In-Fab Parameter Characterization for Pinned Photodiodes in CMOS Image sensors

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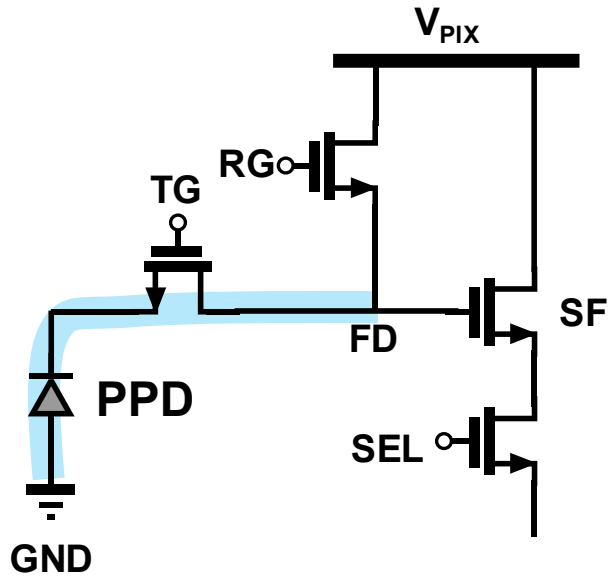
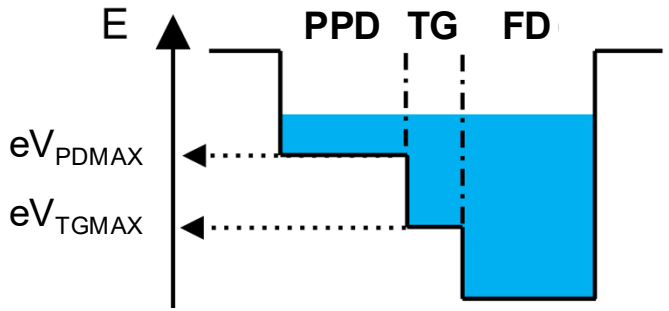
Motivation 1 : PPD Characterization



[Pixel schematic]



[Band diagram]

PPD : Pinned Photodiode

FD : Floating Diffusion

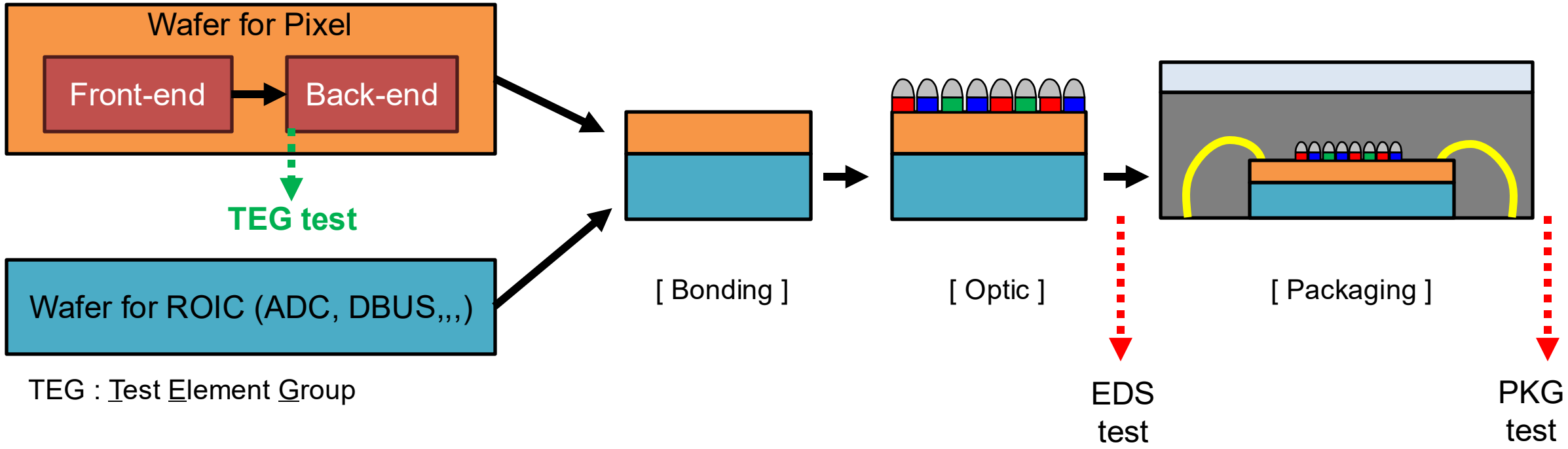
TG : Transfer Gate

EDS : Electrical Die Sorting

■ Key parameters

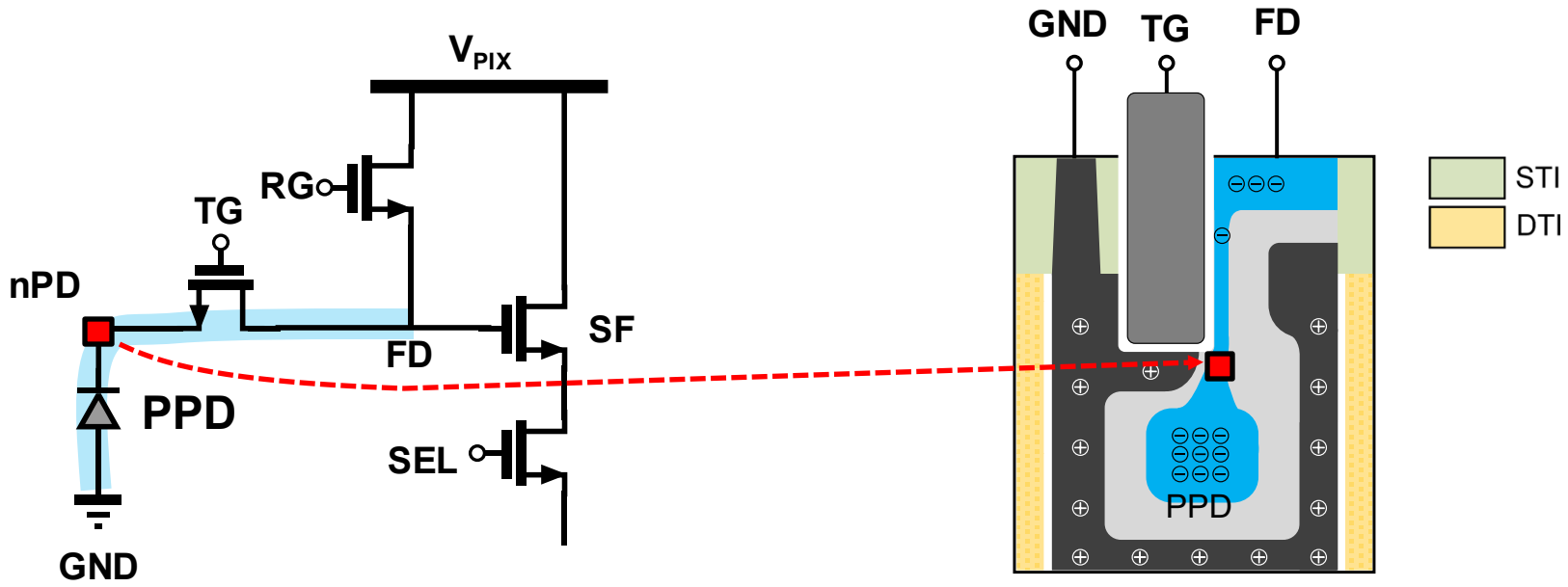
- V_{PDMAX}, V_{TGMAX} → Charge transfer characteristics.
- C_{PPD} → Full well capacity (FWC).

Motivation 2 : In-Fab Evaluation



- **PPD is formed early in CIS process.**
- **EDS/PKG evaluation → Delayed verification of PPD design.**

Challenges



[Pixel schematic] [Vertical structure]

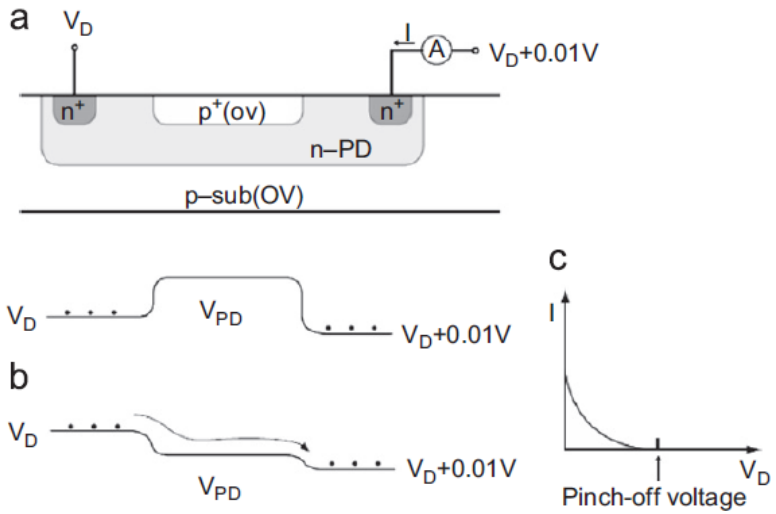
nPD : n-type region of PPD

- **Biasing nPD is difficult due to buried node.**
- **Small PPD capacitance (< 10 fF) makes measurement difficult.**

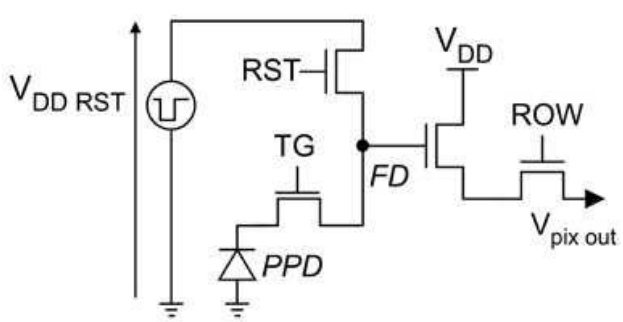
Conventional Technology

[1] S. Park, *Microelectronics Journal*, vol. 40, no. 1, pp. 137–140, 2009.

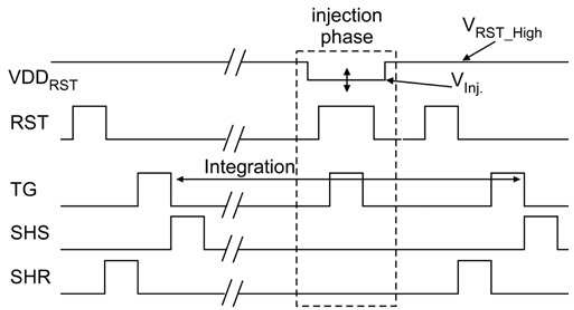
[2] V. Goiffon, *Proc. Int. Image Sensor Workshop*, 2013.



[[1]TEG test]



Schematic



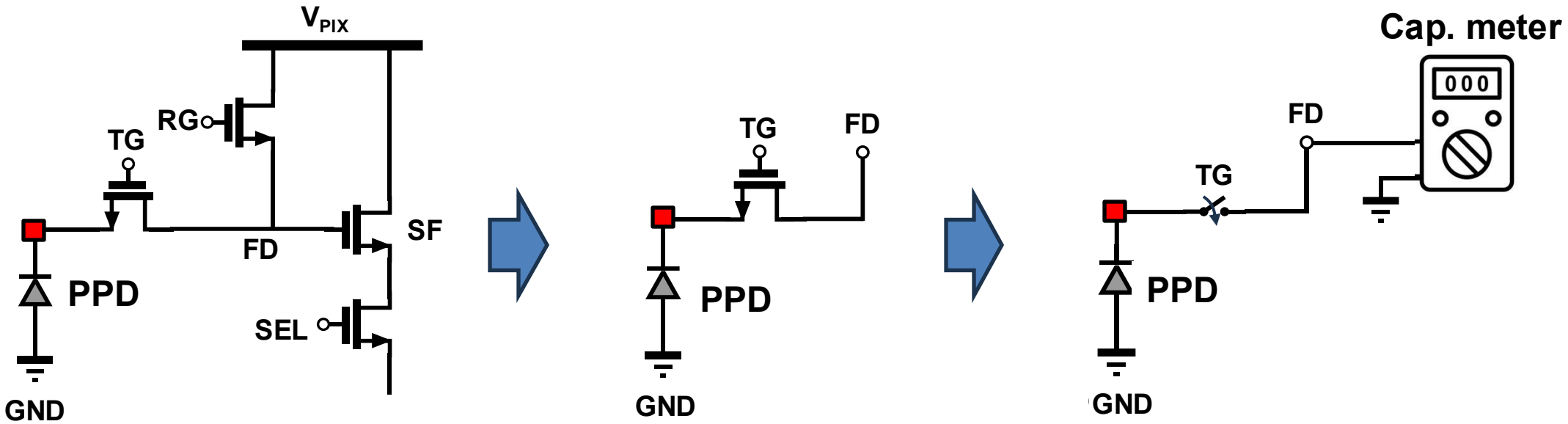
Timing diagram

[[2]Chip test]

- **TEG test → Requires structural modification.**
- **Chip test → Requires a dedicated driving circuit for testing.**

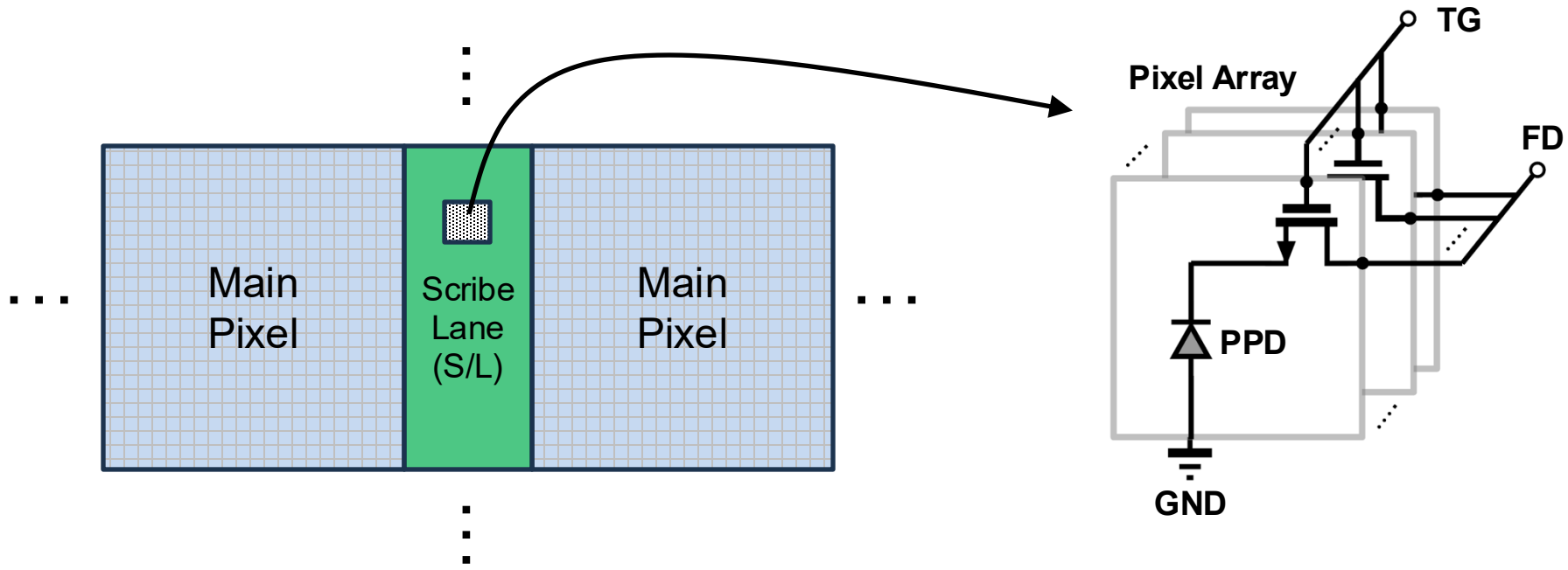
→ <u>In-fab evaluation method needed without modifying PPD.</u>

Basic Strategy



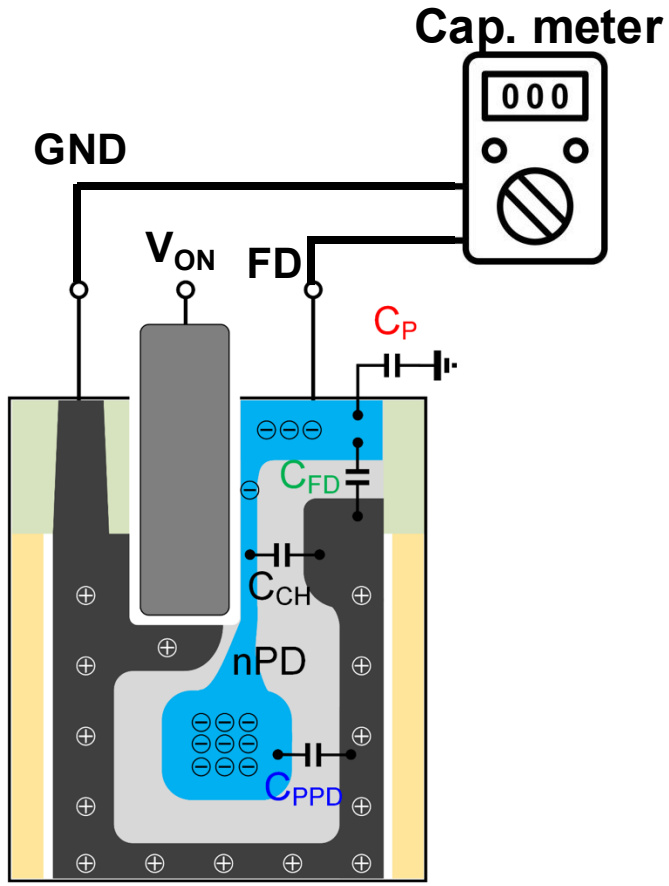
- **Simple TEG configuration : Only FD, TG, and GND connected.**
  - PPD evaluation via TG → No PPD modification needed.
- **Use capacitance-voltage (C-V) measurement.**
  - Suitable method for floating / buried node.

Proposed TEG Structure



- **Configure TEG in S/L identical to main pixel.**
- **Connect TG, FD, and GND in parallel for C-V measurement.**
  - Ensure measured capacitance > tens of pF

Proposed Method : FD-GND Capacitance



C_{PPD} : PPD - GND

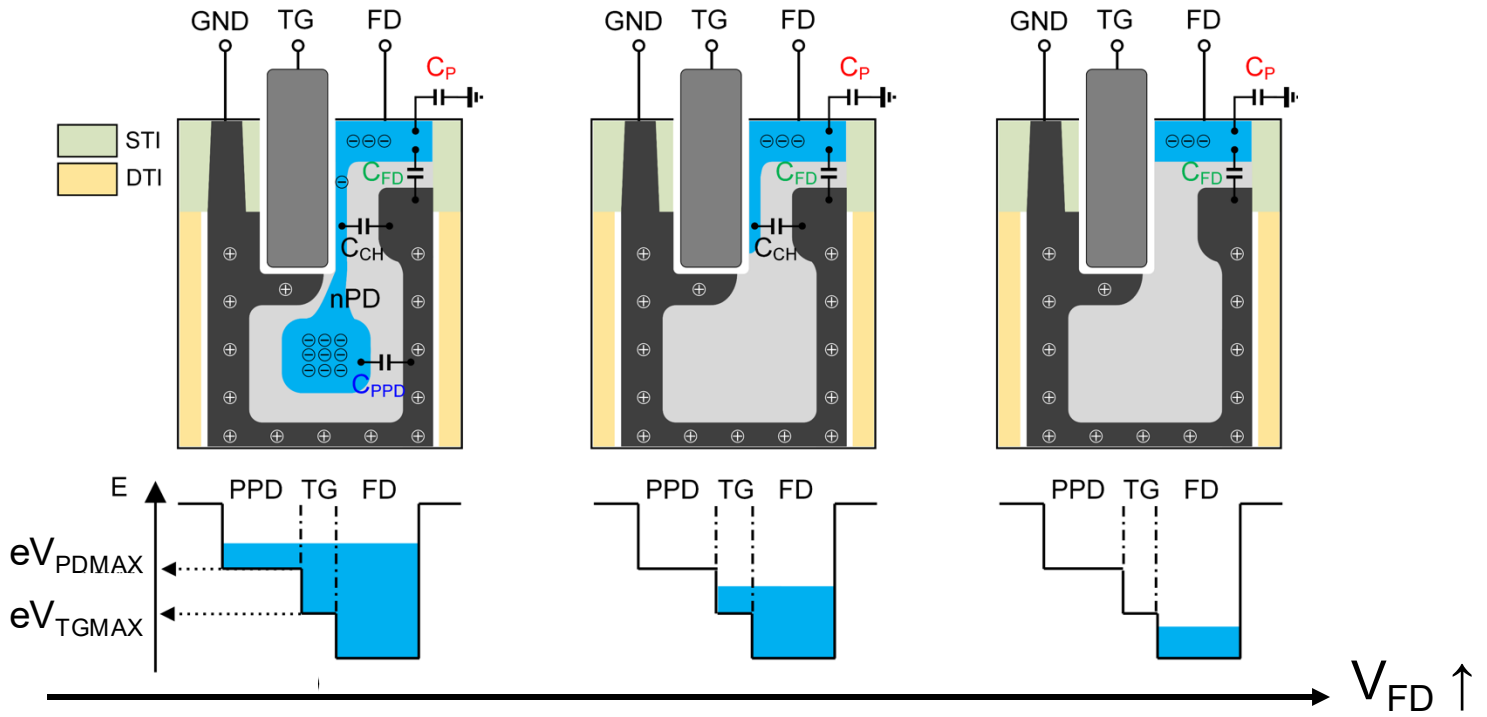
C_{CH} : TG channel - GND

C_{FD} : FD – GND

C_P : Parasitic component

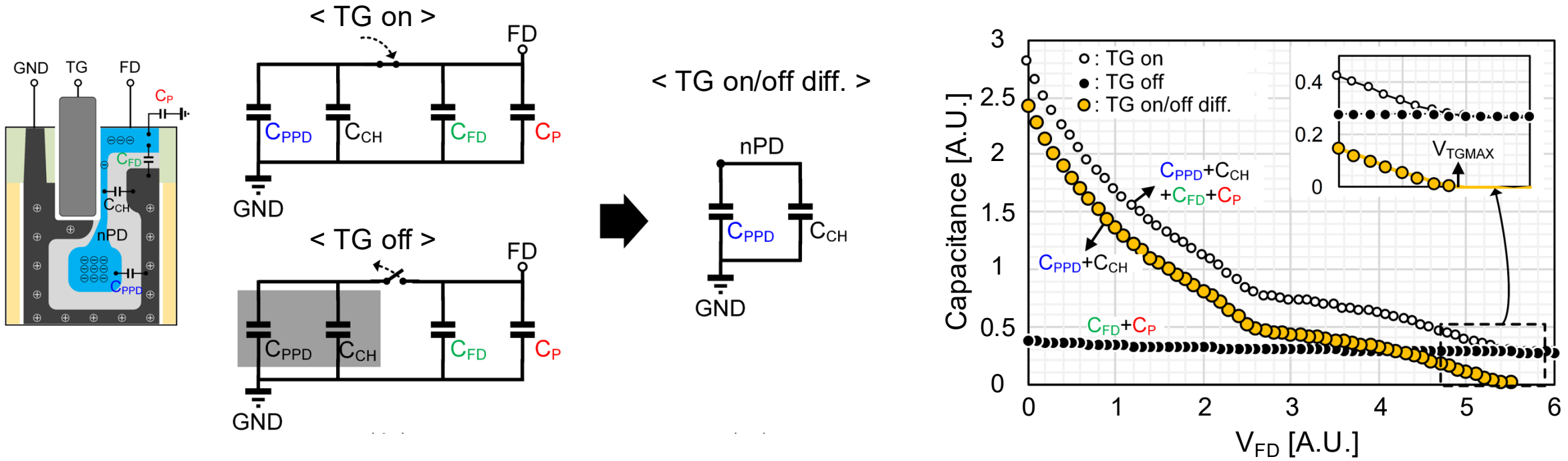
- **C-V measurement between FD and GND.**

Proposed Method : Capacitance Segmentation



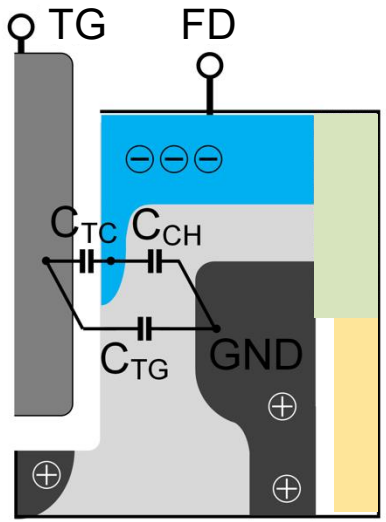
- **Capacitance components as a function of FD voltage (V_{FD}).**
  → C_{PPD}, C_{CH}, C_{FD}, C_P.
- **V_{FD} at which C_{PPD} and C_{CH} begin to appear : V_{PDMAX}, V_{TGMAX}.**

Proposed Method : (C_{PPD}+C_{CH}) Extraction

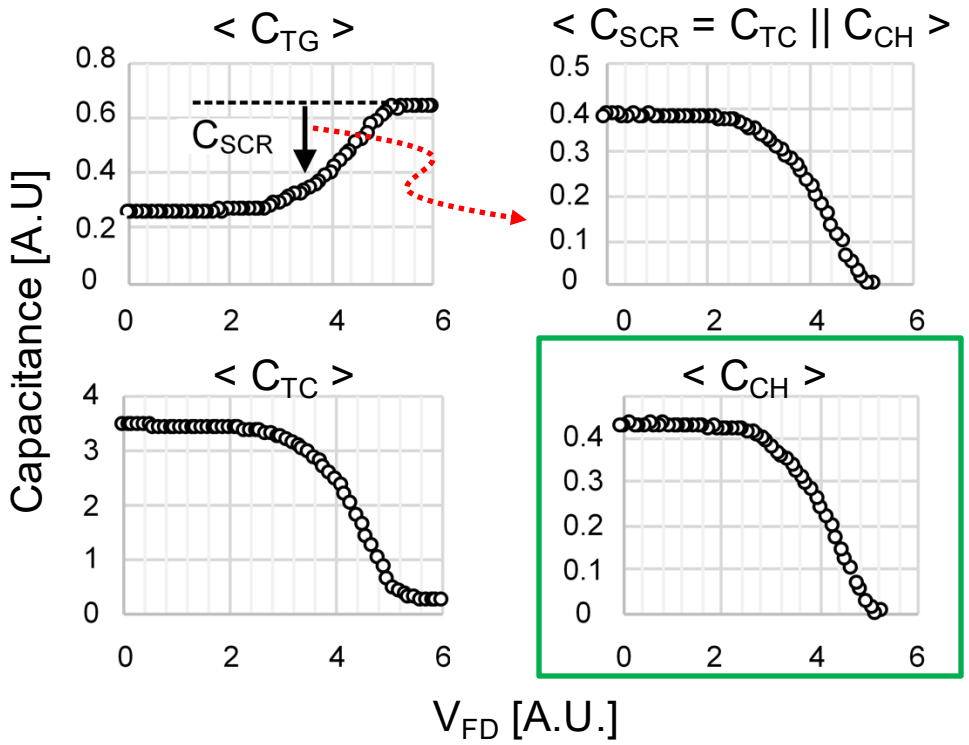


- **Capacitance difference between TG on/off → C_{PPD} + C_{CH}.**
  - Parasitic capacitance (C_P) cancellation.
- **X-axis intercept of (C_{PPD} + C_{CH}) curve → V_{TGMAX}.**

Proposed Method : C_{CH} Extraction



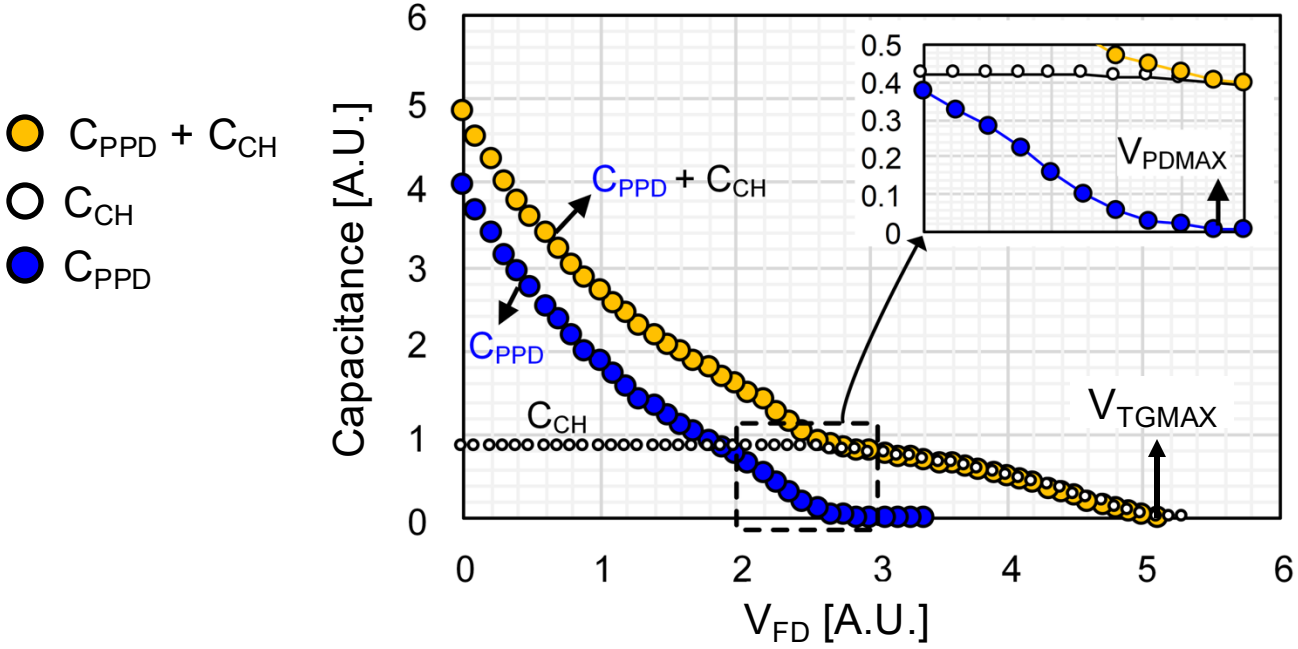
$$\frac{1}{C_{SCR}} = \frac{1}{C_{TC}} + \frac{1}{C_{CH}}$$

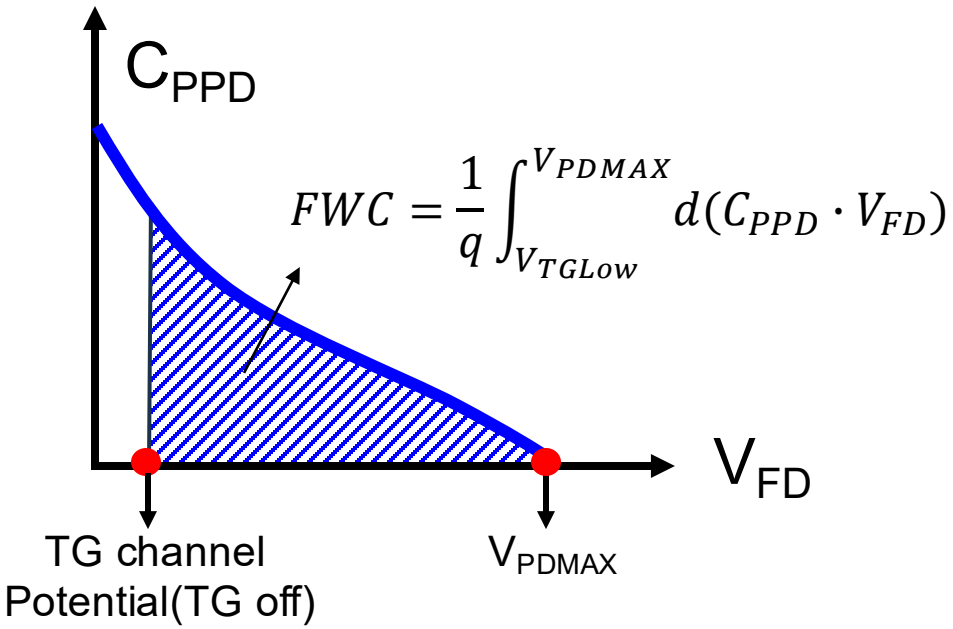


C_{TG} : TG-GND capacitance
C_{TC} : TG-channel capacitance
C_{CH} : Channel-GND capacitance

- **C_{TG} decrease due to screening effect when lowering V_{FD}.**
  - Amount of decrease : $C_{SCR} = C_{TC} \parallel C_{CH}$.
- **Direct C_{TC} measurement available.**

Proposed Method : PDCV Plot

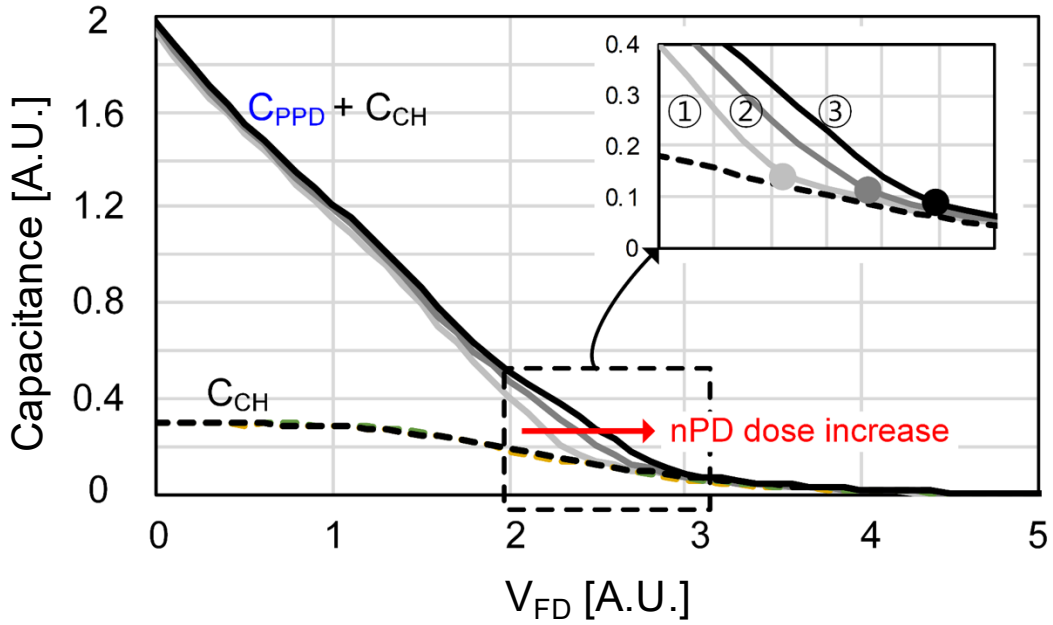




- **C_{PPD}+C_{CH}, C_{CH} capacitance vs. V_{FD}.**
  → PPD shape and characteristics.
- **PPD Key parameters : V_{PDMAX}, V_{TGMAX} , and C_{PPD} (→ FWC).**

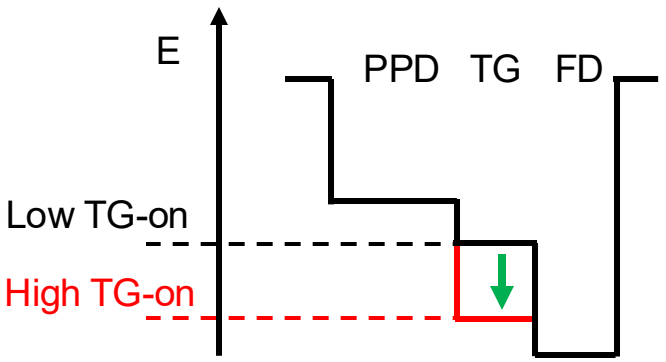
FWC : Full Well Capacity

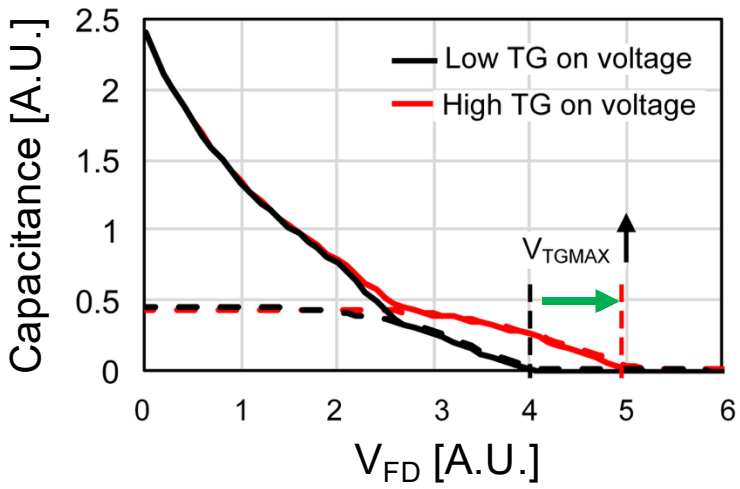
Measurement : nPD Dose Effect

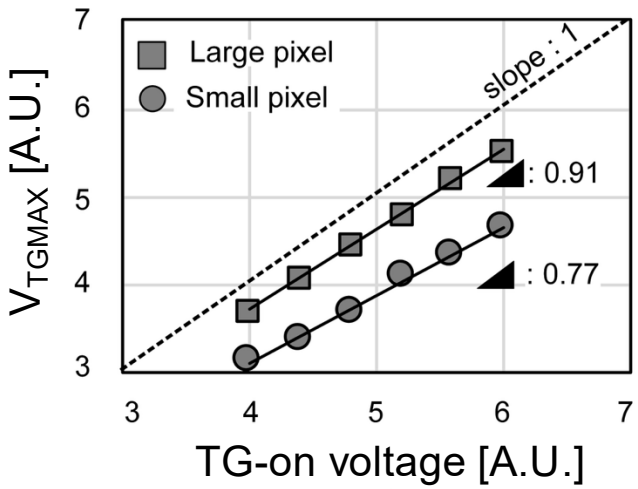


- nPD dose ↑ → More reverse bias required for full depletion.
  → Increase in V_{PDMAX}.

Measurement : TG-on Bias Effect

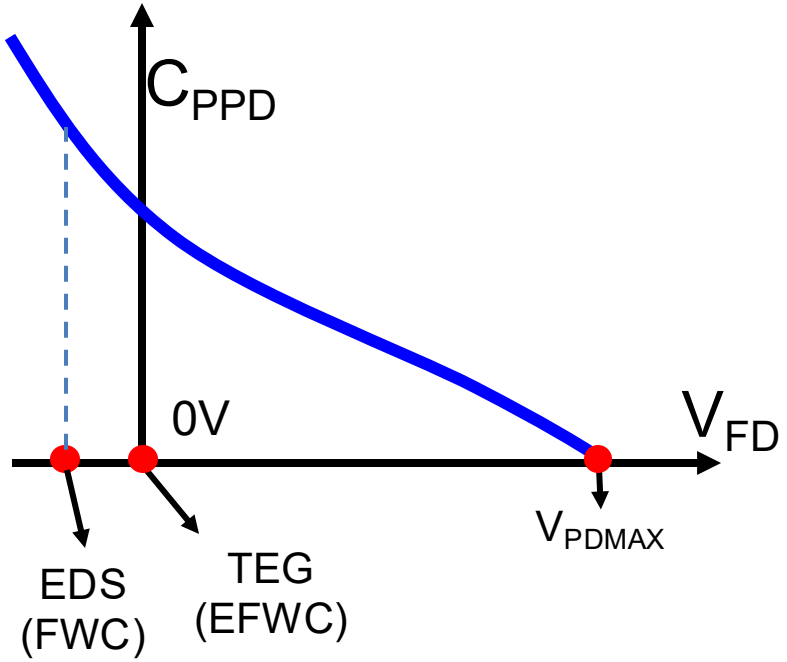


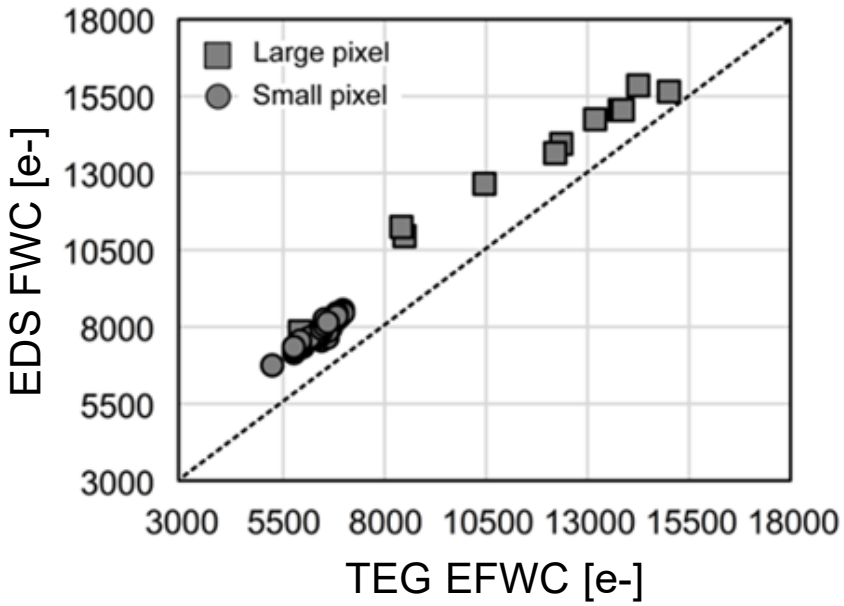




- Increasing TG-on bias → Increase in V_{TGMAX}.
- The slope of TG-on bias vs. V_{TGMAX} → TG gate controllability.

Measurement : Full Well Capacity





- **Area under the PPD curve (0 to V_{PDMAX}) → EFWC.**
- **Strong correlation between FWC and EFWC.**
  - Offset observed due to more a negative TG-off bias during EDS measurement.

Conclusion

- **Reliable method for PPD characterization during fabrication.**
  - Early confirmation of PPD design parameters using TEG.
    - 3 to 4 times faster than conventional method.
  - Enables monitoring of PPD process even in the smallest pixel.
  - Using only C-V measurements.