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Plasma Shaping in Silocon Diodes by Cathode-Side Lifetime Recovery

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Introduction

- Silicon fast recovery diodes (FRD) need careful balancing of the injection level and carrier lifetime.
- A light injection level coupled with uniform lifetime control (Fig. 1, top) is a simple way to achieve acceptable soft recovery & losses.
- Tailoring the lifetime in the drift region (Fig. 1, bottom) greatly improves soft switching behavior.

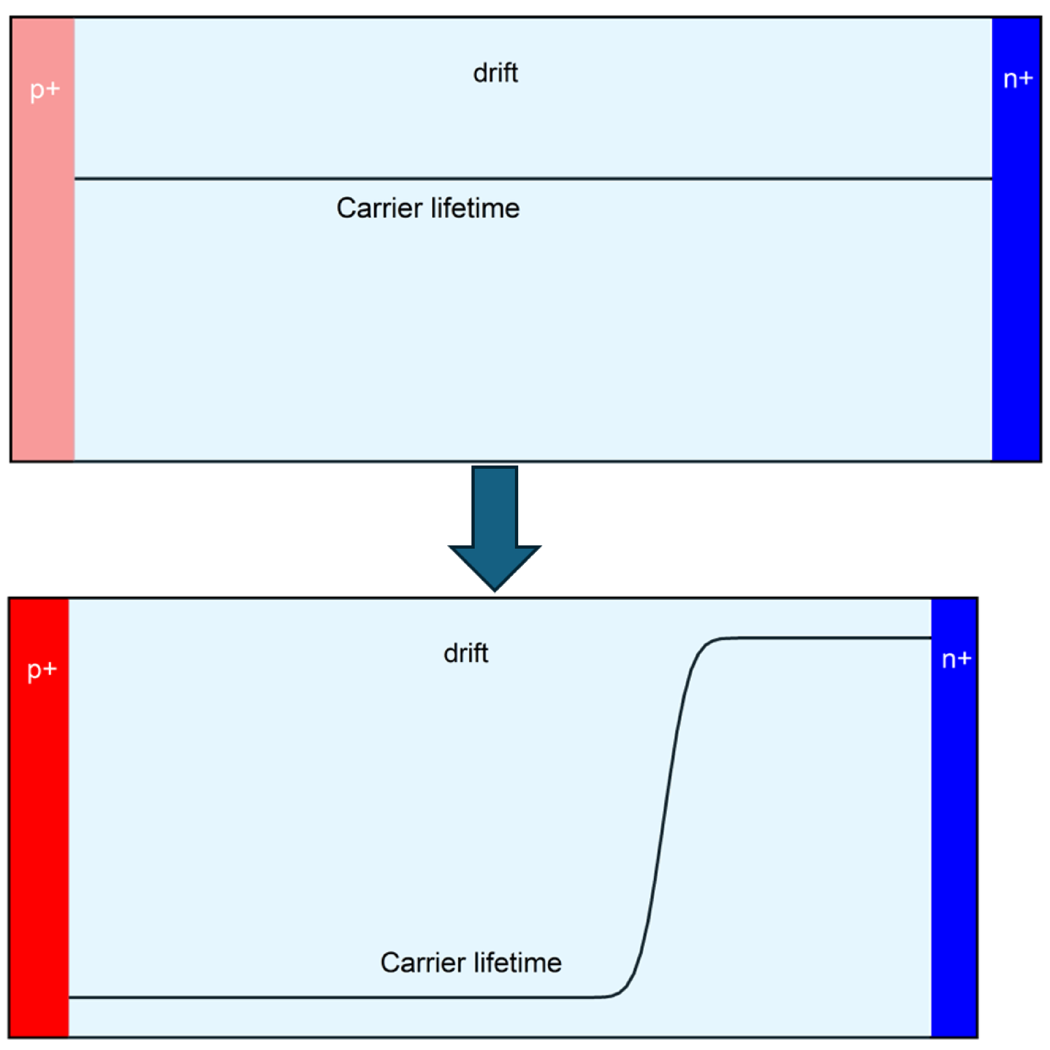

Fig. 1: Schematic illustration of the baseline diode (top) and the novel device (bottom).

New Approach

- Traditionally, local defect peaks are used to achieve the desired lifetime distribution.
- The new method uses high energy electron irradiation for uniform defects and a subsequent H+ implant from the backside.
- Suitable tailoring of the e- and H+ irradiation, as well as the annealing conditions leads to defects being passivated from the cathode side to a certain depth.

Simulation Study

- To assess the impact of the carrier lifetime distribution in the drift region, TCAD simulations are conducted.
- Table 1 shows key process parameters for the manufactured devices. Based on an internally developed and verified model, the simulation parameters are extracted.
- A simple model is used, where a step-function is applied to the traps added in the model.
- The resulting excess carrier concentrations at 10% nominal current are plotted in Fig 2.

Table 1: Fabricated and tested devices.

Device	Process parameters			
	Anode dose	***Electron dose Φ_e***	***Hydrogen dose Φ_H***	***Thickness (µm)***
Previous gen	d_0	e_0	-	170
Baseline	2 x d_0	2 x e_0	-	160
A	2 x d_0	2 x e_0	H_0	160
B	2 x d_0	5 x e_0	2 x H_0	160
C	2 x d_0	10 x e_0	20 x H_0	160

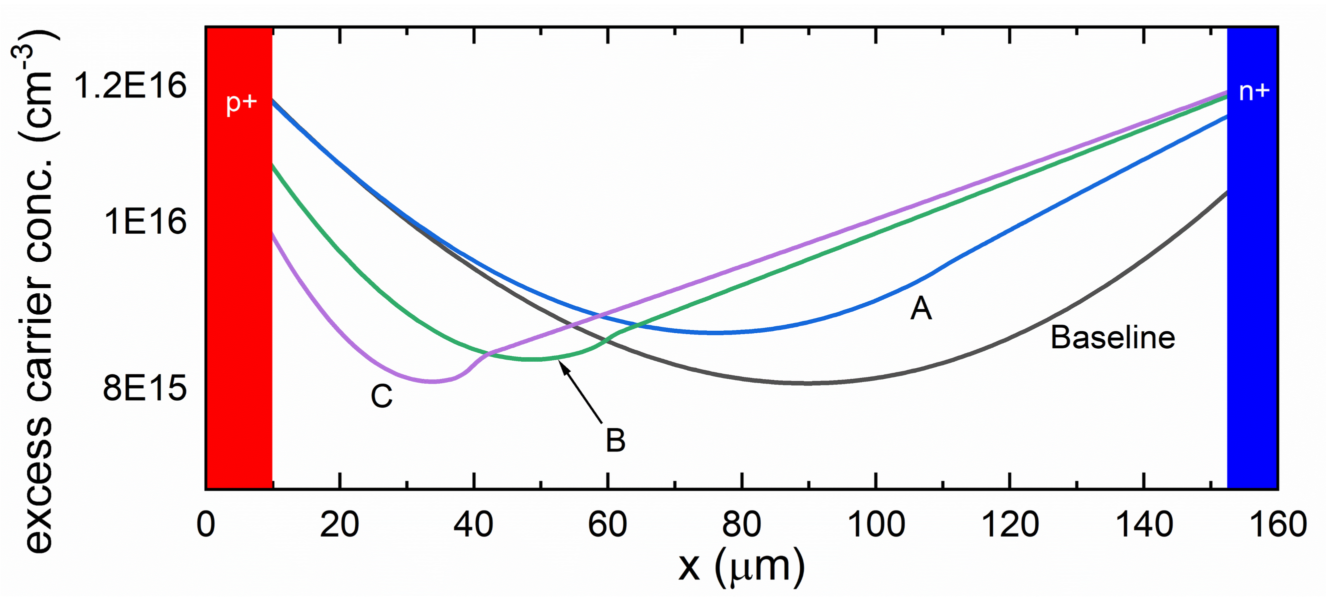

Fig. 2: Excess carrier concentration under forward conduction at T = 25 °C, J_F = 0.1 J_{nom} obtained by TCAD device simulation.

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Experimental Results

- The technology curve at 175 °C and the recovery waveforms at 25 °C are shown in Fig. 3.
- The devices can be tuned along the technology curve by combining different electron and hydrogen doses.
- The soft recovery behavior is simulated and measured at harsh switching conditions, and the results shown in Fig. 4 and Fig. 5.

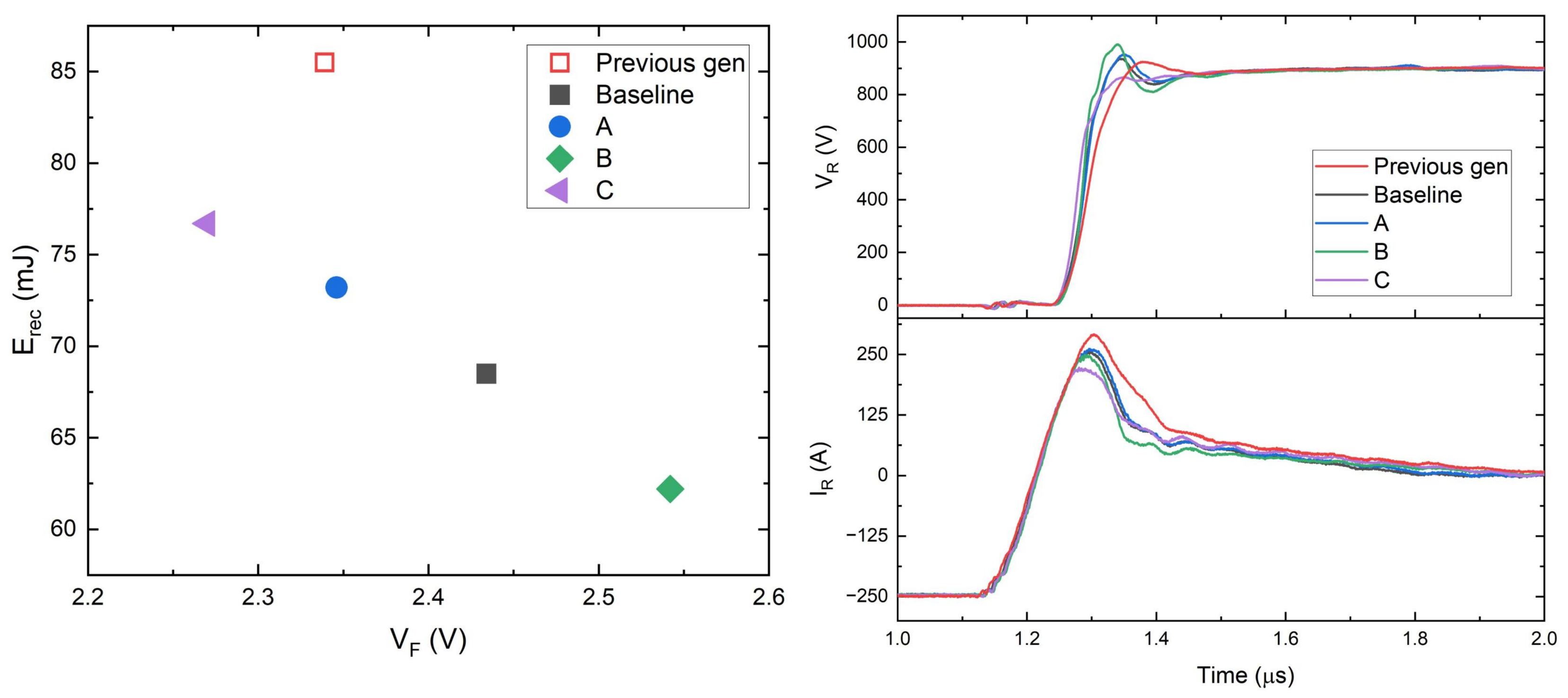

Fig. 3: Technology curve measured at T = 175 °C (left), measured switching waveforms at T = 25 °C (right). I_F = 250 A, V_{DC} = 900 V, L_σ = 105 nH.

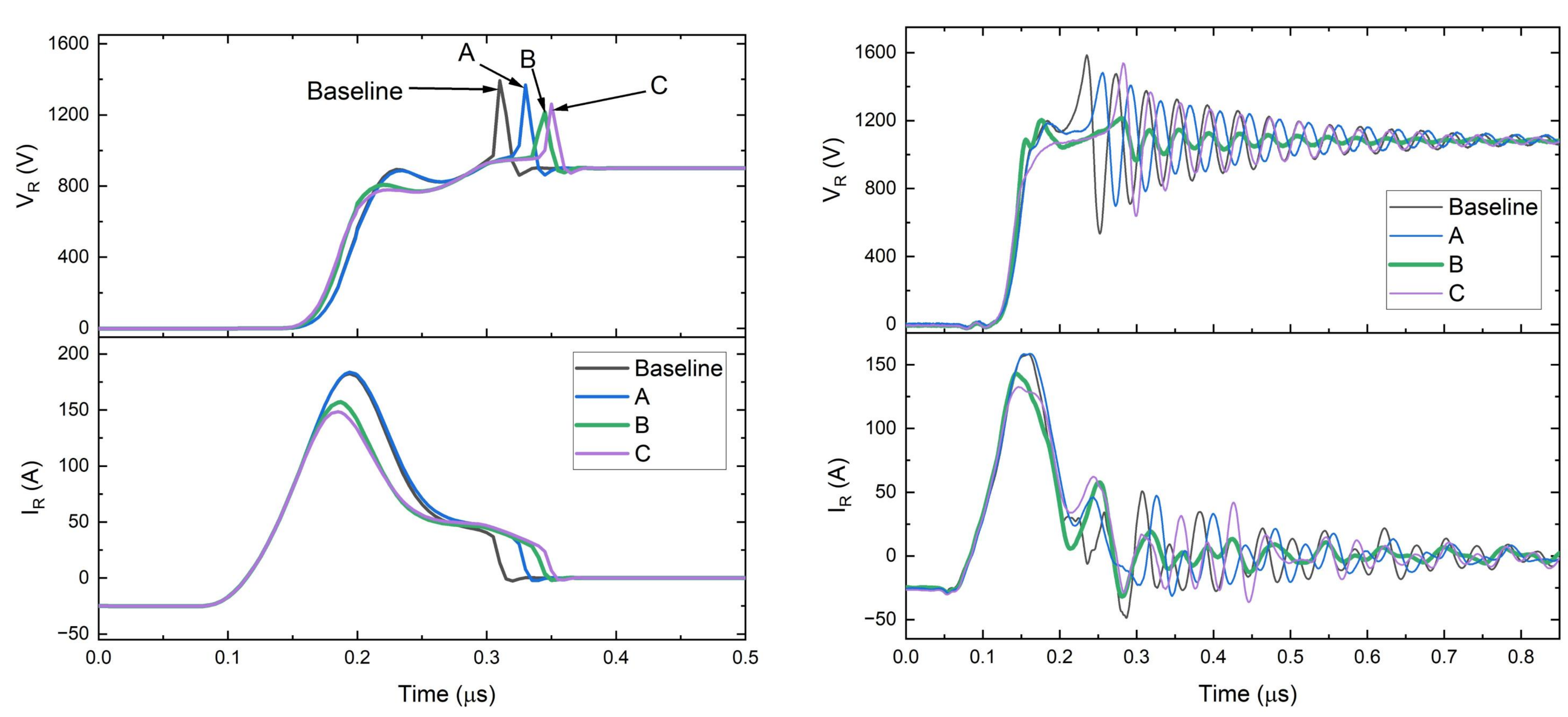

Fig. 4: Simulated (left) and measured switching waveforms at I_F = 25 A, T = 25 °C, V_{DC} = 1100 V, L_σ = 160 nH.

Summary and conclusion

- 1.7 kV diodes rated at 250 A were produced with the novel Cathode-Side Lifetime Recovery process.
- This process offers a very simple solution to achieve a desirable carrier lifetime shape shown in Fig. 1, bottom.
- With the new process, the diodes can be thinned down by an additional 10 µm and the anode dose increased, which improves the technology curve of the diode (Fig. 3).
- Thanks to the optimized lifetime shape, the softness of the new diodes (Fig. 4, Fig. 5) could retained, despite the improvement in the technology curve.

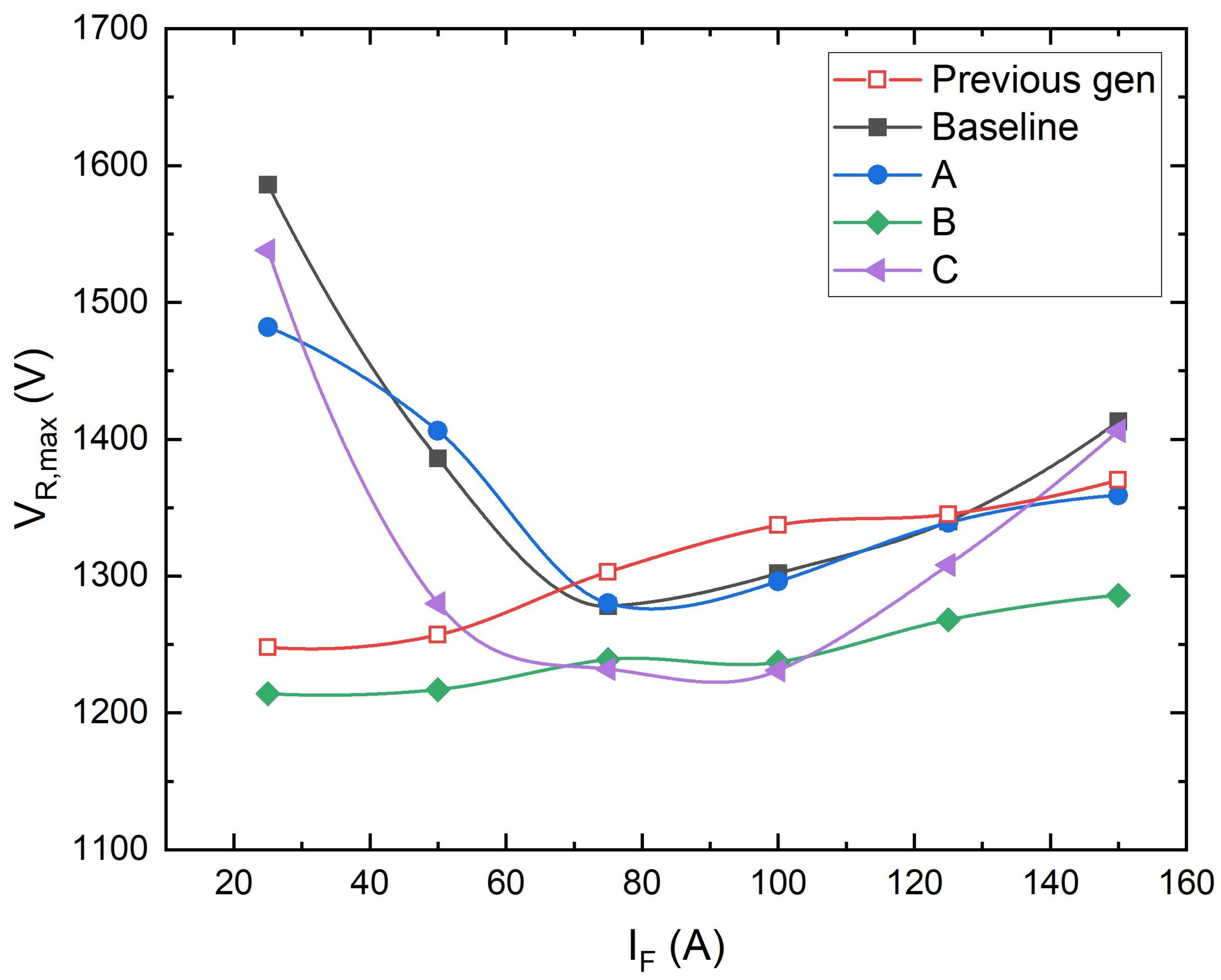

Fig 5: Measured voltage overshoot ($V_{R,max}$) during reverse recovery at T = 25 °C, V_{DC} = 1100 V, L_σ = 160 nH and different current levels. The dI/dt is elevated to induce snap-off.