Quantitative Simulation of Bipolar Degradation in 4H-SiC Using UV Pulsed Laser: Considerations on the Critical Duration of Threshold Minority Carrier Density

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Keywords

- Bipolar degradation (REDG (recombination-enhanced dislocation glide) mechanism)
- Correlation between current density and UV irradiance
- **Critical duration of threshold minority carrier density** (New finding)

The objective of this study

1. To establish, in quantitative terms, the UV **irradiation conditions** capable of inducing bipolar degradation phenomena equivalent to those caused by **current injection**.
2. To theoretically validate **the correlation**.

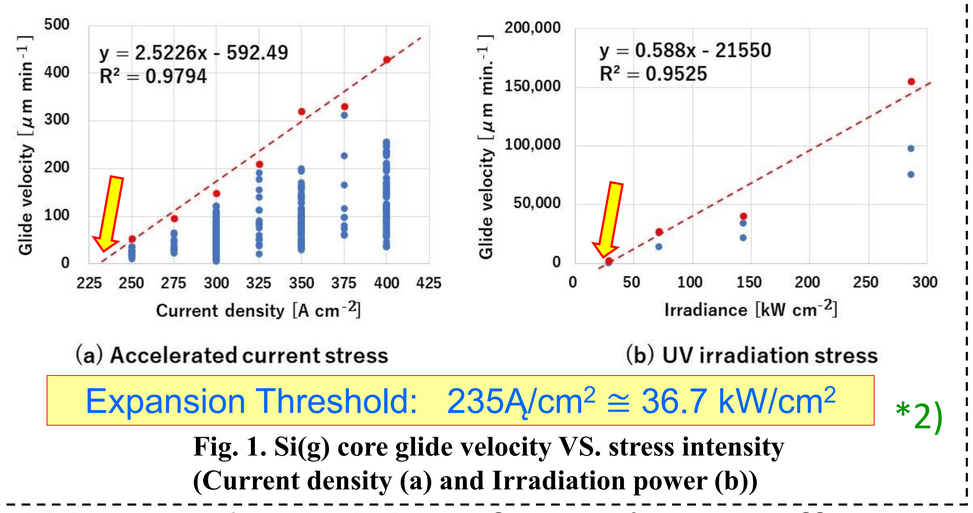
Experiments and Discussion

Basic Assumptions

i. **Definition of Equivalence** (Current density VS. UV irradiance): To equally distinguish between BPD related defects that will expand and those do not.

ii. Whether expansion occurs or not is determined by **the hole density around the defect**. (**Expansion threshold**) *1)

*1) Tawara, et al, J. Appl. Phys. 123, 025707 (2018).



*2)

Fig. 1. Si(g) core glide velocity VS. stress intensity (Current density (a) and Irradiation power (b))

SSF expansion threshold estimated from the experiments

Sample: PiN diodes on a commercially available n-type 100 mm Φ 4H-SiC wafer with a 4°off-cut angle.(p+:0.5μm,3×10^{18} cm^{-3}, n-(drift):4.9μm, 5×10^{15} cm^{-3},n+(buffer):0.5μm, 1×10^{18} cm^{-3}. *2)

*2) Igarashi, et al., Defect and Diffusion Forum 434, 23 (2024).

Theoretical estimate of the hole density

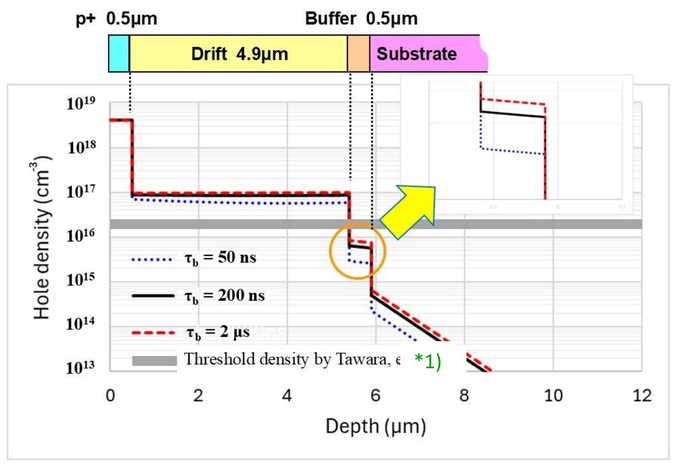


Fig. 2. Depth profiles of hole density under forward bias stress

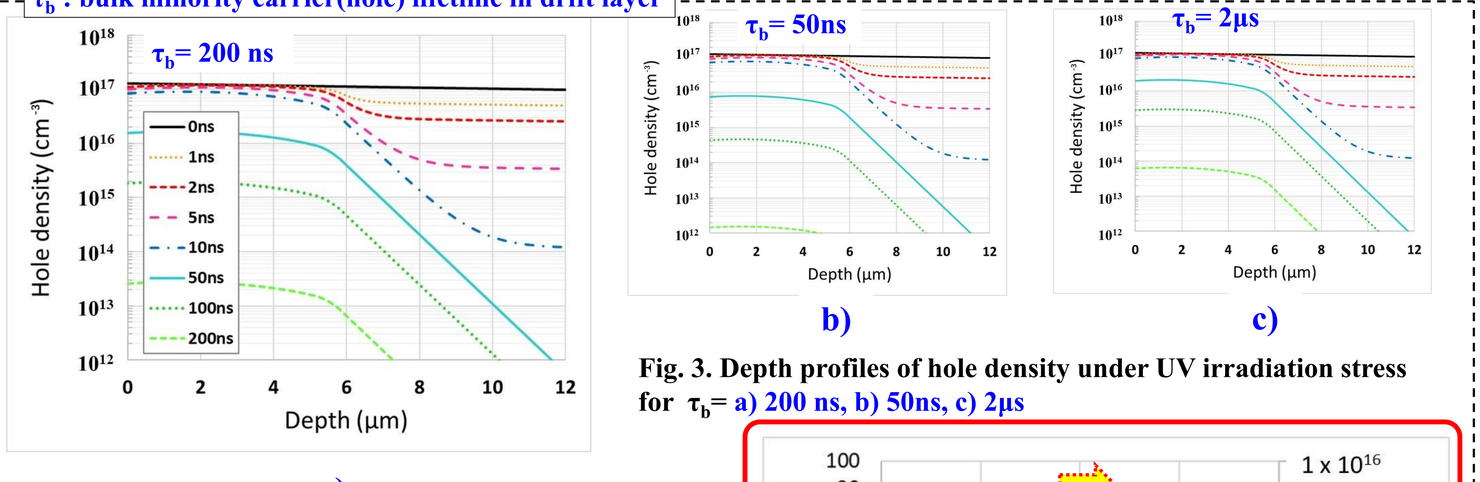


Fig. 3. Depth profiles of hole density under UV irradiation stress for τ_b= a) 200 ns, b) 50ns, c) 2μs

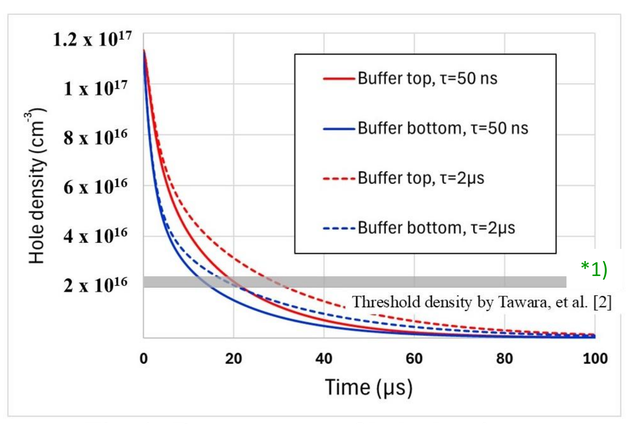


Fig. 4. Decay curves of hole density

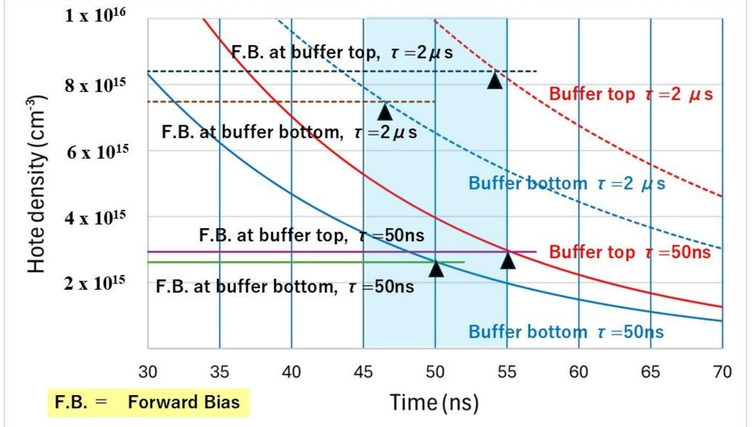


Fig. 5. The same hole density points ▲ (Superimposed on Fig. 4 with Fig. 1)

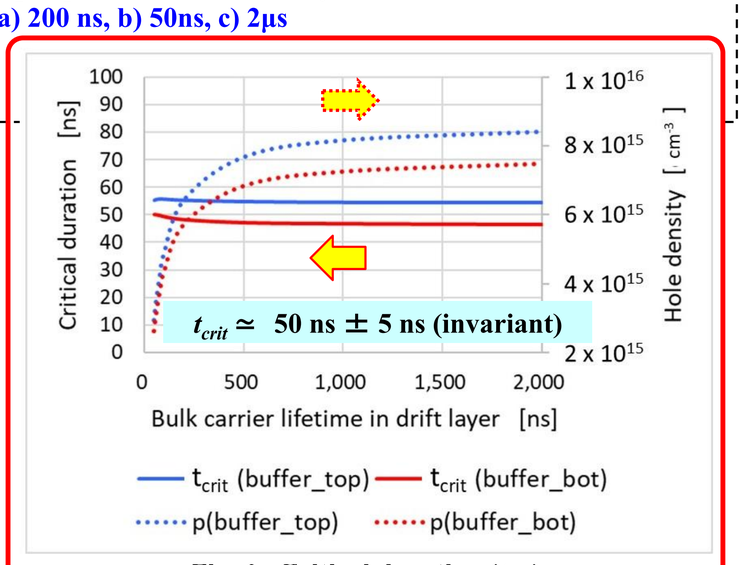


Fig. 6. Critical duration (t_{crit}) over the range of carrier lifetime from 50 ns to 2 μs

New Findings

- For the expansion of SSFs induced by either forward bias or UV irradiation, not only a threshold hole density but also a "**critical time**", t_{crit}—the minimum duration for which the density must be sustained—is required for the expansion to occur. (to overcome the Peierls barrier associated with the 4H→3C transformation.)
- The t_{crit} is a parameter that exhibits **little dependence on the bulk carrier lifetime** in the drift layer.
- To reproduce an expansion phenomenon equivalent to forward bias (bipolar) degradation using pulsed laser irradiation, it is necessary to set irradiation conditions such that the hole density matches that generated by forward bias and is maintained for the duration of the "critical time".

$\Delta p_{UV}(x_0, t_{crit}) = \Delta p_{FB}(x_0)$ where $\Delta p_{UV}(x, t)$ (UV-induced) and $\Delta p_{FB}(x)$(current-induced) hole density at n^-/n^+ interface (x_0)