

Development of TPA laser irradiation
system with a Cr:forsterite laser
and its application to MCU analysis
of thin-BOX SOI SRAMs

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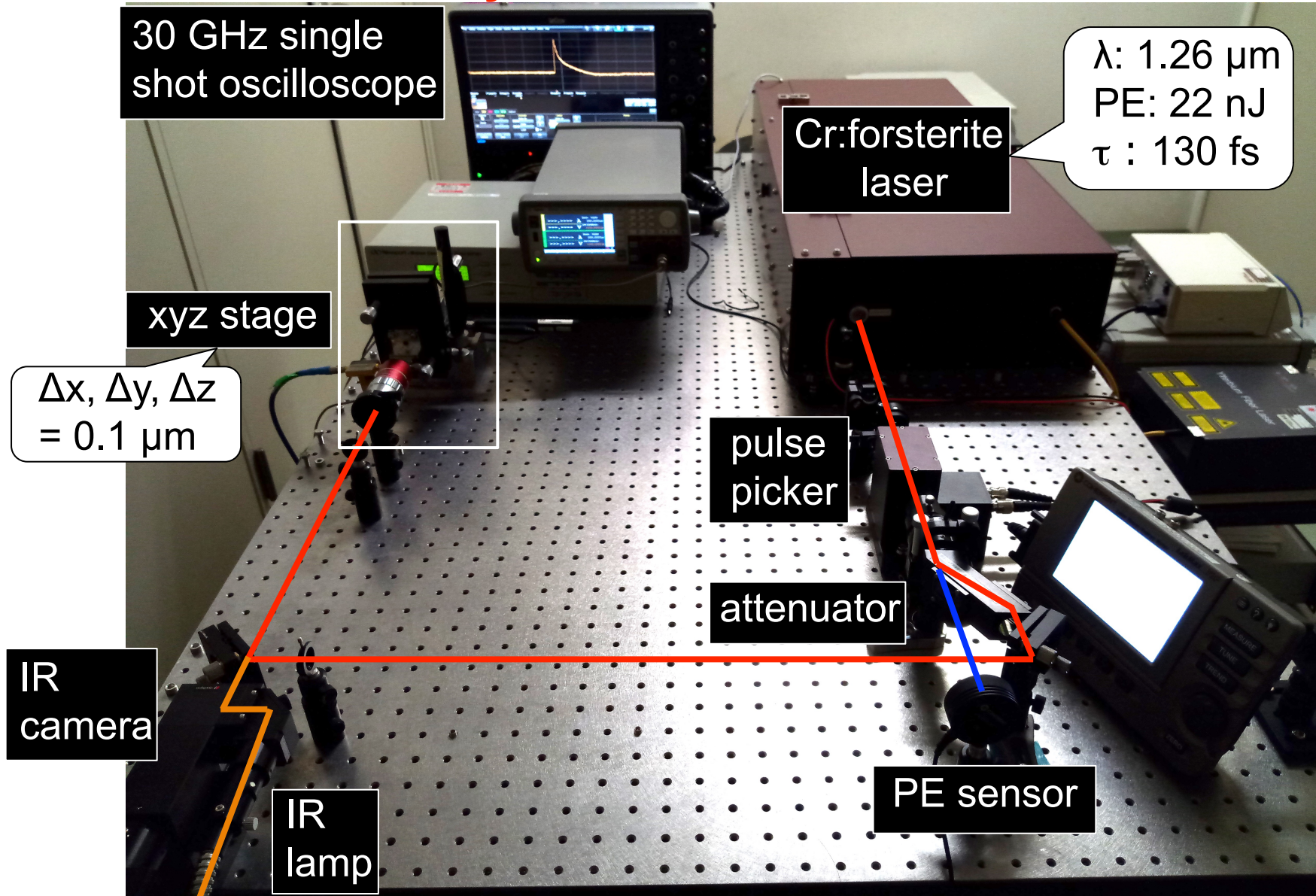
Outline

- Developed TPA irradiation system with a Cr:forsterite laser
- **Experiment A :**
Charge generation length in the depth direction by TPA, estimated from **SET** currents in a Si PIN photodiode
- **Experiment B :**
Application to **MCU** analysis of thin-BOX SOI SRAMs
- **Experiment C :**
Effects of variations in the amount of generated charge in thin-BOX SOI SRAMs

Developed TPA system

SET analysis

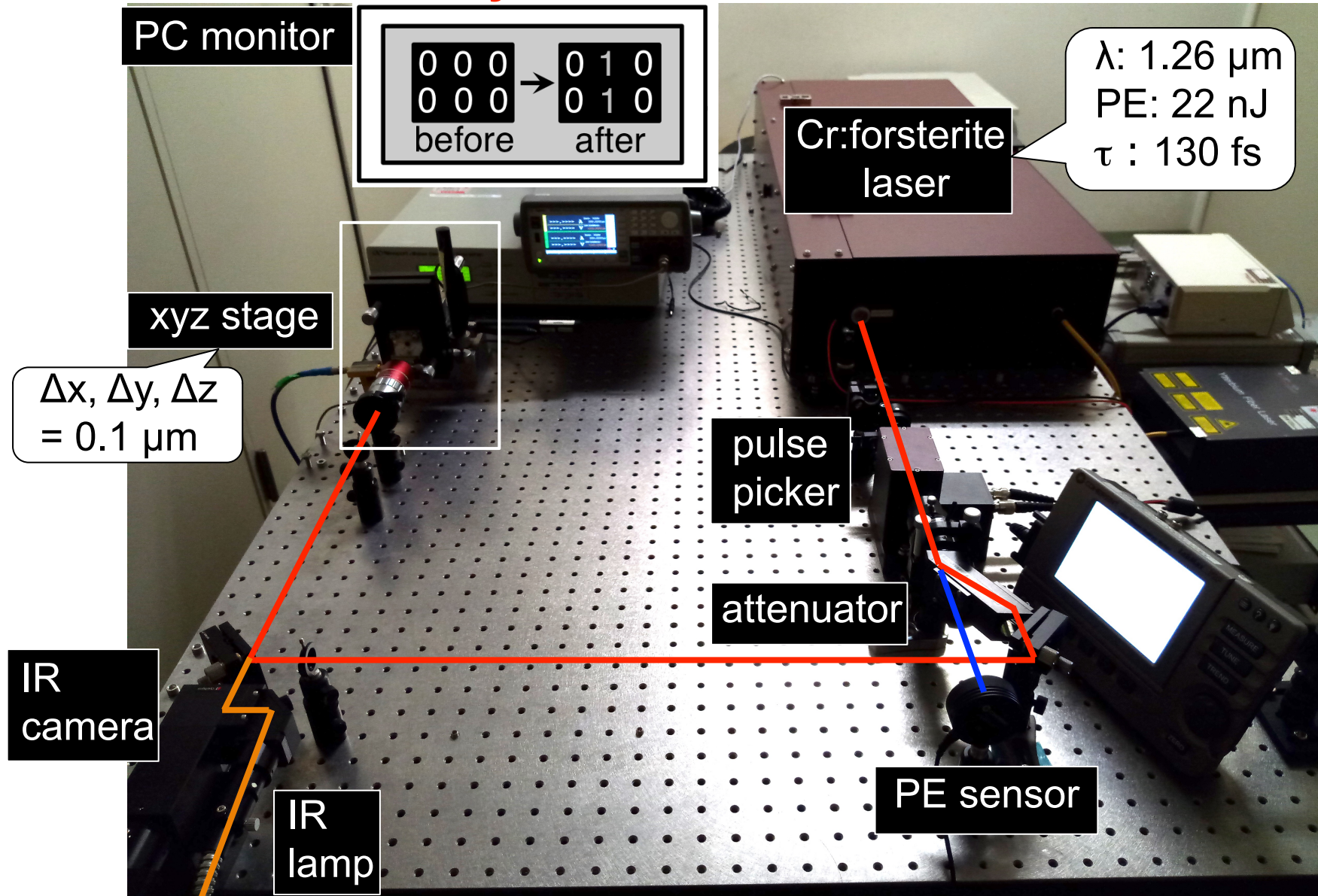
※ PE = pulse energy



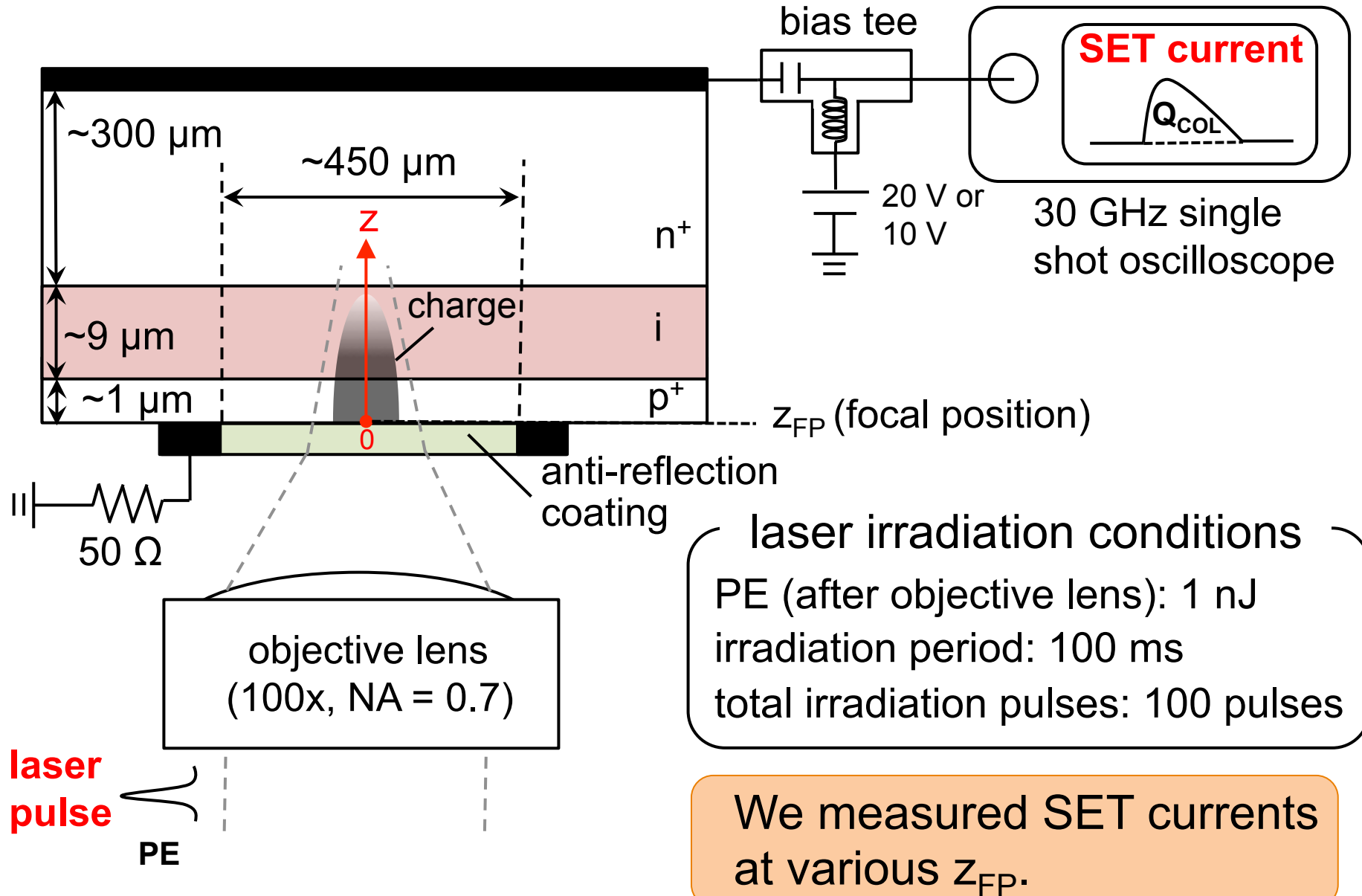
Developed TPA system

MCU analysis

※ PE = pulse energy



Experiment A: Si PIN photodiode

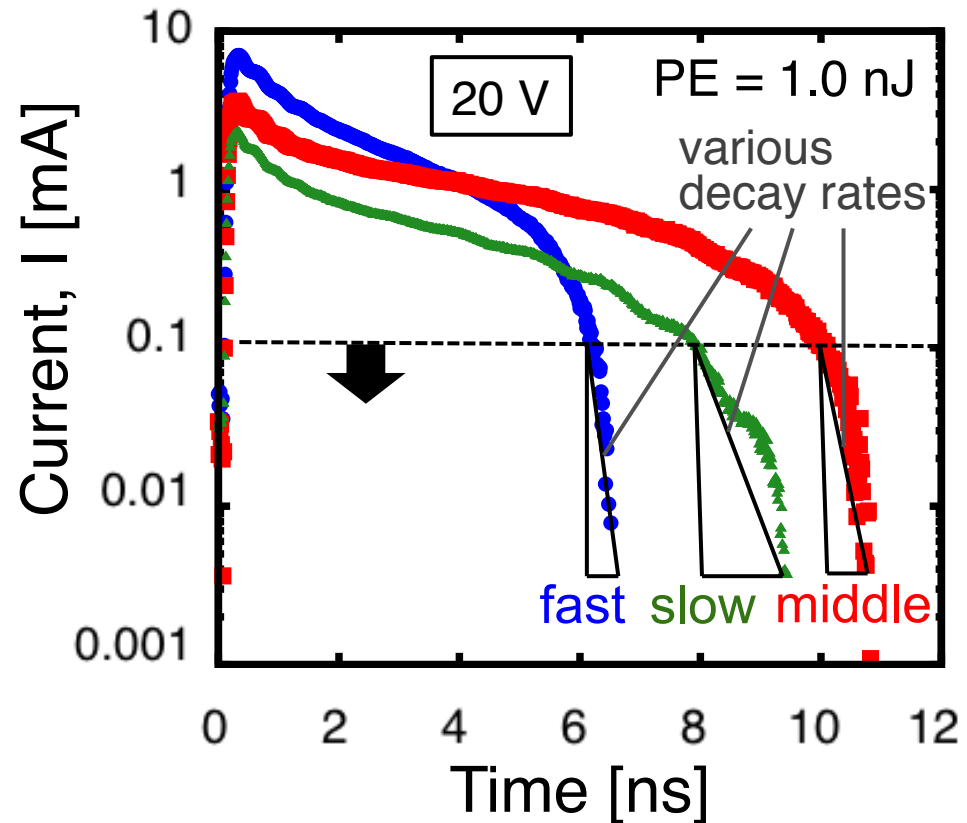


Experiment A: SET currents^{*)}

A. $z_{FP} = 0.0 \mu\text{m}$ ● →

B. $z_{FP} = 10.3 \mu\text{m}$ ■ →

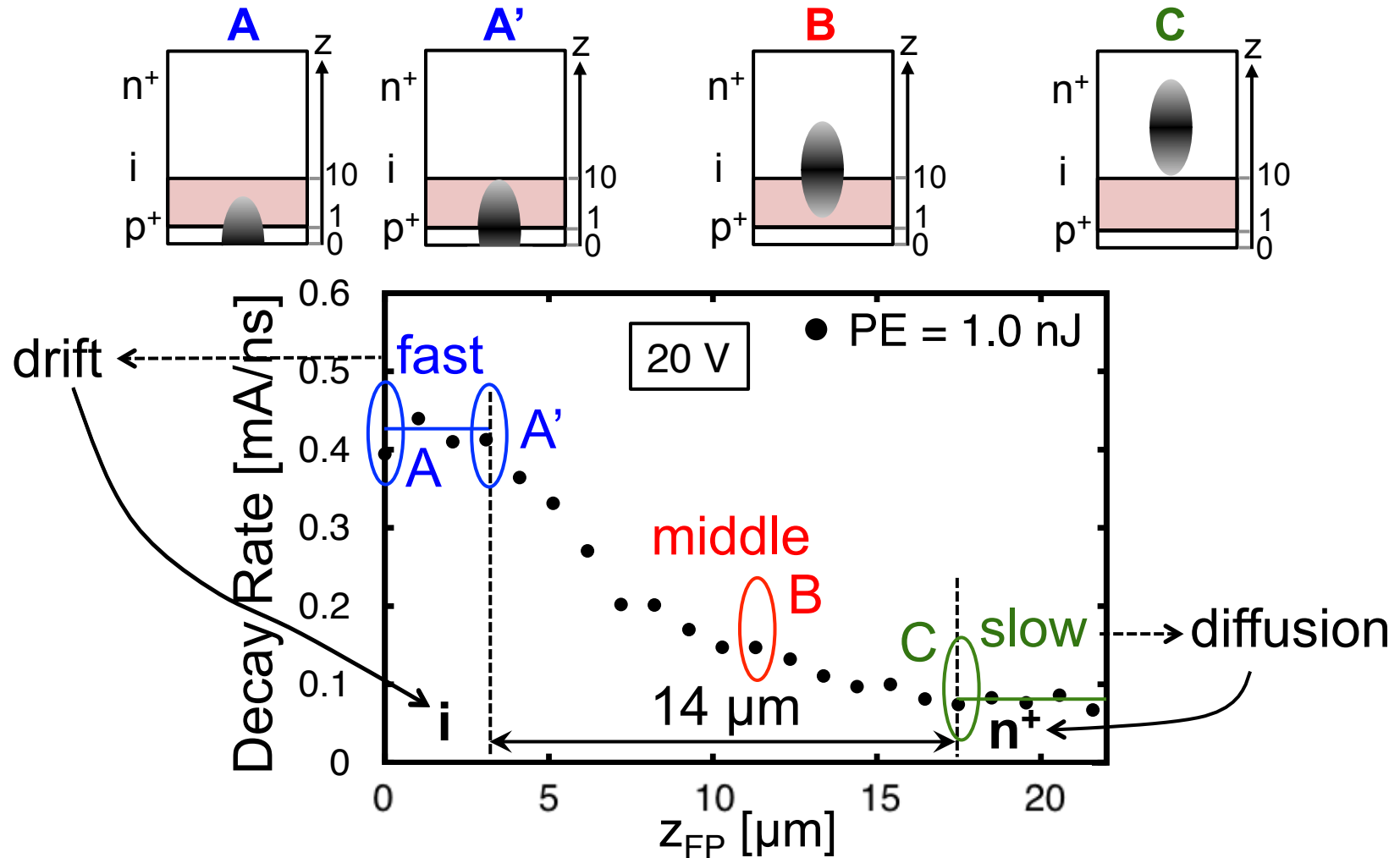
C. $z_{FP} = 17.5 \mu\text{m}$ ▲ →



We analyzed decay rates
when $I \leq 0.1 \text{ mA}$ at multiple z_{FP} .

^{*)} H. Itsuji *et al.*, *Jpn. J. Appl. Phys.*, vol. 56, p. 04CD16, 2017

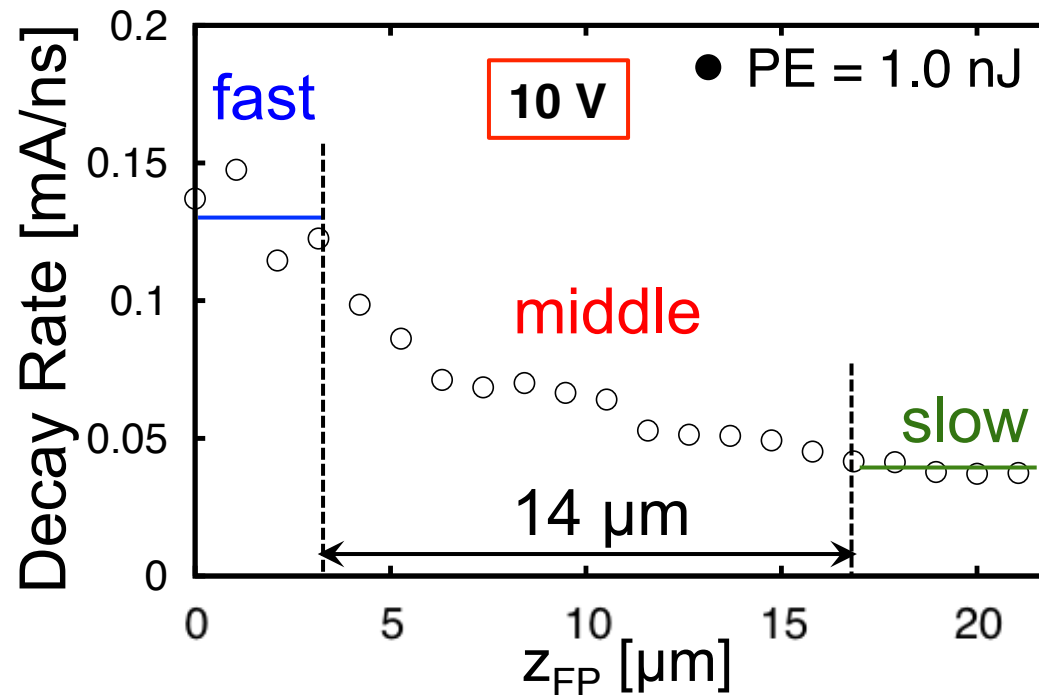
Experiment A: Decay rate^{*)}



The charge generation length in Si, 14 μm, closely matched the 16 μm (FWHM) when PE = 1.0 nJ, extracted by the 3D knife-edge approach^{**)}

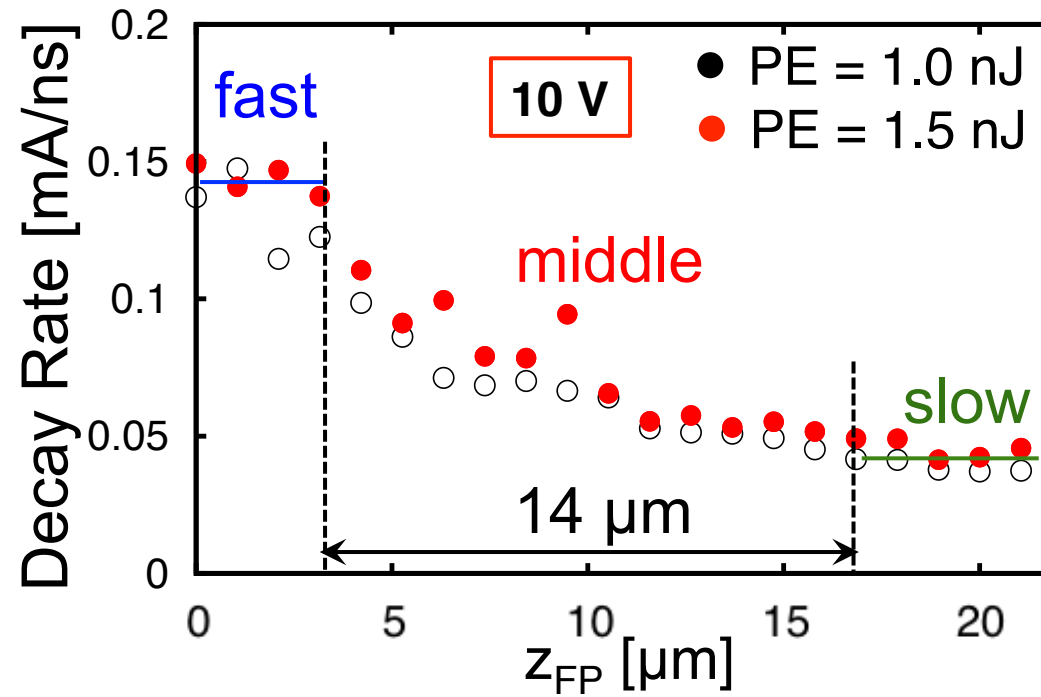
^{*)} H. Itsuji *et al.*, *Jpn. J. Appl. Phys.*, vol. 56, p. 04CD16, 2017
^{**)} K. Shao *et al.*, *Opt. Express.*, vol. 19, p. 22594, 2011.

Experiment A: Decay rate

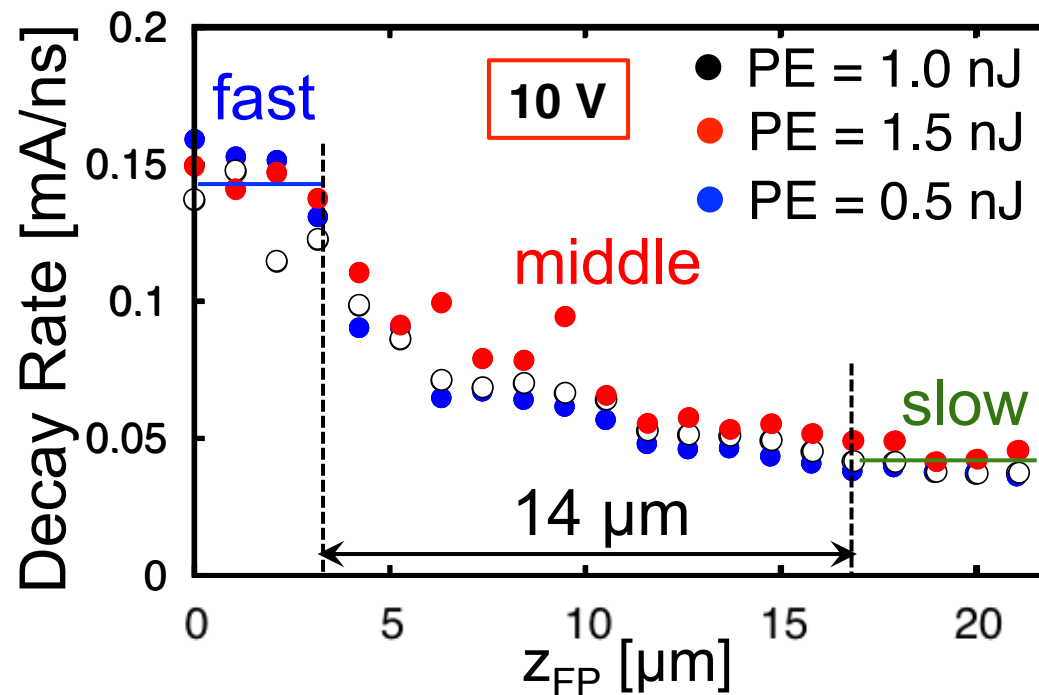


The extracted charge generation length did not change by lowering bias voltage from 20 V to 10 V.

Experiment A: Decay rate



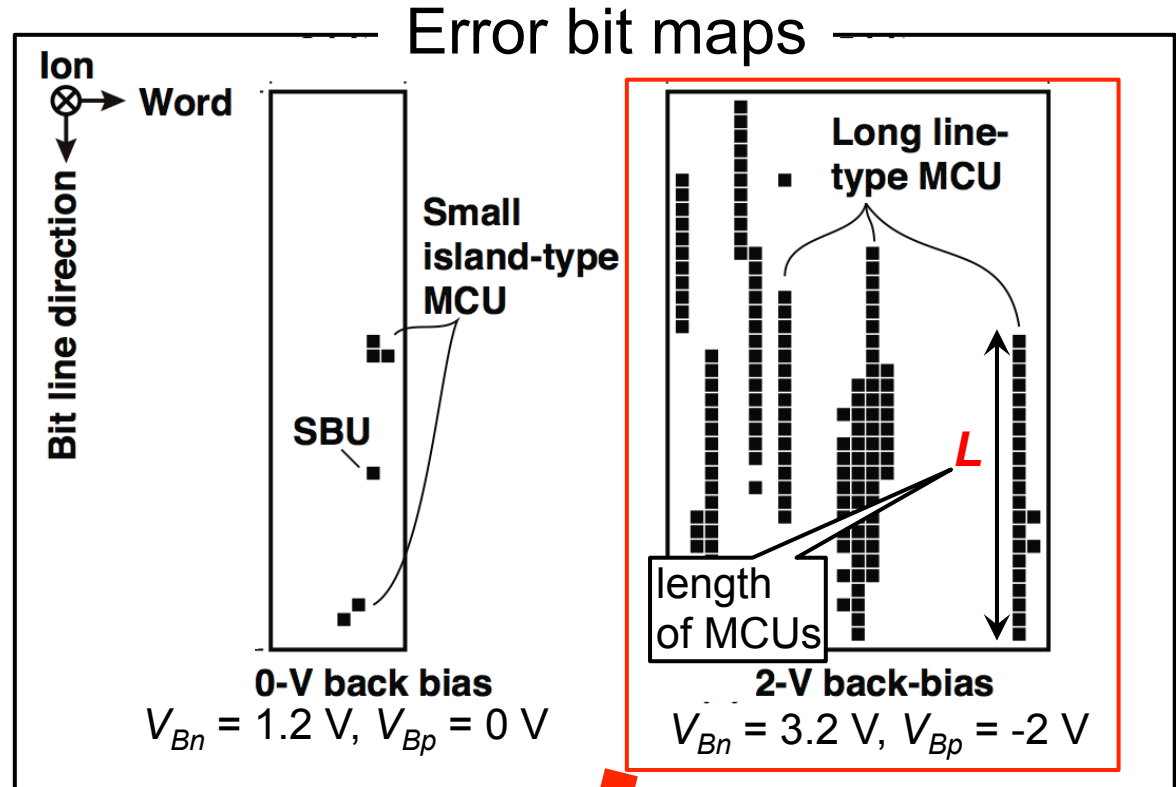
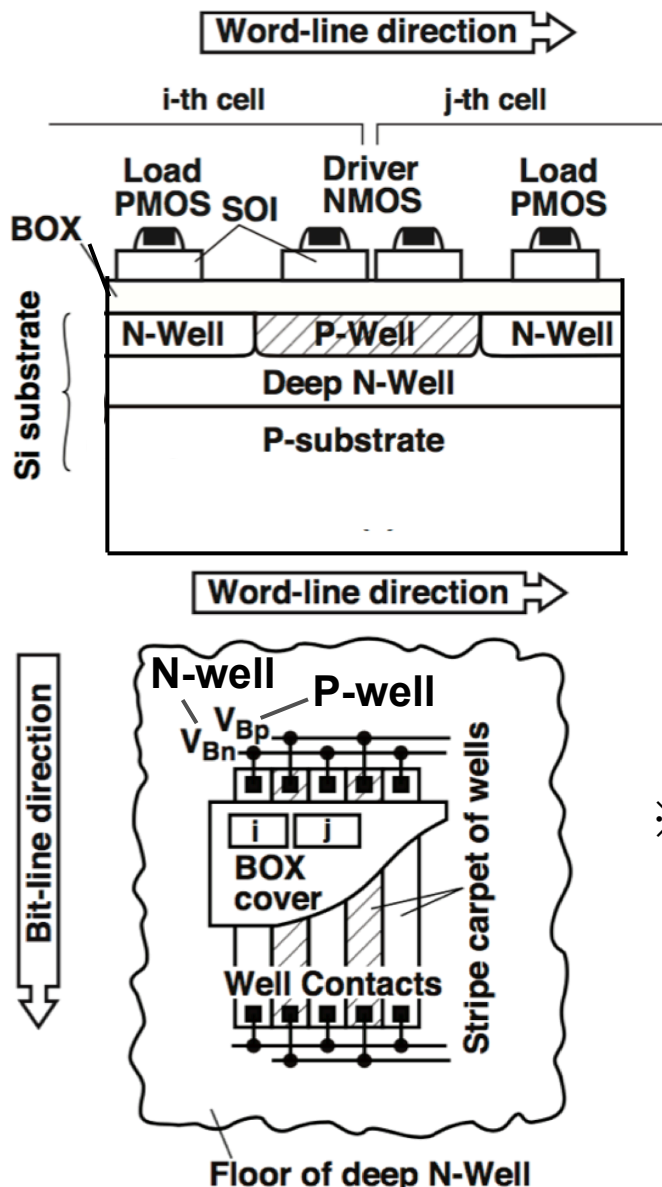
Experiment A: Decay rate



The charge generation length was independent of PE; this independence was consistent with an analytical model*).

*) D. McMorrow *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 49, pp. 3002-3008, 2002.

Heavy-ion induced abnormal MCUs in thin BOX SOI-SRAM



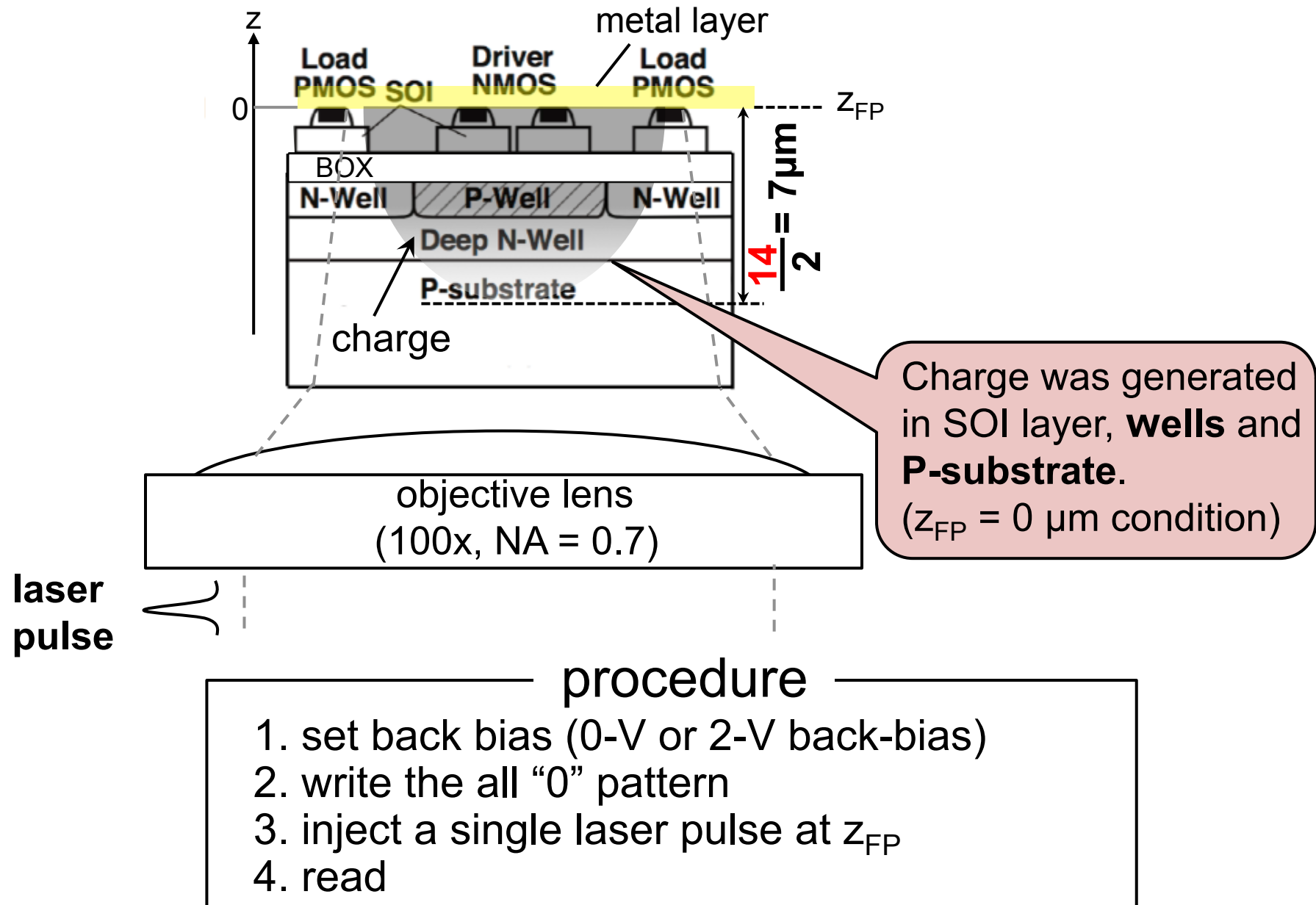
※ SBU = single bit upset
MCU = multiple cell upset

Q. Where was generated charge, caused these abnormal MCUs?

We used the TPA system to elucidate where generated charge caused the long line-type MCUs.

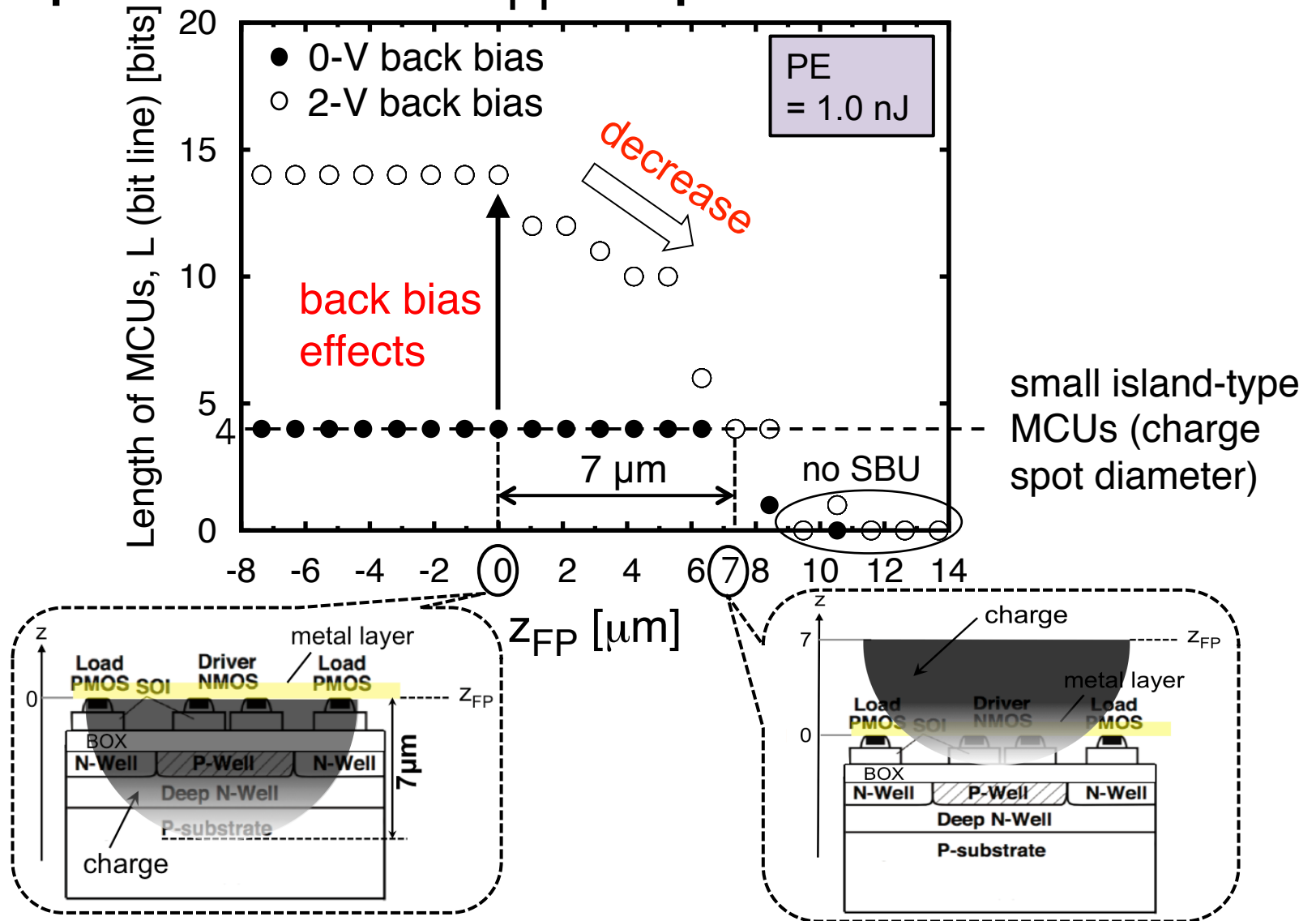
*) D. Kobayashi et al., in Proc. IEEE IRPS, 2017, paper 3D-2.

Experiment B: thin-BOX SOI SRAMs



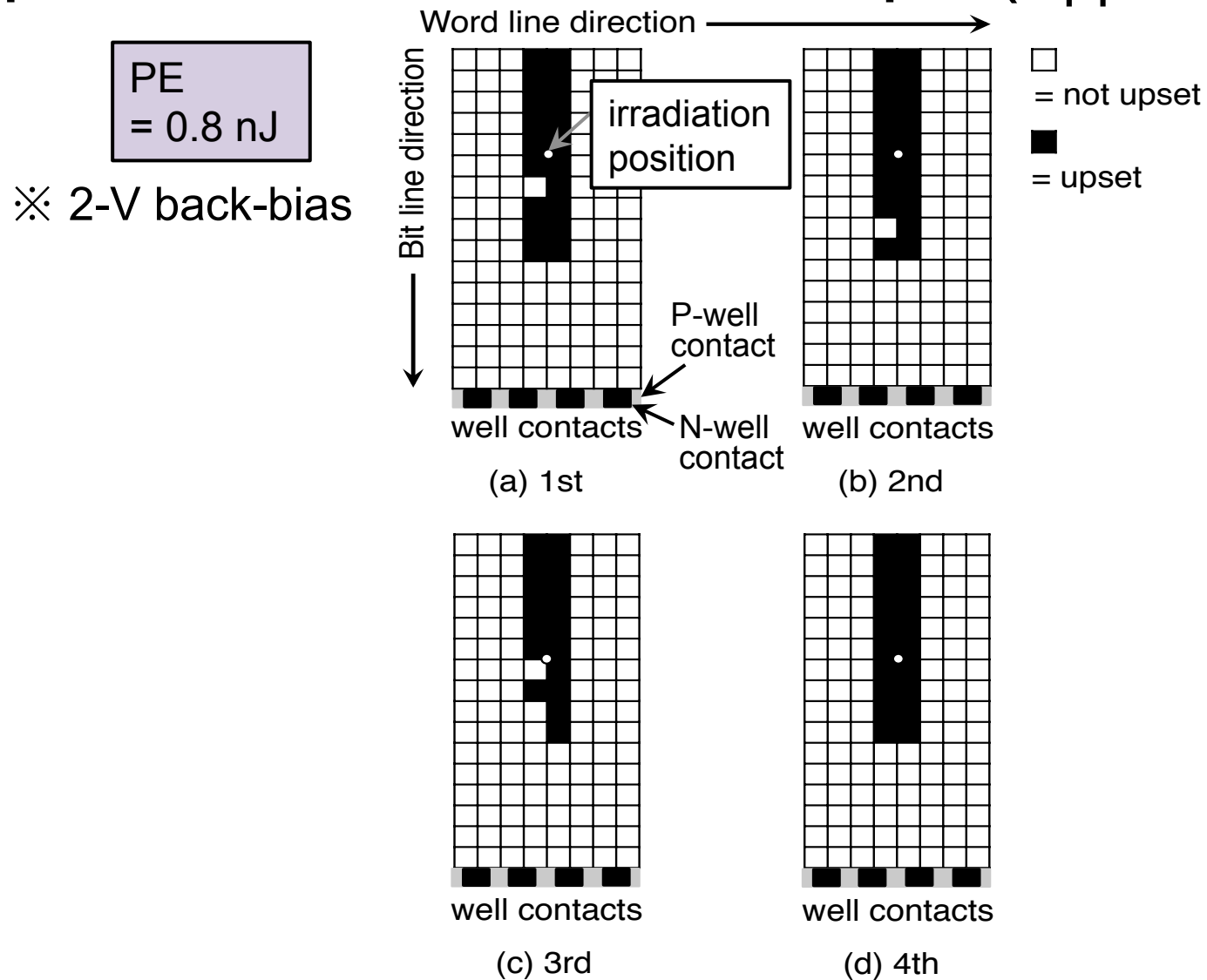
*) H. Itsuji *et al.*, in NSREC, 2017, poster PE-5L (late news).

Experiment B: z_{FP} dependence of L



Charge generated in the P-substrate and the wells caused the long line-type MCUs.

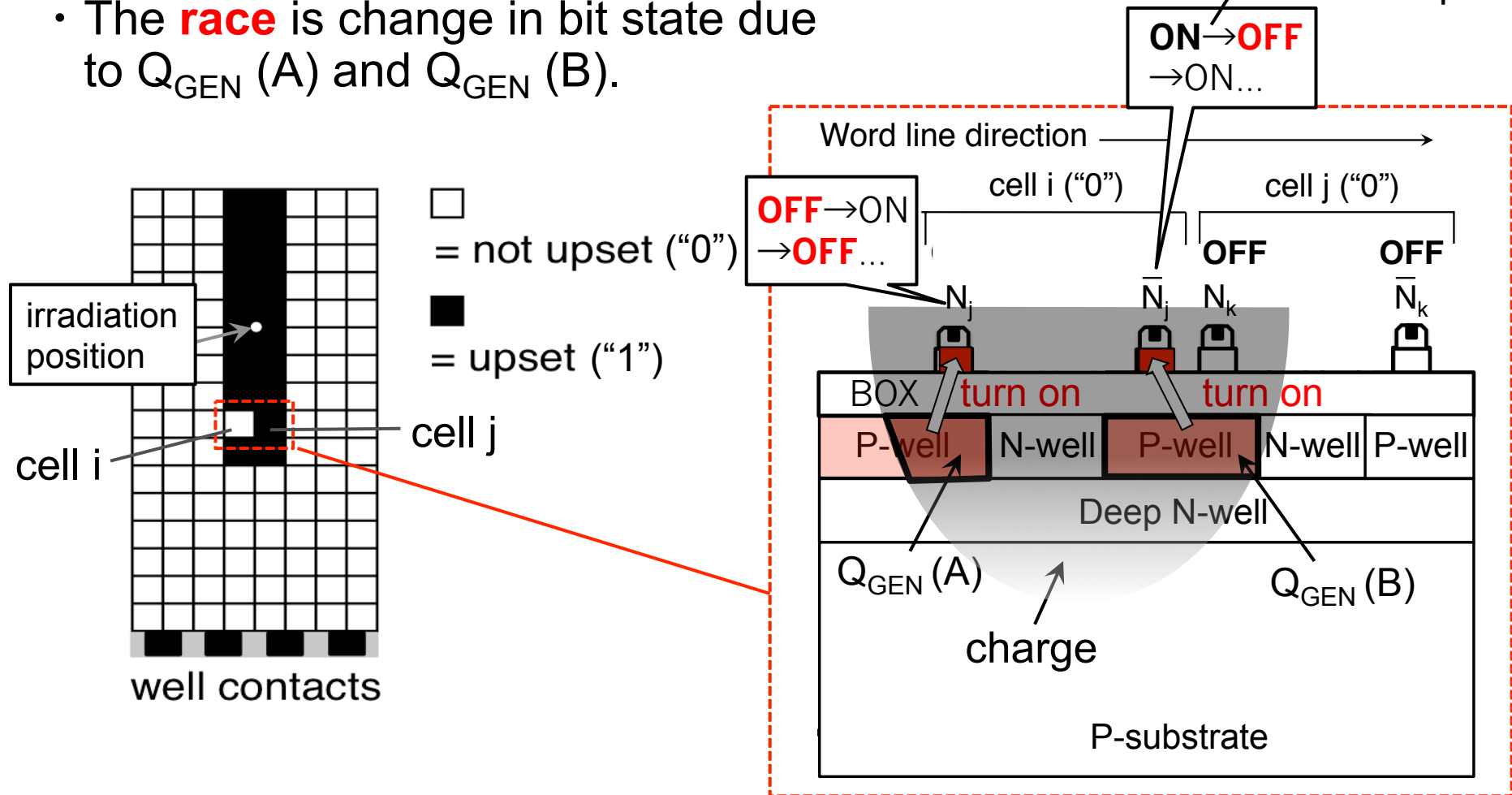
Experiment B: error bit maps ($z_{FP} = 0 \mu\text{m}$)



Error bit maps changed even under the same experimental conditions.

Experiment B: supposed origin for the observed change in error bit map

- We attributed the change in error bit maps to a **race**^{*)}. typical switching time < 100 ps^{**)}
- The **race** is change in bit state due to Q_{GEN} (A) and Q_{GEN} (B).

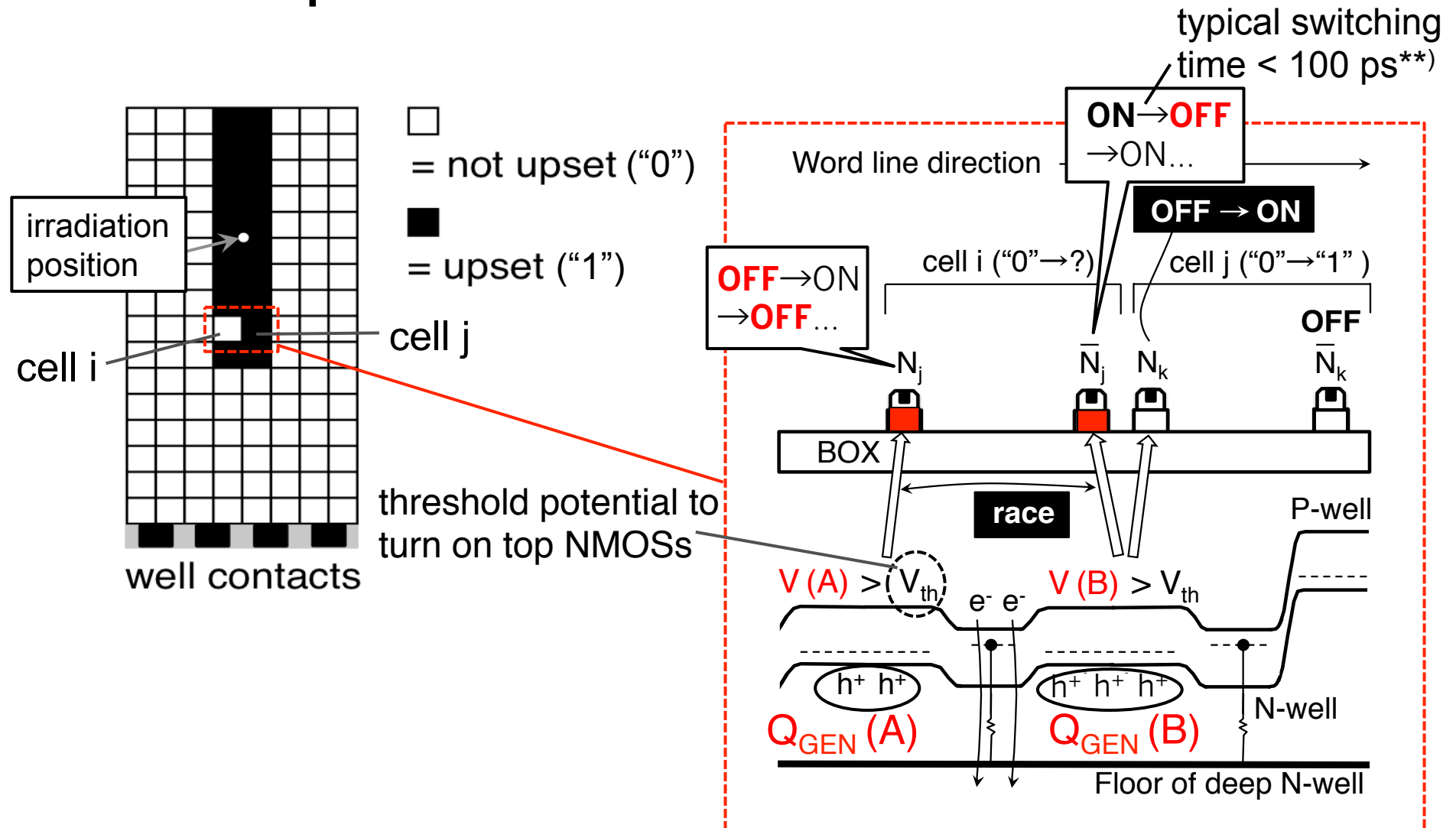


Q_{GEN} : the amount of generated charge

^{*)} H. Itsuji *et al.*, in *NSREC*, 2017, poster PE-5L (late news).

^{**)} Y. Morita *et al.*, in *Proc. Symposium on VLSI Technology*, 2008, pp. 166-167.

Experiment B: race mechanism^{*)}

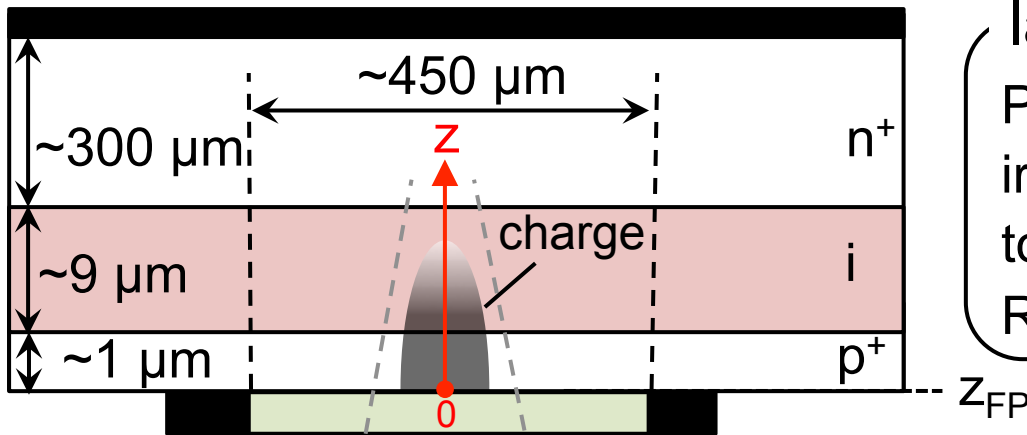


The change in error bit maps were observed probably because Q_{GEN} variations changed the race result.

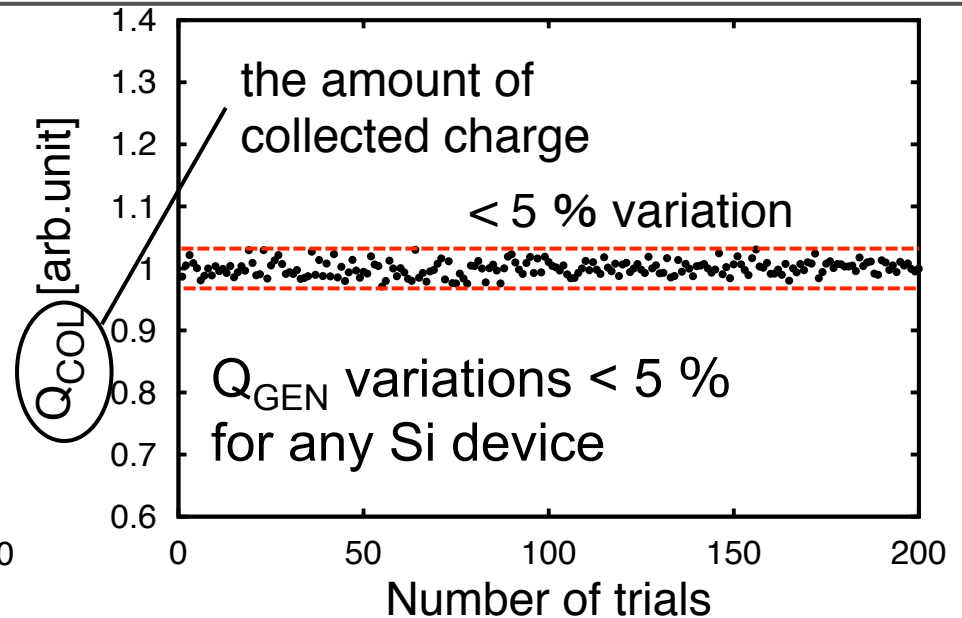
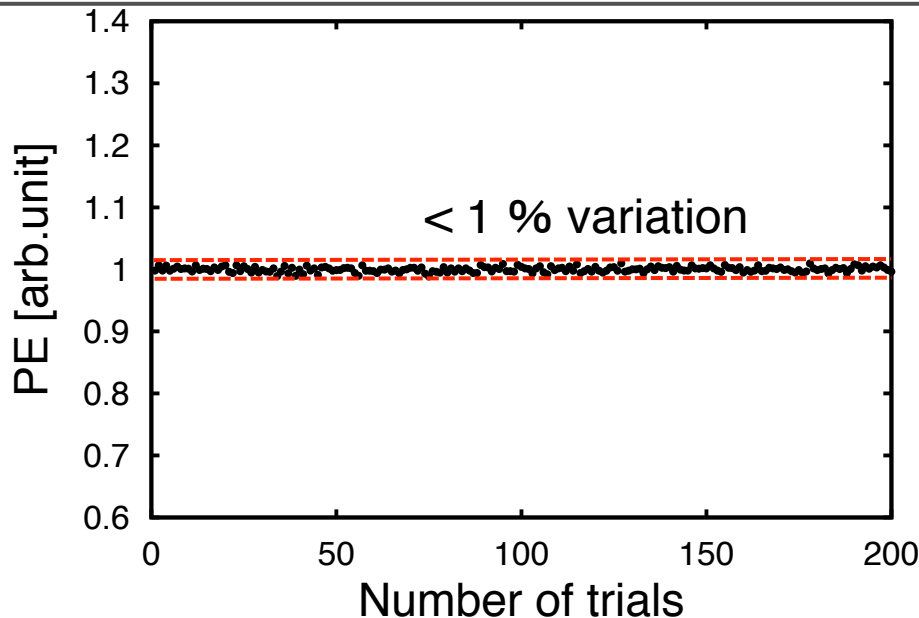
^{*)} H. Itsuji *et al.*, in *NSREC*, 2017, poster PE-5L (late news).

^{**)} Y. Morita *et al.*, in *Proc. Symposium on VLSI Technology*, 2008, pp. 166-167.

Experiment C: Q_{GEN} variations



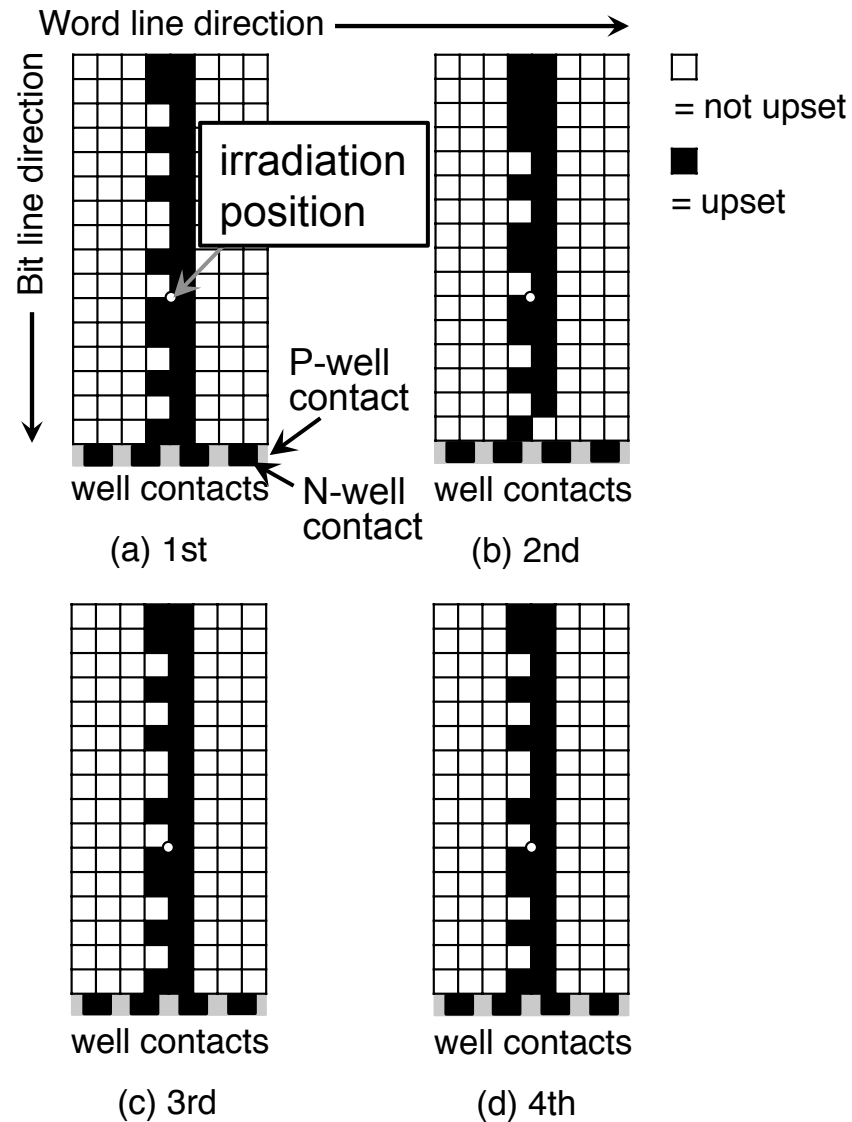
laser irradiation conditions
 PE (after objective lens): 1 nJ
 irradiation period: 100 ms
 total irradiation pulses: 200 pulses
 Reverse bias : 20 V



When PE is high, the absolute value of Q_{GEN} (B) becomes much larger than that of Q_{GEN} (A). $\rightarrow Q_{\text{GEN}}$ (B) should turn on the top NMOS eventually \rightarrow We predict error bit maps do not change for high PE under the same condition.

Experiment C: confirmation of prediction

PE = 0.8 nJ
→ PE = 1.2 nJ
※ 2-V back-bias



As predicted, error bit maps did not change. → When PE is high, Q_{GEN} variations < 5 % do not affect the race result.

Summary

- Developed TPA irradiation system with a Cr:forsterite laser has been introduced.
- Charge generation length in Si in the depth direction was estimated to be $\sim 14 \mu\text{m}$ when $\text{PE} = 1.0 \text{ nJ}$ (**experiment A**).
- Considering the charge generation length, we found that the charge generated in the P-substrate and the wells in thin-BOX SOI-SRAMs caused the long line-type MCUs (**experiment B**).
- Error maps, showing the long line-type MCUs, changed even in the same experimental condition due to the race (**experiment B**).
- We found that when PE is high, Q_{GEN} variations $< 5 \%$ do not significantly affect the race result (**experiment C**).