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Formation of Silicon $P^+\pi PN\nu N^+$ structure by Epitaxial Growth

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The $P^+\pi PN\nu N^+$ structure is known as the profile of impurity densities of Read-like double drift IMPATT diodes. This structure may be the ideal one of high efficiency IMPATT diodes. However, very few works about this structure have ever been reported, because the formation of this complicated structure, particulerly achieving steep profile and balanced impurity densities of the P and N layers, is very difficult. Only Seidel et al. have shown an example of the structure being formed by ion implantation together with epitaxial growth(1).

The authors tried to form $P^+PN\nu N^+$ and $P^+\pi PN\nu N^+$ structures by epitaxial growth alone (proviso P^+ : diffusion, N^+ : the substrate) using the two-step epitaxial growth technique(2), which have previously been developed by the authors to restrain the autodoping phenomenon.

In the authors' experiments, a conventional horizontal epitaxial reactor was used, and the epitaxial layers were grown by pyrolysis of SiH_4 with PH_3 or B_2H_6 as the doping gas on the arsenic doped ($<$ 0.003 ohm-cm) (111) Si substrates. The temperature of the substrates were 1,050°C, and the growth rate was 0.4 μm/min. All layers of $PN\nu$ or $\pi PN\nu$ were grown successively without pulling out the wafers from the reactor to change the doping levels.

The profile of the effective impurity densities of a $P^+PN\nu N^+$ sample is shown in Fig.1. The effective densities were calculated from voltage dependency of the junction capacitance. The left hand half of the density profile is dominated by the impurity density of the P layer, while the other half is dominated by that of the ν layer. A density profile of one of the $P^+\pi PN\nu N^+$ samples is shown in Fig.2, where the previous data by Seidel et al. is also shown. Comparison of the two data tells that the authors' sample has steeper gradients of the impurity densities near the junction and a narrower zone than those of the previous work. Figure 3 shows respective carrier densities of n(x) and p(x), which were obtained from the spreading resistance profile shown in Fig.4. Though the carrier density profiles of π layer and ν layer are unbalanced, those of N layer and P layer are steep and well balanced.

The method of forming the $P^+\pi PN\nu N^+$ structure by epitaxy together with ion implantation has much complicated processes such as ion implanting process between two epitaxial processes and the annealing process of the implanted layer. In case of multi-epitaxy, on the other hand, it was thought to be rather difficult to form the steep impurity profile because of the autodoping phenomenon.

However, this work shows the multi-epitaxy, with the aid of the two-step epitaxial growth technique, can provide such a steep and well controlled impurity profile as that obtained by ion implantation.

1. T. E. Seidel, W. C. Niehaus, and D. E. Iglesias, IEEE Trans. Electron Devices, vol. ED-21, No. 8, August 1974.
2. T. Ishii, K. Takahashi, A. Kondo, and K. Shirahata, J. Electrochem. Soc. vol. 122, No. 11, November 1975.

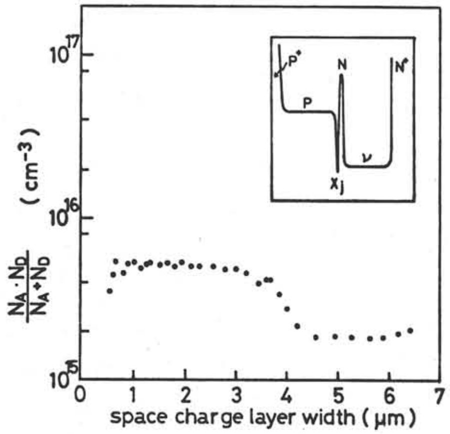

Fig. 1 Impurity density profile of $P^+PN\nu N^+$ structure

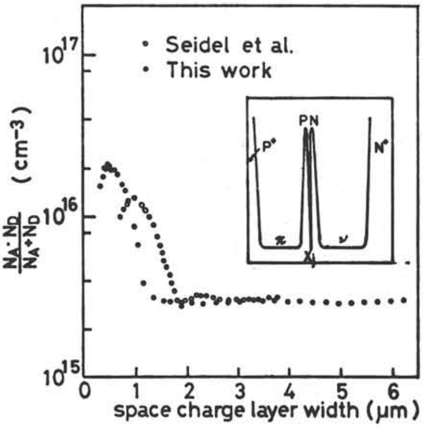

Fig. 2 Impurity density profile of $P^+\pi PN\nu N^+$ structure

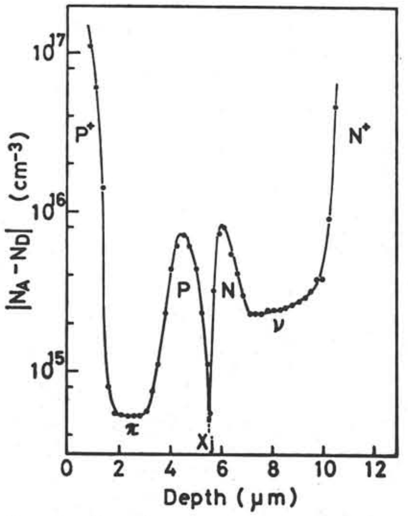

Fig. 3 Carrier density profile of $P^+\pi PN\nu N^+$ structure

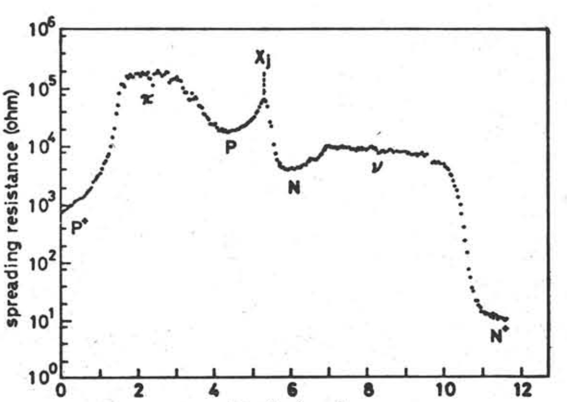

Fig. 4 Spreading resistance profile of $P^+\pi PN\nu N^+$ structure