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Observation of Nonradiative Microdefects in GaAs Wafers with a New Photo-Thermal-Radiation Microscope

Kazuo TSUBOUCHI, Yoshikazu AKUTSU and Nobuo MIKOSHIBA

Research Institute of Electrical Communication, Tohoku University,
Katahira 2-1-1, Sendai 980, Japan

We observed nonradiative microdefects in GaAs wafers with a new photo-thermal-radiation(PTR) microscope. We measured the PTR signal as a function of excitation energy(PTR spectrum) and the spatial distribution of the PTR intensity(PTR topograph). As a result of In-doping in GaAs, we found a new fact that the nonradiative microdefects gettered by dislocations were released by excluding the dislocations. The defect which we observed by the PTR microscope seems to be a new intrinsic nonradiative microdefect other than EL2.

1. Introduction

When a semiconductor surface is irradiated by a light beam, the absorbed energy of the light is converted partially to photoluminescence(PL) through radiative relaxation process and partially to local heating through nonradiative relaxation process. The local heating induces strains or ultrasonic waves which are detected with a piezoelectric transducer or a microphone. We have applied the photoacoustic(PA) technique using a piezoelectric transducer to investigate nonradiative processes and defects in semiconductors.[1-3] Although this technique is sensitive to the local temperature rise (~0.001K) at a nonradiative defect in semiconductors, its general use is limited because of the necessity of contact. As a nonradiative and noncontact method for the evaluation of the local temperature rise due to the nonradiative defects, we have developed a new photo-thermal-radiation(PTR) microscope using a sensitive HgCdTe IR detector.[4,5]

Recently, high quality GaAs wafers are required for advanced GaAs devices. The present GaAs wafer, however, includes various defects such as dislocations, impurities, microdefects and so on. A dislocation-free GaAs wafer has been obtained by In-doping[6,7] and now micro-defect other than dislocation has been a problem for an origin of inhomogeneity of GaAs wafer.

In this paper, we report on nondestructive and noncontact observation of microdefects in Si-doped n-GaAs and Si/In doped n-GaAs wafers. We compared the PTR topographs with the PL topographs, the X-ray topographs and etch-pit-density(EPD) distributions.

2. Experimental Apparatus

Figure 1 shows a schematic diagram of the measurements of PTR spectra, PTR topographs and PL topographs; all the measurements were carried out at room temperature(~23°C). A tunable dye laser (HITC, 850~920nm, the average power;~30mW) excited with a Kr ion laser (red multiline, ~5W) was used as a light source. The laser beam was chopped with an optical chopper (~333Hz) and focussed on a spot of about 200μm diameter at the sample surface. The IR

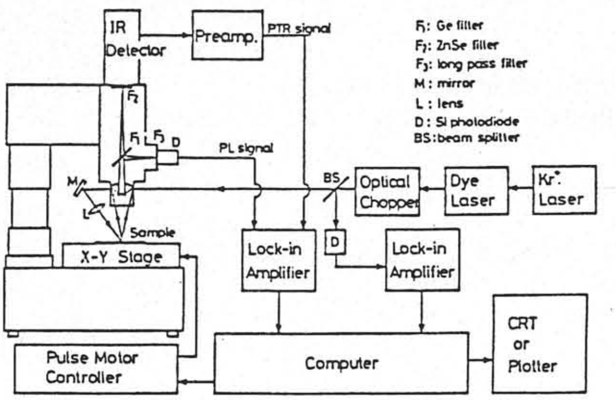


Fig.1 Schematic diagram of the measurements of PTR spectra and PTR topographs.

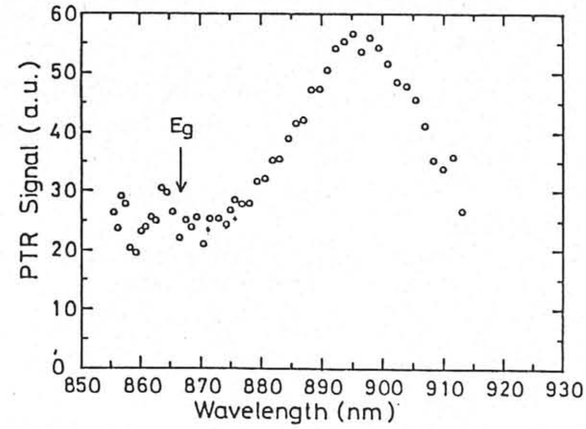


Fig.2 PTR spectrum of a n-GaAs wafer with dislocation.

radiation emitted from the heated spot was collected with a reflecting objective mirror and detected with a photoconducting $Hg_{0.8}Cd_{0.2}Te$ IR detector(NERC,MPC-11-2-AD1), which was sensitive to IR radiation in the wavelength ranging from 8 to 13μm and detectable up to the local temperature rise less than 0.05K.

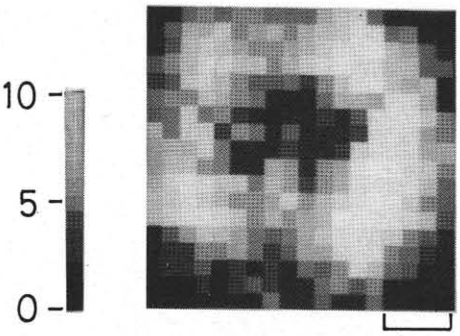
We designed the experimental setup so that we could measure the PL signal at the same time as the PTR measurement. A Kr ion laser (676.4nm, ~150mW) was used as the excitation light source. For the PL measurement the reflecting light from the Ge filter(F_1) was detected with a Si photodiode(D) through a long wavelength pass filter(F_3). The wavelength range of the final PL signal was from 830 to 960nm.

To reveal dislocation-etch-pits and observe their distribution, the etching was performed at 370°C for 15 minutes using molten KOH. The distribution of EPD was evaluated with a Wafer Defect Analyzer (Mitsubishi Chemical Industries,GX11).

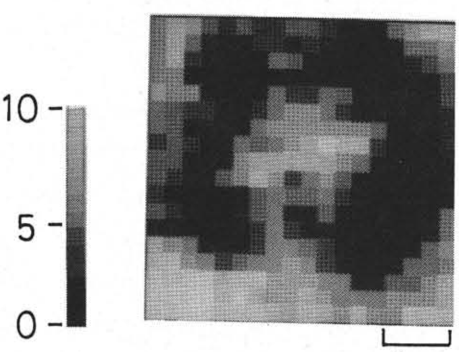
3. Experimental Results

3.1 PTR spectrum and topograph of an n-GaAs wafer with dislocation

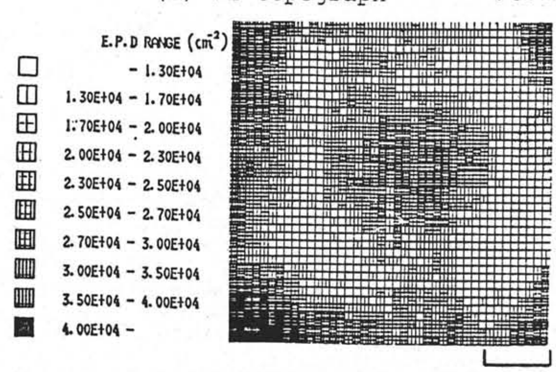
Figure 2 shows the PTR spectrum of an n-GaAs wafer(Si-doped;~$1x10^{18}cm^{-3}$, 310μm thick) with EPD's of the order of 10^4cm^{-2}. The PTR spectra has a peak at the wavelength



(a) PTR topograph 1cm



(b) PL topograph 1cm



(c) EPD distribution 1cm

Fig.3 (a) PTR topograph, (b) PL topograph and (c) EPD distribution of a Si-doped(~$1x10^{18}cm^{-3}$) LEC GaAs wafer.

of 895nm. The PTR topograph was obtained by fixing the excitaion wavelength at 895nm. The white area in Figs. 3(a) and 3(b) indicates the high intensity area of the PTR and PL signals. The increase of the PTR signal clearly corresponds to the decrease of the PL signal. Figure 3(c) shows the EPD distribution of the GaAs wafer. It should be pointed out that the PTR topograph which shows an inhomogeneous distribution of non-radiative defects has the negative correlation with the EPD distribution.

3.2 PTR spectrum and topograph of an In-doped n-GaAs wafer

Figure 4 shows the PTR spectra at three points in an In-doped n-GaAs LEC wafer (In-doped;~$1x10^{20}cm^{-3}$,Si-doped;~$1x10^{18}cm^{-3}$). The measuring points are indicated by A, B and C on the X-ray topograph in Fig 5.(c). The point A and B are the area with dislocations and the point C is the dislocation-free area. It is very clear that the PTR peak in Fig.4 is caused by a non-radiative state due to the microdefect rather than the dislocation. The present data of Fig.4 are more reliable than those reported in Ref.(5). We found a discrepancy between the values of the PTR peak wavelength in Fig.2 and Fig.4. The shift of the PTR peak from 895nm to 903nm seems to be caused by the change of band gap energy of GaAs due to In-doping. Using the same measuring conditions of the excitation power and the detecting sensitivity as those in Fig.3, the PTR topograph and PL topograph of the In-doped GaAs wafer were obtained in

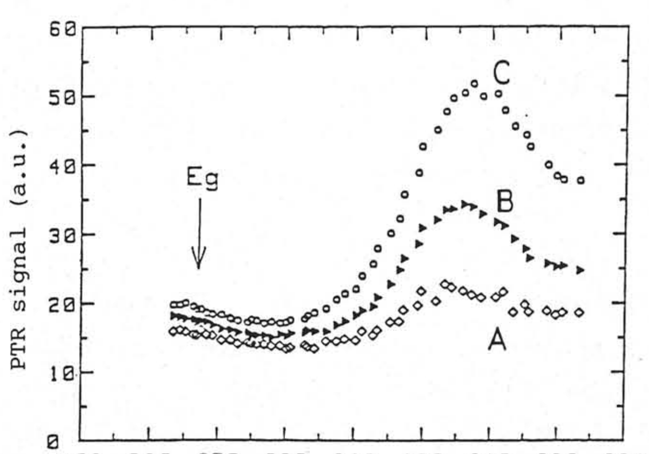
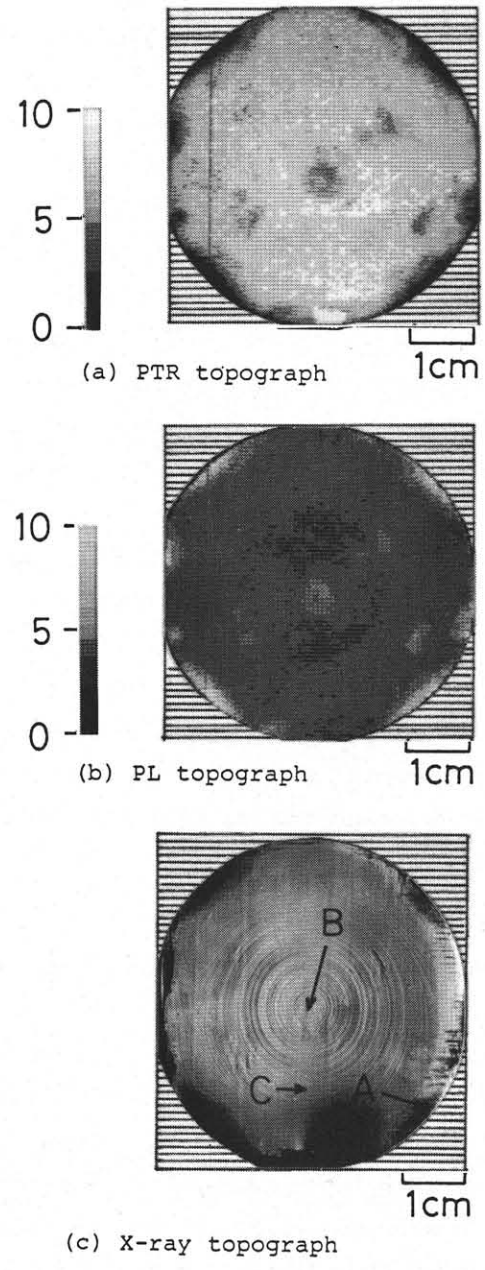


Fig.4 PTR spectra of an In-doped n-GaAs wafer. A, B and C points are shown in Fig.5(c). A and B were dislocation area and C was dislocation-free area.



(a) PTR topograph

(b) PL topograph

(c) X-ray topograph

Fig.5 (a) PTR topograph, (b) PL topograph and (c) X-ray topograph of an In-(~$1x10^{20}cm^{-3}$) and Si(~$1x10^{18}cm^{-3}$) doped LEC GaAs wafer.

Fig.5(a) and (b), respectively. The topograph in Fig.5(a) was obtained by fixing the excitation wavelength at 903nm. In this case, the measuring resolution was increased up to 500μm from 2.5mm which had been used in Fig.3 and in the previous paper.[5)] Comparing Fig.5(a) and (b) with Fig.3(a) and (b), we found that the PTR intensity was increased in the whole region of the In-doped GaAs wafer, while the PL intensity was decreased. At the four edge parts with dislocations as shown in Fig.5(c), the PL intensity remained at the white level, while the PTR intensity remained at the dark level. The PTR topograph of Fig.5(a) also shows clearly the decrease at the small black spots which are a spot at the center and four spots at the middle areas with 4 times symmetry, and on the contrary, the PL topograph of Fig.5(b) at the same spots (white spots) shows the increase of the intensity, while the X-ray topograph of Fig.5(c) at the same spots shows the small inhomogeneity in the striation area. The weak inhomogeneity of the above five spots in the X-ray topograph means the dislocations which are normal to the surface, and on the other hand, the line-like inhomogeneity at the four edge parts of the wafer means the dislocations which are parallel to the surface.

4. Discussion and Summary

We have demonstrated that the present PTR microscope can provide a nondestructive and noncontact observation of nonradiative microdefects in GaAs wafers at room temperature. As a result of In-doping, we found a new fact that the nonradiative microdefects gettered by the dislocations were released by excluding the dislocation. An EL2 microdefect is assumed not to exist in the wafer in consequence of the Si-heavily-doping($\sim 1\times10^{18}cm^{-3}$).[8)] The defect which we observed by the PTR microscope seems to be an new intrinsic nonradiative microdefect other than EL2. The new micro-defects absorb the light energy of about 900nm and generate a local heating around the microdefects. Therefore, we should study more about the new microdefects in conjunction with degradation mechanism of a light emitting and a laser diodes.

Acknowledgements

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