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Recent Advances in Photoluminescence Analysis of Si: Application to Epitaxial Layer and Nitrogen in Si

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§1. Introduction The photoluminescence (PL) method is now prevailing as a powerful tool for the quantitative impurity analysis of Si crystals. The basic idea of this method is that the PL intensity ratio between the impurity and intrinsic components can be used as a measure of the impurity concentration.[1] The revised calibration curves for the PL method make it possible to determine both B and P concentrations simultaneously in the range between 10^{11} and 10^{15} cm^{-3} within a ± 30 % deviation.[2] However, this method has hitherto been used only for the characterization of shallow impurities in bulk materials.

In this paper, we report two new applications of the PL analysis. First one is the characterization of shallow impurities in an epitaxial layer. Although the precise impurity analysis of an epitaxial layer is urgently required by present silicon industries, no techniques are available to detect directly various impurities in an epitaxial layer in the concentration range below 10^{16} cm^{-3}. We demonstrate the sensitive detection of the PL signal associated with impurities in an epitaxial layer and the concentration dependence of the PL signal. Second application is the characterization of nitrogen. The properties of N have been reported to be completely different from those of other group V impurities. Recently, Abe et al. reported that N is a quite useful impurity to improve the mechanical properties of an FZ crystal.[3] We have observed the PL line due to N for the first time.[4] The characterization of N by the PL method has some advantages over activation analysis and infra-red spectroscopy.

§2. Impurity analysis of an epitaxial layer As a typical example, we report here the PL analysis of a P-doped epitaxial layer grown on a B-doped substrate. The thickness of the layer is 2.5 μm. The PL experimental method was described previously.[1,2] Figure 1 shows the PL spectra from the substrate and epitaxially grown layers, where the resistivity of the substrate is 30 Ω·cm (p-type) and that of the epitaxial layers is (b) 2.7, (c) 1.0, (d) 0.3 Ω·cm (n-type). The spectral components are labeled with the chemical symbol of the associated impurities, where 'I' denotes the intrinsic luminescence. The epitaxial layer is so thin that photo-excited carriers diffuse not only within the layer but into the substrate followed by radiative recombination. Therefore, the PL in Fig. 1(b), (c) and (d) is from both the epitaxial layer and the substrate. The spectral pattern of the B-components in Fig. 1(b), (c) and (d) is exactly the same as that for the substrate, (a). All the spectra are normalized by the peak intensity of the B^{1}_{TO}-component. It should be noted the relative intensity of the P-component increases with decreasing the resistivity. In Fig. 2, the intensity ratio between the P^{1}_{NP}- and B^{1}_{TO}-lines is plotted against the P concentration obtained from the resistivity. The relationship in Fig. 2 suggests the possibility of the quantitative impurity anal-

ysis of epitaxial layers by the PL method in the same way as the case for the bulk material.[1,2] The simultaneous analysis of P, As, B and Al in epitaxial layers will be shown at the session.

§3. Characterization of Nitrogen PL spectra from N and P-doped FZ crystals (n-type, $\rho \sim 50\ \Omega\cdot$cm) are shown in Fig. 3 as a function of a N-doping level. The N concentration, varying from 0.8 to 3.2×10^{15} cm^{-3}, was determined by activation analysis. The spectra are so normalized as to be of equal peak magnitude. The spectral patterns for the three samples are nearly the same as those for conventional P-doped FZ crystals except for the line, labeled 'N', at 1.1223 ± 0.0001 eV. The N-line never appears unless the crystal is intentionally doped with N. It should be noted the relative intensity of the N-line increases with N concentration. The donor activity of N can be estimated from a combination of the PL and resistivity results. The fraction of the concentration of the N-related shallow donors to the total N concentration is about 1 %.

§4. Conclusion We have demonstrated for the first time that the PL method can be applied to the quantitative impurity analysis of an epitaxial layer and also to the characterization of N in Si.

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1) M. Tajima: Appl. Phys. Lett. 35 (1978) 719.
2) M. Tajima et al.: Semiconductor Silicon 1981 (Electrochem. Soc., Pennington, 1981) p. 72.
3) T. Abe et al.: ibid, p. 54.
4) M. Tajima et al.: to be published in Jpn. J. Appl. Phys. Lett. (June, 1981).

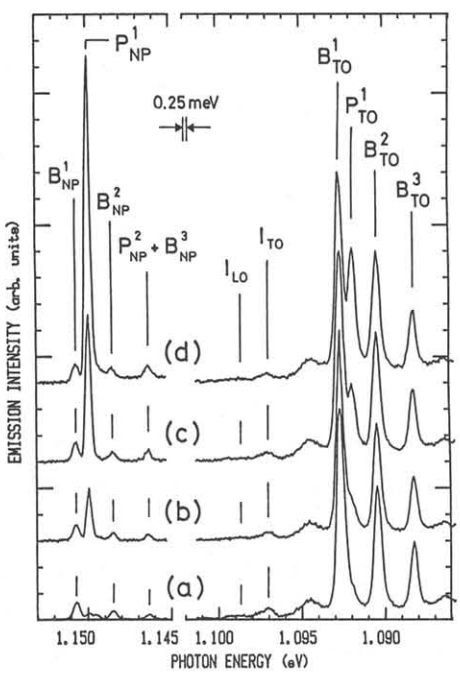

Fig. 1. PL spectra at 4.2 K from the substrate ((a) B-dope, $\rho \sim 30\ \Omega\cdot$cm), and epitaxial layers (P-dope, (b) 2.7, (c) 1.0, (d) 0.3 $\Omega\cdot$cm).

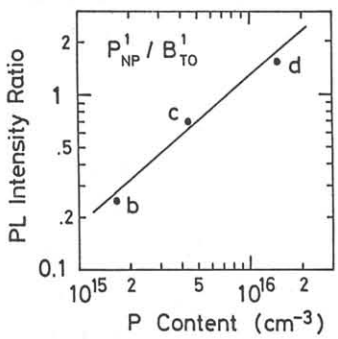

Fig. 2. Relationship between the PL intensity ratio of P^1_{NP}/B^1_{TO} and the P concentration.

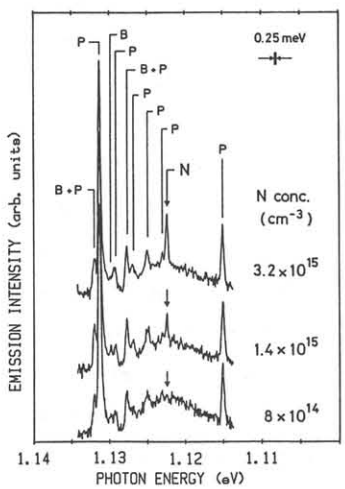

Fig. 3. PL spectra at 4.2 K from N and P-doped FZ crystals as a function of N-doping level.