A NOVEL COMMERCIAL SCANNING-DLTS EQUIPMENT

O. Breitenstein, H. Raith

► To cite this version:

O. Breitenstein, H. Raith. A NOVEL COMMERCIAL SCANNING-DLTS EQUIPMENT. Journal de Physique IV Proceedings, 1991, 01 (C6), pp.C6-343-C6-348. 10.1051/jp4:1991651 . jpa-00250737

HAL Id: jpa-00250737

<https://hal.science/jpa-00250737>

Submitted on 1 Jan 1991

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

A NOVEL COMMERCIAL SCANNING-DLTS EQUIPMENT

O. BREITENSTEIN and H. RAI TH*

*Institute of Solid State Physics and Electron Microscopy, Weinberg 2, D-4050 Halle/S., Germany***Raith GmbH, Emil-Figge-Strasse 76, D-4600 Dortmund 50, Germany*

Abstract.— A highly sensitive PC-controlled SDLTS-equipment is introduced, which enables Capacitance- and Current-SDLTS, double-pulse SDLTS, standard-DLTS, and EBIC-imaging to be carried out. The comprehensive "Windows-like" operation software supports a time-efficient measurement process. This system fits to any SEM and represents a valuable supplement e.g. to CL or scanning-PL techniques. Its availability now renders this promising technique accessible also to laboratories not engaged in developing such sophisticated characterization techniques.

1.- Introduction

As early as in 1977 Petroff and Lang at Bell Laboratories proposed to combine the DLTS-principle of detecting deep-level impurities in semiconductors /1/ with the local excitation facility of the SEM, thus enabling a spatially resolved investigation of non-radiative point defect levels /2-4/. Their system, running in the Current-DLTS mode without any computer control, however, still lacked sensitivity and was considered too complicated for routine use. Later on the technique was further developed to measure also capacitance changes /5;6/, to use special techniques like double pulse-SDLTS (SDDLTS) and the selected area- (pixel-) scan /7/, and to be controlled by a microcomputer system /8;9/. Independently, related techniques like Scanning Isothermal Transient Spectroscopy (SICTS /10/) or Scanning Minority-Carrier Transient Spectroscopy (SMCTS /11/) have been developed, working with focused light excitation and scanning the excitation position by computer-controlled stepper-motor action. Until now, however, no commercial system has been available that would meet the special demands for local deep level investigations, considerably differing from the demands for a standard-DLTS system.

2.- Special demands for a Scanning-DLTS system

The most critical point in carrying out local deep-level investigations is the demand for the highest possible detection sensitivity. Since here the signal measured is only that of the beam-excited area, which is a very small part of the whole sample area, the SDLTS-signal is a factor of at least one thousand smaller than the standard-DLTS signal of the same sample. Therefore, the operator usually has to make a compromise between the detection limit and the spatial resolution attained. Note that the operator

is able to change the extension of the excited area by varying the excitation intensity and/or by choosing a well-defined area of radiation incidence; these possibilities have been discussed in detail elsewhere /12/. Thus, the higher the detection sensitivity of the system, the lower is the detection limit for a given spatial resolution, and the better is the spatial resolution attainable for a given defect concentration.

In addition to the sensitivity requirement, the flexibility of the computer control of the system is a key factor to a sufficiently straightforward system operation. Note that the actual SDLTS-investigation proceeds rather slowly, each measuring point requiring a signal integration time of typically one second. Thus, capturing a two-dimensional image of 1000 points needs a measure time of as much as 20 minutes; hence the optimization of the imaging conditions using the trial-and-error method is hardly manageable. Therefore, special techniques like the pulse width scan (for optimizing the excitation intensity /12/), optimizing the imaging conditions in linescan-mode and then switching to image scan, and the possibility of computer processing the image measured, are necessary to guarantee a time-efficient SDLTS operation. Moreover, in between the system always has to be switched to EBIC-imaging for the operator to orient on the sample area and to find the interesting positions of extended crystal defects. The fulfilment of all these special demands strongly depends on the optimum distribution of the functional tasks of the system among the actual measurement hardware, the computer system involved, and the operation software.

3. SDLTS system hardware

The block scheme of the developed SDLTS system is shown in Fig.1. All special electronic components of the system, including the analog-digital conversion means and the SEM-interface, are included in a compact SDLTS-unit. Only the preamplifier for the Current and the Capacitance Meter is placed within the SEM-chamber to fulfil sensitivity requirements, and the temperature control unit (as a part of the cryostat chosen) is separately connected with the computer. As Fig. 1 shows, the completion of the SDLTS-system requires -besides the SDLTS-unit- a SEM equipped with a cryostat and a beam blanking unit, and an IBM/AT-compatible PC. An important design feature of this system is its "distributed intelligence" concept. Hence, the SDLTS-unit has its own microprocessor, not only coordinating the internal operations of the unit, but also managing intelligent spectrometer actions like auto-ranging, EBIC image-scan and pixel-scan, and linking the spectrometer to the PC. Only in this way a standard IBM/AT-compatible PC can be used to control this complex measurement via a standard RS232 serial interface.

Fig.1.- Functional scheme of the computer-controlled SDLTS-system

Fig. 2 shows a simplified scheme of the internal components of the SDLTS-unit. The Current Meter enables the preamplifier gain and the post-amplification factor to be set separately, thus allowing one to choose between high-bandwidth and high-sensitivity operation. The Capacitance Meter is designed according to the parallel-resonance bridge-circuit principle described elsewhere /5/, with the possibility of electronically adjusting (manually or automatically) both the sample capacitance and its conductance. The measuring frequency of the bridge can be selected by exchanging a plug-in unit in the preamplifier unit to be optimum either for low-conductivity samples (1 MHz) or for high-conductivity ones (10 MHz). In the biasing unit some scaling-signal may be superimposed on the sample bias for performing a reliable scaling measurement. The DLTS-signal post-amplification factor can be set either manually or automatically (auto range) to always fit the dynamic range of the ADC. In the "computer control" mode all relevant signals (DLTS-signal, sample capacitance- and conductance-values, T-signal (external), as well as the three possible sample biases) are digitized and continuously displayed on the PC-screen. The basic technical data of this spectrometer are given in Tab. 1.

Tab. 1.- Technical data of the SDLTS-spectrometer

operation modes:	DLTS, SDLTS, SDDLTS, EBIC
measurement signal:	capacitance, conductance, current
C-measuring frequencies:	1 or 10 MHz
sensitivity limit:	10^{-6} pF at 10 MHz
rate window:	$1...32000 \text{ s}^{-1}$; 16 stages
pulse width:	$1 \mu\text{s}...32 \text{ ms}$; 16 stages
integration time:	$128 \text{ ms}...16 \text{ s}$; 8 stages
sample bias range:	$-10...+10 \text{ V}$
current gain factor:	$10^5...10^8 \text{ V/A}$; 4 stages
current-amplification:	$*1...*100$; 3 stages
current detection bandwidth:	5 MHz (TV) at 10^5 V/A

Fig.2.- Simplified scheme of the SDLTS-unit

4.- Operation software

Generally, the spectrometer is able to work either computer-controlled or without any computer control in order to carry out e.g. on-line standard-DLTS experiments. Hence, all operation parameters can be set either manually at the spectrometer front, or (in the "computer control" mode) by the controlling PC. The SDLTS operation software developed allows the programming and elaboration of different measurement tasks, the setting of spectrometer parameters, the selection of different data display modes, and an efficient data file management. Because of the numerous possibilities of this program, only its most characteristic features will be described here.

In general, the user surface is consequently designed to be "Windows-like" using VGA colour graphics with all actions to be controlled alternatively either by mouse clicks or via keyboard commands. According to the usual standard of many software surfaces, the program is self-documenting using hierarchical pop-up menus. Different "help"-windows may be opened providing the user with additional information at each operation stage. Independently, short on-line operator hints are always displayed, informing the operator about the current activity of the system and what is to be done next.

The basic measurement tasks are as follows: EBIC (on-line scanning at 3 selected speeds, or 256*256 points image digitalization and capturing), SDLTS image scan, SDLTS line scan, pulse width scan (see /12/), rate window scan, rate window- line scan (spectroscopical linescan, see /9/) temperature scan (standard-DLTS or electron beam-excited local DLTS), and high energy resolution temperature scan (see /13/). All parameters such as the scanning ranges, the spectrometer parameters, the measurement mode, or the beam position, are easy to select and are automatically stored in the resulting data file. One-dimensional results like those of a temperature scan are graphically displayed on the computer screen "as usual" over automatically scaled axes. For two-dimensional results (EBIC, SDLTS image scan, rate window- line scan) the operator may choose between a quasi 3-dimensional "topographical" representation, a grey-scale or a false-colour representation. In the latter cases two images are displayed on the screen side by side, one being the currently active image and the other a reference one (usually the previously measured one). This enables the operator to directly compare an SDLTS-image with an EBIC- or another SDLTS- one of the same area. Moreover, this display-splitting permits one to display a scaled linescan of the data of any line of a two-dimensional image on the reference-field, thus allowing a reliable quantitative evaluation of some details of an image. The easiest way to make a hardcopy consists in zooming the image to fit the whole PC-screen, and in making a video-printer copy of the VGA-screen. Alternatively, all graphical and grey-scale representations can be hardcopied by using a 24-pin line printer.

A special feature of this software is its transparency with respect to the measurement process. Already during the measurement each result measured is displayed and the operator may already optimize the display parameters (contrast and brightness) without affecting the experiment running. This allows the operator to judge whether the image fulfils his expectations, or not, and to abandon a useless measurement before having finished it. Altogether, this SDLTS operation software allows convenient and time-efficient measurements of one- and two-dimensional data fields to be carried out; it enables a straightforward, reliable and quantitative data representation and an easy comparison of different images. With these features available this software concept should be promising not only for SDLTS but also for other slowly running physical imaging techniques as e.g. spectral CL, scanning PL, scanning SIMS, scanning-AES, or EDS-imaging.

5.- Discussion

Fig.3 shows some typical results attainable by the SDLTS-system described. The sample was an n-type GaAs Schottky diode containing a 400 meV hole trap level. The 256*256 points EBIC-image (a) shows differently shaped extended crystal defects present in the sample region imaged. The 32*32 points SDLTS-image (b) shows a

strong dark contrast around the positions of the two central defects. This proves that unlike the other crystal defects these types are strongly getter-active to the 400meV-levels. A linescan extracted from the middle horizontal line of (b) is displayed in (d), proving that the SDLTS-contrast is $\sim 5 \cdot 10^{-5}$ pF, and that the diameter of the getter zone is $\sim 15 \mu\text{m}$. Fig. 3(c) shows the result of a rate window-linescan across the central defect (see /9/). Here, the y-axis is the beam position, and the x-axis represents the rate window as a spectral parameter of the SDLTS-technique, with a peak in the x-direction indicating the presence of a point defect level. This result proves that the dark contrast in (b) is indeed due to the absence of the 400 meV level, and not to the presence of different levels with their signal superimposing on the 400 meV-signal.

Fig.3.- EBIC-image (a) and SDLTS-image of a 400 meV hole trap level (b) in an n-type GaAs Schottky-diode. (c): "rate window-linescan" across the centre of the imaged region. (d): SDLTS linescan extracted from the middle horizontal line of (b).

It should be shown that the SDLTS-system described is a convenient and powerful tool of performing spatially resolved investigations of non-radiative deep level defects in semiconductors. This makes the technique an ideal supplement to local luminescence imaging techniques such as CL or local PL, which give only indirect evidence of non-radiative recombination centres and little evidence of trapping centres. The commercial availability of this system now renders this promising technique accessible also to laboratories engaged in characterizing electronic materials rather than in developing sophisticated characterization techniques.

References:

- /1/ Lang, D V, J. Appl. Phys. 45 (1974) 3023
- /2/ Petroff, P M and Lang, D V, Appl. Phys. Lett. 31 (1977) 60
- /3/ Petroff, P M, Lang, D V, Logan, R A and Johnston (jr.), W D, Inst. Phys. Conf. Ser. 46 (1979) 427
- /4/ Petroff, P M, Lang, D V, Strudel, L J and Logan, R A, Scanning Electron Microscopy, AMF O'Hare (1978) 325
- /5/ Breitenstein, O, phys. stat. sol. (a) 91 (1982) 159
- /6/ Breitenstein, O and Heydenreich, J, J. de Physique C4 (1983) 207
- /7/ Woodham, R G and Booker, G R, Inst.Phys. Conf. Ser. 87 (1987) 781
- /8/ Breitenstein, O and Heydenreich, J, Scanning 7 (1985) 273
- /9/ Breitenstein, O and Heydenreich, J, in SEM Microcharacterization of Semiconductors, ed. Holt, D B and Joy, D C, London (1989) 340
- /10/ Tokumaru, Y, Okushi, H and Naka, H, Jap. J. of Appl. Phys. 45 (1974) L1061
- /11/ Heiser, T, Mesli, A, Courcelle, E and Siffert, P, J. Appl. Phys. 64 (1988) 4031
- /12/ Breitenstein, O, contribution to DRIP-4, Mottram (1991), in print
- /13/ Crowell, C R and Alipanahi, S, Solid-State Electron. 24 (1981) 25