Ge/Si Photodetectors and Group IV Alloy Based Photodetector Materials

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Abstract— **Photodetecctors using Si, Ge and other group IV alloys are of current interest for use at telecommunication wavelength 1550 nm. We have presented in this paper our work on resonant cavity enhanced (RCE) Si/SiGe multiple Quantum Well (MQW) and Ge Schottky photodetectors. Tensile strained Ge layers grown with suitable barriers show direct gap type I band alignment. Predicted performance of photodetectors using strong Quantum Confined Stark Effect and Franz-Keldysh effects in these structures and properties related to photodetection using these new materials are also described.**

I. INTRODUCTION

Photodetectors using III-V semiconductor materials and Multiple Quantum Wells (MQWs) made by using such compounds and their alloys are extensively used in present day long haul fiber optic communication systems operating at 40 Gb/s and beyond. Due to low cost, CMOS compatibility and ease of integration with other electronic systems, Si based photodetectors have always attracted attention from workers [1]. For operation at 1550 nm, Ge or SiGe alloys having high Ge content is used. Even then, the low absorption coefficient and the requirement to limit the alloy thickness below the critical layer thickness due to large lattice mismatch between Si and Ge or SiGe alloys demand special techniques to improve the performance. The methods include growth of strain symmetric structures, use of resonant cavity to increase effective absorption etc.

Si, Ge and in general Group IV alloys are indirect gap materials exhibiting low absorption, high recombination lifetime, no electro-optic effect and insignificant Franz-Keldysh (FK) effect [2]. The materials are not useful as light emitters and high speed modulators. Development of Si Photonics or Group IV Photonics is thus a challenging and active area of research even today [3]. Recently, direct gap type I heterostructures have been realized in tensile strained Ge using GeSiSn barriers [4]. The direct gap in Ge gives rise to large absorption coefficient, strong Quantum Confined Stark Effect (QCSE) [5] as well as large Franz-Keldysh (FK) effect [6]. Though the direct band gap in Ge is below 0.8 eV and cannot give emission at 1550 nm, the large absorption at 0.8 eV is attractive for efficient photodetection. Additionally, the observed large QCSE and F-K effects make the study of the photodetector performance in these new materials and structures encouraging.

In the present paper, we present our work on RCE structures using Si and SiGe and recent results using the direct gap nature of Ge. In the first part, we report our work and results on RCE Si/Ge MQW [7,8] as well as RCE Ge Schottky diode photodetectors [9], and discuss how to increase the responsivity by choosing Ge content, well parameters and applied bias. In the second part, the problems and prospects of the new material systems as photodetector materials are examined. The responsivity, quantum efficiency etc of photodetectors in tensile strained Ge layers exploiting QCSE and FK effects are then estimated. Some preliminary results on avalanche gain by simulation are also obtained.

II. RCE Si-Ge MQW DETECTORS

A detailed calculation of the responsivity of a RCE $Si_{1-x}Ge_x$ MQW photodetector for different Ge contents is made considering the effect of confinement of carriers in the potential trap at the heterointerfaces. The responsivity is calculated by solving continuity equation, position dependent generation rate due to absorption and standing wave effect. A representative data for responsivity is given in Fig. 1. The comparison with experimental data shows excellent agreement.

The quantum efficiency for a Ge based RCE Schottky photodiode is shown in Fig. 2 along with experimental data. The simulation results of Dosunmu et al [10] are also included for comparison.

The prospect of using Ge rich SiGeC for photodetection at 1550 nm is examined and the composition is estimated [11].

III. DIRECT GAP IN Ge

The Γ valley in Ge is only 140 meV above the L valleys in unstrained Ge. It has been mentioned in Sec. I that application of a tensile strain induces an indirect to direct crossover in Ge. The direct gap is associated with strong QCSE and large FK

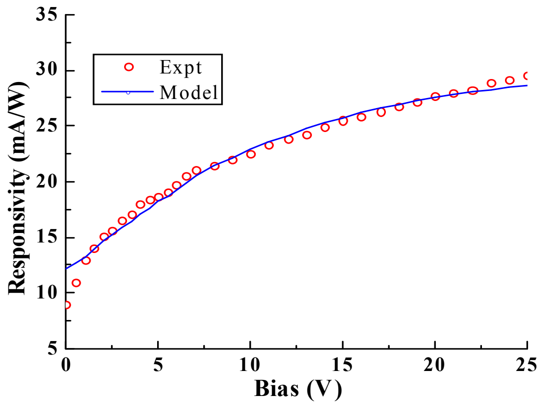

Fig. 1. Responsivity vs reverse bias for RCE SiGe MQW photodetectors

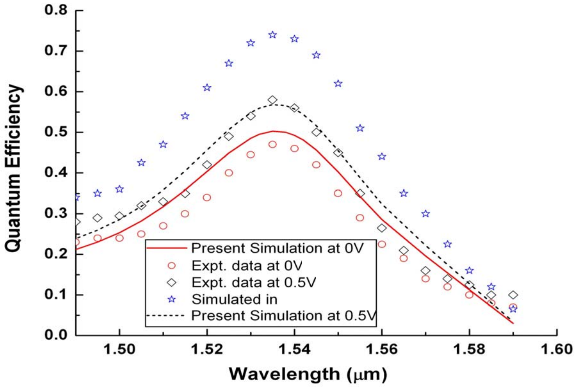

Fig.2. Quantum efficiency vs wavelength in Schottky photodetector

effects, both of which have been studied for possible application as photodetctors [6, 12].

The QCSE is due to shift of absorption peak of excitons formed by Γ valley electron and light hole in Ge by an external bias [5]. We have modeled the excitonic electroabsorption by two Gaussian curves for discrete excitons and an exponential distribution for the continuum. The simulated curves are used to calculate the responsivity and quantum efficiency of the photodetectors. A representative plot of quantum efficiency vs bias voltage is shown in Fig. 3.

The maximum Quantum efficiency and its corresponding energy for different bias voltages is shown in Fig. 4. The figure shows that maximum quantum efficiency is obtained for 3V bias.

In the present work a study has been made of the responsivity of Ge photodetectors in a pin configuration under high reverse bias exploiting FK effect.

We have also examined some physical properties like avalanche multiplication factor, saturation drift velocity etc. by lucky drift or Monte Carlo simulation of these new materials.

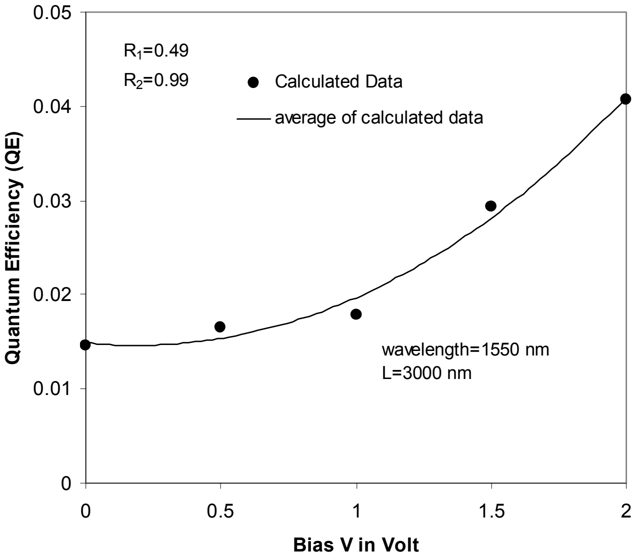

FIG. 3. Quantum efficiency vs. bias for RCE photodetector

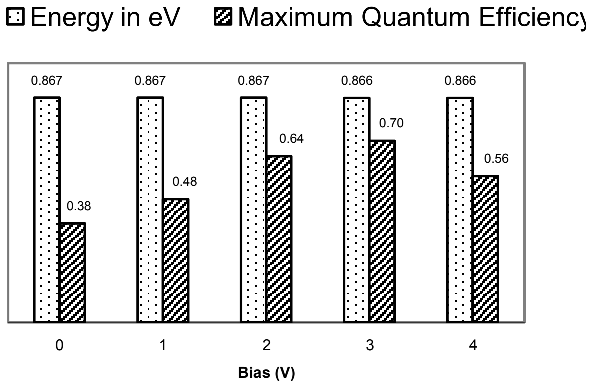

FIG.4. Maximum Quantum efficiency and corresponding energy vs bias voltage for RCE PD

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