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Well transmission coefficient in indium arsenic resonant tunneling microwave structures

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ABSTRACT

The $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$ resonant tunneling microwave structures (InAs-based RTMS) is designed in energy band structure of interband with double quantum wells. The influences of carrier transmission coefficient in RTMS device with central barrier thickness which varied from 10Å to 30Å are studied by using theoretical calculation procedure. The transmission coefficients are calculated in considering band gap narrowing (BGN) effect due to the heavily doped effect. The well defined transmission coefficient has been expressed in use of smaller central barrier width, which results in the larger transmission coefficient as considering BGN effect.

KEYWORDS

Indium arsenic;
Resonant tunneling microwave;
Quantum well;
Transmission coefficient;
BGN.

INTRODUCTION

Microwave devices play an important role in the wireless and radio frequency communications. The radio frequency oscillator is an important element in use of microwave system. The Esaki tunneling diodes have been widely used in the application of radio frequency communication[1]. But the operational frequency of traditional microwave devices is limited by the junction capacitance of microwave device[2,3]. Recently, the high quality heterojunction and quantum structures are designed in resonant tunneling microwave device which will be with the advance of the microwave characteristics, among the all double barrier and double quantum resonant tunneling structures[4,5]. Although the designed resonant tunneling structures can be operated at near microwave frequency of THz, the thermal current of resonant tunneling device is large due to the low barrier height of microwave device. Therefore, the double quantum well interband resonant tunneling microwave structure (DQWI RTMS) is studied in this research. The carrier transmission coefficient with negative differential resistance (NDR) characteristics in RTMS plays a more important role in the improvement of characteristic of microwave devices, which decided the peak to valley current ratio (PVCR) value of current-voltage curve. More recently, the PVCR value is studied how to be raised from lower value to close to one hundred in using differential structures such as double quantum well structures, double barrier quantum well (DBQW) structures and heavily doping resonant interband tunneling structures[6-9]. To further improve the characteristics in the RTMS, the influence of central barrier thickness with bandgap narrowing (BGN) effects for energy level of quantum well and central barrier thickness in transmittance coefficient have been investigated. Although the PVCR value is decided by the carrier transmission characteristic of resonant tunneling structures of RTMS, the carrier transmission characteristic is absolutely influenced by the energy barrier structure of quantum well in the RTMS.

DESIGN AND CALCULATION OF RTMS

This pseudomorphic $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ RTMS reported here were designed on (100)-oriented n^+ Sn-doping InP substrate, as shown in figure 1. The sandwiched $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ resonant tunneling structures were constructed on the top of a 1μm n^+-3×10^{19} cm^{-3} InAlAs electrode layer. The another 0.4μm p^+-3×10^{19} cm^{-3} InAlAs electrode layer was arranged on the top of $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ resonant tunneling structures. The top capping layer was designed with the dopant of p^+-3×10^{19} cm^{-3} and its thickness is 200Å. The sandwiched resonant tunneling structures of RTMS between the n^+ and p^+ InAlAs electrodes were respectively the undoped InAlAs central barrier layer and the undoped InGaAs well layers with 40Å thick. This resonant interband tunneling structure of RTMS is the structure of calculation works. The theoretical characteristics of InAs-based resonant tunneling structures of RTMS are calculated by using k-p theory and transfer-matrix technique (TMT)[10]. The energy states, wave function, and transmittance coefficient are obtained as isotropic materials.

RESULTS AND DISCUSSION

To investigate the effect of the central barrier on the interband tunneling transmission coefficient, three samples with central barrier thicknesses of 10Å, 20Å, and 30Å were respectively calculated by using TMM and K.P theory. The BGN effect is considered in the calculation of transmittance coefficient of RTMS. The energy levels of quantum well in the RTMS are shifted down with the increased bias forward voltage in any devices. Then, it results in the decrease of transmission coefficient in the resonant tunneling structure of RTMS, as expressed in figure 2. The transmission coefficient of

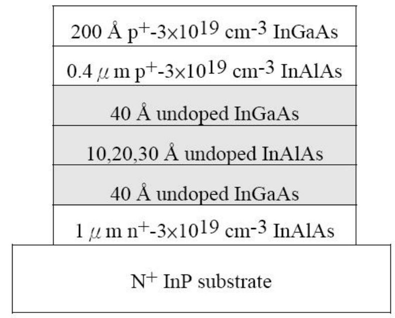

Figure 1 : The basic schematic cross section of $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/In_{0.53}Ga_{0.47}As$ resonant tunneling structure of InAs-based RTMS

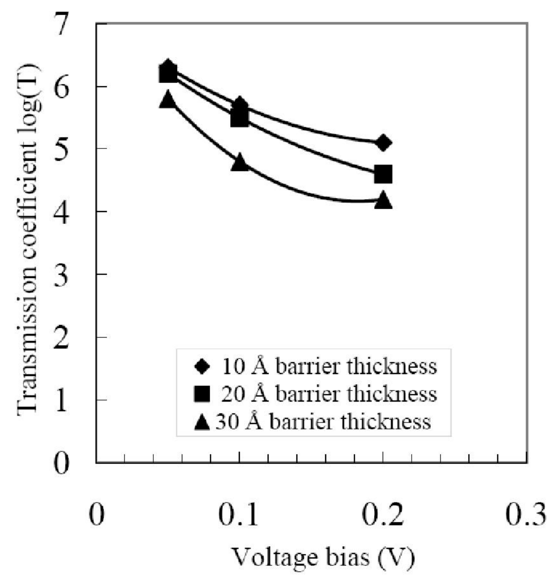

Figure 2 : The relation of the transmission coefficient and voltage bias for InAs-based RTMS with 10 Å, 20 Å, and 30Å central barriers thickness and 40Å well widths

resonant tunneling structure of RTMS with central barrier of 10Å in thick is larger than of the others, as shown in figure 2, due to its smaller effective tunneling barrier. The quantized levels are obtained in 238 mev, 181 mev, and 138 mev for RTMS devices with 10Å, 20Å, and 30Å central barrier thicknesses, respectively. Because of higher built-in electric field, the quantized level of device with smaller central barrier thickness is higher. The well transmission coefficient of RTMS device with central barrier thickness of 10Å is possessed three quantum levels which near the energy level 248 mev, 202 mev, and 186 mev. The electron and light-hole levels are not well lined each other when the RTMS devices are with central barrier of 20Å and 30Å thickness, respectively. For the RTMS device with 30Å central barrier thickness, the electron level is moved down to the lower energy level, the light-hole level is shifted up to

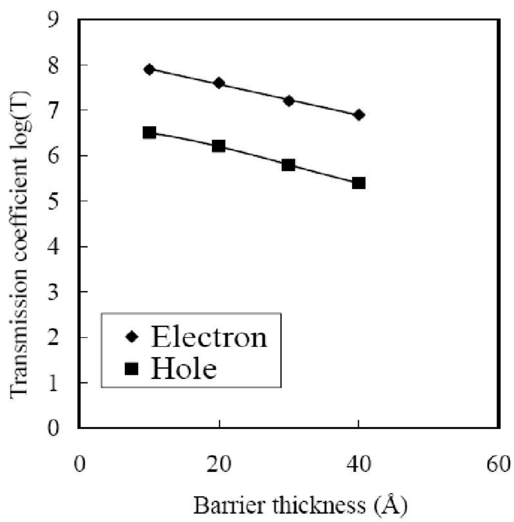

Figure 3 : The electrons and light-hole dominated between transmission coefficient and central barrier thickness for InAs-based RTMS with 40Å well widths

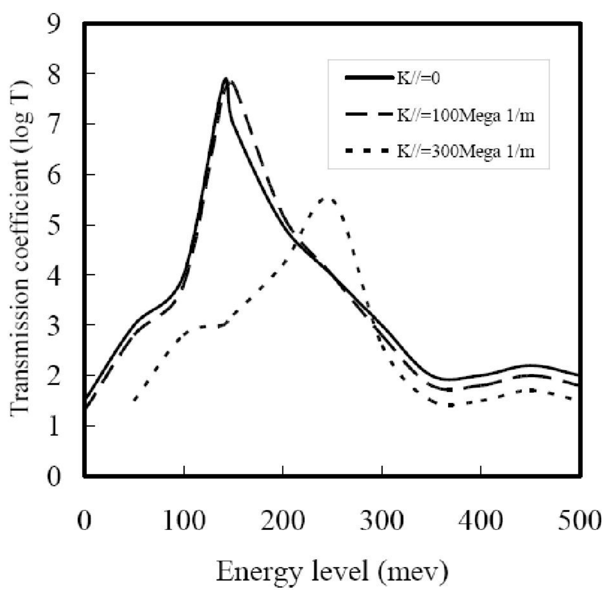

Figure 4 : The transmission coefficients for InAs-based RTMS with a 30Å central barrier calculated for a series of $k_{//}$ values

the higher energy level, and the resonance is occurred at about energy levels of 182 mev, 126 mev, and 102 mev. The transmission coefficient of electron is larger than of the light-hole energy levels which are lined at $k_{//}=0$, as shown in figure 3. The larger transmission coefficient in electron carrier will result in the major contribution of the RTMS current by electron carrier. The line-up of electron and light-hole energy levels are at the energy levels of 283 mev and 112 mev with wave vector of $k_{//}=3\times10^{8}\,m^{-1}$ for the RTMS device with 30Å central barrier thickness, as shown in figure 4. The effective bandgap is increased and the peak transmission coefficient is decreased when the device is with central barrier of 30Å thick. This cause is due to the split of electron and light-hole levels. The well transmission coefficient is occurred at the energy level of 238 mev which the resonant tunneling microwave structure is with central barrier thickness of 10 Å.

CONCLUSIONS

For the fixed central barrier width, the transmission coefficient will decrease with increasing the applied voltage. We also have proved that the smaller central barrier width will result in the larger transmission coefficient. The RTMS device with narrower barrier width possessed larger bandgap difference between its electron energy level and light hole energy level, which can result in the well tunneling properties. The transmission coefficient will be decreased, when the $k_{//}$ value is increased at the same central barrier width. The current density of RTMS device with BGN effect will be raised with decreased the barrier thickness, because of high transmission coefficient.

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