Feasibility Study on Neutron Retrospective Dosimetry Using Minority Carrier Life Time Measurement

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1. Introduction

Radition irradiation using fast neutron, gamma-ray and fast proton and so on has been utilized to improve semiconductor performance by effectively controlling the lifetime of minority carriers in semiconductor materials. In particular, the high-speed neutron has the advantage of improving the production yield of the material as it can create uniform and effective lattice defects throughout the semiconductor material.Recently, in many semiconductor fields such as power semiconductors and memory semiconductors, research related to radiation irradiation for performance improvement has been made, among which defect analysis and lifetime studies of minority carriers have been actively conducted.

Minority carriers are involved in speed in the performance of semiconductors and are known to have a lot of influence, especially in switching devices.

When the lifetime of minority carriers is prolonged, the semiconductor switching speed is slow, resulting in a problem of inferior efficiency. To solve this problem, radiation irradiation methods such as fast neutrons, protons, and electrons are used.

In this study, fast neutrons were investigated on N-type and P-type silicon wafers, which are major materials for semiconductors, and the resulting minority carrier lifetime was analyzed. fast neutron dose evaluation was conducted together. Through this, the correlation between the minority carrier lifetime and the dose was investigated to investigate the possibility of use in the neutron retrospective dosimetry..

2. Experiment

The samples used in this experiment are N-type and P-type 4-inch silicon wafers with a thickness of 500 µm, and have the characteristics shown in Table 1.

Table 1. Silicon wafer characteristics

Type	Diameter [um]	Dopant	Resistivity	Crystal Orientation
N	525	P	1 – 20	100
P		B	1 – 20	100

Due to the lack of fast neutron irradiation facilities in Korea, the MC50-Cyclotron, a proton accelerator possessed by the Institute of Nuclear Medicine, was used.

A proton beam with a kinetic energy of 30 MeV was irradiated onto a 0.5 cm thick beryllium target to generate a neutron beam. The neutron spectrum at the position 1 cm after the opening of the graphite collimator was simulated using MCNP6.

Fig 1 shows the simulated neutron spectrum generated by a 20-μA incident proton.

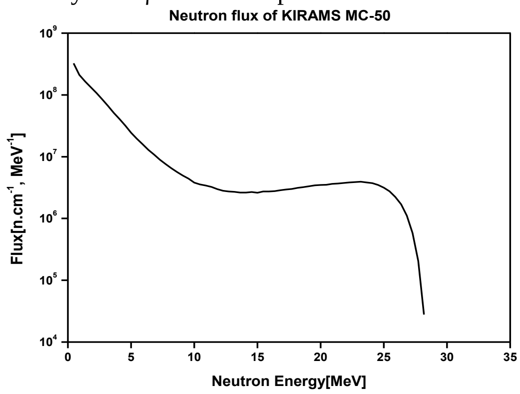


Fig. 1 Neutron spectrum generated by the ^{9}Be(p,n) reaction in the MC-50 cyclotron

The fast neutron was irradiated using the MC-50 cyclotron at the KIRAMS as shown in fig 2. The Silicon wafer was irradiated in the horizontal direction. The dose of the irradiated fast neutron was varied between 1 × 10^8 and 1 × 10^{11} n/cm^2 [6].

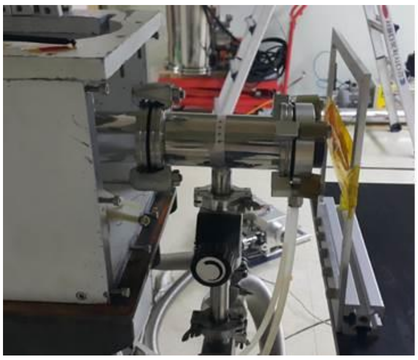


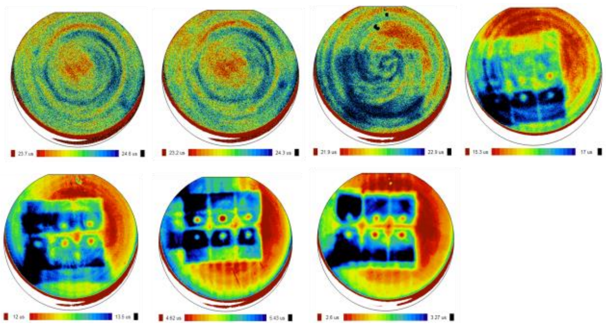
Fig. 2 Neutron irradiation by the the MC-50 cyclotron

To confirm the effect of the irradiation defects formed by fast neutron irradiation on the electrical properties of n-type and p-type silicon wafers, the lifetime of minority carriers was measured using WT-2000 of Semilab, applied with a microwave photoelectric effect attenuation method. Compared with the results before neutron irradiation.

3. Results

Figure 3 and Table 2 show the MCLT measurement results before and after fast neutron irradiation. Figure 3 shows the result of mapping the minority carrier lifetime value of the silicon wafer according to each irradiation dose. It can be seen that the minority carrier lifetime decreases as the fast neutron irradiation dose increases for both N-type and P-type silicon wafers, resulting in red color.

Before the fast neutron irradiation, the minority carrier lifetimes of N-type and P-type silicon wafers were 24.189 and 10.602 μs, respectively. At this time, the reason that the minority carrier lifetime of the N-type silicon wafer is longer than that of the P-type silicon wafer is that the minority carrier of the N-type is a hole. In contrast, the minority carrier of the P-type is an electron. As a result, the P-type silicon wafer has a lower minority carrier lifetime. After fast neutron irradiation, the N-type silicon wafer rapidly decreased according to the irradiation dose. It decreased to 2.86 us, and the P-type silicon wafer gradually decreased according to the irradiation dose, and then rapidly decreased from the irradiation dose of 1×10^{10} n/cm^2. Thus, it can be seen that the minority carrier life is reduced to 2.388 us.



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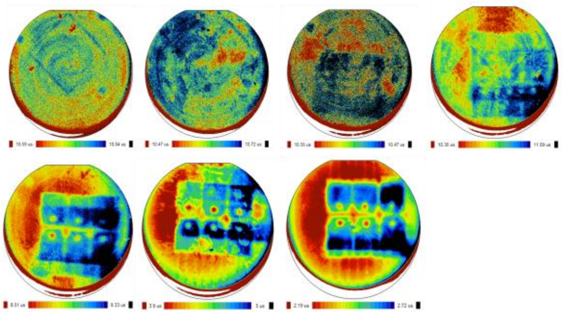
(a)



(b)

Fig3. (a) N-type and (b) P-type Silicon wafer MCLT Mapping data.

Table 2. N-type and P-type silicon wafer MCLT

Irradiation	N-type		P-type	
Condition	MCLT [μs]	Δ MCLT [μs]	MCLT [μs]	Δ MCLT [μs]
Before	24.189	-	10.602	-
$1 \cdot 10^8$	23.495	0.694	10.523	0.079
$1 \cdot 10^9$	22.058	2.131	10.266	0.336
$5 \cdot 10^9$	16.075	8.114	10.432	0.170
$1 \cdot 10^{10}$	12.522	11.667	8.686	1.915
$5 \cdot 10^{10}$	4.9228	19.266	4.299	6.303
$1 \cdot 10^{11}$	2.8606	21.328	2.388	8.214

Uniform lattice defects were formed on N-type and P-type silicon wafers due to fast neutron irradiation, and it was found that lattice defects can effectively control the lifetime of minority carriers. Besides, it is interesting to note that the minority carrier lifetimes of N-type and P-type silicon wafers have similar values near high dose irradiation (Figure 4). This means that the lifetime of the minority carrier of the wafer, which was determined by the defects of the wafer before irradiation, is more affected by the defects caused by irradiation than by the defects at later high irradiation doses. You can see that you can control the lifetime.

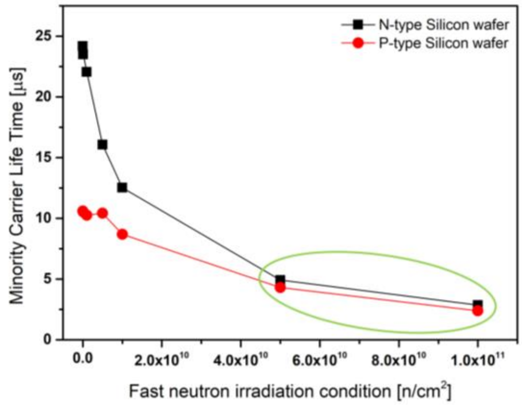


Fig 4. N-type vs. P-type silicon wafer MCLT data

3. Conclusions

Through fast neutron irradiation, uniform lattice defects were formed on N-type and P-type silicon wafers, and the characteristics of changes in the lifetime of minority carriers were analyzed. In both N-type and P-type silicon wafers, as the irradiation dose increased, the lifetime of minority carriers tended to decrease, especially at high irradiation doses.

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REFERENCES

[1] F. H. Ruddy, A. R. Dulloo, J. G. Seidel, F. W, Hantz, and L. R. Grobmyer, Nuclear Reactor Power Monitoring Using Silicon Carbide Semiconductor Radiation Detectors, Nuclear Technology, Vol.140, p. 198, 2002.

[2] F. H. Ruddy, A. R Dulloo, J. G Seidel, J.W.Palmour, and R. Singh, The Charged Particle Response of Silicon Carbide Semiconductor Radiation Detector, Nuclear Instruments and Methods In Physics Research, Vol.505, p.159, 2003.