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A-2-3 Application of Diffusion from Implanted Polysilicon to Bipolar Transistors

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A new impurity doping method utilizing diffusion from implanted polysilicon has been developed. The method was applied to low noise transistors, and the characteristics have been extremely improved. Pulsive noise was completely eliminated and noise figure at 10 Hz was 3.5 ∽ 4.0 dB. An excellent flat dependence of h_{FE} on collector current was obtained.

It is well known that ion implantation to the base of bipolar transistors results in the excessive noise and poor performance. This is referred to residual damage introduced by ion implantation. This problem has been a bottleneck for the application of ion implantation to bipolar devices. A new method which is like a combination of ion implantation and DOPOS technique (called IDOPOS) is found to be advantageous to solve the problem.

Figure 1 shows a typical process for the base formation utilizing the IDOPOS method. After base patterning, non-doped polysilicon was deposited to a thickness of 1500 A, typically, and was doped with boron by ion implantation. Implanted boron energy was 25, 30, and 50 keV, which give projected ranges of 870, 1170, and 1870 A, respectively, according to Hofker et al.$^{1)}$ The dose ranged from 5×10^{14} to 2×10^{15} /cm^2. Boron was diffused from the polysilicon into the substrate to form the base, then the polysilicon layer was oxidized for an emitter mask. A conventional phosphorous diffusion was carried out for the emitter.

The variation of the device parameter with implanted dose and energy has been investigated. The characteristics of the transistors were also compared with those obtained by conventional thermal diffusion or by direct base implantation. The direct base implantation was carried out at 50 keV with the dose of 4.5×10^{14} /cm^2 through a thin oxide layer.

Figure 2 shows the collector current I_C dependence of h_{FE} of transistors fabricated by using the above three methods. While the h_{FE} decreased rather drastically as the current level became lower in the case of the direct base implantation or even of the thermal diffusion, that of IDOPOS-transistors showed an excellent flat dependence on I_C level. The n values in the forward V-I characteristics, which is expressed as $I = I_S \exp(\frac{qV}{nkT})$, of E-B junction are listed in Table 1. In the case of low energy implantation (25, and 30 keV), n was 1.1 and it increased to about 1.2 at the implanted energy of 50 keV. These values are much better than 1.67 for the base implantation or 1.26 for the conventional thermal diffusion, indicating that an improved E-B junction was obtained by the IDOPOS method. This is the reason why the h_{FE} at low current level does not reduce significantly. This would come from the fact that the base was formed by solid state diffusion from implanted polysilicon. Another reason would be the base impurity profile near the surface. In the IDOPOS method, a polysilicon layer containing high concentration of boron was oxidized, while in the conventional process the substrate was oxidized. The carrier concentration obtained by the IDOPOS method was found to be higher near the surface.

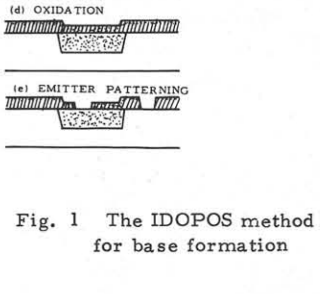

Fig. 1 The IDOPOS method for base formation

The IDOPOS method exhibited extremely small reverse leakage of both E-B and C-B junctions. The leakage current increased as the implanted energy increased, but still kept low level. In the case of 50 keV implantation, the projected range is deeper than the thickness of polysilicon layer, and more than half of boron ions would be implanted directly into the substrate. This is the main reason for the increase of the leakage current.

Figure 3 shows the noise figure (NF) at 10 Hz of the transistors. NF of 3.5 ∽ 4.0 dB was obtained at low implantation energy and is much better than that of the conventional diffusion. The NF became worse as the boron ions directly implanted into the substrate increased, i.e., implanted energy or dose became higher.

The resultson the generation of pulsive noise of the transistors are summarized in Table 1, which shows the pulsive noise can be completely eliminated by using the IDOPOS method at the implantation of 25 keV. The generation of the pulsive noise increased drastically at the implanted energy increased.

These results indicate that the IDOPOS method is effective for the improvement of the transistor characteristics and that the ions should be implanted into polysilicon at the energy which gives projected ranges sufficiently shallower than the thickness of the polysilicon layer.

The uniformity of base resistivity within 3 % in a wafer was obtained by the IDOPOS method. Figure 4 shows a typical distribution of h_{FE} values in a wafer. The uniformity was also improved.

CONCLUSION

Diffusion from implanted polysilicon was found to be very useful to improve the characteristics of the bipolar transistors and to make use of both merits of ion implantation and solid state diffusion. The method can be easily applied to other devices requiring high concentration doping such as bipolar IC's.

1) W. K. Hofker ; Radiation Effects (to be published)

Table 1 n values of E-B junctions and pulsive noise generation ratio (No. of Trs which generate pulsive noise/ No. of Trs examined) of transistors fabricated by utilizing three kinds of methods.

	Thermal Diffusion	Direct Ion Implantation	IDOPOS (2×10^{15} cm^{-2})		
			25 keV	30 keV	50 keV
n-value	1.26	1.67	1.10	1.10	1.18
Pulsive Noise		100 %	0 %	12 %	56 %

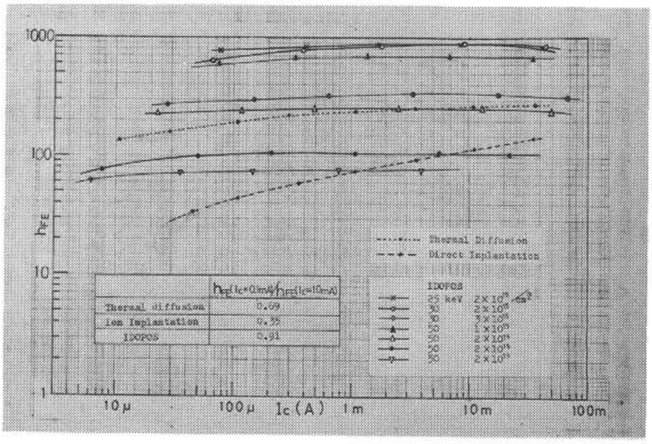

Fig. 2 I_C dependence of h_{FE} of transistors fabricated by using the three kinds of method. The IDOPOS transistors which had the same specification of the implantation had different values of h_{FE}. This is due to the difference of the base driving time.

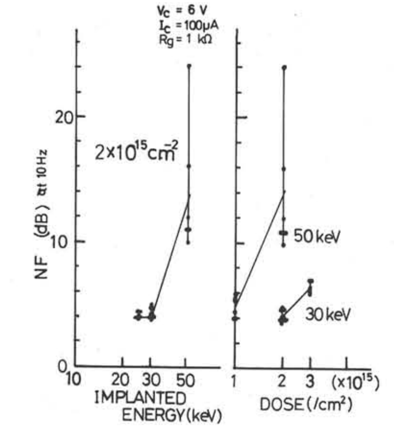

Fig. 3 Implanted energy and dose dependences of NF at 10 H_z of transistors fabricated by using the IDOPOS method.

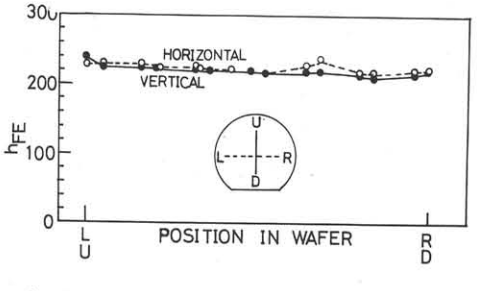

Fig. 4 A typical distribution of h_{FE} of the IDOPOS transistors in a wafer.