diode (VID), that had five NDR regions. The five tunneling structures were separated from each other by 500-Å n^+ InGaAs layers which destroyed electron coherence between the tunneling regions such that each resonant-tunneling structure switched sequentially with increasing bias. The room-temperature $I-V$ characteristics of the VID (diameter of 62 μm) were near-ideal: $I_{Pi} \simeq 0.88$ mA, $I_{Vi} \simeq 0.35$ mA, $V_{Pi} = (1.9 + 0.7 \cdot i)$ V, $1 \leq i \leq 5$, where i denotes the ith current peak/valley. We have used the VID to demonstrate a multilevel memory element which has five distinct voltage states that can be set by using small current pulses. The VID was also used in a circuit to generate the parity of an 11-bit word.

[1] H. C. Liu and D. D. Coon, *Appl. Phys. Lett.*, vol. 50, p. 1246, 1987.
[2] S. Sen, F. Capasso, A. Cho, and D. Sivco, *IEEE Trans. Electron Devices*, vol. ED-35, p. 2185, 1987.
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VB-4 Multiple-Valued Logic Application of a Triple Well Resonant Tunneling Diode—C. Kusano, T. Tanoue, H. Mizuta, and S. Takahashi, Central Research Laboratory, Hitachi Ltd., Kokubunji, Tokyo 185, Japan.

A new resonant tunneling diode (RTD) with four potential barriers and three quantum wells is proposed and applied to multiple-valued logic devices which are one of the most promising applications of RTD's [1]. This is the first report of a single diode exhibiting significant double negative differential resistance (NDR) characteristics and operating as a triply stable device with a single supply voltage.

A 500-nm Si-doped (1×10^{18} cm^{-3}) GaAs buffer layer, a 10-nm GaAs spacer layer, then a triple well structure consisting of undoped AlAs (1 nm)/GaAs (6.9 nm)/$Al_{26}Ga_{76}As$ (3 nm)/GaAs (5.7 nm)/$Al_{26}Ga_{76}As$ (3 nm)/GaAs (11.9 nm)/AlAs (1 nm), and finally a 300-nm Si-doped (1×10^{18} cm^{-3}) GaAs layer, were successively grown on an n^+-GaAs substrate by MBE. These structures were determined by numerical simulation.

The device showed significant double NDR between 180 K and room temperature, exhibiting the best characteristics at 219 K; peak/valley current ratios were 2.8 and 1.4 with the same peak currents of 4×10^2 A/cm^2 for both NDR peaks. With load resistance of 100 Ω and applied voltage of 1 V, this diode exhibited three stable states at 0.066, 0.158, and 0.249 V. These voltages were in excellent agreement with numerically simulated values. The numerical simulation also showed that the two resonance voltages can be adjusted independently by varying the width of the wells, thus illustrating the advantage of a triple well structure. These results indicate that this new triple well RTD can realize triple valued logic devices with a single supply voltage. Details of the device fabrication and analysis, as well as a new theoretical approach taking random scattering into consideration, will be described.

[1] F. Capasso *et al.*, *IEEE Electron Device Lett.*, vol. EDL-8, pp. 297–299, 1987.

VB-5 Experimental Analysis of Resonant-Tunneling Hot-Electron Transistors Operated at Room Temperature—T. Mori, K. Imamura, H. Ohnishi, Y. Minami, S. Muto, and N. Yokoyama, Fujitsu Limited, 10-1 Morinosato Wakamiya, Atsugi 243-01, Japan.

This paper reports on the fabrication of AlAs/InGaAs resonant-tunneling hot-electron transistors (RHET's) operating at room temperature, and shows the evidence of intervalley scattering from the Γ-valley to the L-valleys in the InGaAs base. This paper also shows that the cutoff frequency (f_T) measured for the RHET reaches 26 GHz and that the resonant-tunneling-barrier response time is estimated to be 1.56 ps.

In 1985, we proposed and fabricated a three-terminal resonant-tunneling device named RHET [1]. The device used an AlGaAs/GaAs/AlGaAs quantum well resonator as a hot-electron injector, and exhibited negative transconductance, thus enabling us to use it as a new "functional device." In 1987, we reported that the RHET using an InGaAs/InAlAs heterostructure has a higher current gain and higher peak-to-valley ratio than the RHET using a GaAs/AlGaAs heterostructure [2]. However, these devices do not work at room temperature because the thermionic emission current surmounting collector barriers cannot be neglected due to their small barrier heights.

The device used for this study has a resonant-tunneling barrier consisting of a 26.4-Å InGaAs layer sandwiched by two 23.7-Å AlAs layers [3], and a collector barrier of 2000-Å $In_{0.52}Al_{0.48}As$. These were grown on a semi-insulating InP substrate by MBE. The resonant-tunneling barrier exhibited negative differential resistance at room temperature, while the collector barrier is a good electrical isolator at room temperature, thus enabling us to operate the RHET at room temperature. This device uses a 500-Å n^+-$In_{0.53}Ga_{0.47}As$ base, doped to a concentration of 1×10^{18} cm^{-3}.

The collector current and base current were measured at room temperature as functions of base-emitter voltage with a constant 3 V on the collector in the common-emitter configuration. It has been found that the current gain (and the differential current gain) increases with the base-emitter voltage and peaks at a base-emitter voltage of 0.64 V (0.56 V). As the base-emitter voltage was increased further, the current gain decreased. The peak differential current gain was measured at 2.3. From the fact that the peak voltages are about equal to the Γ-L separation energy, the decreased current gain is considered to be due to the intervalley scattering of electrons from the Γ-valley to the L-valleys in the InGaAs base.

The scattering parameters of the RHET were measured in a frequency range from 0.2 to 20.2 GHz using the collector current density as a parameter. This was then analyzed using the equivalent RHET circuit that we proposed. The cutoff frequency (f_T) was measured at 0.76 GHz at a collector current densi.y of 3.3×10^2 A/cm^2 and 26 GHz at collector current of 3.3×10^4 A/cm^2. Device parameters such as the collector capacitance and base resistance derived from the equivalent circuit analysis agree well with those estimated by dc measurements or the theory. The high-frequency capacitance and conductance of the resonant-tunneling-barrier could be determined using this analysis. The capacitance and conductance were determined to be 93.0 fF (emitter area is 1.5×20 μm^2) and 1.98 mS/μm^2 at collector current density of 3.3×10^4 A/cm^2. The resonant-tunneling-barrier response time was determined to be 1.56 ps.

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VB-6 Negative Differential Resistance in AlAs/NiAl/AlAs Metal Base Quantum Wells: Toward a Resonant Tunneling Transistor—N. Tabatabaie, T. Sands, J. P. Harbison, H. L. Gilchrist, and V. G. Keramidas, Bell Communications Research, Red Bank, NJ 07701.

Stoichiometric NiAl is a Hume-Rothery, $\frac{3}{2}$-electron metallic alloy, and has been studied extensively in the literature. We have recently shown that high-quality epitaxial layers of NiAl can be grown nearly lattice-matched to GaAs substrates.* Furthermore, NiAl films with the proper crystallographic variant provide excellent seeding for low defect density semiconductor overgrowth. As the growth technology matures, progressively thinner continuous films are being grown epitaxially, making the GaAs/AlAs/NiAl system ideal for the fabrication of new quantum interference devices.