Accurate equivalent-network modelling of GaAs/AlAs based resonant tunnelling diodes with symmetrical thin barrier and spacer layers

ACCURATE EQUIVALENT-NETWORK MODELING OF GaAs/AlAs BASED RESONANT TUNNELING DIODES WITH SYMMETRICAL THIN BARRIER AND SPACER LAYERS

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Abstract

Both the classical Esaki and the Quantum-Inductance equivalent-network models [1,2,3] are used in this work to describe the bias-voltage and microwave frequency dependency of the small-signal intrinsic impedance of our MBE grown GaAs/AlAs based Double Barrier Resonant Tunneling Diodes (DBRTDs). They have 5 nm quantum wells and symmetrical thin barrier and spacer layers, each nominally 2.5 nm thick (Fig.1). The devices under investigation are planar types (Fig. 2) with coplanar microwave probe access from the network analyser to the metallized SIG (signal) and GND (ground) pads on the SI-substrate. The DC I-V curve and the microwave reflection coefficient S11 of the extrinsic DBRTD, and S11 of the OPEN and SHORT reference structures are measured at the reference planes (pads) indicated. The SHORT and OPEN structures are used to determine the bias-voltage independent extrinsic elements of the equivalent circuits, Cex, Rex and Lex (Fig. 4a,b), describing the microwave behaviour of the Au interconnections. Only Rex is frequency dependent due to skin losses.

A prerequisite for accurate determination of the actual intrinsic elements Rd (dynamic resistance), Cd (dynamic device capacitance), Lqw (quantum inductance) and Rs (series resistance) is a stable, non-oscillating DBRTD in the negative differential resistance (NDR) region. A stable DBRTD has at least no plateaus in the NDR region of its I-V curve, so the conductance Gd (=1/Rd) has only one negative peak there (Fig. 6a,b). By a proper choise of the device area (36 um^2, /Rd+Rs+Rex/ > 50 Ohms at the largest S11, at 50 MHz) and a specially designed bias circuit, the stability condition was met in our experiments.

An S11 data array was collected in the 0 to +2V range of the I-V curve (mesa top = +), where S11 of the extrinsic DBRTD was measured at 75 bias points and from 0.05-40.05 GHz (401 points) after network analyser calibration with on-wafer standards. Fig. 3 shows some of these S11's in a compressed Smith chart, amongst them S11 of the steepest NDR bias-voltage point (largest negative Gd, /S11/ ~ 3.9). The prober-chuck temperature was 20.5°C.

Carefull optimisation of the equivalent-circuit S11 to match the measured S11 data at each bias point, leads to the conclusion that the 3-element Esaki model only fits the measured S11 data array in the NDR region sufficient accurate if (in contrast to the usual opinion in a number of papers) the dynamic conductance Gd and capacitance Cd are taken frequency as well as bias-voltage dependent (see Gd and Cd versus frequency at the steepest NDR point shown in Fig. 5).

The same measured small-signal S11 datasets can be described perfectly by the behaviour of the 4-elements Quantum-Inductance circuit model over the whole bias voltage (0-2 V) and frequency range (0.05-40.05 GHz) with only bias-voltage dependent elements (Fig. 6b-e). The measurement of S11 on the stable DBRTD throughout the whole NDR region results in the correct determination of the parameter τ, defined as τ=Lqw/Rd=Lqw.Gd indicating the carrier lifetime of the quasibound states in the quantum well. The display of this parameter continuously over the whole undistorted NDR is a novelty. Fig. 6f shows τ versus the bias voltage. The (small) voltage region immediately after the peak voltage and preceeding the valley voltage give less reliable values of τ due to inaccuracies in the (large negative) values of Lqw and Rd. τ is not defined where Gd=0. The peak value of τ (~22 ps) corresponds with the negative Gd peak (same bias-voltage) and when τ is compared with the calculated quasi-bound state lifetime given in [4] an AlAs barrier thickness of 8 monolayers (2.264 nm) is found as closest result.

References :

[1] E.R. Brown, *et al*, Appl. Phys. Lett., Vol. 54, March 1989, pp. 934-936.
[2] O. Vanbesien, *et al*, Microwave and Opt. Techn. Lett., Vol.5, No.8, July 1992.
[3] D.B. Janes, *et al*, J. Appl. Phys., Vol. 78, No. 11, Dec. 1995, pp. 6616-6625.
[4] H. Brugger, *et al*, Proc. 18th Int. Symp. GaAs and Related Compounds, Seattle, Sept. 1991.

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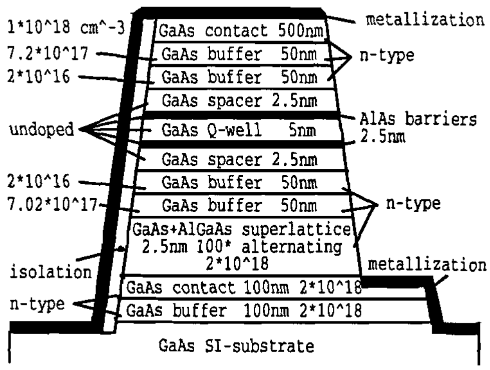

Fig. 1 MBE grown DBRTD layer structure

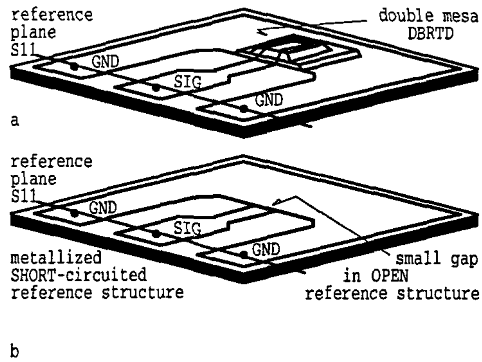

Fig. 2a Planar DBRTD with coplanar line
2b SHORT and OPEN reference structure

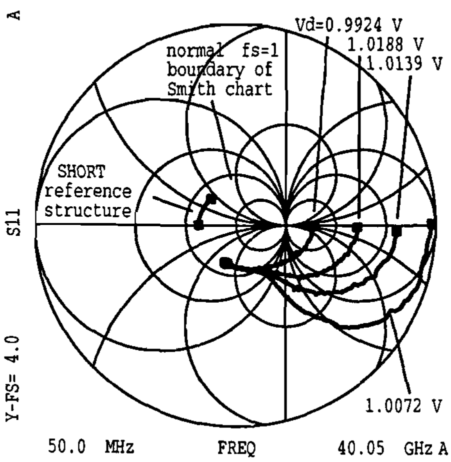

Fig. 3 S11 of SHORT (Zint=0) and S11 of extrinsic DBRTD at several bias voltages Vd

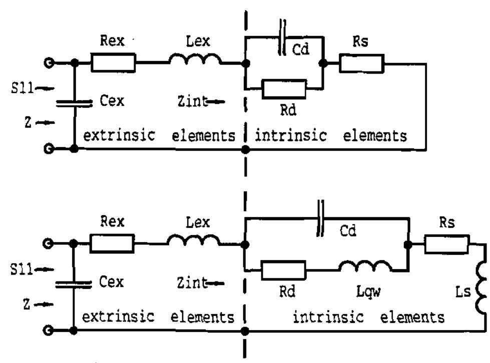

Fig. 4a Extrinsic elements and Esaki model
4b Extrinsic elements and Quantum-Inductance model
Ls<= 1pH

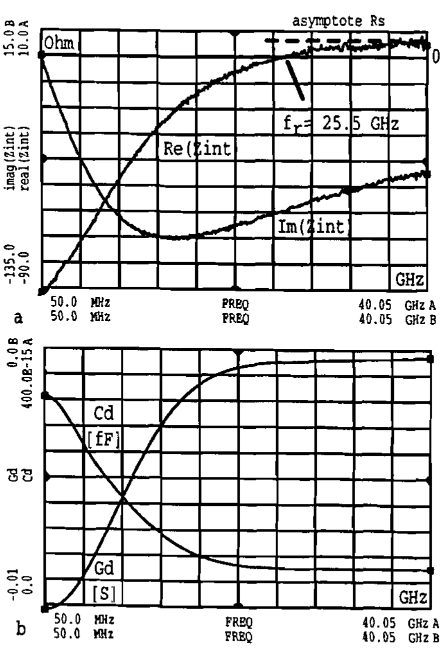

Fig. 5 In steepest point of the NDR region (1.0072 V) : a) Re(Zint) and Im(Zint)
b) Gd-f, Cd-f

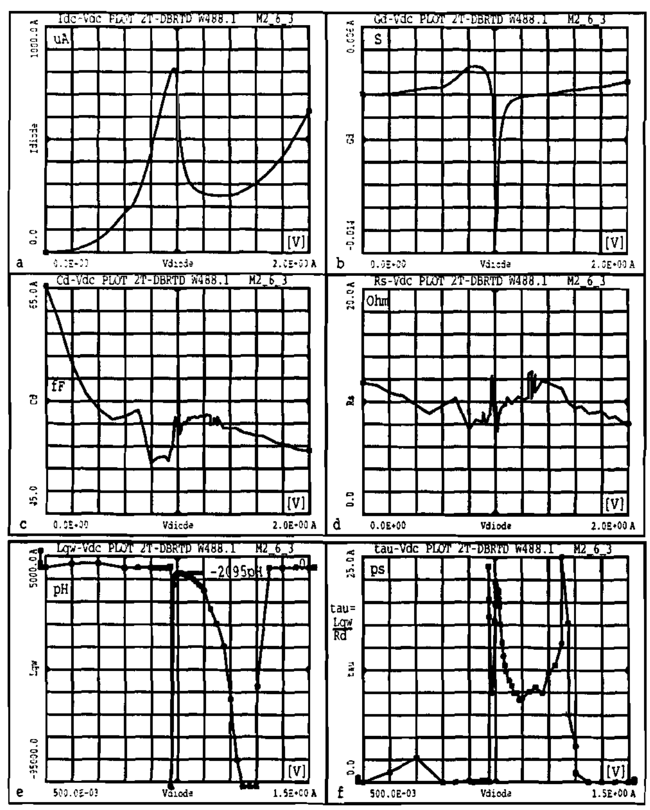

Fig. 6 a) measured DC I-V, b-e) dynamic Gd-Vd, Cd-Vd, Rs-Vd, Lqw-Vd and
f) tau-Vd, tau=Lqw/Rd