

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

Citation for published version (APA):

Kwaspen, J. J. M., Lepsa, M. I., Roer, van de, T. G., Vleuten, van der, W. C., Heyker, H. C., & Kaufmann, L. M. F. (1997). Accurate equivalent-network modelling of GaAs/AIAs based resonant tunnelling diodes with symmetrical thin barrier and spacer layers. In *Proc. 21st Workshop on Compound Semiconductor Devices and Integrated Circuits in Europe, WOCSDICE '97* (pp. 83-84)

Document status and date: Published: 01/01/1997

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.

• The final author version and the galley proof are versions of the publication after peer review.

 The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
 You may not further distribute the material or use it for any profit-making activity or commercial gain
 You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

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

J.J.M. Kwaspen, M.I. Lepsa, T.G. van de Roer, W. van der Vleuten, H.C. Heyker, L.M.F. Kaufmann

COBRA Institute, Eindhoven University of Technology, Eindhoven, The Netherlands

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, $/S11/ \sim 3.9$). The prober-chuck temperature was $20.5^{\circ}C$.

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 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 AIAs 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.

*Permanent address: National Research Institute for Material Physics, P.O.Box Mg-7 Magurele, 76900, Bucharest, Romania



Fig. 1 MBE grown DBRTD layer structure



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





b

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



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



f) tau-Vd, tau=Lqw/Rd