Sn Content Dependent Absorption in GeSn Quantum Well Layer for Infrared Sensing

Prakash Pareek[1], Ravi Ranjan[2], Mukul K. Das[3]
[1,2,3]Indian School of Mines, Department of Electronics Engineering,
Dhanbad, India-826004.
E-mail: ppareek1@gmail.com

Abstract— Recently there has been a great deal of interest among researchers on the design and analysis of photosensitive devices based on Tin (Sn) incorporated Group-IV alloys. Alloying Ge with α-Sn can effectively reduce the direct-bandgap of Ge more than its indirect bandgap and, hence, a direct-bandgap GeSn alloy can be realized [1]. This paper focuses on the potential of Tin doped group-IV alloys specially GeSn. Sn dependent direct-absorption characteristic in strain balanced SiGe/GeSn quantum well(QW) is determined by solving time independent Schrödinger equation. Finite difference method is used to solve the Schrödinger equation for Γ-valley, heavy hole(HH) band and light hole(LH) band. The model, considered in our analysis, consists of tensile strained SiGeSn barriers and compressive strained GeSn well which ensure the strain balanced condition for quantum well. The strain balanced condition minimizes the total strain energy to reduce the strain-misfit dislocation density. A 76Å thick $Ge_{1-x}Sn_x$ layer is sandwiched between two tensile strained $Si_{0.09}Ge_{0.8}Sn_{0.11}$ layers to form a type-I single quantum-well (QW). A fully relaxed GeSn layer is used as a buffer layer. Width of the barrier layers is determined to be 34.6 Å by using the strain balanced condition for a cubic based multilayer system [2]. The band alignments are calculated using the model solid theory [3], and band offsets are calculated considering bowing parameter. Schrödinger equation for QW considering the strain effect and effective-mass is given as [4]

$$\left(\frac{-\hbar^2}{2}\frac{\partial}{\partial Z}\frac{1}{m_p}\frac{\partial}{\partial Z}+\frac{\hbar^2 K_t^{\,2}}{2m_p}+V_p(Z)-qF(z)\right)\psi=E\psi \qquad (1)$$

where, p=c for Γ conduction-band(CB), p=hh for heavy-hole(HH) valence-band. After evaluating Eigen energies, absorption coefficient in QW can be calculated with the help of Fermi golden rule [4] and is given as

$$\alpha=\frac{\pi q^2}{n_r c\varepsilon_0 m_0^{\,2}\omega}\sum_{n,m}\left|I_{hm}^{en}\right|^2\left|e.\hat{p}_{cv}\right|^2\rho_r.(f_v-f_c)\,H(\hbar\omega-E_0-E_{c1}+E_{v1}) \qquad (2)$$

Where, H is the Heaviside function which is replaced by Gaussian lineshape function to account inhomogeneity in GeSn layer. In this work Sn content in well is varied from x=0.15 to 0.18, as it is already reported that direct band gap induced in $Ge_{1-x}Sn_x$ for x≥0.15. Absorption coefficient is calculated for different Sn (x) concentration (x=0.15-0.18), for transverse electric(TE mode) is plotted in Fig.2. It is clearly observed from figure that the HH- Γ valley transition has higher absorption coefficient in 3-5μm range of wavelength. The transition energy for HH- Γ valley reduces and peak absorption wavelength red shifted with increase in Sn concentrations. This is due to the addition of the Sn which lowers the energy bandgap of GeSn. It can also be observed that with addition of Sn, absorption coefficient increases. This is due to upshift of HH band in the well due to compressive strain which strengthens further on addition of Sn concentration. It leads to increase in optical matrix element. So, the structure can be used for the mid infrared sensing application.

Fig. 1: Schematic of Quantum well structure

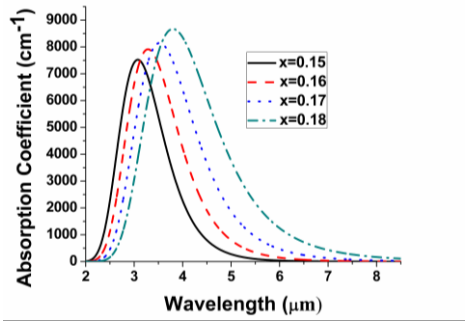

Fig. 2: Plot of absorption coefficient HH- Γ valley transition as a function of wavelength for different Sn (x).

References

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