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Operation of resonant-tunnelling oscillators beyond tunnel lifetime limit

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Abstract – The tunnel lifetime of the electrons in the quantum well of a resonant-tunnelling diode (RTD) is usually assumed to be imposing an inherent fundamental limitation on the operating frequencies of RTD oscillators. Here, we experimentally demonstrate that one can overcome the limitation by heavy doping of the RTD collector. We present RTD oscillators with the fundamental oscillation frequency up to a factor of 3 above the tunnel lifetime limitation. Our results indicate that the inherent frequency limitations of RTDs should lie far above the state-of-the-art frequency of the contemporary RTD oscillators.

Double-barrier resonant-tunnelling diodes (RTDs) [1, 2], see fig. 1, are the fastest active electronic devices nowadays [3–6]. The N-type I-V curve of the diodes with a negative-differential-conductance (NDC) region allows one to use them as an active element and to build oscillators on their basis. The fundamental frequency of such oscillators can be as high as 1.04 THz, as was recently demonstrated [5,6]. As a passive device, RTDs operate up to the frequency of 3.9 THz [7,8]. Nevertheless, the question of how fast RTDs can operate and what is the limitation mechanism of their operating frequency still remains to be answered.

The relaxation time (τ_{rel}), which is the time-constant of the tunnel transient processes inside an RTD, is one of the parameters determining the dynamic properties of the diode. The electron transport through an RTD occurs via the tunnel capture/escape processes to/from the resonant states in the quantum well (QW) between the barriers of an RTD. Because of this, it is commonly accepted [9,10], that τ_{rel} is equal to (or at least cannot be shorter than) the tunnel lifetime (τ) of the resonant states. However, it has been shown theoretically [11,12], that the Coulomb interaction between electrons has a dramatic impact on τ_{rel}. As a consequence of the Coulomb interaction τ_{rel} is shorter and sometimes even much shorter than τ in

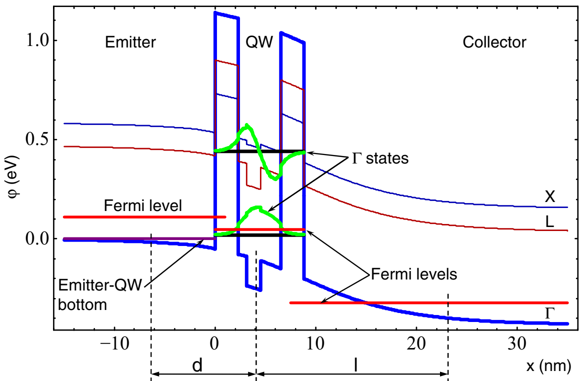

Fig. 1: Band diagram of the investigated RTDs. The barriers are sandwiched by $In_{0.53}Ga_{0.47}As$ layers lattice matched to a InP substrate with an undoped spacer of ≈ 1 nm close to the barriers and n-doping (1.5×10^{18} cm^{-3}) in the more distant layers. The AlAs barriers have a thickness of 2.7 nm (shown in the figure) and 2 nm for wafers W1 and W2, respectively. The barriers were sandwiching a composite quantum well consisting of three layers $In_{0.53}Ga_{0.47}As/InAs/In_{0.53}Ga_{0.47}As$ with a thickness of (nominally) 1.2 nm each.

the positive-differential-conductance (PDC) region of the RTD's I-V curve. On the other hand, τ_{rel} is always longer and can be even much longer than τ in the NDC region. The large value of τ_{rel} slows down the RTD response in the

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