Spatial distribution of defects in GaAs:Te wafers studied by cathodoluminescence

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Cathodoluminescence (CL) scanning electron microscopy and positron annihilation techniques have been used to investigate the distribution of defects in GaAs:Te wafers. Dislocation density and near-band-edge CL profiles along the wafer have different shapes. Positron lifetime measurements do not show spatial changes of vacancy concentration in the wafers, but a higher vacancy concentration has been detected in the Te-doped samples relative to SI samples. Results are discussed in terms of vacancies and impurity vacancy complexes.

INTRODUCTION

The spatial distribution of defects across liquid-encapsulated Czochralski (LEC)-GaAs wafers is of great interest in semiconductor technology and has been previously studied by different methods such as dislocation etching,[1] infrared absorption,[2–6] x-ray topography,[5,7] photoluminescence,[8,9] etc. The distribution of defects and of several physical parameters has been found to be inhomogeneous across the wafer, showing W-, M-, or U-shaped profiles. Cathodoluminescence (CL) technique in the scanning electron microscope (SEM) has also been used to study the distribution of near-band-edge emission and midgap emission in GaAs crystals.[2,7,10–13] The emission has been found to be related to the presence of dislocations through the impurities and point defects surrounding them. For this reason the CL images of SI LEC-GaAs frequently show a cellular structure which corresponds to dislocation cells and single dislocations show a black dot or a dot and halo contrast. The latter has been explained in earlier works[14,15] by dislocation decoration by impurities. Previous CL results on GaAs refer to the basic relation between emission and presence of defects rather than to problems related to the uniformity of emission and of defect concentration across wafers. On the other hand, previous works refer mainly to SI material. In the present work the CL technique has been used to characterize the uniformity of Te-doped GaAs wafers by measuring the dislocation density and the intensity of near-band-edge luminescence along the wafer diameter. On the other hand, positron annihilation measurements were performed in order to investigate the distribution of vacancies along the wafer and the possible influence of the vacancies on the observed luminescence variations.

EXPERIMENTAL METHODS

The samples used in this study were Te-doped 100-oriented GaAs wafers of 50 mm diameter. The sample had a free-carrier concentration n of about 4.5×10^{17} cm^{-3}. The measurements were done on a 5-mm-wide strip, containing the center of the wafer, which was cut with a diamond saw along a wafer diameter. The samples were observed in a Cambridge S4-10 scanning electron microscope at 30 kV, at temperatures between 300 and 90 K, in the emissive and CL modes. The experimental method for CL measurements in the range 350–850 nm has been previously described.[16] For the observations in the SEM, the strip was cut in ten parts (of about 5×5 mm^2 each) which were placed in a single specimen holder in order to perform the CL measurements under the same experimental conditions. This set of samples was also used for positron annihilation measurements.

The positron lifetime measurements were performed at room temperature by using a conventional fast-fast coincidence system with a time resolution of 315 ps (FWHM). The positron source was prepared by evaporating ^{22}NaCl solution onto a thin nickel foil (0.44 mg cm^{-2}). The lifetime spectra were recorded by shifting the positron source along the wafer using the same reference sample for the sandwich. All the spectra could be decomposed with only one component after subtracting the source correction for both the nickel foil (180 ps, 4.7%) and the salt (500 ps, 2.7%).

RESULTS

Figure 1 shows the CL image of a Te-doped sample. The dot and halo contrast, associated with the presence of dislocations, is observed. Dislocation arrangement consists of an ill-defined cellular structure with the dislocations more concentrated in cell walls. The cell's interior appears, in the CL image, brighter than the walls in any position of the wafer. However, comparison of the CL images from different parts of the wafer shows that the cell interior in the wafer center has a lower emission than the cell interior in regions at some distance from the center. Consequently, dislocation halos show a higher contrast in the wafer center. Figure 2 shows the CL spectrum, at room temperature, with the peak at about 840 nm (1.476 eV). By decreasing the temperature the peak slightly shifts to higher energy so that at 90 K it appears at 824 nm (1.504 eV). The halfwidth changes from 154 meV at room temperature to 37 meV at 90 K, and the CL intensity

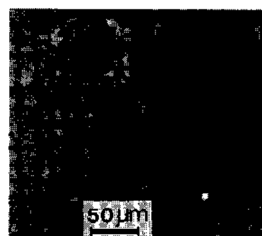

FIG. 1. Cathodoluminescence (CL) image of a Te-doped GaAs sample.

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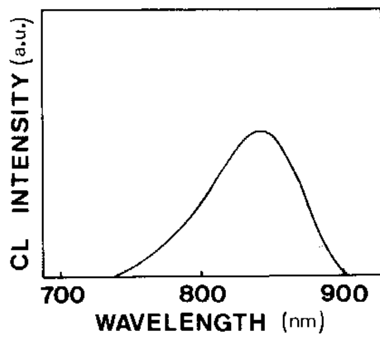

FIG. 2. Cathodoluminescence spectrum at room temperature from a Te-doped GaAs sample.

markedly increases by decreasing temperature. No spectral variations are observed along the wafer diameter, but the total CL intensity exhibits the profile shown in Fig. 3. From the dot and halo images the dislocation density profile along the wafer diameter, shown in Fig. 4, was obtained. The mean lifetime of positrons has been found to be constant along the wafer diameter with a value of 239 ps.

DISCUSSION

The presence of the halos surrounding the dislocations observed in the CL images of some semiconductors has been explained by spatial variations in the concentration of impurities and native point defects around the dislocations. Point defect diffusion to the dislocations contributes to this effect. In GaP, recombinations involving vacancies compete with green band transitions, and consequently, if vacancies are removed by diffusion to dislocations, the green emission is enhanced in the vacancy-poor region surrounding the dislocation, and halos are observed. In the GaAs the halos have been related to impurity distribution[14,15] and has also been proposed[19] that intrinsic point defects, vacancies, and/or antisites act as electron-hole recombination centers competing with the near-band-edge transitions. If halos in GaAs were formed by vacancy diffusion to the dislocations, regions with a higher density of dislocations with halos would have a lower vacancy concentration and consequently higher near-band-edge luminescence emission. Comparison of

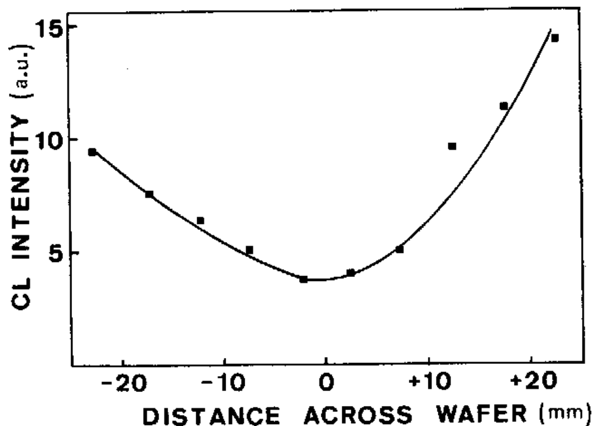

FIG. 3. Profile of the near-band-edge luminescence across the diameter in a GaAs:Te-doped wafer.

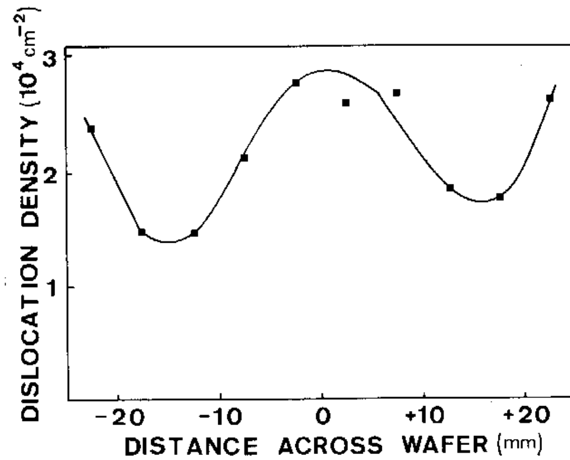

FIG. 4. Dislocation density across the diameter in a GaAs:Te-doped wafer.

Figs. 3 and 4 shows that this correspondence between dislocation density and luminescence is only partial, because the CL profile is U shaped and the dislocation density profile is W shaped.

In a recent work on GaP:S wafers[20] W- and U-shaped profiles have also been found for dislocation density and green CL, respectively. In Ref. 20 the vacancy concentration profile, obtained by positron techniques, was found to be inverse to the green luminescence profile along the wafer, which agrees with the idea that, in GaP, vacancies act as competitors of the green luminescence. In the present work it has not been detected, by positron annihilation, a variation of vacancy concentration along the wafer. This can be explained if the possible variations of vacancy concentration are too small to be detected by positron lifetime measurements or if the vacancies are positively charged and do not trap positrons. The latter situation is produced when vacancies form certain complexes. Hughes and Narayanan[21] have proposed that in Te-doped (10^{18} cm^{-3}) GaAs the positively charged complex Te_{As} V_{Ga} V_{As} is formed. Hautojärvi *et al.*[22] have found in Te-doped (10^{16} cm^{-3}) GaAs that the positron lifetime is 250 ps. They interpret this high value, compared to the bulk value in GaAs (235 ps), by the positron trapping in as-grown defects, As vacancies, typically found in *n*-type GaAs.[23,24] The lifetime observed in the present work (239 ps) is lower than in Ref. 22, which shows that in our samples the concentration of vacancies able to trap positrons is lower although our *n* value is higher. This result could be related to the above-mentioned positive complexes of impurity and vacancies. In SI undoped GaAs, As vacancies are supposed to be positive and do not trap positrons. The positron lifetime in a SI wafer has been found in the present work to be 235 ps and is considered to represent the bulk value in GaAs.

The CL images of the different parts of the wafer show that the qualitative dot and halo contrast do not change across the wafer, but the background luminescence is lower in the central part. Although dislocations can cause CL increase by a gettering effect of nonradiative centers, probably vacancies, the effect of the dark background can be higher so that the CL profile shows a minimum in the center of the wafer and do not follow the W profile shown by the disloca-

tion density. The fact that the cell interior in the Te-doped samples appears brighter than the walls, in the CL image, suggests that impurities, isolated or complexed with native defects, influence the CL spatial distribution across the wafer. Actually, impurity concentration in LEC-GaAs wafers has been found to have a W profile.[25,26]

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[1] R. T. Chen and D. E. Holmes, J. Cryst. Growth **61**, 111 (1983).

[2] M. Dussac, M. Dupuy, and E. Molva, in *Proceedings of the International Symposium on Defect Recognition and Image Processing in III-V Compounds*, Montpellier, 1985, edited by J. P. Fillard (Elsevier, Amsterdam, 1985), p. 209.

[3] M. S. Skolnick, in *Proceedings of the International Symposium on Defect Recognition and Image Processing in III-V Compounds*, Montpellier, 1985, edited by J. P. Fillard (Elsevier, Amsterdam, 1985), p. 165.

[4] J. Windscheif, M. Baeumler, and U. Kaufmann, Appl. Phys. Lett. **46**, 661 (1985).

[5] H. Ch. Alt and G. Packeiser, J. Appl. Phys. **60**, 2954 (1986).

[6] J. Windscheif and W. Wettling, in *Gallium Arsenide and Related Compounds*, Las Vegas, 1986, Inst. Phys. Conf. Ser. 83 (Institute of Physics, Bristol, 1987), p. 197.

[7] T. Kamejima, F. Shimura, Y. Matsumoto, H. Watanabe, and J. Matsui, Jpn. J. Appl. Phys. **21**, L721 (1982).

[8] M. Tajima, Jpn. J. Appl. Phys. **21**, L227 (1982).

[9] M. Tajima, in *Defects and Properties of Semiconductors: Defect Engineering*, edited by J. Chikawa, K. Sumino, and K. Wada (KTK Scientific, Tokyo, 1987), p. 37.

[10] A. K. Chin, R. Caruso, M. S. S. Young, and A. R. Von Neida, Appl. Phys. Lett. **45**, 552 (1984).

[11] B. Wakefield, P. A. Leigh, M. H. Lyons, and C. R. Elliot, Appl. Phys. Lett. **45**, 66 (1984).

[12] C. A. Warwick and G. T. Brown, Appl. Phys. Lett. **46**, 574 (1985).

[13] J. Ding, J. S. C. Chang, and M. Bujatti, Appl. Phys. Lett. **50**, 1089 (1987).

[14] D. A. Shaw and P. R. Thornton, J. Mater. Sci. **3**, 507 (1968).

[15] L. J. Balk, E. Kubalek, and E. Menzel, in *Scanning Electron Microscopy/1976*, edited by O. Johari (SEM, Chicago, 1976), p. 257.

[16] J. Llopis and J. Piqueras, J. Appl. Phys. **54**, 4570 (1983).

[17] M. Tajima, Y. Okada, and Y. Tokumaru, Jpn. J. Appl. Phys. **17**, Suppl. 17-1, 93 (1978).

[18] C. Werkhoven, J. H. T. Hengst, and C. van Opdorp, Appl. Phys. Lett. **35**, 136 (1979).

[19] W. Frank and U. Gösele, Physica **116B**, 420 (1983).

[20] F. Domínguez-Adame, J. Piqueras, N. de Diego, and J. Llopis, J. Appl. Phys. **63**, 2583 (1988).

[21] B. Hughes and G. H. Narayanan, Phys. Status Solidi A **46**, 627 (1978).

[22] P. Hautojärvi, P. Moser, M. Stucky, C. Corbel, and F. Plazaola, Appl. Phys. Lett. **48**, 809 (1986).

[23] G. Dlubek, O. Brümmer, F. Plazaola, and P. Hautojärvi, J. Phys. C **19**, 331 (1986).

[24] M. Stucky, R. Paulin, B. Geffroy, C. Corbel, and J. Suskij, in *Proceedings of the 7th International Conference on Positron Annihilation*, New Delhi, 1985 (World Scientific, Singapore, 1985), pp. 714–716.

[25] D. E. Holmes, R. T. Chen, and J. Young, Appl. Phys. Lett. **42**, 419 (1983).

[26] M. Henini, B. Tuck, and C. J. Paull, Solid-State Electron. **29**, 483 (1986).