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A−5−2 Deep Levels Introduced by Iron Implantation in N-Type Silicon and Its Application to Switching Devices

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Minority carrier life time is an important parameter for many devices, especially for switching devices. A standard life time control process is gold diffusion method. The main disadvantages for the use of gold in life time control are (1) increase of the resistivity of silicon substrate and (2) strong temperature dependence of minority carrier life time. These effects are due to the fact that gold forms a donor center and an acceptor center in p-type and n-type silicon, respectively, and each center is coulomb attractive to minority carriers. Since the capture cross sections for coulomb attractive centers are proportional to $T^{-2} \sim T^{-4}$ and these for electrically neutral centers are $T^{0} \sim T^{-1}$, we expect a much less temperature dependence for the life time determined by neutral centers than by coulomb attractive centers.[1] It is generally accepted that iron forms only donor levels[2] and those disadvantages stated above are expected to be removed by doping iron instead of gold into n-type silicon. In the present paper a new method is suggested to introduce iron into silicon switching devices by making use of ion implantation method.

In order to study hole life time in n-type silicon we fabricated p^{+}-n diodes by the usual planar process. We used phosphorous-doped wafers of 60 $\sim$ 80 ohm-cm resistivity. Iron ions were implanted from the back surface at 100 KeV which corresponds to a projected range of 1300 A. The dose of iron and the anneal temperature varied from 1×10^{10} to 1×10^{15} cm^{-2} and from 900 to 1200°C, respectively. The hole life time is plotted versus iron dose in Fig. 1 with anneal temperature as a parameter. The hole life time decreases with increasing iron dose and/or rising temperature in a lower dose range. It exhibits complex behavior in a higher dose range which is presumably due to the formation of amorphous layer at the iron implanted region. The temperature dependence of hole life time is shown in Fig. 2 with iron dose as a parameter. By choosing suitable iron dose, the hole life time shows a quite weak temperature dependence. The resistivity of p-type and n-type silicon after either gold or iron implantation and diffusion was measured by two-point probe spreading resistance method and the results are shown in Fig. 3(a) and (b), respectively. The resistivity of both p-type and n-type silicon increased by gold diffusion. On the contrary, no changes of the resistivity were observed in n-type silicon and the increase and anomalous depth profile of it was first observed in p-type silicon diffused with iron. It can be concluded from these results that implanted iron forms donor centers in silicon.

The deep impurity levels introduced by iron implantation were determined by deep level transient spectroscopy(DLTS).[3] Typical DLTS spectra of p^{+}-n diodes implanted with iron are shown in Fig. 4. Two majority traps, E_1 and E_2, and one minority trap , H_1, were observed under majority- and minority carrier pulses. The energy levels and the capture cross sections of these traps were determined to be E_c-0.27, E_c-0.58, E_v+0.30 eV, 4.2×10^{-19}, 2.5×10^{-16} and 4.7×10^{-16} cm^2, respectively.

The concentrations of E_2 and H_1 depend strongly upon the iron dose and the anneal temperature. They are correlated with the hole life time and in inversely proportional relation. E_2 and H_1 levels may originate from the implanted iron and the damage introduced by the iron implantation, respectively.

This new method has been applied to gate controlled switches(GCS's). The forward-voltage drop across the iron-doped GCS's increased with temperature rise, which is contrary to the characteristic of conventional gold-doped GCS's, as shown in Fig. 5. This behavior makes it possible to operate the new GCS's in parallel without certain precaution, since current flowing the GCS's decreases with temperature rise. Fig. 6 shows the temperature dependence of gate trigger current of the new GCS's is weak compared with that of conventional GCS's. Moreover, the temperature coefficient of the turn-off gain of the new GCS's is half as much as that of conventional GCS's and the new devices can satisfactorily operate at higher junction temperatures. In conclusion, the iron implantation method is very suitable to be applied to switching devices.

References

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2) C. B. Collins and R. O. Carlson, Phys. Rev. 108(1957) 1409.
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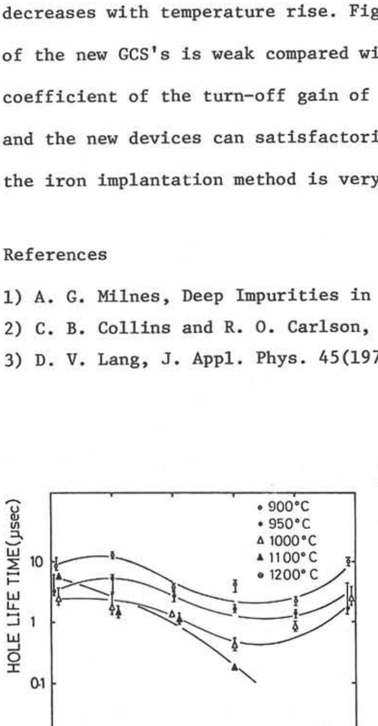

Fig. 1

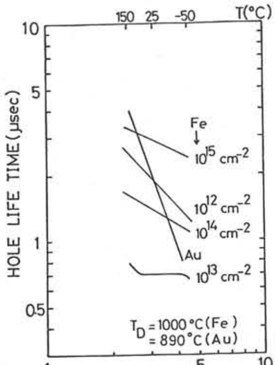

Fig. 2

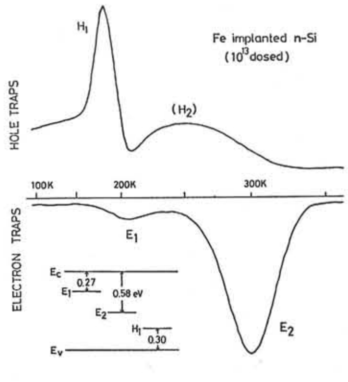

Fig. 4

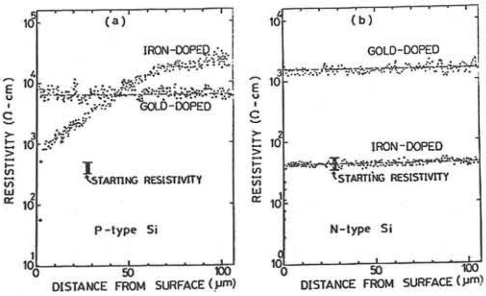

Fig. 3

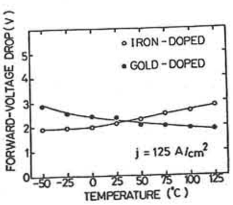

Fig. 5

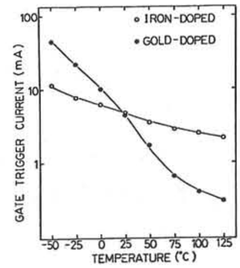

Fig. 6