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

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1. Introduction

- The minority carrier lifetime is defined as the average time of optically or electrically excited minority carriers to exist before recombining with majority carriers.
- The lifetime of a semiconductor wafer is sensitive to impurities and crystal defects in the wafer.
- Irradiation with high energy particles such as electrons, protons, and neutrons generates crystal defects in a semiconductor wafer and device.
- Irradiation-induced defects affect not only the recombination lifetime, but also the resistivity of semiconductors.
- A series of studies have been conducted for irradiation effects on the recombination lifetime of Si wafers in moderate to high fluence ranges, and have demonstrated that the lifetime decreases as irradiation fluence increases.
- The recombination lifetime in wafers were measured using microwave photoconductance decay (u-PCD) in these studies and also in many recent studies.
- u-PCD method provides a contactless measurement of the recombination lifetime of free carriers in semiconductors following a pulse of optical excitation, and has been widely used to provide a simple and reliable measurement of the recombination lifetime in wafers.
- In this work, carrier lifetimes as well as resistivity were evaluated for both n- and p-type Si wafers irradiated by neutrons in low to high fluence ranges. A systematic comparison between n- and p-type silicon has yet been published especially in low fluence range. A possible practical application of this study will be discussed

2. Experimental

- n- and p-type Si (100) wafers with 100 mm diameter and 525 mm thickness were used for neutron irradiation.
- Neutron irradiation was performed at ambient temperature (~25°C) by using neutrons produced by bombarding a beryllium target with 30 MeV protons accelerated by the MC-50 cyclotron in KIRAMS.
- The neutron fluence was in the range from 10^8 to 10^{11} cm^{-2} with a flux of 10^8 $cm^{-2}\cdot s^{-1}$.
- Insulated gate bipolar transistors (IGBT) devices packaged in a TO-3 package were placed in front of Si wafers during neutron irradiation in order to evaluate the effect of neutron interaction with semiconductor devices.

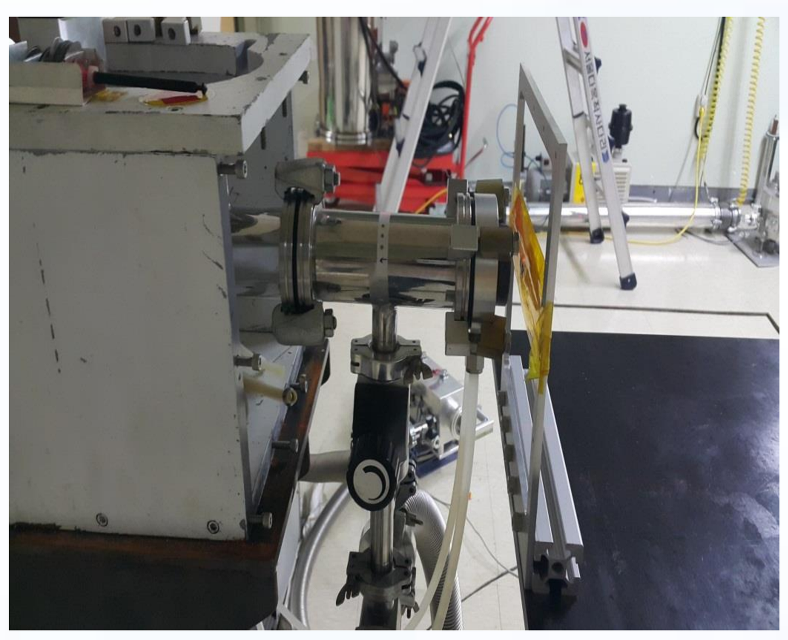

Fig 1. Neutron Irradiation at MC-50 cyclotron

- Mapping of carrier lifetime has been conducted for unirradiated and irradiated silicon by Semilab WT-2000 u-PCD. The mapping used a laser with 904 nm wavelength and 200 ns pulse width to generate excess carriers.

3. Results and discussion

- Fig. 2 shows the spatial lifetime mapping of n-type and p-type Si wafers measured before neutron irradiation.

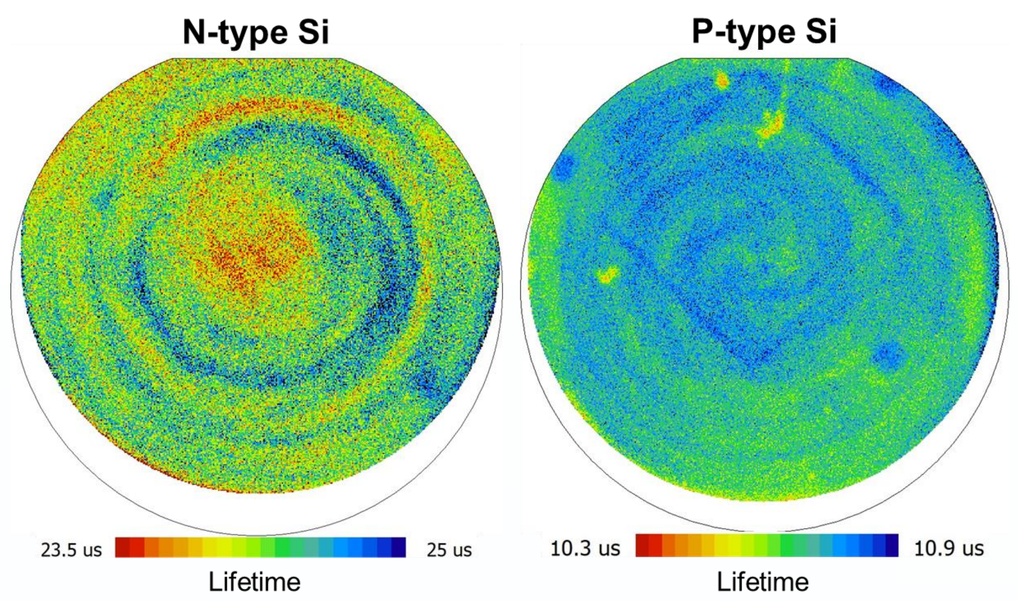

Fig 2. u-PCD mapping measured before neutron irradiation

- Concentric rings can be observed on both Si wafers, which are characteristic of a Czochralski silicon induced by inhomogeneous distribution of impurities.
- The histograms shown in Fig 3 indicate quite uniform variation of the lifetime over the entire surface of both n- and p-type Si wafers.
- The lifetime of n-type Si wafer (24.27 ± 0.34 us) is greater than that of p-type Si wafer (10.72 ± 0.68 us).

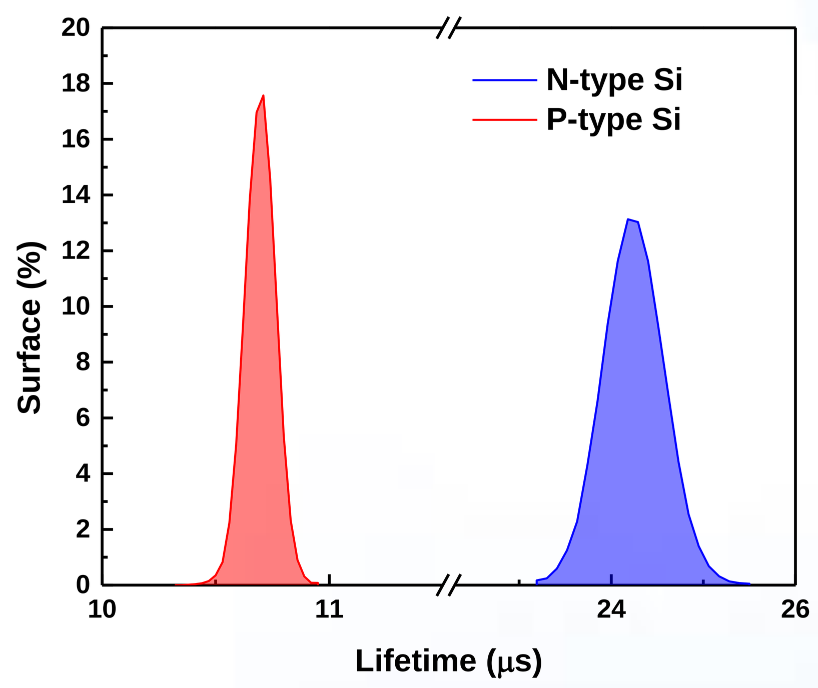

Fig 3. Lifetime histograms measured before neutron irradiation

- The histograms of neutron-irradiated Si wafers are shown in Fig. 4(a) and 4(b) for n- and p-type Si, respectively.
- The histograms overlap at fluences less than 1×109 cm^{-2}, but shift to the left at higher neutron fluences for both types of Si wafers.
- The measured lifetime using u-PCD method is an effective lifetime, which is a combination of lifetimes associated with recombination processes in both the sample surface and the bulk.
- The fluence-dependent lifetimes manifested in Fig. 4 indicate that the surface recombination does not dominate the measured effective lifetime.
- A probable cause for the suppressed surface recombination can be the native oxide layer on the Si wafer.

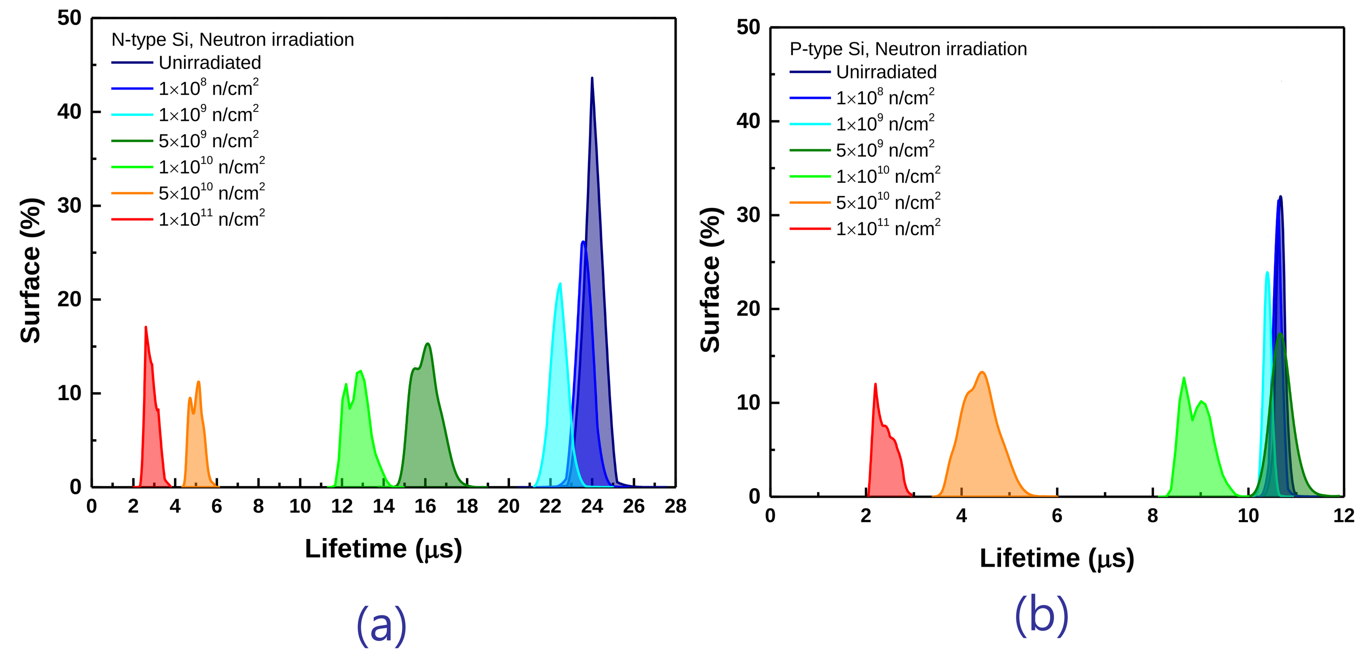

Fig 4. Lifetime histograms of neutron irradiated (a) n-type and (b) p-type Si wafer

- Fig. 5(a) shows the lifetime mappings of neutron-irradiated Si wafers in monochrome colors.
- As the influence increases, the two-dimensional images of IGBT devices become apparent.
- The device is covered with plastic cap with a hole in the middle, and has three protruding terminals from metal base made of aluminum.
- The total device thickness is 5 mm.
- The three terminals can barely be recognized from the lifetime mappings, because aluminum is almost transparent to neutrons.
- The plastic caps are seen with greater contrast because the Si area shaded by the devices were irradiated by less neutrons due to the scattering of neutron with plastic, which has a high hydrogen content, inducing longer lifetime on the shaded area.

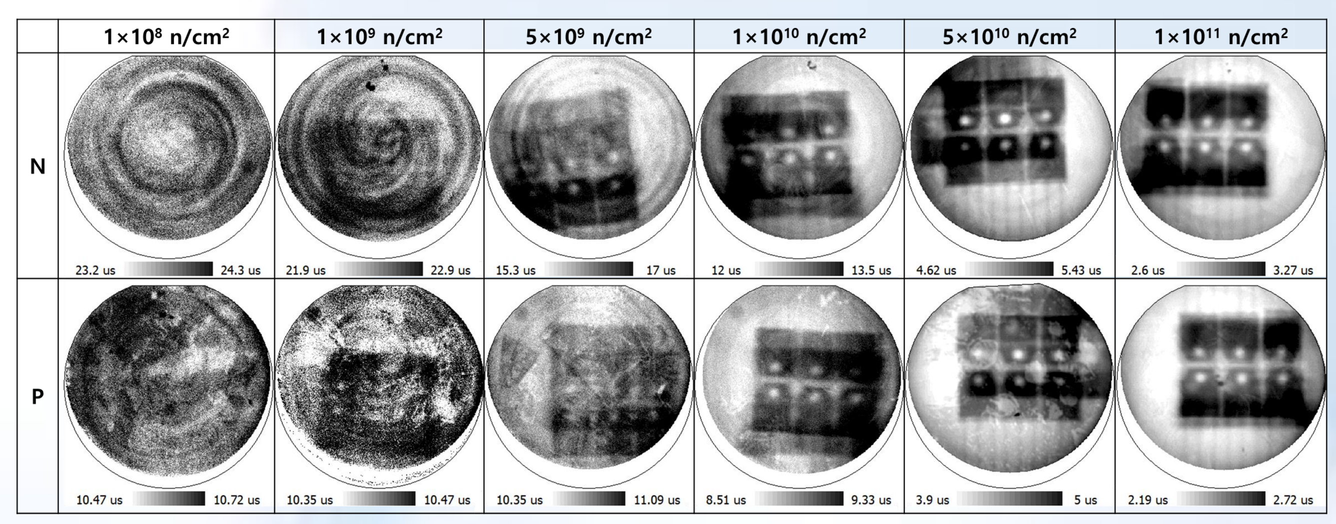

Fig 5. Monochrome lifetime mappings of neutron-irradiated n- and p-type Si wafers

4. Conclusion

- The carrier lifetimes were evaluated by the m-PCD method in n- and p-type Si irradiated by neutrons in the fluence range of 10^8 ~10^{11} cm^{-2}
- Unirradiated n-type Si had a longer lifetime than unirradiated p-type Si.
- Both n- and p-type Si had a threshold fluence above which the lifetime decreases almost linearly with fluence, then the slope of decreasing lifetime became smaller at higher fluence range.
- The lifetimes of neutron-irradiated Si exhibited similar irradiation fluence dependency, manifesting formation of similar types of radiation defects (recombination centers).