Non-Ionizing Radiation Effects on the Surface Recombination Velocity of AlGaAs/GaAs Double Heterostructures

Andrew Hudson*, Daniele Monahan

The Aerospace Corporation

Abstract

We used time resolved photoluminescence to extract the room temperature surface recombination velocities and bulk carrier recombination lifetimes for a series of AlGaAs/GaAs heterostructures exposed to 1 MeV equivalent in Si neutron radiation. While the measured exposure effects were dominated by the bulk, a statistically significant increase in the surface recombination velocity was determined for fluences in excess of 5×10^{12} n/cm^2. This result suggests that radiation effects on the surface recombination velocity become an important factor for modeling and qualification purposes when devices are exposed above a threshold fluence.

Heterostructure

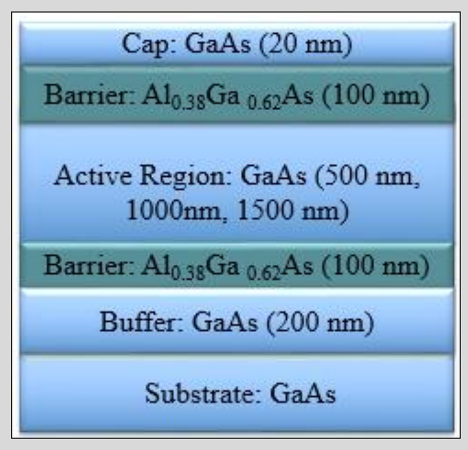

Figure 1: Sample structure.

TRPL System

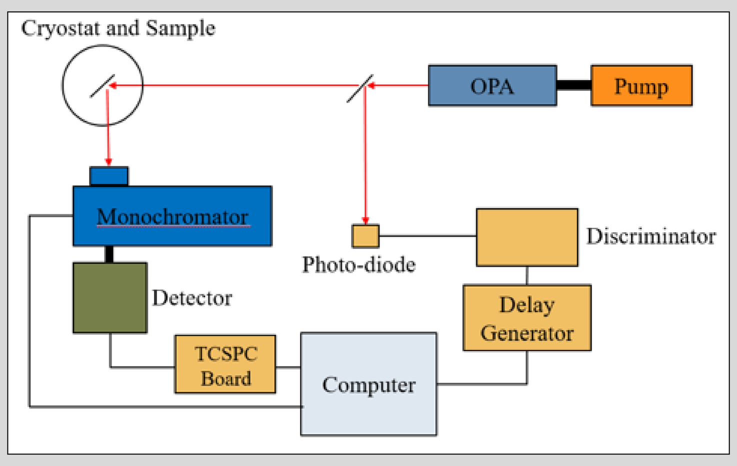

Figure 2: TRPL characterization system.

Equations: Carrier Recombination Dynamics

$$\tau_{PL}^{-1} = k_{PL} = (k_{rad} + k_{nr-SRH})$$

Eq.1: Carrier recombination rate.

$$k_{PL} = k_{bulk} + (S_1 + S_2)L^{-1}$$

Eq. 2: Bulk and surface recombination.

$$Lk_{bulk}^{1/2} / D^{1/2} \ll 1$$

Eq. 3: Uniform carrier excitation condition.

$$k_{PL} = k_{rad} + k_{nr-SRH} + 2SL^{-1}\ ; \quad S_1 = S_2$$

Eq. 4: Simplified bulk and surface recombination.

Silvaco Simulations, T ~ 295 K

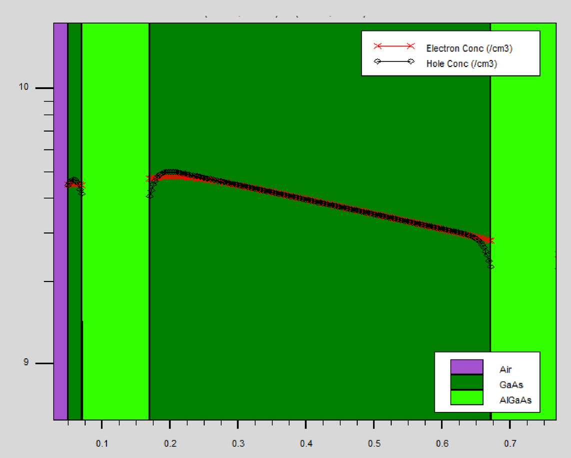

Figure 3: 500 nm active region.

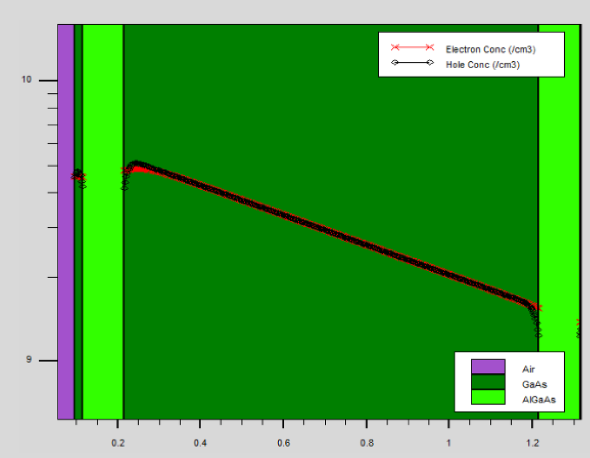

Figure 4: 1000 nm active region.

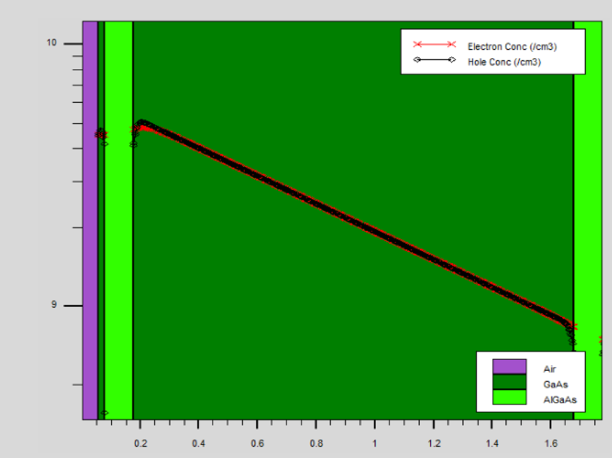

Figure 5: 1500 nm active region.

To determine the relative pulse energies to be used for the time resolved characterization the ratios of the concentrations derived from Figs. 3 – 5 were considered. The average of the front and back interface concentrations were determined for each structure and then compared. The analysis suggests that the pulse energy for the 1000 nm and 1500 nm test articles should be increased by 20% and 30% respectively relative to that of the 500 nm sample to maintain a near constant carrier density. This was performed for the TRPL data collection to minimize carrier density dependent effects.

Effects of Neutron Exposure on Bulk and Surface Recombination Rates, T ~ 295 K

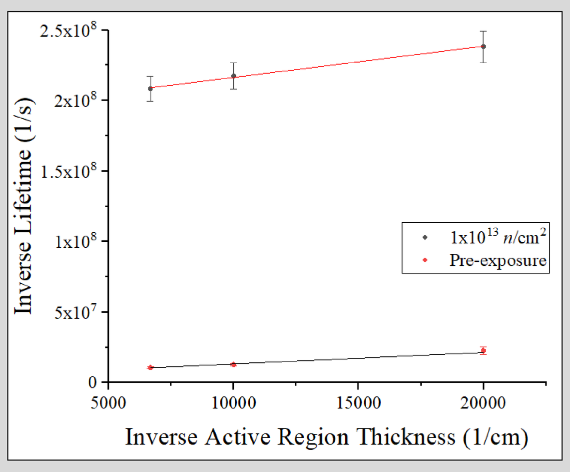

Figure 6: SRV extraction.
Unexposed: SRV = 460 +/- 37 cm/s.
1×10^{13} *n*/cm^2: SRV = 1100 +/- 70 cm/s.

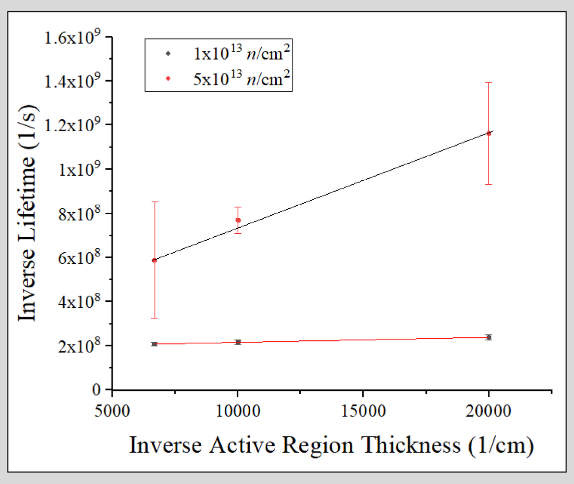

Figure 7: SRV extraction.
1×10^{13} *n*/cm^2: SRV = 1100 +/- 70 cm /s.
5×10^{13} *n*/cm^2: SRV = 21000 +/- 1500 cm/s.

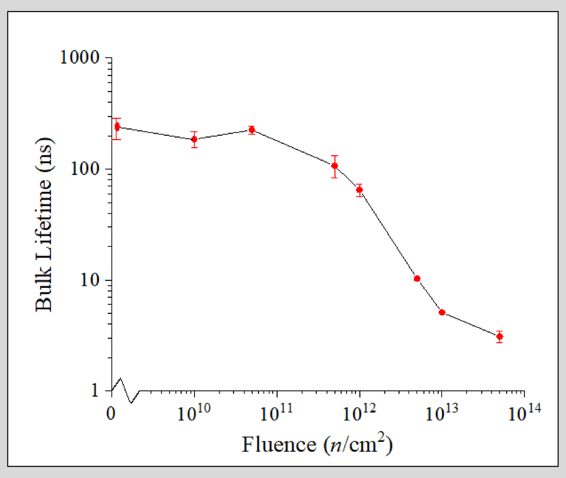

Figure 8: Bulk carrier lifetime.

Linear fits of the extracted *1/e* carrier recombination lifetimes as a function of active region thickness (Eq. 4) were used to extract the bulk carrier lifetime and the SRV for a given exposure fluence. For simplicity, this analysis assumes that the surface recombination characteristics at each AlGaAs/GaAs interface are comparable ($S_1 = S_2$). A comparison of the unexposed test articles to those subjected to a fluence of 1×10^{13} n/cm^2 is shown in Fig. 6. The slope of each is proportional to the SRV. Similarly, a comparison of the data for test articles exposed to fluences of 1×10^{13} n/cm^2 and 5×10^{13} n/cm^2 appears in Fig. 7. An examination of the extracted bulk carrier lifetime as a function of fluence appears in Fig. 8. A reduction in the carrier lifetime relative to the unexposed value is significant to 1 – s becomes evident for fluences in excess of 5×10^{10} n/cm^2. An overall lifetime reduction by over two orders of magnitude occurs for the largest fluence of 5×10^{13} n/cm^2.

Changes to Bulk and Surface Recombination Rates

An increase in the SRV significant to 1-σ becomes apparent for fluences in excess of 5×10^{12} n/cm^2. For comparison, the bulk carrier recombination rates (inverse of the extracted bulk carrier lifetime) are plotted alongside the SRV in Fig. 9. The results show that statistically significant radiation-induced degradation begins to occur at a lower fluence in the bulk than at the AlGaAs/GaAs interfaces. However, at the highest fluence the SRV increases by over one order of magnitude relative to the unexposed value.

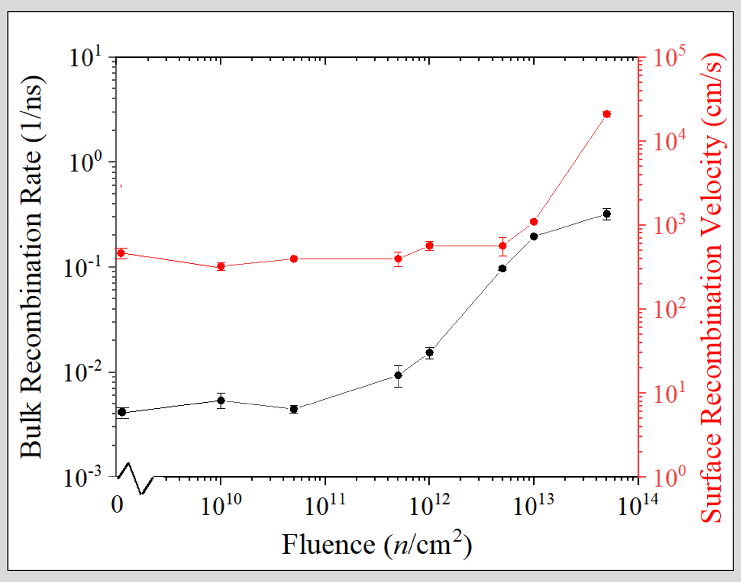

Figure 9: Bulk and surface recombination rates.

Summary

It was determined that 1 MeV equivalent in Si neutron radiation has a measurable impact on the bulk recombination rate for AlGaAs/GaAs test structures, likely through the generation of non-radiative recombination centers. Non-ionizing radiation exposure also increases the surface recombination velocity for fluences in excess of 5×10^{12} n/cm^2. The results indicate that at lower radiation fluences the impact of non-radiative recombination at interfaces in complex structures might not represent a significant source of degradation or performance reduction. However, the SRV radiation threshold suggests that this may be a concern for applications in severe environments, especially if the photovoltaic device structure incorporates multiple interfaces, such as for a superlattice.

Acknowledgements

Dr. Wesley Frey of the University of California, Davis performed the neutron exposures at the McClellan Nuclear Research Center.

This work was supported by funding from the Aerospace Technology Investment Program.

* andrew.i.hudson@aero.org

AEROSPACE