Room Temperature Oscillation in Si/Si$_{1-x}$Ge$_x$ Resonant Tunneling Diode

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1. Introduction

Si/Si$_{1-x}$Ge$_x$ resonant tunneling diodes (RTDs) have been intensively studied as one of next-generation quantum effect devices formed with Si-system materials. However, their oscillations have not been reported at any temperature yet.

We have so far applied a combination of electron tunneling and double quantum well (DQW) using the type II band offset [1-5], and have reported high PVCRs of >180 at RT [2-5]. To form the type II hetero structure, a strain-relaxed SiGe buffer should be first formed on a Si substrate. For the buffer, a thick Si$_{1-x}$Ge$_x$ graded buffer, where the Ge composition, x, is varied by 0.1 µm$^{-1}$, is commonly used [6]. To save the production energy and time, we have previously proposed a thin triple-SiGe-layer (TL) [3,4] and a thin quadruple-SiGe-layer (QL) [5] buffer. Each thickness is about one-fifteenth of that of the graded buffer. Especially, the QL buffer also exhibits high surface crystallinity even when it is highly P-doped to increase the current density.

In this paper, we first report the observation of oscillation in a Si/Si$_{1-x}$Ge$_x$ RTD at room temperature (RT). The RTD has an electron-tunneling type-II DQW structure and is formed with a highly P-doped QL buffer.

2. Experimental

Si and Si$_{1-x}$Ge$_x$ layers were grown on 0.01 Ωcm n-type Si(001) at a substrate temperature of 600 ºC by gas-source molecular beam epitaxy in a vacuum chamber with a base pressure of < 1×10$^{-9}$ Torr using Si$_2$H$_6$, GeH$_4$ and PH$_3$ for Si, Ge, and P dopant gas sources, respectively.

3. Results and Discussion

3.1 Strain-relaxed doped quadruple-layer (QL) buffer

In the case of the TL buffer (Fig. 1(a)) [3,4], the first and second SiGe layers are grown almost coherently, and when the top (third) SiGe layer is grown, misfit dislocations are mainly generated in the lowest interface and the buffer relaxes. The top SiGe layer prevents the threading dislocations from being propagated to the top layer. The surface threading dislocation density, $D_T$ is low as indicated in Fig. 2(a). However, when the TL buffer is highly doped with P to increase the current density, the buffer surface crystallinity degrades and the $D_T$ increases by a factor of 1000 as shown in Fig. 2(b).

3.2 Si/Si$_{1-x}$Ge$_x$, RTD and its room-temperature oscillation

Using the highly P-doped QL buffer with a high crystalline surface, electron tunneling symmetrical DQW RTD was fabricated on a 0.01 Ωcm n-type Si(001) substrate as shown in Fig. 3. The undoped double-well part is sandwiched by 10-nm undoped Si. The doping densities of the n-type layers were all ~4×10$^{18}$ cm$^{-3}$.
Typical $I$-$V$ curves obtained from a DQW RTD with a diameter of 25 µm at RT are shown in Fig. 4. Self-oscillations were observed in the $I$-$V$ curves at ~1.7 V at RT. The RTD shows a good resonance curve and a high current density. We have first observed oscillation in the Si/Si$_{1-x}$Ge$_x$ RTD at RT. The oscillation frequency was limited by the bias-T circuit parameters. The average number of the surface threading dislocations of the RTD is less than 1 estimated from the $D_T$ value indicated in Fig. 2(c). The oscillation generation may be connected with the low defect density in addition to the high resonant peak current density.

### 4. Conclusions

We fabricated an electron-tunneling Si/Si$_{1-x}$Ge$_x$ DQW RTD using the previously proposed highly P-doped quadruple-layer buffer with a high crystalline surface. The average number of the buffer surface threading dislocations is $< 1$. The RTD shows a good resonance curve and a high peak current density. We have first observed oscillation in the Si/Si$_{1-x}$Ge$_x$ RTD at RT. The oscillation frequency was limited by the measurement circuit and was 11 MHz. The estimated max frequency, $f_{\text{max}}$, is ~3 GHz. The $f_{\text{max}}$ will increase by the reduction in the series resistance, $R_s$. The Si/Si$_{1-x}$Ge$_x$ DQW RTD technology is expected to evolve by our room-temperature oscillation observation result.

### References