$Si_{1-x}Ge_x$/Si Triple-Barrier RTD with a High Peak-to-Valley Ratio of ≥ 180 at Room Temperature

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Resonant-tunneling-diode (RTD) quantum devices have attracted considerable attention as promising devices for future ultrahigh-speed and low-dissipation applications. In addition to these merits, SiGe RTDs have also been focused for their potential feasibility of being integrated with Si CMOS circuits.[1] However, only RTDs made from III-V materials have been applied in practice to logic circuits because of their much larger negative-differential-resistance (NDR) resonances than those of SiGe RTDs. The degree of the NDR effect is determined using the peak-to-valley current ratio (PVCR) as a figure of merit, and for III-V RTDs, PVCR values of more than 50 are obtained at room temperature (RT).[2] For quantum devices to be useful, they must operate at RT.[1]

As for SiGe RTDs, RTD structures have been designed mainly for hole tunneling,[3-6] since large valence band offsets are easily obtained. A double-barrier (DB) and a triple-barrier (TB) structure have been applied to these RTDs; however, they exhibit poor temperature performance with PVCR ≈ 2 at temperatures of ≤ 77 K and the NDR has not been observed at RT due to thermally assisted tunneling through closely spaced light-hole and heavy-hole levels.[4] On the other hand, Ismail *et al.* observed for the first time an electron-tunneling NDR at RT.[7] All reported electron-tunneling RTDs have a DB structure and the highest PVCR value has been 2, which was measured at 4.2 K.[8] On the basis of our theoretical analysis, we have recently applied for the first time a combination of electron tunneling with a single mass and multiple wells to a SiGe RTD, and have demonstrated that a $Si_{0.7}Ge_{0.3}$/Si TB RTD exhibits a PVCR value of ~ 7.6 at RT.[9] Comparison of the PVCR values is summarized in Table 1. The large NDR effect at RT is explained by the simple conduction band configuration and the necessity of the double-well coresonance condition.

To further improve the NDR characteristics, we have optimized the layer structure and growth method for the TB RTD and have proposed the use of an annealed thin stepwise $Si_{1-x}Ge_x$ multilayer as a strain-relief relaxed buffer on which the TB structure is grown.[10] An electron-tunneling $Si_{0.67}Ge_{0.33}$/Si TB RTD formed using the annealed thin double-layer buffer exhibits a PVCR value of≥180 at RT [10] which is ~ 100 times as high as those reported by other researchers (Table 1) and is comparable to the values obtained from III-V RTDs. The typical *I-V* curve is shown in Fig. 1. The high PVCR behavior is explained as being related to the strain-relief relaxed buffer surface with high crystalline quality and low dislocation and defect density in addition to the use of a combination of electron tunneling and the double-well coresonance condition. The proposed SiGe RTD gives rise to great potential to SiGe RTDs for future practical integrated device applications.

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Table 1. Comparison of PVCR (peak-to-valley current ratio) values of $Si_{1-x}Ge_x$ resonant tunneling diodes (RTDs)

x	Carrier	Number of Barrier	Temperature (K)	PVCR	Ref.
0.21	hole	2	4.2	2.2	H. C. Liu *et al.* (1988)[3]
			77	1.8	
0.22	hole	3	10	1.1	D. X. Xu *et al.* (1992)[4]
			≥ 100	NO	
0.4	hole	2	4.2	2.1	S. S. Rhee *et al.* (1988)[5]
			77	1.6	
0.5	hole	2	15	1.5	U. Gennser *et al.* (1991)[6]
0.3	electron	2	77	1.5	K. Ismail, *et al.* (1991)[7]
			300	1.2	
0.35	electron	2	4.2	2.0	Z. Matutinović-Krstelj
			≥ 220	NO	*et al.* (1993)[8]
0.3	electron	3	300	7.6	H. Koyama *et al.* (1998)[9]
0.33	electron	3	300	~180	S. Yamaguchi *et al.* (2001)[10]

NO: Negative differential resistance was not observed

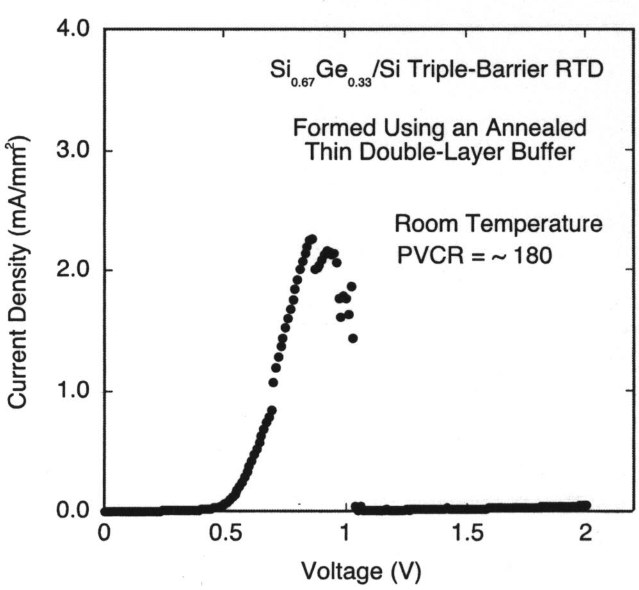

Fig. 1. A typical *I-V* curve obtained at room temperature from a $Si_{0.67}Ge_{0.33}$/Si asymmetric triple-barrier RTD formed using the annealed thin double-layer buffer. The data shows a PVCR value as high as ~ 180 which is comparable to the values obtained from III-V RTDs.