Effect of germanium concentrations on tunnelling current calculation of Si/Si$_{1-x}$Ge$_x$/Si heterojunction bipolar transistor

L Hasanah$^\dagger$, E Suhendi$^\dagger$ and Khairurrijal$^\ddagger$

$^\dagger$Department of Physics Education, Indonesia University of Education (UPI), Bandung, Indonesia
$^\ddagger$Physics of Electronic Materials Research Division, Institut Teknologi Bandung, Bandung, Indonesia

*Corresponding author’s e-mail: lilikhasanah@upi.edu

Abstract. Tunelling current calculation on Si/Si$_{1-x}$Ge$_x$/Si heterojunction bipolar transistor was carried out by including the coupling between transversal and longitudinal components of electron motion. The calculation results indicated that the coupling between kinetic energy in parallel and perpendicular to Si$_{1-x}$Ge$_x$ barrier surface affected tunneling current significantly when electron velocity was faster than $1 \times 10^5$ m/s. This analytical tunneling current model was then used to study how the germanium concentration in base to Si/Si$_{1-x}$Ge$_x$/Si heterojunction bipolar transistor influenced the tunneling current. It is obtained that tunneling current increased as the germanium concentration given in base decreased.

1. Introduction

Nowadays the development of microelectronic devices is growing very rapidly with increasingly impressive performance. Silicon is a material that has dominated the semiconductor industry for over 30 years. While silicon dominates microelectronic integrated circuits, there are areas where low mobility, low saturation velocity and indirect bandgap allow other semiconductor materials to be used. This promotes the use of SiGe technology with bandgap and strain techniques on silicon wafers to improve the weaknesses of silicon but maintains an advanced and inexpensive fabrication process that also suitable with existing silicon technology [1-3]. SiGe is an interesting and important material because it can be used with the development of the latest electronic and optical electronic devices [4,5]. The Si$_{1-x}$Ge$_x$ material system, in addition to improving the performance of silicon-based devices, also has the potential to produce new devices that can be integrated into the new silicon VLSI technology [4]. The study of the properties of anisotropic Si/Si$_{1-x}$Ge$_x$/Si heterojunction bipolar transistor was done theoretically by using quantum transport models [6-9].

Here, we reported the influence of the germanium concentration in base to the Si/Si$_{1-x}$Ge$_x$/Si heterojunction bipolar transistor collector current. We performed the analytical tunneling current calculation for variation electron velocity.

2. Method

The transport of electrons in the heterostructure can be determined by solving the Schrödinger equation. The wave function, which is the solution of the Schrödinger equation, is used to determine the dynamics of electrons. The square of the wave function represents the chance of finding an
electron. There are two kinds of methods that can be used to solve the Schrödinger equation; ie analytically [6,7,10] and semi numerical [11,12].

Analytical model of the tunneling current used in this research refers to previous work [8]. This model is used to study how the effect of germanium concentration on the basis of tunneling currents in anisotropic heterostructure bipolar transistor Si/Si$_{1-x}$Ge$_x$/Si. First, variation of germanium concentration evenly distributed along the base will be discussed. This will result in a flat-down potential profile, as shown in Figure 1.

![Figure 1. Energy-band diagram of n-p-n anisotropic Si/ Si$_{1-x}$Ge$_x$ /Si heterojunction bipolar transistor Si$_{1-x}$Ge$_x$ virtual substrate for the distribution current on the emitter is greater than the current on the base and the container on the base is greater than that of the collector under normal operating conditions.](image)

3. Results and Discussion
The discussion begins with a breakthrough on the bipolar transistors Si (110)/Si$_{0.5}$Ge$_{0.5}$(110)/Si (110), Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110) and Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110). Band transient on Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110) is 133 meV10 with the effective mass inversion tensor elements given by Table 1.

| Valley | Si(110) | Si$_{0.5}$Ge$_{0.3}$ |
|--------|---------|---------------------|
| 1 (L1) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.91                |
|        | 0       | 3.86                |
| 2 (L2) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.91                |
|        | 0       | 3.86                |
| 3 (L3) | 1.09    | 0                   |
|        | 0       | 5.26                |
|        | 0       | 5.91                |

| Valley | Si(110) | Si$_{0.5}$Ge$_{0.3}$ |
|--------|---------|---------------------|
| 1 (L1) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.68                |
| 2 (L2) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.68                |

| Valley | Si(110) | Si$_{0.5}$Ge$_{0.3}$ |
|--------|---------|---------------------|
| 1 (L1) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.68                |
| 2 (L2) | 5.26    | 0                   |
|        | 0       | 3.14                |
|        | 0       | 2.12                |
|        | 0       | 5.68                |
To see how the effect of germanium concentration on the tunneling current in the anisotropic Si/Si$_{1-x}$Ge$_x$/Si heterostructure bipolar transistor, examine Figure 2 which shows the tunneling current density of the anisotropic heterostructure bipolar transistor Si(110)/Si$_{0.5}$Ge$_{0.5}$(110)/Si(110), Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110) and Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110) in the tensile strain and compressive strain states with electron velocity 0 (without coupling) and 5x10$^5$ m/s. It appears that, for all germanium concentrations, the tunneling current density without coupling is greater than the current density with coupling in the tensile strain and the coupled current density without coupling is less than the current density with the coupling in the compressive strain. In the tensile strain, the tunneling current density will decrease as the electron velocity increases. In the compressive strain, the tunneling current density tends to increase with the greater of the electrons velocity. In both the tensile and the compressive strain, it is seen that, when the coupling effect is neglected, the tunneling current density is the same as the tunneling current density when the electron velocity is 1x105 m/s.

For all electron velocities, it can be seen that the Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110) current are larger than Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110) current and Si(110)/Si$_{0.5}$Ge$_{0.5}$(110)/Si(110) current is larger than Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110). This relates to an effective mass inversion of $\beta_{ij}$ Si$_{0.5}$Ge$_{0.5}$ greater than $\beta_{ij}$ Si$_{0.7}$Ge$_{0.3}$ dan $\beta_{ij}$ Si$_{0.8}$Ge$_{0.2}$ which results in $2\beta_{ij}(1-(\beta_{ij}/\beta_{ij}))$ Si$_{0.5}$Ge$_{0.5}$ being valued most negatively than $2\beta_{ij}(1-(\beta_{ij}/\beta_{ij}))$ Si$_{0.7}$Ge$_{0.3}$ and Si$_{0.8}$Ge$_{0.2}$ so that the effective potential of Si$_{0.5}$Ge$_{0.5}$ is greater than the effective potential of Si$_{0.7}$Ge$_{0.3}$ dan Si$_{0.8}$Ge$_{0.2}$. The greater the effective potential will be the smaller the resulting tunneling current produced.

![Figure 2](image_url)

**Figure 2.** Tunneling current density in heterostructure bipolar transistor Si(110)/Si$_{1-x}$Ge$_x$(110)/Si(110) anisotropic structure with germanium x concentrations equal to 50%, 30% and 20% for state (a) tensile strain and (b) compressive strain

### 4. Conclusion

A tunneling current calculation in the anisotropic heterojunction bipolar transistor Si/Si$_{1-x}$Ge$_x$/Si has been carried out analytically by including quantum effects. Upon variation of germanium concentration, it was found that the resulting current of the Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110) was greater than the current in Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110). Additionally, the current of Si(110)/Si$_{0.7}$Ge$_{0.3}$(110)/Si(110) was greater than the current in Si(110)/Si$_{0.8}$Ge$_{0.2}$(110)/Si(110).
5. References

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