Sloping Lifetime Control by Electron Irradiation for 4.5kV PT-SIThs

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Abstract

This paper describes the possibility of realizing the sloping lifetime control by electron irradiation. 4500V class SIThs which have the wider n-base region are irradiated 1MeV electron beam on the cathode side or the anode side. These devises have the sloping lifetime distributions. As the result, in the case of the devices of cathode-side irradiation, we successfully improved the trade-off relationship.

Introduction

Due to the development of the power electronics, it has been desired to realize the high blocking voltage and high frequency power semiconductor devices, which can be used in place of GTOs used as high voltage devices so far. In Static Induction Thyristors(SIThs, also called Field Controlled Thyristors), it is easy to develop large current devices with press contact because of the structure without MOS gate.

A diffusion of heavy metal such as Au and Pt had been used for carrier lifetime control in order to reduce switching power dissipation of the power devices. Recently, an electron irradiation has been widely used[1] because of its uniformity, controllability and productivity. On the other hand, it is reported that a local lifetime control using an ion irradiation such as proton and helium, which have a very narrow full-width half-maximum (FWHM) of defect distribution, is useful to improve the performance of devices[2]. However, it is pointed that the very narrow FWHM causes serious large scattering of device characteristics because of the relatively large scattering of Si wafer thickness[3].

Generally, the FWHM of an electron irradiation in Si is over 1mm, so that the electron irradiation is regarded as the uniform lifetime control method. However, in the high voltage devices which have more thick n-base width, the absorbed doze distribution of the electron irradiation may affect device characteristics. In this paper, the relationships between the electron distribution of absorbed doze in Si and the device characteristics for 4500V class SIThs are described.

Depth-doze distributions of electron irradiation

We assumed that the depth-doze distribution and the depth-lifetime distribution are related. To calculate the electron absorbed doze in a uniform absorber, we adopted the semiempirical algorithm[4].

Semiempirical algorithm

To calculate the behavior of electrons in the absorber, the semiempirical algorithms had been developed with combination of empirical equations and semiempirical equations which were based on experimental measurement and Monte Carlo calculation[5]. A basic equation to calculate the absorbed doze : D(x) is given by

$$D(x)dx=\{-d[\eta(x)E(x)]/dx\}dx \quad \cdots(1)$$

Here η is the electron transmissivity and E(x) is the average energy. Then, the improved equation[6] is given by

$$D(x)dx=(1-f_b-f_{rt})\{-d[\eta(x)E(x)]/dx\}dx \quad \cdots(2)$$

Here f_b is the correction term of backscattering and f_{rt} is the correction term of braking radiation. We calculated the electron absorbed doze in Si by using the calculation program : EDMULT[7,8] based on the equation(2).

Differences of absorbed doze distributions with irradiation energy

Fig.1 shows the calculation result of absorbed distribution in Si with irradiation energy as a parameter on condition that air gap width is 90cm.

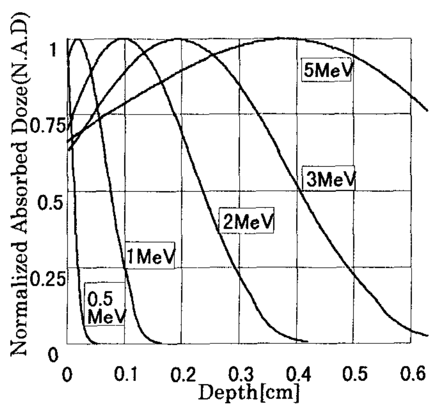

Fig.1 Absorbed distribution with irradiation energy as a parameter(air gap width:90cm)

Fig.2 also shows the calculated peak position and FWHM as a function of irradiation energy. With increasing the irradiation energy, the FWHM becomes wide and the peak position becomes deep.

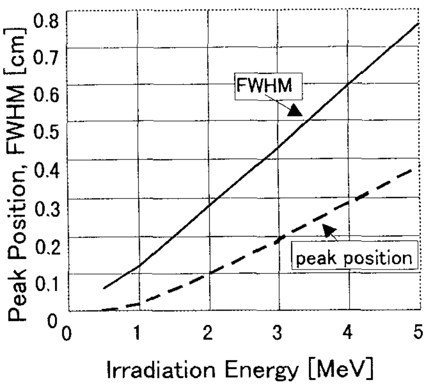

Fig.2 Peak position and FWHM as a function of irradiation energy

In the case of 1MeV, peak position locates in Si of 600μm thickness.

Differences of absorbed doze distribution with air gap width

Because the electron irradiation is performed in the air in general, the air gap between irradiation apparatus and absorber(device) affects the absorbed distribution.

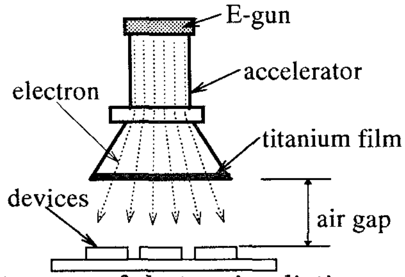

Fig.3 Structure of electron irradiation apparatus

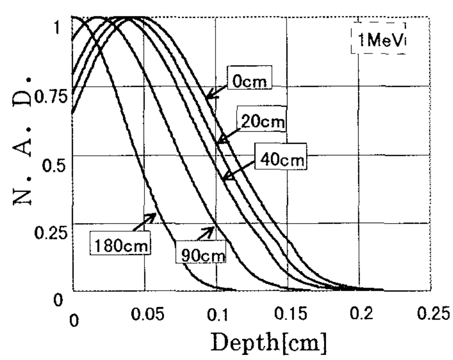

Fig.4 Absorbed distribution with air gap width as a parameter

Fig.3 shows the structure of electron irradiation apparatus.

Fig.4 shows the calculation result of absorbed distribution in Si with air gap width as a parameter on condition that the irradiation energy is 1MeV. Fig.5 also shows the calculated peak position and FWHM as a function of air gap width.

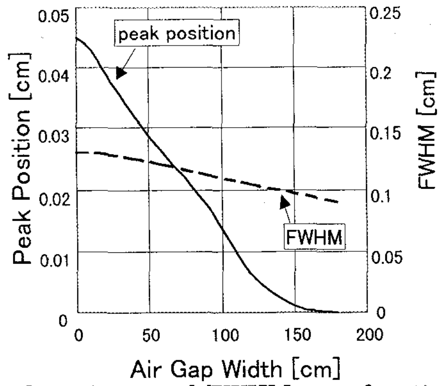

Fig.5 Peak position and FWHM as a function of air gap width

Experiments

Device Structure

Fig.6 shows a fabricated punch-through(PT) SITh structure. The device chip size is 10mm× 10mm. Field limiting rings are arranged in the edge part of device to achieve the high blocking voltage. This PT-SITh is a normally-off type device. Using FZ Si wafer with a concentration of 2× 10^{12}cm^{-3}, the buffer and the p-emitter layer are fabricated with epitaxial growth. The thickness of the n-base is 450μm, which is enough to achieve 4500V as blocking voltage.

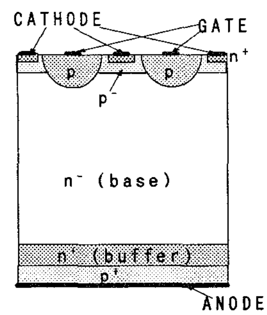

Fig.6 SITh structure

Irradiation Conditions

To be located the peak position in Si wafer, 1MeV as the irradiation energy was used. 2 different apparatus are used in order to change the air gap width. Besides, devices were irradiated on 2 different surfaces — namely cathode side and anode side. Table 1 shows irradiation conditions and IN/OUT ratio measured with dosimeter. The IN/OUT ratio is the ratio of the irradiation doze at the irradiated surface to the doze at the backside surface of 600μm Si. Fig.7 shows the calculated IN/OUT ratio and the normalized doze as a function of air gap width. From this figure, it can be found that the calculated ratio is different from the measured ratio. This reason is that the organic film is used on the wafer for protecting. So, it may be better to use the effective air gap width which takes account of the organic film. The effective air gap width is also shown in Table 1.

Table.1 Irradiation conditions and IN/OUT ratio

apparatus	A	B
irradiation energy	1MeV	1MeV
irradiation current	2mA	10mA
air gap width	20cm	90cm
IN/OUT ratio	1.02	2.00
effective air gap width	60cm	130cm

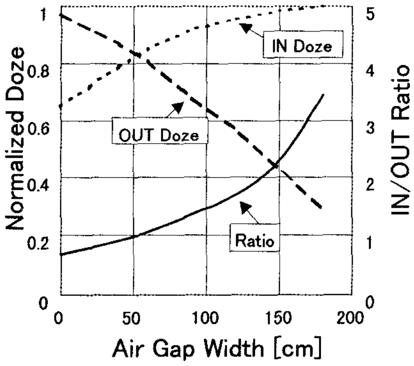

Fig.7 IN/OUT ratio and normalized doze as a function of air gap width

Experimental Results

On-state Voltage

Fig.8 shows on-state voltage as a function of irradiation doze at the irradiated surface for various conditions. These are good agreement with a calculated result.

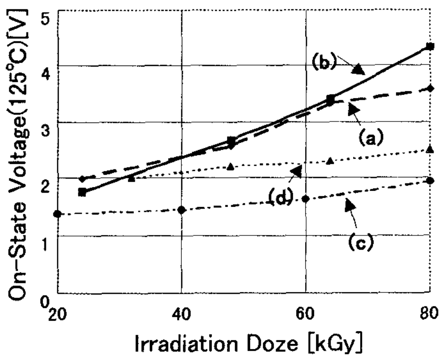

Fig.8 On-state voltage as a function of irradiation doze for various conditions
(a)cathode-side, apparatusA, (b)anode-side, apparatusA
(c)cathode-side, apparatusB, (d)anode-side, apparatusB

Anode Current during Turn-Off

(a)Cathode-side Irradiation using Apparatus A

Fig.9 shows the measured anode current during turn-off with irradiation doze as a parameter. At the low irradiation dose such as 24kGy, tail current is comparatively large. Then, with increasing irradiation doze, the tail current rapidly decreases.

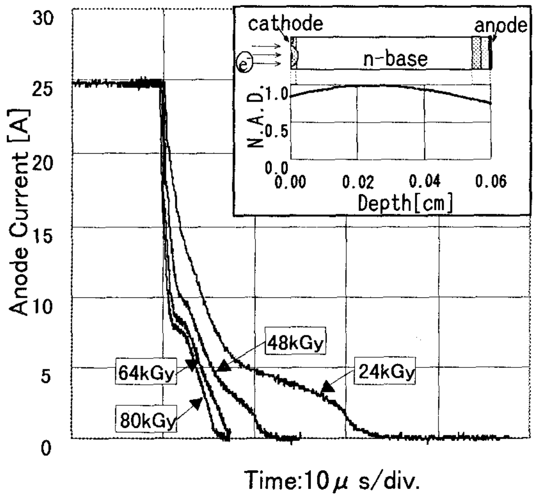

Fig.9 Anode current during turn-off with irradiation doze as a parameter ,case(a)

(b)Anode-side Irradiation using Apparatus A

Fig.10 shows the measured anode current during turn-off with the irradiation doze as a parameter. The tail current is smaller than that of the case of (a), but the tendency of tail current is almost same as (a). The slope of fall current is gentle compared with (a).

From the insert, it seems that the lifetime of anode side of n-base is slightly shorter than that of the cathode side.

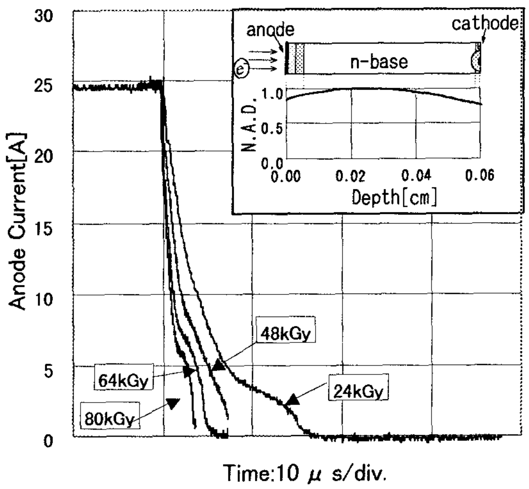

Fig.10 Anode current during turn-off with irradiation doze as a parameter,case(b)

(c)Cathode-side Irradiation using Apparatus B

Fig.11 shows the measured anode current during turn-off with the irradiation doze as a parameter. The tail current is comparatively large and slightly decreases with the increasing of the irradiation doze. The slope of the fall current becomes sharp with increasing of the irradiation doze.

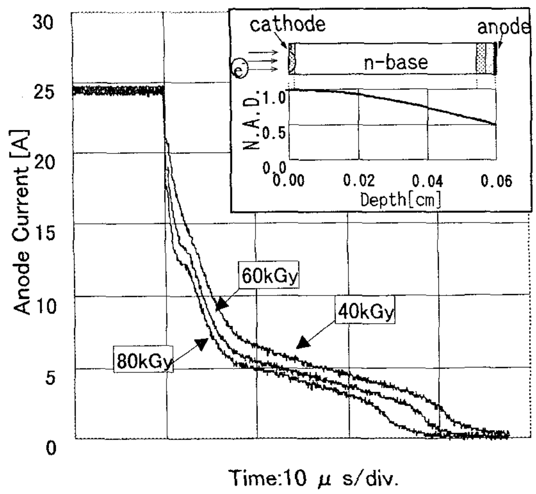

Fig.11 Anode current during turn-off with irradiation doze as a parameter, case(c)

Since the effective air gap width is wider than that of the case of (a) and (b), the peak position in the insert is located in the n-base layer of cathode side. So, it seems that the lifetime of cathode side of n-base is considerably shorter than that of the anode side.

(d)Anode-side Irradiation using Apparatus B

This case is opposite to the case of (c), so the peak position in the insert is located in the n-base layer of anode side.

Fig.12 shows the measured anode current during turn-off with the irradiation doze as a parameter. The tail current is very small. The waveform of turn-off current changes very little with the irradiation doze. Probably, one of these reasons may be high irradiation doze levels which were chosen to adjust the on-state voltage levels among these various conditions.

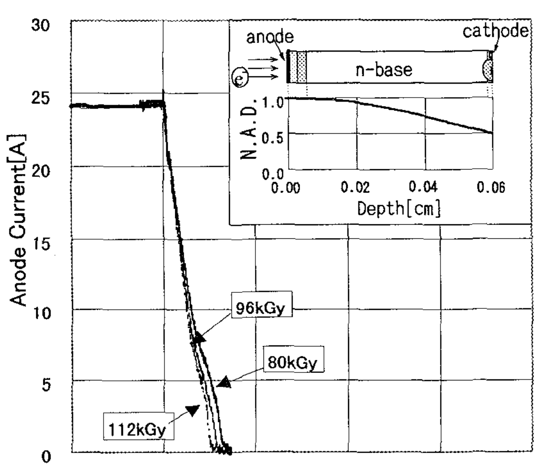

Fig.12 Anode current during turn-off with irradiation doze as a parameter, case(d)

Trade-off relationships

Fig.13 shows the trade-off relationships for various irradiation conditions. Here measured points are in accord with the irradiation doze in Fig.9-12. The trade-off relationship of the anode-side irradiation is superior than that of cathode-side irradiation. Especially, it is remarkable in the case using apparatus B which has more steep slope of the distribution of the absorbed doze. Therefore, the slope lifetime control using the electron irradiation of low energy is useful to improve the trade-off relationship.

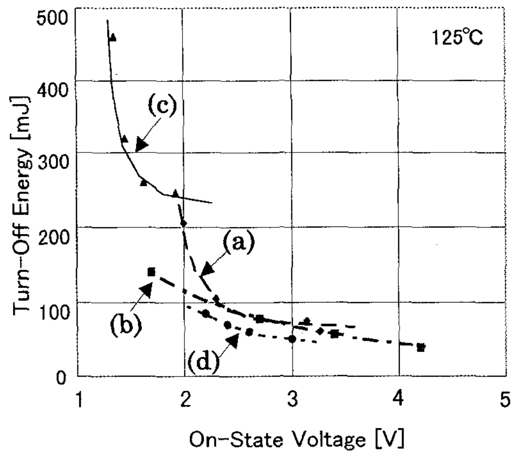

Fig.13 Trade-off relationship for various irradiation conditions

Conclusion

Using the electron irradiation of low energy like 1MeV, the slope distributions of the absorbed doze can be produced in the devices. These distributions also can be changed with the air gap width and the irradiation side. The 4500V class SIThs with various irradiation conditions had been fabricated and evaluated. In conclusion, the sloping lifetime control by the electron irradiation of low irradiation energy has been realized.

References

[1]R.O.Carlson,Y.S.Sun,H.B.Assalit, IEEE Trans. , Vol.ED-24, NO.8, August (1977)
[2]Mogro-Campero,R.P.Love,M.F.Chang, R.F.Dyer,IEEE, EDL-6, p.224 (1985)
[3]Y.Konishi,Y.Onishi,S.Momota,K.Sakurai, Proc.of ISPSD'96,p335-338(1996)
[4]H.Tanaka, Sumitomo Heavy Industries Technical Report,Vol.38, NO.113, 51 (1990)
[5]E.J.Kobetich,R.Katz, Nicl.Instrum.& Methods, 118,269(1974)
[6]T.Tabata,R.Ito,Jpn.J.Appl.Phys.,20, 249 (1981)
[7]T.Tabata,R.Ito,Nucl.Sciz & Eng.,53, 226 (1974)
[8]T.Tabata and R.Ito, Radiat. Center Osaka Prefect. Tech. Rep., No.8 (1987)