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EFFECT OF CRYSTAL ORIENTATION ON ELECTRON TRANMITTANCE OF SI/SI0.5/GE0.5/SI ANISOTROPIC HETEROJUNCTION BIPOLAR TRANSISTOR

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ABSTRACT

Study analytical of electron transmittance modeling on Si/Si1-xGex/Si heterojunction bipolar transistor anisotropic is done by including the coupling between transversal and longitudinal components of electron motion. The effects of crystal orientations to electron transmittance of transistor were studied. The results show that transmittance will be higher when the incoming energy Ez higher.

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1. INTRODUCTION

Nowadays, Si/Si1-xGex/Si heterojunction bipolar transistor has gained wide attention among scientists and gave impressive results. This is because Si/Si1-xGex/Si heterojunction bipolar transistor has made it possible to obtain higher amplification, higher speed performance. Theoretical studies of Si/Si1-xGex/Si heterojunction bipolar transistor have been done by using carrier transport model. Several researchers had done theoretical studies about tunneling phenomena in Si/Si1-xGex/Si hetero-structure. Kim and Lee had derived electron transmittance that tunnel through anisotropic Si0.5Ge0.5 barrier grown on Si(110) substrate by solving effective mass equation which taking into account the elements of effective mass tensor, except its diagonal elements, without giving bias voltage to potential barrier [1],[2].. Furthermore, we had calculated electron transmittance in anisotropic Si/Si0.5Ge0.5/Si hetero-structure when bias voltage given into potential barrier by using Airy function [3]. On the other side, Mao had shown that coupling between transversal and longitudinal components of electron movement in nano-scale metal-oxide-semiconductor field effect transistors (MOSFETs) affect it leakage current significantly [4]. In this research, the relationship between substrate orientation and coupling effect and its effects to electron transmittance and tunneling current of anisotropic Si/Si1-xGex/Si heterojunction bipolar transistor will be studied.

2. METHOD

Theoretical Model

Calculation of current in solar cell analytically was done by solving Schrodinger equation in semiconductor n-p junction, referring to previous work [5]. Schrödinger equation has to be solved to obtain electron behavior in anisotropic heterostructure. From there, we can obtain the coupling between transversal and longitudinal components of electron movements which will affect effective potential value in region 2 as shown in below equation [5] :

$$-\frac{\hbar^2}{2m_o}\alpha_{zz,II}\frac{\partial^2\varphi(z)}{\partial z^2}+\left(V(z)-\frac{\hbar^2}{2m_o}\sum_{i,j\in(x,y)}\beta_{ijI}\left(1-\frac{\beta_{ijII}}{\beta_{ijI}}\right)k_i k_j\right)\varphi(z)=E_{zI}\varphi(z)\,. \quad (1)$$

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Anisotropic Material's Effective Mass

Effective mass tensor elements, which shows anisotropic material, is depend on material's type and orientation. This effective mass tensor elements can be obtained because the formulation of general effective mass equation is done by defining three orthogonal coordinat systems as shown schematically in Figure 1. These coordinate systems are device, crystal, and ellipsoid coordinate system [6]. Three unit vectors $\hat{k}_1$, $\hat{k}_2$, and $\hat{k}_3$ stretch the device coordinate system and form its base. $\hat{k}_2$ is taken along its body thickness (that is inversion carrier of quantum barrier), $\hat{k}_3$ is taken along the direction from emitter to collector (that is transport direction) and $\hat{k}_1$ taken along its width. Device coordinate system depends on its fabrication choice, for example layer orientation and direction from emitter to collector in chips design layout. Second coordinate system is crystal coordinate system where it defined by three unit vectors $\hat{k}_1'$, $\hat{k}_2'$ dan $\hat{k}_3'$ oriented along three crystalography directions $\langle 100 \rangle$ orthogonal to base material. Crystal coordinate system is unique for every simulation. The last coordinate system, ellipsoid coordinate system consists of unit vectors $\hat{k}_{//}$, $\hat{k}_{\perp 1}$, dan $\hat{k}_{\perp 2}$ that choosen along main axis of each ellipsoid energy constant. Ellipsoid coordinate system depends on base material specifications and unique for every ellipsoid.

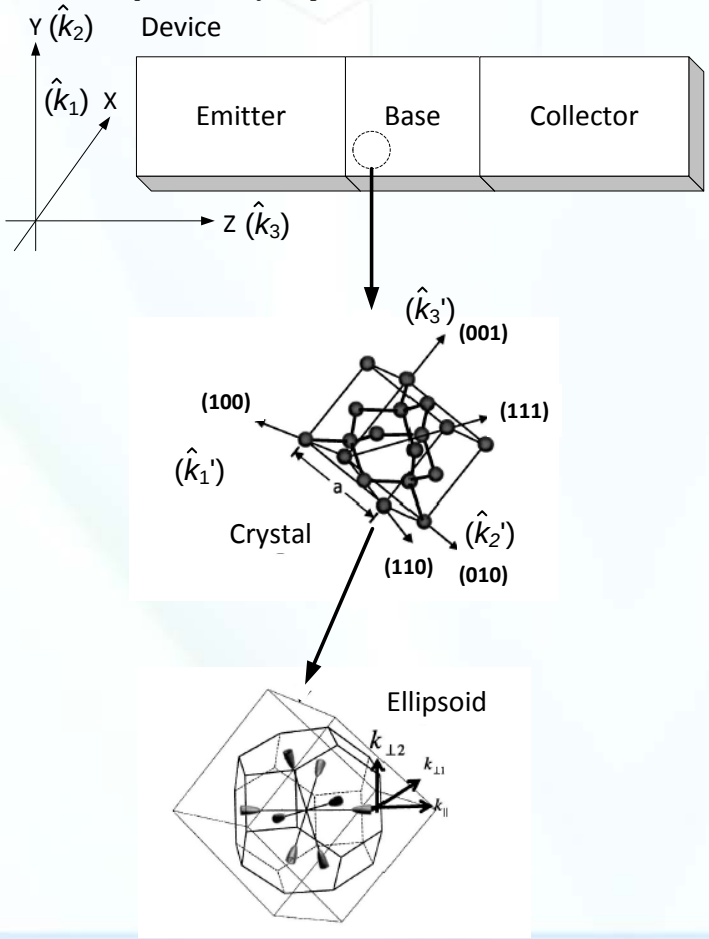

Figure 1. Three orthogonal coordinate system: device, crystal, and ellipsoid coordinate systems [6]

Table 1 shows effective mass inversion tensor for (100) orientation (Yi, et al., 1983; Rahman, et al., 2005).

Table 1. Effective Mass Inversion Tensor for (100) orientation

Valley 1	$\frac{m_o}{m_t}$	0	0
	0	$\frac{m_o}{m_t}$	0
	0	0	$\frac{m_o}{m_l}$
Valley 2	$\frac{m_o}{m_t}$	0	0
	0	$\frac{m_o}{m_l}$	0
	0	0	$\frac{m_o}{m_t}$
Valley 3	$\frac{m_o}{m_l}$	0	0
	0	$\frac{m_o}{m_t}$	0
	0	0	$\frac{m_o}{m_t}$

3. RESULT AND DISCUSSION

In tunneling current calculation for Si(100)/$Si_{1-x}Ge_x$ structure, only valleys with lowest energy that used in the calculation. This can be explained from the fact that only valleys with lowest energy that filled with electron while high energy valleys are not filled with electron [7]. Other Si/$Si_{1-x}Ge_x$ orientations are also have six valleys as shown in Table 2. Differences are on which valleys that has low energy.

Table 2 . Tensor elements α_{ij} from Si(100) and $Si_{0,5}Ge_{0,5}$.

Valley	**Region I (E) and III (C) Si(100)**			**Region II (B) $Si_{0,5}Ge_{0,5}$**		
1 (L1)	1,02	0	0	0,76	0	0
	0	5,26	0	0	6,45	0
	0	0	5,26	0	0	6,45
2 (L2)	5,26	0	0	6,45	0	0
	0	1,02	0	0	0,76	0
	0	0	5,26	0	0	6,45
3 (L3)	5,26	0	0	6,45	0	0
	0	5,26	0	0	6,45	0
	0	0	1,02	0	0	0,76

Tunneling current is produced because the presence of electron that move from emitter through base to collector, so it is impossible that there is collector current when no electron moves from emitter to collector. The number of electrons that tunnel through base to collector is called transmittance.

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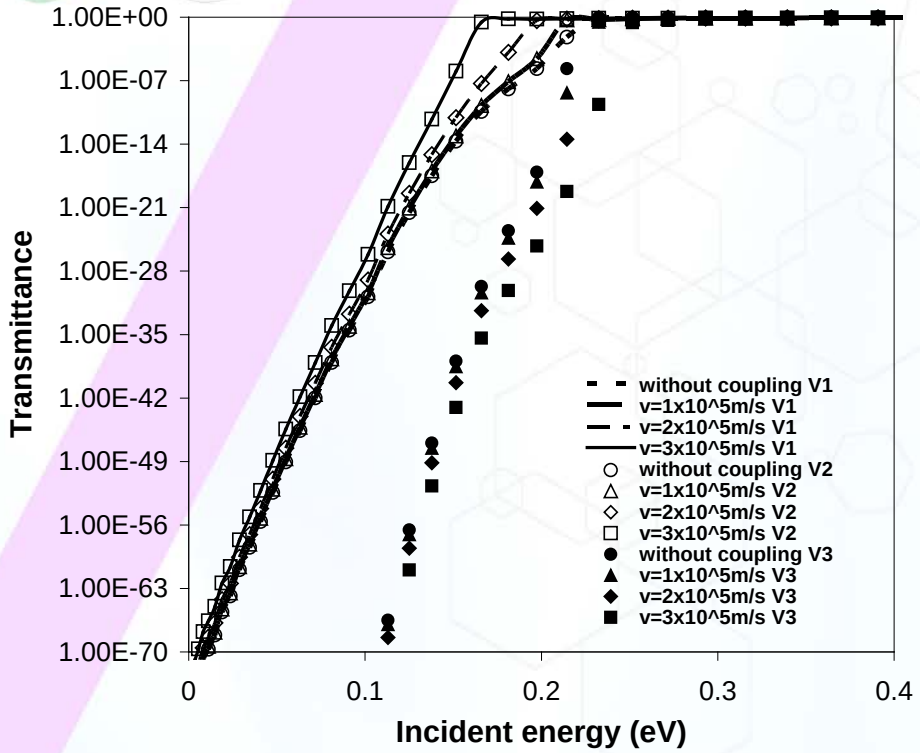

Figure 2.Electron transmittance in Valley 1 (V1), Valley 2 (V2), and Valley 3 (V3) as function to incoming energy E_z for various electron velocity withoug coupling, $1x10^5$ m/s, $3x10^5$ m/s, and $5x10^5$ m/s through barrier thickness of 25 nm.

Figure 2 shows graph between electron transmittance in Valley 1 (V1), Valley 2 (V2), and Valley 3 (V3) as function of electron incoming energy (longitudinal), Ez. It is clear that transmittance will be higher when Ez gets higher. When electron has higher energy, then electrons are more easily to tunnel through barrier so that the probability of electron to reach region 3 is also higher. When coupling effect between transversal and longitudinal movements are ignored, then electron velocity at that time is equal to zero. From Figure 2, transmittance when coupling effect is ignored is almost the same with transmittance when electron thermal velocity at $1x10^5$ m/s. At low incoming energy E_z, electron transmittance will be lower when electron velocity is faster. When incoming energy E_z is higher than the height of potential barrier, then its electron transmittance will osilate between value one. Thus, the faster electron velocity the higher the incoming energy E_z that will make the electron transmittance to osilate between value one.

4. CONCLUSION

It has been discussed about theoretical study of electron transmittance in $Si(100)/Si_{0.5}Ge_{0.5}(100)/Si$ (100) heterojunction bipolar transistor anisotropic by including the coupling between transversal and longitudinal components of electron motion. This calculation only use valleys with lowest energy. It is clearly shows that transmittance will be higher when the incoming energy E_z higher.

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