INVESTIGATION OF QUANTUM EFFECTS IN MONOLITHIC INTEGRATED CIRCUITS OF RESONANT TUNNELING STRUCTURES AND HIGH ELECTRON MOBILITY TRANSISTORS BASED ON $\mathbf{IN_{0.53}GA_{0.47}AS/IN_{0.52}AL_{0.48}AS/INP}$ BY SIMULATIONS WITH A NEW QUANTUM HYDRODYNAMIC TRANSPORT MODEL

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Circuits which using resonant tunneling diodes (RTDs) hold promise as a technology for ultra dense high speed integrated digital logic circuits. The negative differential resistance of the current-voltage characteristic in RTDs can be used to reduce device counts per circuit functions, thus increasing circuit integration density. The very fast switching capability makes them suitable for high speed circuits. High electron mobility transistors (HEMTs) integrated with RTDs can give similarly avails as well as also reducing power consumption, due to the gain and high input to output isolation provided by the transistors.

This paper describes the first reported numerical simulations of monolithic integrated circuits of resonant tunneling structures and high electron mobility transistor based on $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/InP$ with a novel quantum hydrodynamic transport model (QHD-Model). For the numerical investigations the device simulator SIMBA is used, which is capable to handle complex device geometries as well as various physical models represented by certain sets of partial differential equations. The quantum potential is implemented to include quantum mechanical transport phenomena in different quantum size devices. The coupled solution of the hydrodynamic transport model and the quantum correction potential, which is included in the transport and in the energy balance equations, allows to model resonant tunneling of carriers through potential barriers and particle build up in potential wells. The quantum hydrodynamic simulations, which is based on a quantum fluid dynamic model [1], offers expanding possibilities for the understanding as well as the design of novel quantum sized semiconductor devices.

The device structure of the monolithic integrated parallel connection between RTD and HEMT based on $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As/InP$, is represented in Fig. 1. Experimental investigations of such structures are shown in [2], where they are applied for high performance monostable-bistable transition logic elements. The calculated operating principle of the integrated parallel connection of the RTD with a HEMT is represented in the output characteristics of Fig. 2. The total drain current (I_D) is equal to the sum of the current passing through the RTD (I_{RTD}) and the HEMT (I_{HEMT}). Since the gate-source voltage (V_{GS}) can modulate I_{HEMT}, I_D is also modulated by V_{GS}. The result is that the peak current of the integrated device, especially of the integrated RTD, is modulated by V_{GS}. It should be noted that the resonant-tunneling current through the RTD remains unchanged at different gate biases. Fig. 3 shows the transfer characteristics at different drain-source voltages of the integrated parallel connection of the RTD and the HEMT. How expected, an increasing of the transfer characteristic by lower drain-source voltages can be detected. The electron density at $V_{DS,peak}$ and $V_{DS,valley}$ in the range of the RTD is illustrated in Fig. 4. The increasing of the electron density between the potential barriers at $V_{DS,peak}$ is identified with the tunnel process through the RTD. Further details of the QHD-Model and the calculated RTD-HEMT device as well as more results of different structure variations, especially the gate width (W_G) and the RTD area (A_{RTD}), will be presented in the paper.

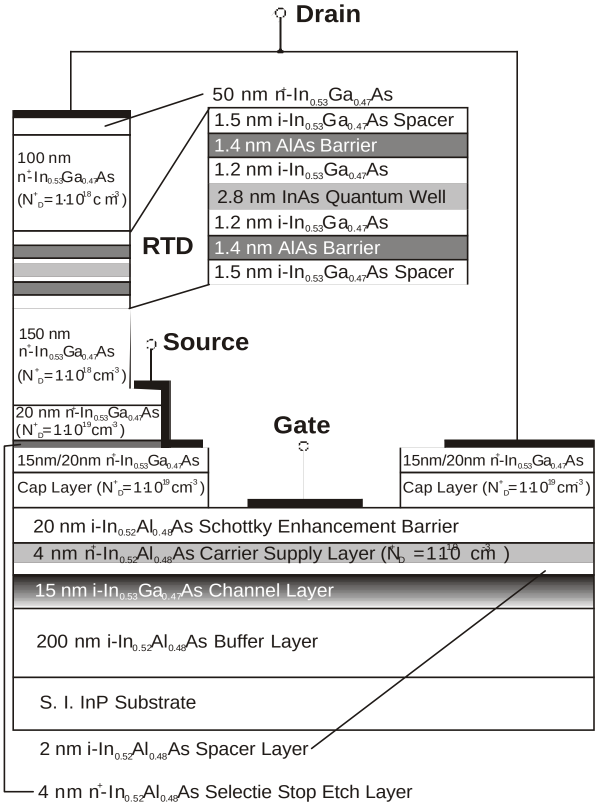

Fig. 1 Structure of the RTD-HEMT

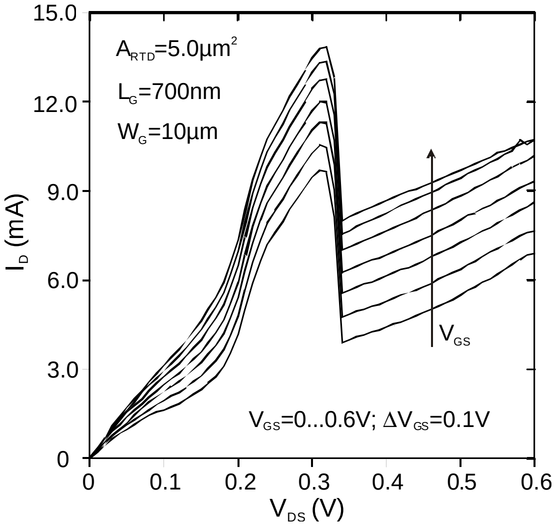

Fig. 2 Output characteristics of the RTD-HEMT

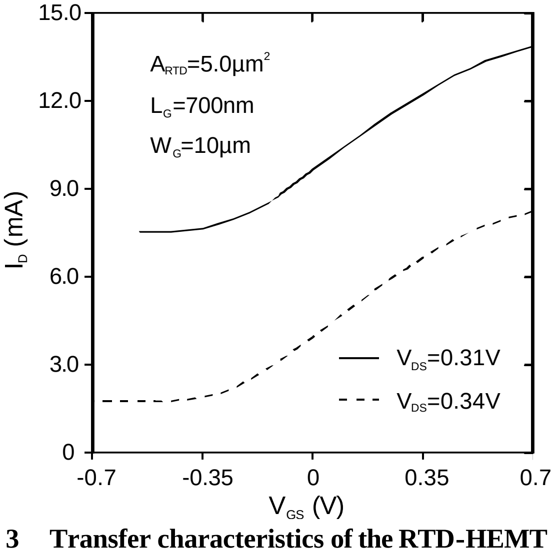

Fig. 3 Transfer characteristics of the RTD-HEMT

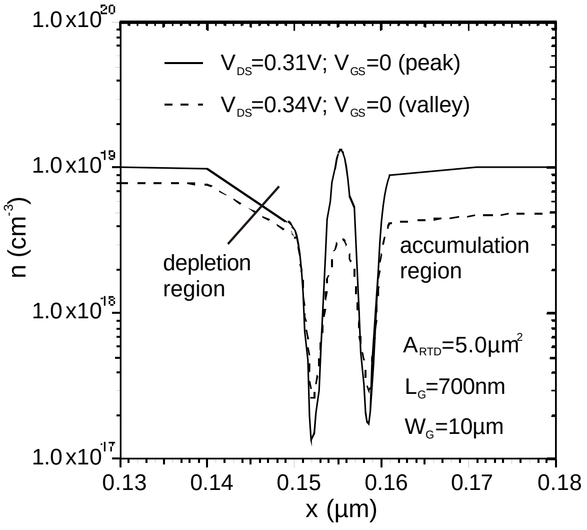

Fig. 4 Electron density at $V_{DS,peak}$ and $V_{DS,valley}$ for the integrated RTD

[1] C.L. Gardner: The Quantum Hydrodynamic Model for Semiconductor Devices. SIAM J. Appl. Math., Vol. 54, No 2, pp. 409-427, (1994).

[2] K.J. Chen, K. Maezawa and M. Yamamoto: InP-Based High-Performance Monostable-Bistable Transition Logic Element (MOBILE): an Intelligent Logic Gate Featuring Weighted-Sum Threshold Operations. Jpn. J. Appl. Phys., Vol. 35, No. 2B, pp. 1172-1177, (1996).