



**HAL**  
open science

# ELECTRICAL RECOMBINATION BEHAVIOUR AT DISLOCATIONS IN GALLIUM PHOSPHIDE AND SILICON

G. Booker, A. Ourmazd, D. Darby

► **To cite this version:**

G. Booker, A. Ourmazd, D. Darby. ELECTRICAL RECOMBINATION BEHAVIOUR AT DISLOCATIONS IN GALLIUM PHOSPHIDE AND SILICON. *Journal de Physique Colloques*, 1979, 40 (C6), pp.C6-19-C6-21. 10.1051/jphyscol:1979604 . jpa-00219020

**HAL Id: jpa-00219020**

**<https://hal.science/jpa-00219020>**

Submitted on 4 Feb 2008

**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.

## ELECTRICAL RECOMBINATION BEHAVIOUR AT DISLOCATIONS IN GALLIUM PHOSPHIDE AND SILICON

G.R. Booker, A. Ourmazd and D.B. Darby

*Department of Metallurgy and Science of Materials, University of Oxford, U.K.*

Résumé.- On revoit ici les récents résultats sur la recombinaison de porteurs aux dislocations dans Si et GaP. Les méthodes utilisées sont TEM, SEM EBIC et CL. Les méthodes SEM ont une résolution spatiale jusqu'à 1  $\mu\text{m}$  et les informations électrique et lumineuse peuvent être obtenues pour des dislocations individuelles. En examinant la même région par TEM et SEM, les informations structurelle, électrique et lumineuse peuvent être comparées. Les résultats indiquent que les taux de recombinaison sont contrôlés par la diffusion des porteurs vers les dislocations pour le GaP, et pour un mécanisme de recombinaison avec dislocation pour le Si. Pour le Si, les taux de recombinaison sont nettement différents pour les dislocations dissociées et nondissociées.

Abstract.- This paper reviews some of the recent results obtained regarding electrical recombination at dislocations in Si and GaP using the TEM method and the SEM EBIC and CL methods. The SEM methods have spatial resolutions down to 1  $\mu\text{m}$ , and so electrical and luminescent information can be obtained from individual dislocations. By examining the same areas by TEM and SEM methods, structural, electrical and luminescent data can be compared. The results indicate that the recombination efficiency is controlled by the diffusion of carriers to the dislocation for GaP, but by the recombination mechanism at the dislocation for Si. For Si, markedly different recombination efficiencies occur at dissociated and undissociated dislocations.

1. Introduction.- The present paper is concerned with the recombination of electrical carriers at dislocations in GaP and Si. The emphasis is on recent experimental results, both by the authors and other investigators, using the methods of electron microscopy.

Considerable advances have been made in this field by using the SEM in the electron beam-induced current (EBIC) and cathodoluminescent (CL) modes to examine bulk specimens. EBIC micrographs can be obtained which exhibit 'electrical' contrast, the dark areas corresponding to specimen regions where enhanced electrical recombination occurs. This method was originally used by fabricating a p-n junction within the specimen, but is now also being used by making a surface Schottky barrier. Such a barrier can be prepared with virtually no specimen heat-treatment, and so meaningful results can be obtained directly from starting materials e.g. melt-grown crystals, epitaxial layers.

CL micrographs can be obtained which exhibit 'luminescent' contrast, the dark areas corresponding to specimen regions where enhanced non-radiative recombination occurs. This method can generally be used without any specimen preparation, but cannot be applied to materials where the luminescence is low.

For both the EBIC and CL methods, spatial resolutions down to 1  $\mu\text{m}$  can be obtained, and contrasts

down to less than 1% observed and measured. Individual dislocations can be imaged as dark spots or lines, the contrast for each dislocation being an indication of its recombination efficiency. Minority carrier diffusion lengths and lifetimes can be measured, and luminescent spectra obtained, from small selected areas of the specimen. Specimens can be subsequently thinned for TEM studies, and the previously observed defects and areas examined. In this way, electrical, luminescent and structural data can all be obtained from the same individual defects or local groups of defects.

2. GaP.- SEM CL images obtained from a Si-doped, (100) liquid phase epitaxial (LPE) GaP layer showed dark spots with a density of  $5 \times 10^5 \text{ cm}^{-2}$  /1/. Comparison with TEM images of the same specimen area showed that there was a precise 1 : 1 correlation between dark spots and dislocation lines, i.e. each dark spot corresponded to a dislocation, and each dislocation gave a dark spot. There was in general no marked difference in the contrast of the individual dark spots, and an analysis of 17 dislocations showed that a complete range of dislocation character was present (screw,  $30^\circ$ ,  $60^\circ$  and edge). It was concluded for this specimen that all the dislocations acted as non-radiative recombination centres: the recombination efficiency did not depend significantly on dislocation character, and was high for all dislocations.

SEM EBIC and CL images obtained from the same

areas of an undoped, (100) vapour phase epitaxial (VPE) GaP layer exhibited dark spots corresponding to a dislocation density of  $2 \times 10^6 \text{ cm}^{-2}$  /2/. There was a precise 1 : 1 correlation between the numbers and positions of the individual spots in the two types of image. This result is to be expected for dislocations acting as non-radiative recombination centres. None of the radiative recombination centres responsible for the luminescence were individually detected (these would have appeared as bright spots in the CL images and dark spots in the EBIC images), presumably because these centres were too numerous to be resolved.

SEM CL images obtained from S- and N-doped VPE and LPE GaP layers showed dark spots corresponding to a dislocation density of  $\sim 10^6 \text{ cm}^{-2}$  /3/. CL spectra recorded either at or away from dislocations showed that there were small differences in the resulting CL peaks. Analysis of these data indicated that there was an impurity atmosphere associated with individual dislocations which contained N and possibly also a vacancy complex.

Several investigators have shown for a variety of GaP specimens that the room temperature minority carrier lifetime  $\tau$  decreases as the dislocation density  $\rho$  increases. When  $\tau$  is plotted against  $\rho$  all of the data tend to fall on a 'standard' curve /4/.

SEM CL images from an undoped, isothermally-grown (100) LPE GaP layer showed dark spots with a wide density range (D.R. Wight, I.D. Blenkinsop and W.R. Harding, 1978, private communication). A specimen area with a dislocation density of  $4 \times 10^5 \text{ cm}^{-2}$  was selected because it had previously been shown that  $\tau$  for this area was controlled by  $\rho$  /4/.  $\tau$  was measured for this area by monitoring the luminescence as the incident electron beam was rapidly switched off. The experimental results showed that  $\tau$  increased in a regular manner as the specimen temperature increased from 100 to 300K. Calculations of  $\tau$  based solely on the diffusion of carriers to the dislocations, and using previously published carrier-diffusion/temperature data for GaP, agreed precisely with the experimental results obtained. It was concluded for this specimen that the electrical recombination behaviour occurring at the dislocations was diffusion controlled.

All of the above results for GaP are compatible with one another. They indicate that the electrical recombination mechanism occurring at all of the dislocations is extremely efficient. The recombination rate does not depend markedly on the character

of the individual dislocations, or on associated impurity atmospheres. It is controlled by the diffusion of carriers to the dislocations.

3. Silicon.- Several investigators have shown for a variety of Si specimens that the room temperature minority carrier lifetime  $\tau$  decreases as the dislocation density  $\rho$  increases. However, unlike GaP, when  $\tau$  is plotted against  $\rho$ , the data taken together exhibit a wide scatter. Calculation of  $\tau$  based solely on the diffusion of carriers to the dislocations gives values which are much too small. These results indicate that for dislocations in Si, the electrical recombination rate is controlled not by diffusion, but by the recombination mechanisms occurring at the dislocations. Different behaviours might be expected in Si for different types of dislocation.

A heavily P-doped, (111) Si specimen comprising the emitter region of a bipolar transistor was investigated /5,6/. It contained a dislocation network lying on the (111) plane parallel to the surface. The dislocations were mainly along  $\langle 211 \rangle$  directions with  $a/2 \langle 110 \rangle$  Burgers vectors, and were of edge character. Stacking faults extending down from the surface on inclined {111} planes were present also. They were extrinsic and bounded on their lower side by  $a/3 \langle 111 \rangle$  Frank partial dislocations. The network depth was  $\sim 1 \mu\text{m}$ , the emitter/base junction depth  $\sim 1.8 \mu\text{m}$ , and the stacking faults reached maximum depths of 2 to 3  $\mu\text{m}$ .

SEM EBIC images showed dark lines corresponding to individual dislocations. The dislocation EBIC contrast varied over a range of 6:1. TEM images of the same area enabled the same dislocations to be examined. Stereo-viewing showed that the differences in EBIC contrast were not due to differences in dislocation depth. Further thinning of the specimens enabled high-resolution weak-beam TEM images to be obtained which showed that the individual dislocations consisted of segments that were alternately dissociated and undissociated, the former comprising pairs of  $a/6 \langle 211 \rangle$  Shockley partial dislocations separated by narrow areas of intrinsic stacking fault. Comparison of the TEM images with the corresponding EBIC images showed a precise 1:1 correlation. Those dislocations which were heavily dissociated gave the greater electrical contrast, and vice-versa. The same effect was also shown by the dissociated and undissociated nodes of the network.

The EBIC contrast for both the dissociated and undissociated dislocations varied markedly as the temperature was changed in the range 100 to 300 K. However, the variations in the two cases followed

completely different curves. SEM EBIC images of the stacking faults gave insignificant contrast. EBIC images of the bounding Frank dislocations gave good contrast when the dislocation was along a  $\langle 110 \rangle$  direction, but insignificant contrast when along a  $\langle 211 \rangle$  direction.

The results for this Si specimen show that the electrical recombination efficiency is different for different defects. This confirms the view that for Si the recombination rate is determined by the mechanism occurring at the defect. Furthermore, although the specimen was heavily P-doped and so impurity atmospheres were likely to be associated with individual dislocations, the results nevertheless suggest that it is the core structure of the dislocations that was mainly responsible for the electrical behaviour.

#### References.

- /1/ Titchmarsh, J.M., Booker, G.R., Harding, W. and Wight, D.R., *J. Mater. Sci.* 12 (1977) 341.
- /2/ Darby, D.B. and Booker, G.R., *J. Mater. Sci.* 12 (1977) 1827.
- /3/ Dimitriadis, C.A., Huang, E. and Davidson, S.M., *Solid State Electron.* (in press).
- /4/ Harding, W.R., Blenkinsop, I.D. and Wight, D.R., *Electron. Lett.* 12 (1976) 503.
- /5/ Ourmazd, A., Darby, D.B. and Booker, G.R., *Inst. of Phys. Conf. Ser. No 36*, (1977) Chapter 7, p. 251.
- /6/ Ourmazd, A. and Booker, G.R., *Solid State Electron.* (in press).