First Insights on Super-g_q DePFET: An Improved High-Performance Sensor with Increased Gain and Sub-Electron Noise Level Capabilities

Sebastian Stadler*, Alexander Bähr*, Jelena Ninković*, Johannes Treis*, Rainer Richter*
*Semiconductor Laboratory of the Max Planck Society

MOTIVATION

Whereas existing DePFET implementations have already shown impressive readout noise values of around 2 e- ENC at a speed of 5µs per line, simulations indicate that further improvements in the SNR are feasible with the so-called super-g_q DePFET technology. Recently a test production of this novel devices and other non-Standard DePFETs have been completed [1,2].

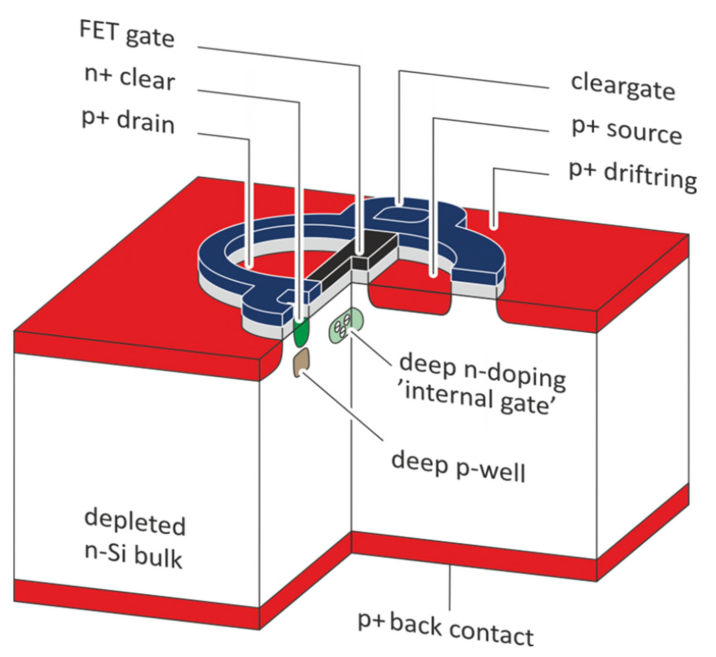


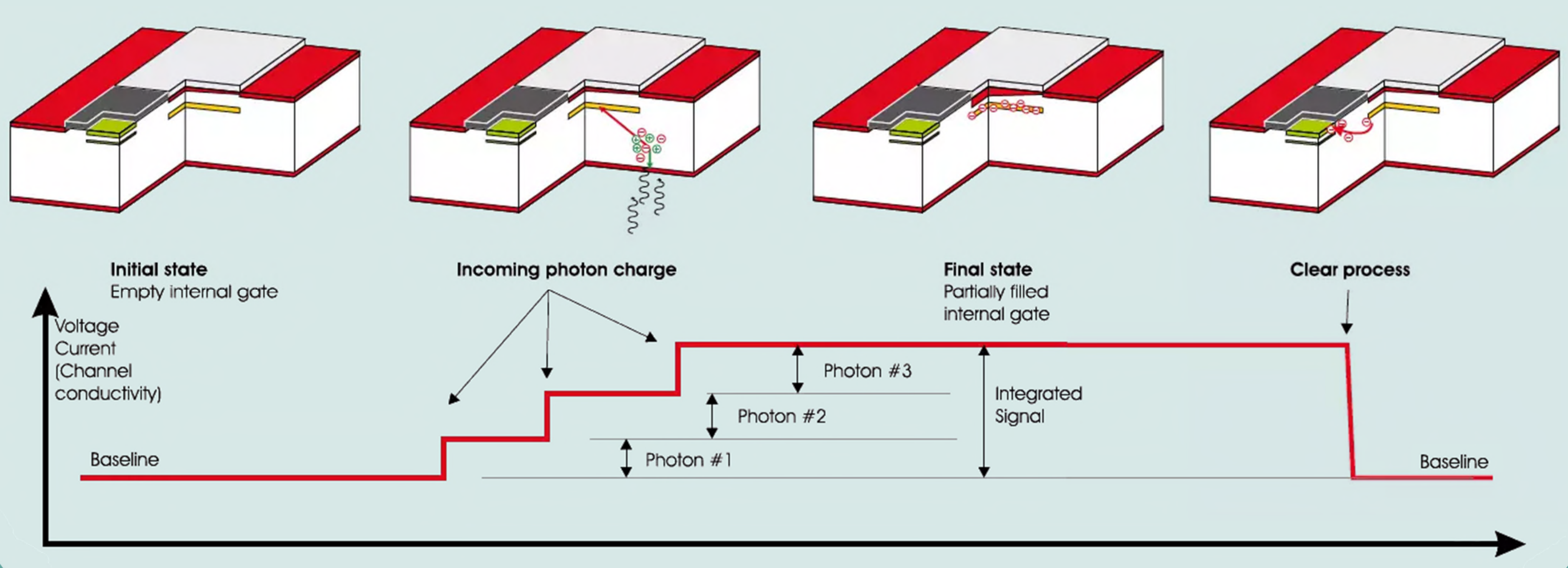
Fig. 1 WFI Athena "Standard"DePFET pixel [3].

Device Structure:

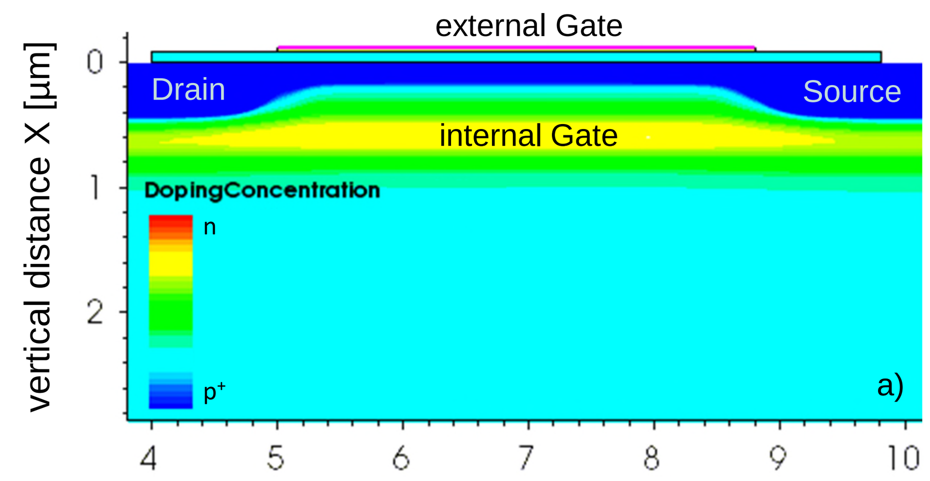
- P-channel MOSFET on a high-resistive n-doped silicon substrate.
- Additional deep-n implant below the transistor channel.
- Forming a potential minimum (internal gate) for electrons.
- Fully depleted from the backside.

❖ **Super-g_q DePFET:** Additional dot-shaped n-implant.
- ➢ Decoupling internal gate from the external gate.
- ➢ Avoiding short channel effects when shrinking the int. gate.

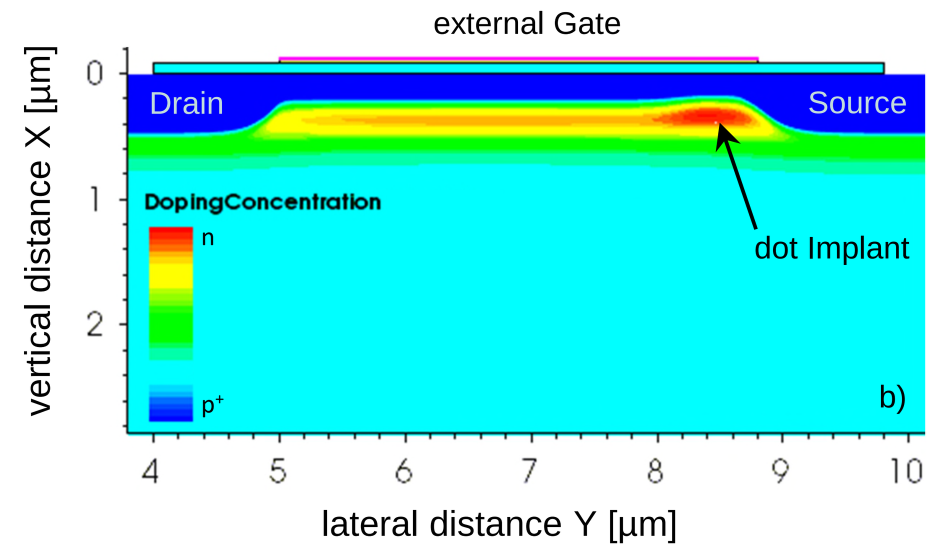
General Working Principle:



Standard-DePFET (WFI | Athena):



Super-g_q DePFET:



DEVICE SIMULATION[2]

- ➢ An increase of gain by factor of 3.
  From 500pA/e- to 1.7nA/e-.
- ➢ Half of the white noise.
  From 2 e- ENC to less than one e- ENC.

< **3·10⁴ e- injected charge:** charge gain constant at 1.7nA/e-.

> **3·10⁴ e- injected charge:** charge gain turns to a non-linear function caused by the in-homogeneously shaped internal gate and the stronger coupling to the channel.

>> **3·10⁴ e- injected charge:** charge gain decreases as internal gate reduces punctual shape and e- subsequently overflow below the source (Fig. 2 and 3).

NOTE: 3·10⁴ e- injected charge covers an energy range of more than 100 keV for X-ray spectroscopy applications.

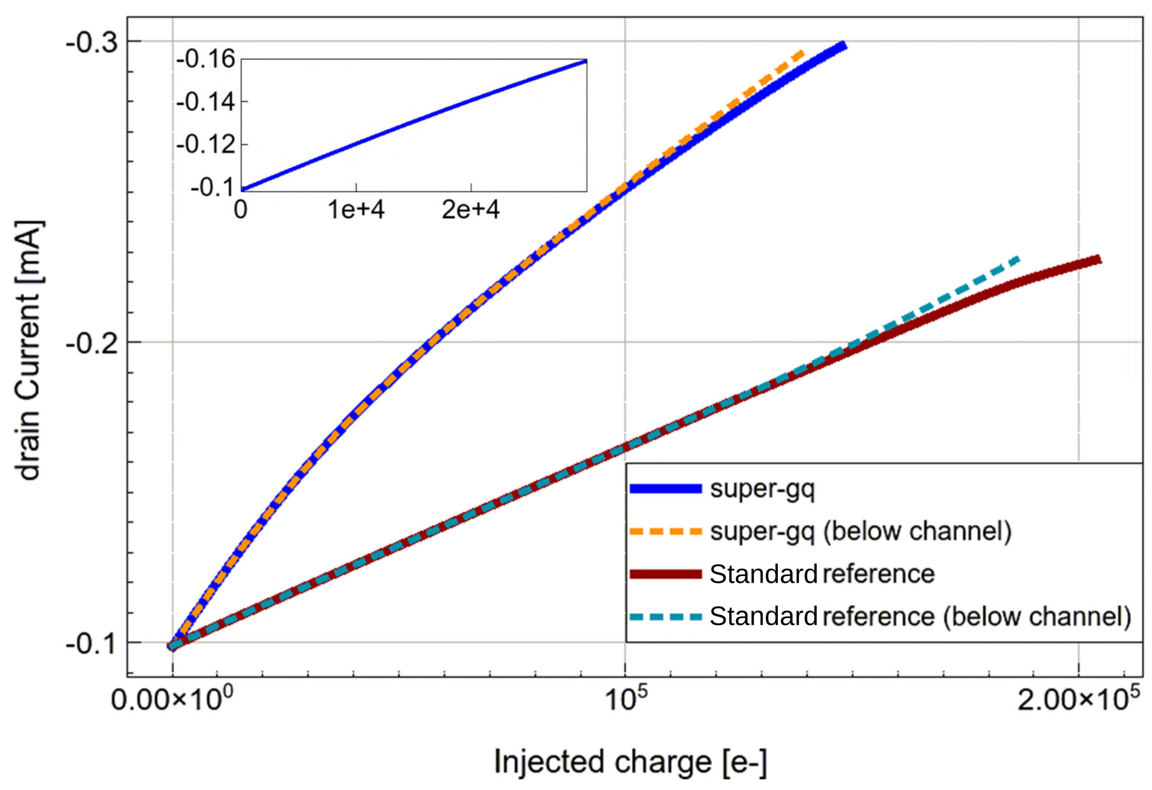


Fig. 2 Drain current as a function of the injected charge.

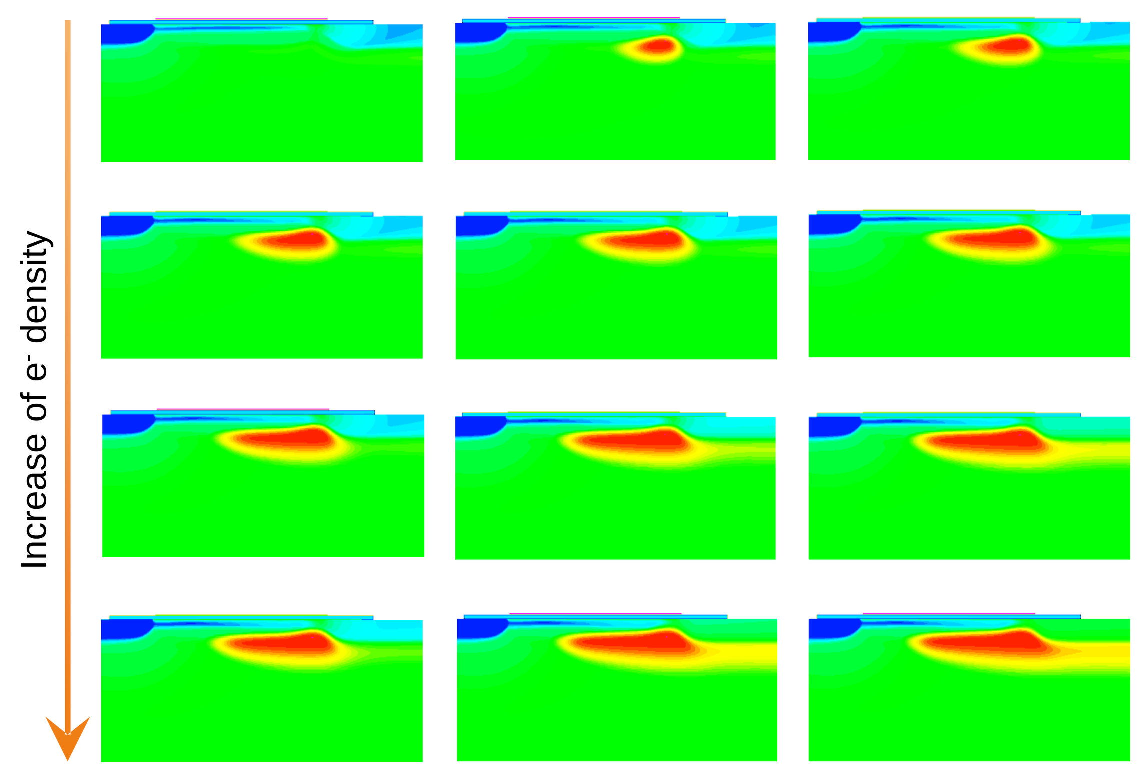


Fig. 3 Accumulation of injected charge in the internal gate.

FIRST INSIGHTS INTO SUPER-G_q DEVICES

- ✓ General DePFET-transistor functionalities.
- ✓ g_m is in good agreement with simulations.
- ✓ Internal gate potential match with simulations.
- – Threshold shift in comparison with simulations.

Super-g_q DePFET: g_m of 120µS at operation point, empty int. gate potential 2V.

Standard DePFET: g_m of 72µS at operation point, empty internal gate potential 5.5V.

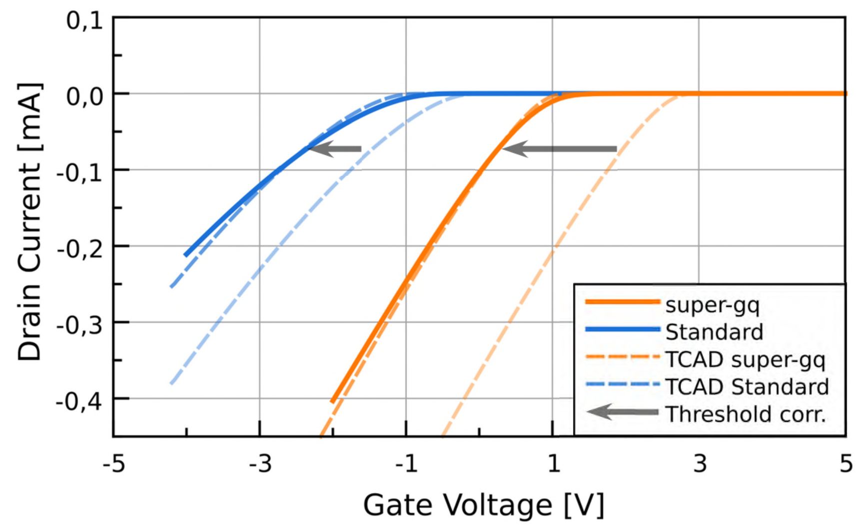


Fig. 4 Drain current as a function of gate voltage.

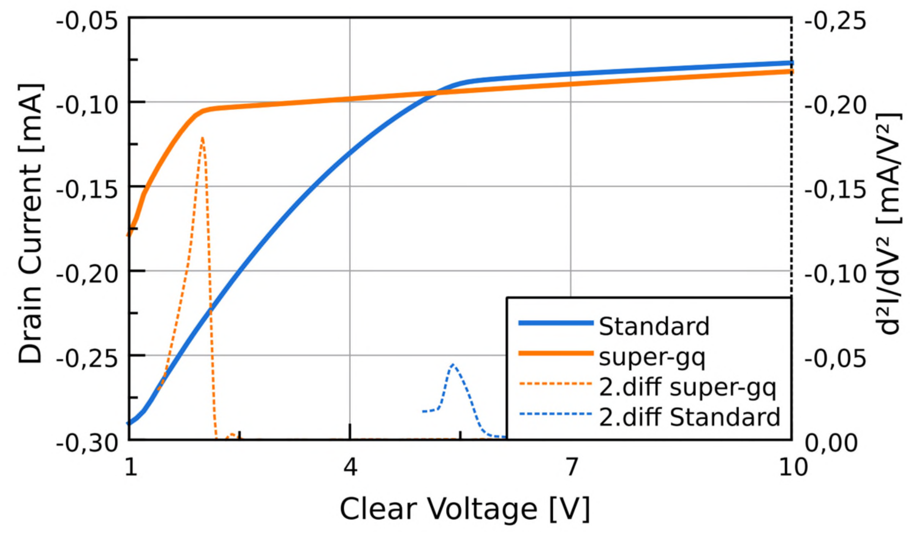


Fig. 5 Drain current as a function of clear voltage.

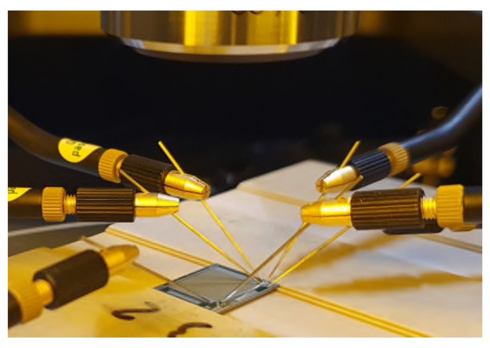


Fig. 6 Top: Needle probe station with device under test (DUT) Right: Front side of the DUT.

CONCLUSION / OUTLOOK

- ➢ Devices are functional and ready for an in-depth analysis.
- ➢ Successful fast-track production at HLL in under nine months.
- ➢ Good agreement with previous DePFET productions (Athena).

Upcoming studies:

- energy resolution,
- gain improvement,
- noise levels of 1/f and white noise,
- optimal operation parameters,
- and cryogenic temperatures for the first time on matrix level (Fig. 7).
- Optional non-Standard DePFETs such as Quadropix, Infinipix, RNDR[1].

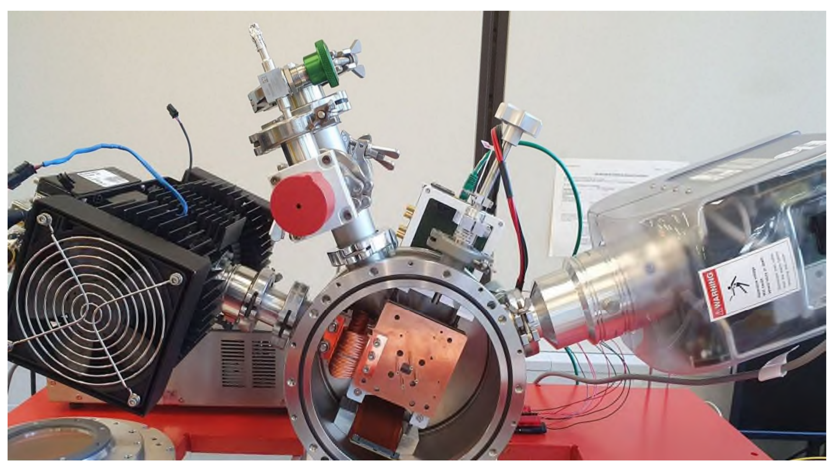


Fig. 7 Super-g_q DePFET measurement setup at the Semiconductor Laboratory of the Max Planck Society.

REFERENCES

[1] L. Andricek et al., "DePFET—Recent Developments and Future Prospects," Front. Phys., vol. 10, Jun. 2022, doi: 10.3389/fphy.2022.896212.
[2] A. Bähr et al., "Advanced DePFET concepts: super gq DePFET," in X-Ray, Optical, and Infrared Detectors for Astronomy IX, SPIE, Dec. 2020, pp. 178–185. doi: 10.1117/12.2562484.
[1] W. Treberspurg et al., "Characterization of a 256 × 256 pixel DEPFET detector for the WFI of Athena," Nuclear Instruments and Methods in Physics Research, doi: 10.1016/j.nima.2019.162555.

Current DePFET Applications:

- PXD for the Belle II experiment
- MIXS sensor aboard the planetary science mission BepiColombo
- ultrafast real-time imagers for direct electron detection (EDET) at transmission electron microscopies (TEM)s
- Wide Field Imager (WFI) of the X-ray telescope Athena

MAX PLANCK SEMICONDUCTOR LABORATORY

Dr. Alexander Bähr
Halbleiterlabor der MPG
Garching bei München
Telefon +49 89 839400 -81
E-Mail: axb@hll.mpg.de

Sebastian Stadler
Halbleiterlabor der MPG
Garching bei München
Telefon +49 89 839400 -21
E-Mail: ses@hll.mpg.de

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