Realization of Nanoelectronic Devices-Resonant Tunneling Diodes Grown on InP Substrates with High Peak to Valley Current Ratio

Zhang Yang†, Zeng Yiping, Ma Long, Wang Baoqiang, Zhu Zhanping, Wang Liangchen, and Yang Fuhua

(Materials Science Center, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China)

Abstract: We report InAs/$In_{0.53}Ga_{0.47}As$/AlAs resonant tunneling diodes (RTDs) grown on InP substrate by molecular beam epitaxy. The peak to valley current ratio of these devices is 19 at 300K. A peak current density of $3kA/cm^2$ is obtained for RTDs with AlAs barriers of ten monolayers and an $In_{0.53}Ga_{0.47}As$ well of eight monolayers with a four-monolayer InAs insert-layer.

Key words: resonant tunneling diode; InP substrate; molecular beam epitaxy
PACC: 7360L; 7980
CLC number: TN31 **Document code**: A **Article ID**: 0253-4177(2007)S0-0041-03

1 Introduction

The terahertz (THz) frequency range remains underdeveloped, though many applications are expected in fields such as ultrahigh speed wireless communication, imaging, environment sensing, astronomy, and various analyses in chemistry and biotechnology. Among these applications, compact and coherent THz sources are important key components. However, development of full electronic devices approaching the THz range is also being carried out from the low frequency side. Resonant tunneling diodes (RTDs) based on InP substrates have been considered to be the most promising candidates for THz oscillators, which have potential to operate up to 3THz at room temperature. Meanwhile, strained AlAs/$In_{0.53}Ga_{0.47}As$/InAs RTDs yield the largest peak current density[1] and nearly the highest frequency characteristics[2] among RTDs. In order to make RTDs operate in the THz range, here we report the fabrication by MBE of RTDs of high crystal quality and superflat heterojunction interfaces as tube cores of oscillators.

2 Experiment

The resonant tunneling diodes were grown in a Veeco GEN Ⅱ MBE system using individual In, Ga, Al, As and Si effusion cells, all of 7N's purity. Polished (100) Fe-doped semi-insulating 50mm InP substrates were used. The native oxides on InP substrates were removed in the cleaning chamber by heating to 520℃ under an As_4 pressure of about 0.133mPa. The growth rate for lattice-matched $In_{0.53}Ga_{0.47}As$ was 0.307nm/s, and those for strained AlAs and InAs were 0.165 and 0.169nm/s, respectively. Silicon was used as the n-type dopant. The substrate holder was rotated at 10r/min during the growth. Growth interruptions and an *in situ* reflection high energy electron diffraction (RHEED) intensity oscillation technique were used to aid the growth of the thin barrier and well layers. The substrate temperature during the growth of $In_{0.53}Ga_{0.47}As$ and AlAs was maintained at 480℃. However, the substrate temperature was lowered to 420℃ during the growth of the InAs well.

3 Results and discussion

Figure 1 shows a schematic cross-section of an InAs/$In_{0.53}Ga_{0.47}As$/AlAs RTD and its energy band diagram. Two Si-doped n-$In_{0.53}Ga_{0.47}As$ buffer layers of 0.2μm thickness each and with doping concentrations of 5×10^{18} and $2\times10^{17}cm^{-3}$, re-

† Corresponding author. Email: zhang_yang@semi.ac.cn
Received 27 November 2006

spectively, were grown on InP substrate. The double barrier structure was sandwiched between 6ML thick, undoped spacer layers. The undoped $In_{0.53}Ga_{0.47}As$ spacer layers were introduced to suppress the possible diffusion of Si. The thickness of the top and bottom AlAs barrier was 10ML. The well consisted of 4ML lattice-matched $In_{0.53}Ga_{0.47}As$, 4ML of strained InAs, and 4ML of lattice-matched $In_{0.53}Ga_{0.47}As$. The active region was covered with three 100nm-thick $In_{0.53}Ga_{0.47}As$ layers with Si-doping concentrations of 2×10^{17}, 2×10^{18}, and 2×10^{19} cm^{-3}, respectively. Growth interruptions before and after each AlAs layer allowed for the smoothing of the AlAs barrier interfaces but did not fully compensate for effusion cell flux transient effects, which caused growth rate variations during the short growth times of the ultrathin layers. After the epitaxial growth, Mesa diodes, with device areas ranging from $2\mu m\times2\mu m$ to $12\mu m\times12\mu m$, were fabricated using conventional photolithographic techniques. Nonalloyed ohmic contacts of Cr/Au = 80/100nm, which were deposited at 100℃, were used for the topside and bottom side.

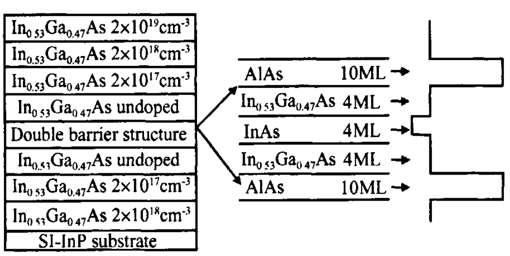

Fig. 1 Cross-sectional layer structure of an AlAs/$In_{0.53}Ga_{0.47}As$ double barrier resonant tunneling diode grown on InP substrate, and its energy band diagram

The DC current-voltage (*I-V*) characteristics were measured with a KEITHLEY 4200 semiconductor parameter analyzer. Figure 2 shows the *I-V* characteristic of a typical device with a peak-to-valley current ratio of 18 and a peak current density of approximately $3kA/cm^2$ in positive bias (corresponding to electron flow from the substrate contact towards the top contact). "Plateau-like" structures can be seen in Fig. 2, which are due to the intrinsic instability of resonant tunneling diodes in the negative differential resistance region. Bistability can also been observed, and is found to be dependent to some extent on external circuit parameters.

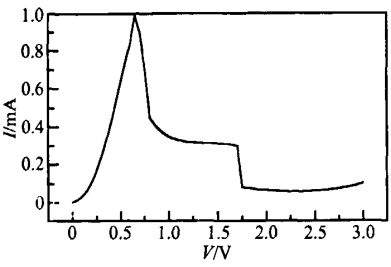

Fig. 2 *I-V* characteristics of a $6\mu m\times6\mu m$ InAs/$In_{0.53}Ga_{0.47}As$/AlAs RTD at $T=300K$ with $J_p/J_v=18$ ($V_p=0.65V$, $V_v=2.29V$)

4 Conclusion

In summary, RTD structures with sub-well InAs and AlAs barrier-based InP substrates have been fabricated, which show improved PVR over that based on GaAs substrates. An important advantage of using InAs in the well is that it permits a thinner well while still maintaining a low resonance energy level with respect to the emitter conduction band and gives an additional degree of freedom in designing RTDs.

Acknowledgements The authors wish to thank Bai Yunxia, and Wang Li for assistance with device fabrication. The authors also acknowledge Li Donglin, Lin Guoqiang, Wang Xiaofeng and Shen Wenjuan for fruitful discussions and continual encouragement.

References

[1] Broekaert T P E, Fonstad G. $In_{0.53}Ga_{0.47}As$/AlAs resonant tunneling diodes with peak current densities in excess of $450kA/cm^2$. J Appl Phys, 1990, 68(8): 4310

[2] Reddy M, Martin S C, Molnar A C, et al. Monolithic Schottky-collector resonant tunneling diode oscillator arrays to 650GHz. IEEE Electron Device Lett, 1997, 18(5): 218

纳米电子器件-高峰值峰谷电流比 InP 基共振隧穿二极管的实现

张 杨[†] 曾一平 马 龙 王保强 朱战平 王良臣 杨富华

(中国科学院半导体研究所 材料科学中心，北京 100083)

摘要：利用分子束外延技术研制出 InP 基 $InAs/In_{0.53}Ga_{0.47}As/AlAs$ 共振隧穿二极管，其中势垒为 10 个单分子 AlAs层，势阱由 8 个单分子层 $In_{0.53}Ga_{0.47}As$ 阱和 4 个单分子层 InAs 子阱组成.室温下峰值电流密度接近 $3kA/cm^2$，峰和谷的电流密度比率达到 19.

关键词：共振隧穿二极管；InP 基；分子束外延

PACC：7360L；7980

中图分类号：TN31 **文献标识码**：A **文章编号**：0253-4177(2007)S0-0041-03

† 通信作者. Email: zhang_yang@semi.ac.cn

2006-11-27 收到