Gain Performance of GeSn based n-p-n Heterojunction Phototransistor

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***Abstract*–A n-p-n heterojunction phototransitor with $Ge_{1-x}Sn_x$ base is presented. The work is focussed on effect of Sn concentration on the gain performance of the device based on optimised base and collector doping.**

***Index terms*– Heterojunction Phototransistor, GeSn alloy, Multiple quantum well,**

I. INTRODUCTION

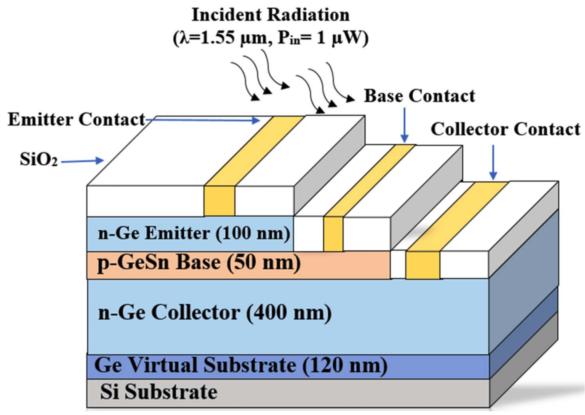
Photonic devices based on silicon (Si) and germanium (Ge) are being prevalent in number of applications [1]. However, Si and Ge have indirect band gap nature which limit the performance of the devices in terms of emission and absorption. Band gap tunability is one of the anticipated property for future semiconductor devices. Two possible approaches can be followed for above mentioned concerns. The first one is the growth of group IV heterostructures in which strains are induced by lattice mismatch contributing towards change in the nature of band gap. The second one is the formation of Ge based alloys with other elements such as tin (Sn). The combination of above two mentioned approaches can be able to provide band gap tunability [2]. In this context, for active material (generally base) or substrate, germanium-tin (GeSn) alloys have emerged as the most promising candidate. Sn alloying can enhance the optical absorption coefficient of Ge for application in C and L bands [3]. The optical absorption band of $Ge_{1-x}Sn_x$ alloy can be extended to higher wavelengths by increasing Sn concentration. Another stimulating property of $Ge_{1-x}Sn_x$ alloys is their direct bandgap nature for Sn concentation more than 8% (i.e., $x > 0.08$) [2].

p-i-n [4] and Avalanche photodetectors (APDs) [5] are the promising photodetectors being used in various application. However, p-i-n photodiode lacks of internal gain and APDs possess excess internal noise due to Avalanche multiplication. Heterojunction phototransistor (HPT) has emergered as a potential competitor because of its high gain and low noise property. In this context, some works have been reported the application of GeSn HPT in communication band and possibilities of detection application at longer wavelength [6]. In a work reported by Kumar et al., the n-p-n HPT was considered with subcollector layer. In this work, a n-p-n HPT without having subcollector layer is simulated to study the effect of different Sn concentration (in base GeSn) on the gain performance of HPT.

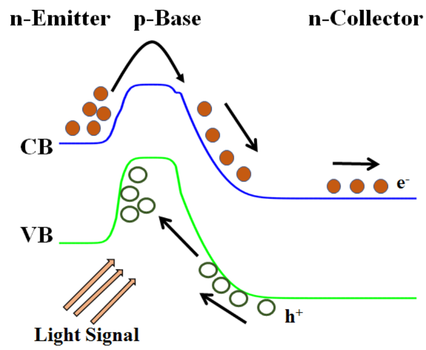
The paper is organized as follows: Section II deals with the structure of GeSn based HPT. Results and discussion are given in Sec. III. The conclusions are drawn in Sec. IV.

II. DEVICE STRUCTURE

Figure 1 shows schematic diagram of the device, consist of four-layers grown on Si substrate. The simulated band diagram is shown in Fig. 1(b). Wavelength and power of incident light are taken as 1.55 μm and ~1μW respectively for device simulations. It is assumed that light signal falls normally on the base.



(a)



(b)

Figure 1(a) Schematic of the n-p-n HPT (b) Simulated band diagram of device structure

Emitter, base and collector regions have doping concentrations of $1\ x10^{18}$, $1\ x10^{18}$ and $1\ x10^{17}$ cm^{-3} respectively.

III. RESULTS AND DISCUSSION

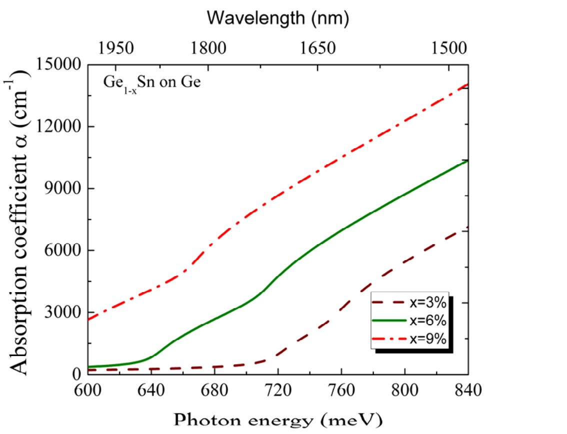


Figure 2 Absorption coefficient for pseudomorphic GeSn on Ge substrate

Figure 2 shows the variation of absorption coefficient for different Sn concentration in GeSn. It is evident that, on increasing Sn concentration the absorption coefficient can be shifted towards longer wavelength. This can provide important detection application in near infrared spectral region.

The device simulation is based on finite element method (FEM). Two modules, semiconductor and electromagnetic frequency domain analysis and are simultaneously used to study the effect of both incident photons and applied voltage bias. Trap assisted recombination mechanism along with Shockley-Read-Hall (SRH) model are used in semiconductor device analysis. Collector-emitter voltage (V_{CE}) and base collector voltage (V_{BE}) are taken as 1 V and 0 V, respectively for device simulation. An antireflecting coating of SiO_2 is applied in order to minimize the reflectivity.

Based on the layer parameters, gain vaiation for fixed base-emitter bias (0.4 V) with Sn concentration (x%) in $Ge_{1-x}Sn_x$ base is shown in fig. 3. Inset of fig. 3 shows the variation of current gain with applied base-emitter bias for different Sn concentration in GeSn. Correspondingly, it is found that, on increasing Sn composition (up to 6%) there is an increase in current gain for the n-p-n HPT structure. The increase in current gain (β) can be explained on the basis of increase in bandgap difference (ΔE_g) between base and emitter region [8]. The emitter region (Ge) has larger bandgap material as compared to that of base region ($Ge_{1-x}Sn_x$). In case of HPT structure it is seen that; for 9% Sn with ΔE_g=0.213 eV the gain start decreasing. Similarly, there is gain reduction for 12% Sn having ΔE_g=0.272 eV. This can be concluded for this device structure that, for $\Delta E_g \geq 0.213$ eV, there is larger band discontinuity at the junction of emitter and base due to larger heterobarrier, which causes current gain to decrease. Thus further analysis will be restricted up to 9% Sn concentration for this n-p-n structure.

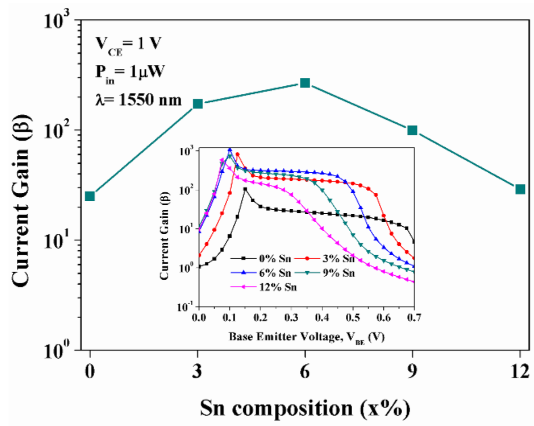


Figure 3 Current gain variation with different Sn concentration in base for a fixed emitter and sub-collector doping. Inset shows the Current gain variation with applied base emitter voltage for different Sn concentration in base for a fixed emitter and sub-collector doping.

IV. CONCLUSION

The effect of Sn concentration in base region of HPT is presented using FEM simulations. The wavelength and power of incident light are considered as 1.55 μm and 1 μW, respectively. The optimised thickness and doping of base region are chosen as 50 nm and 1 x10^{18} cm^{-3} respectively. A considerable high gaini is calculated for proposed structure. Calculation of other paameters such as, responsivity, reflectivity and quantum efficiency are the future scope of the presented work.

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