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Multiple-barrier resonant tunneling structures for application in a microwave generator stabilized by microstrip resonator

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Abstract. One of the main goals of contemporary electronics is the expansion of device capability to high frequencies up to the terahertz range. In this paper the results of comparison investigation of vertical transport and high frequency oscillatory properties of double-barrier and triple-barrier resonant tunneling structures (DBRTS and TBRTS) combined with a microstrip resonator stabilizing circuit are presented. The I–V characteristic of measured TBRTS shows higher values of a peak-to-valley current ratio than the values measured for DBRTS in agreement with theoretical predictions. Microwave oscillations from semiconductor quantum well resonant-tunneling structures, stabilized by use of the microstrip resonator, are observed for the first time. The microstrip system, compatible with MBE methods, provides appropriate circuit conditions for realization of high frequency oscillations by use of planar active structures and looks rather encouraging for millimeter and submillimeter wavelength applications.

Double barrier and triple barrier resonant tunneling structures as microwave oscilators

The recent theoretical and experimental investigations of negative differential conductivity (NDC) effects in double barrier resonant tunneling structures (DBRTS) prove the extremely fast frequency response of charge transport (less than about 100 fs) [1, 2]. Systems, which are expected to be more efficient, are the asymmetric double- and triple-quantum-well structures [3–5]. A variation of the structure parameters in such systems allows one to control independently the current peak-to-valley ratio and peak current values, which is impossible in the case of DBRTSs. The numerical simulation data confirm [3–5] the higher efficiency of a triple-barrier resonant structure (TBRTS) compared with a double-barrier one. The peak current value J_p for the TBRTS may be significantly higher than for a DBRTS with the same current peak-to-valley ratio J_p/J_v. This is due to sharp resonant properties of the inner interwell region and high electron transparency of the outer barriers, that is rather promising to achieve required power level and discernible oscillations at upper frequencies.

Resonant tunneling diode samples and microstrip resonator circuitry

The implementation of a resonant tunneling GaAs/AlAs quantum-well generator stabilized by use of the microstrip resonator is presented. Resonance-tunneling structures with one and two quantum wells (QW) were fabricated in the same MBE technique conditions. The structures were grown by MBE on semi-insulating GaAs(001) substrates in "Tsna-18" MBE system. Silicon was used as a donor impurity. The substrate temperature during growth was 630 and 690°C for GaAs and AlAs respectively. GaAs growth rate 0.58 μm/h, and the ratio of As-to-Ga equivalent beam pressures 15:1. Substrate temperature was changed

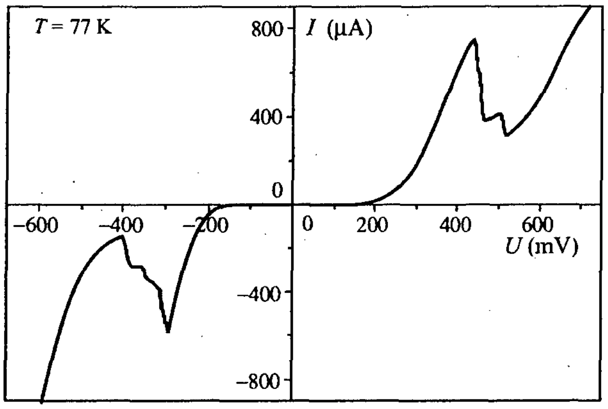

Fig. 1. Measured current-voltage curve of the double-barrier resonant tunneling structure.

during growth interruption under arsenic stream. The duration of interruption has made 30 seconds. The quality of the heteroepitaxial film was carried out in situ by RHEED technique. As-stabilized (2×4) — reconstruction was observed.

On an n^+-GaAs buffer layer by a thickness 1 μm doped to 2×10^{18} cm^{-3}, which acts as the lower contact layer and barrier for a diffusion of impurity from substrate, structure of barriers and quantum wells claded by spacer layers from undoped GaAs was grown. The undoped spacer layers inserted between the heavily doped electrodes and tunneling barriers are used to prevent the incorporation of segregated impurities into the active part of the structure during epitaxial growth, and to improve its frequency response [3, 6–9]. The thicknesses of lower and upper undoped layers have made 10 and 5 nm respectively. The upper contact layer consists of a 50 nm n-GaAs layer doped to 2×10^{17} cm^{-3} and 500 nm n^+-GaAs doped to 2×10^{18} cm^{-3}. AlAs by a 3 nm thickness was used as barriers of resonance-tunneling structures. GaAs is a quantum well material. In case of DBRTS the width of QW has made 4 nm, and in case of TBRTS — 5 and 4 nm for the lower and upper quantum well respectively.

After MBE grow to the highly doped semiconductor layers 0.35 μm Au-Ni – (Au + 12 percent Ge) ohmic contacts were created. Resonant tunneling diode was formed as the mesa-structures with $16 \times 16\,\mu$m^2 area of upper contact. The other contact was formed sideways from the mesa-structure on lower n^+-GaAs layer. The system of coplanar contacts used provides the extremely low RC time delay in the negative-differential conduction (NDC) region of the current-voltage (I–V) curve due to a decrease in the capacitance and the series resistance of a device.

The asymmetrical quantum well resonant tunneling structures are investigated in combination with the microstrip resonator configuration providing a best circuit conditions for realization of high frequency (up to THz band) oscillations by use of planar active structures. In preparation for high-frequency experiments, the fabricated chips containing DBRTS mesas were mounted in a microstrip resonator. The resonator was designed as a quarter-wave tee coupled microstrip line with one end short-circuited [3].

Comparison static vertical transport characteristics

The measured current-voltage (I–V) characteristics of the representative DBRTS are shown in Fig. 1. The data reveal asymmetry in values of J_p/J_v, which are equal to 4.1 and 2.4 at $T = 77$ K for negative and positive bias applied to the top contact of mesa, respectively.

The corresponding peak current densities are around 2.3×10^2 A/cm^2 and 3.2×10^2 A/cm^2 at 77 K and resonant bias values are −292 mV and +435 mV. The observed asymmetry is caused by different electrical properties of lower and upper cladding layers (mainly of spacer layers) of the structure and is characteristic of the regimes of MBE process. These results were used to estimate the real profiles of impurity distribution in the cladding layers.

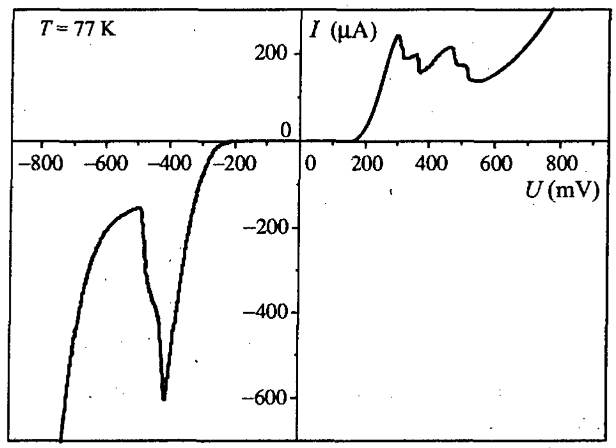

Fig. 2. Measured current-voltage curve of the triple-barrier resonant tunneling structure.

The so obtained impurity distribution profiles in cladding layers were exploited for numerical simulations of the measured I–V characteristics of TBRTS, shown in Fig. 2. The modeling dependence agrees with the experimental data rather well and allows the interpretation of the observed features in the I–V characteristic of this asymmetric double-well structure. The I–V characteristic of measured TBRTS shows higher values of a J_p/J_v ratio around 5 (77 K) than the values around 4 (77 K) measured for DBRTS grown under the similar conditions in agreement with theoretical predictions. Obtained results are encouraging for numerical simulation and development of real efficient multi-barrier resonant tunneling systems with predictable resonant properties.

Resonant tunneling microwave oscillations in DBRTS and TBRTS

Microwave oscillations have been found from GaAs/AlAs TBRTS stabilized by a microstrip resonator for the first time. The microwave oscillations in the spacer-cladded TBRTS were observed in the microstrip resonator at frequencies around 1 GHz with negative or positive bias applied in any point of the NDC region (Fig. 2). The output power was about 10^{-5}–10^{-6} W. The stable monochromatic microwave oscillations were obtained at 77 K The comparative analysis of the TBRTS and DBRTS statical and dynamical characteristics manifests the use of multiple quantum well-barrier resonant tunneling structures in narrow-band as well as in broad-band pulsed mm and sub-mm applications.

Acknowledgements

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