,5], and germanium QWIPs have only been demonstrated by exploiting intersubband transitions in the conduction band [6]. Here p-type Ge MQWs structures are investigated as a platform for the fabrication of QWIPs which, thanks to the non-parabolicity and band-mixing effects in the valence band, present both TE and TM absorption and can therefore be employed in both vertical illuminated and waveguide geometries, while having a larger absorption coefficient compared to SiGe designs.

RESULTS

Three different Ge MQW designs, each with a different quantum well width, were grown by LEPECVD on high-resistivity Si wafers. Moreover, a second set of samples was grown with the same quantum well thickness to investigate the effect of different doping levels. A virtual substrate with a linearly graded concentration profile from pure Si to SiGe 80% was used as a buffer layer to achieve high quality QW superlattices with a low density of defects.

High resolution x-ray diffraction (XRD) reciprocal space maps were then acquired and the relevant parameters (i.e. quantum well thickness, superlattice period, average Ge content of the MQW stack) and used as the starting point of the **k·p** simulations. The theta scan of the three samples are shown in Fig. 1 together with the fitted curves.

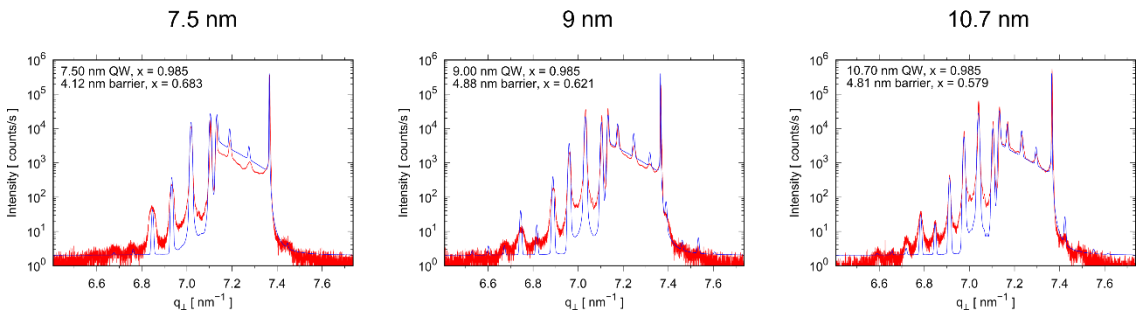

Fig. 1 Theta scan of the samples with different MQW design, showing the goodness of the fitted curves and the extracted parameters.

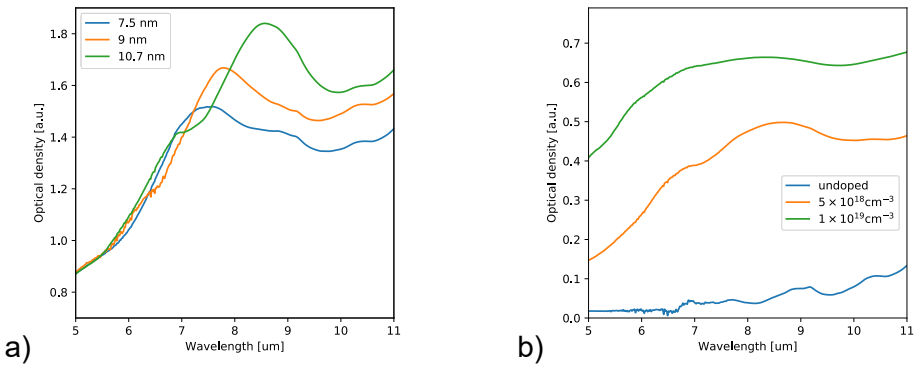

*Fig. 2 FTIR room-temperature absorption spectra of MQW designs with a) different quantum well thickness for a 5x10^{18} cm^{-3} p-type doping, superimposed to **k·p** simulations (dashed lines), and b) different p-type doping levels of the 10.7 nm quantum well.*

Room-temperature absorption spectra of the MQW stacks were obtained by measuring the transmittance and reflectance spectra at normal incidence with a FTIR spectrometer and a LN_2-cooled MCT detector, and the resulting spectra are shown in Fig. 2 for the two sets of samples.

Finally, 8-band **k·p** simulations were performed to attribute the experimental peaks to an intersubband transition, using the structural parameters extracted from the XRD data.

DISCUSSION

Clear absorption peaks can be observed in the spectra in Fig. 2a in the 7-9 µm wavelength range, which is the desired one for many sensing applications. Moreover, it can be clearly seen that the absorption peak shifts to longer wavelengths (i.e. lower energies) as the quantum well width increases, thus reducing the spacing between the confined energy levels. The **k·p** simulations confirm that this peak is related to the LH1-LH2 and show the same experimental shift due to the different quantum well widths.

The absorption spectra for a 10.7 nm QW design with different doping levels in Fig. 1b shows that p-type doping is indeed needed to move the Fermi level in the valence band and populate the LH1 energy level. Further increase of the doping is not beneficial as more transitions toward weakly or non-confined states become available, leading to a very wide peak compared to the 5x10^{18} cm^{-3} sample. Moreover, free carrier absorption is also expected to be stronger.

Therefore, it can be concluded that p-type doped Ge MQWs structures are a promising platform for the fabrication of inexpensive QWIPs, and that their optical properties can be tuned by changing the quantum well width.

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