

710 V Breakdown Voltage in Field Plated Ga₂O₃ MOSFET

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Motivation

Ga₂O₃ has:

- Higher Baliga's Figure of Merit (BFoM) than SiC and GaN [1].
- A mature growth technology for large area substrates [1] (Figure 1).
- Potential to revolutionize power electronics industry.

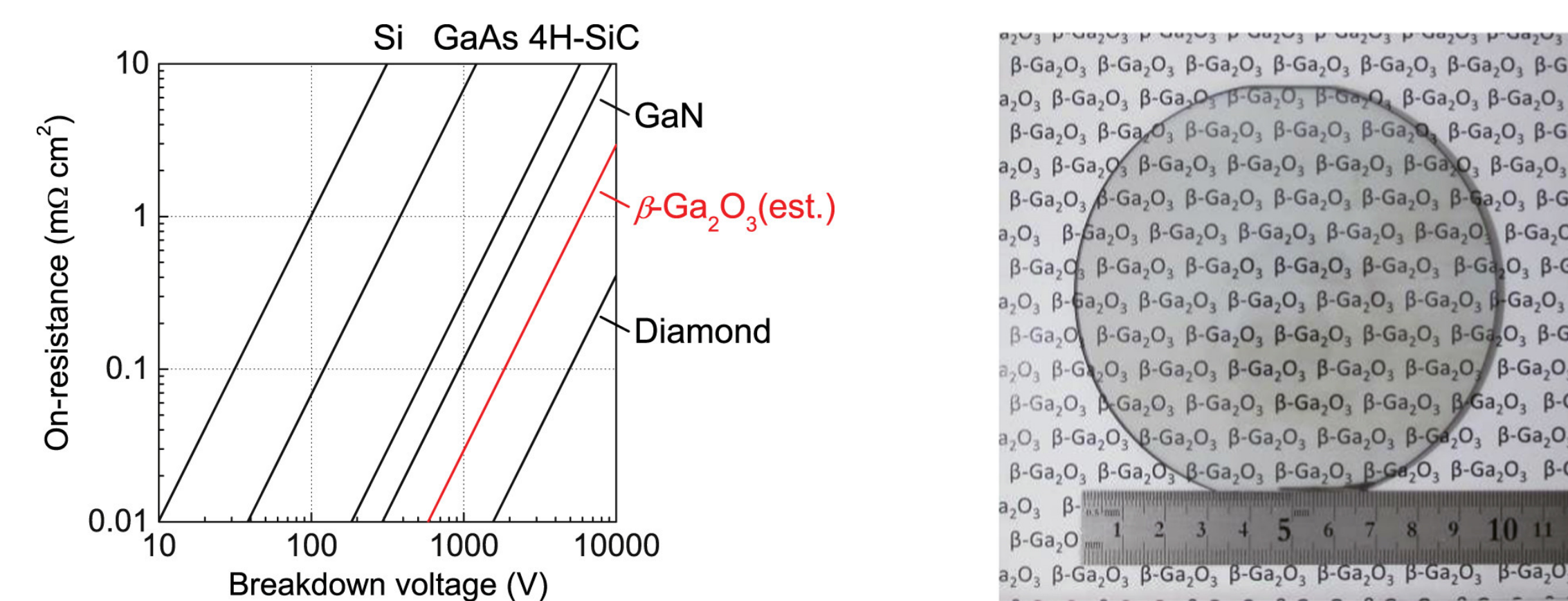


Fig. 1. Theoretical performance dependence of R_{on} on breakdown voltage (left) and photograph of a 4-inch Ga₂O₃ wafer. [1]

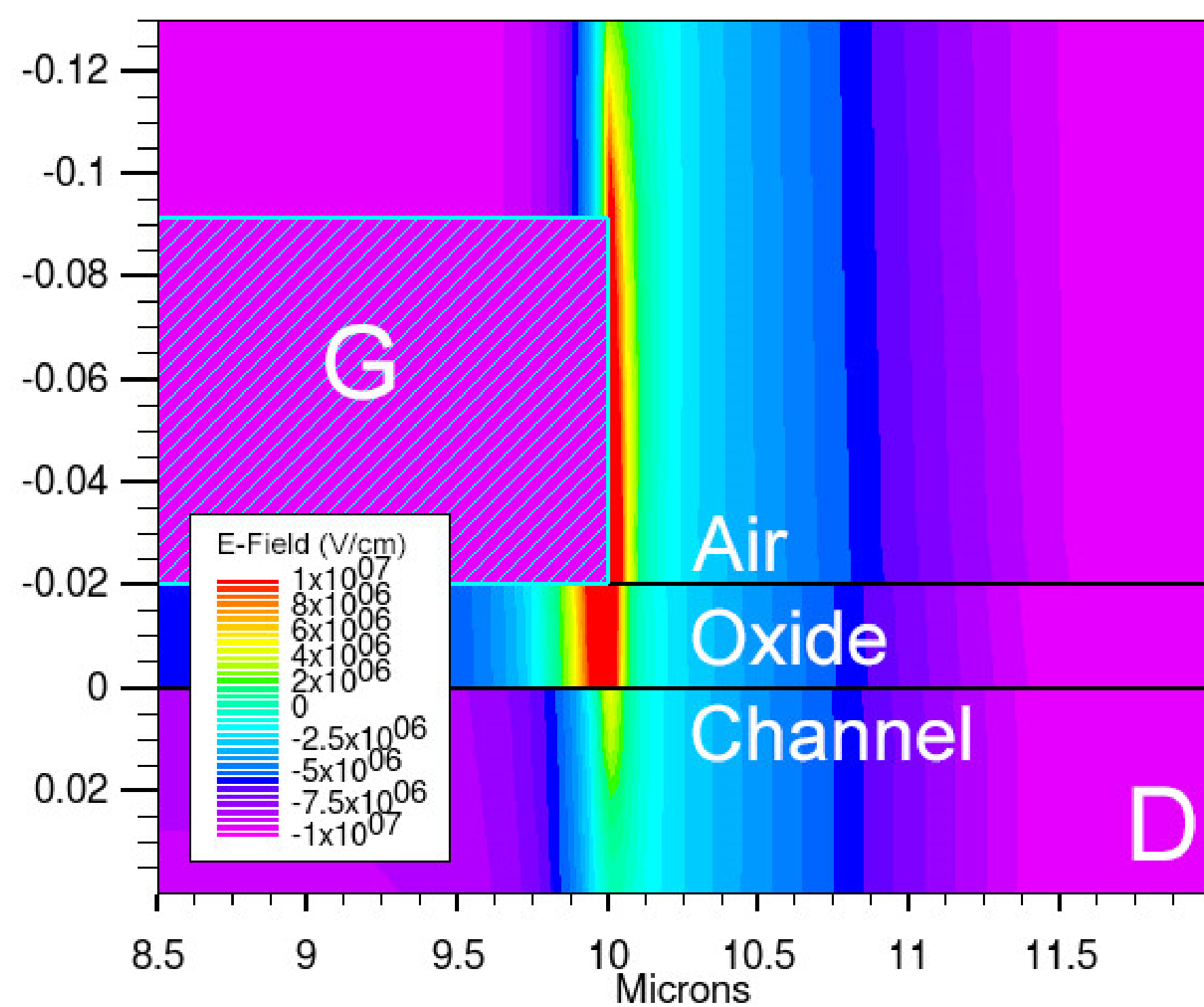
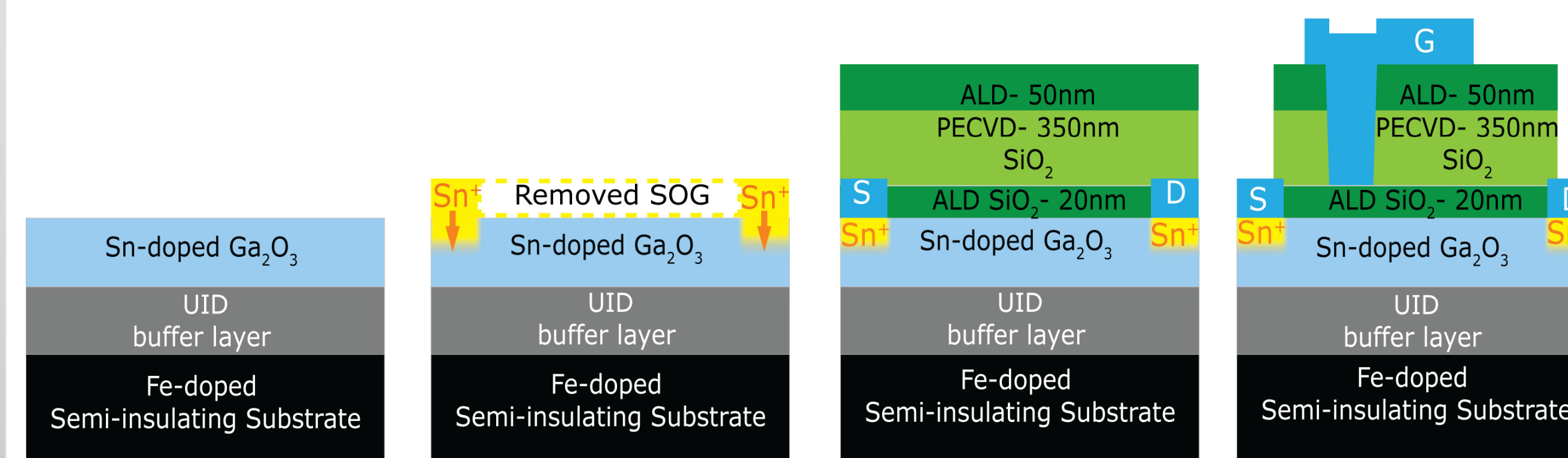


Fig. 2. Electric field distribution across an optimized Ga₂O₃ MOSFET under 350V drain bias and -30V gate bias.

Pre-mature Extrinsic breakdown is the bottleneck at improving V_{BR} in Ga₂O₃ MOSFET at this stage:

- Breakdown will be determined by the weakest part not the strongest part.
- Simulation shows much higher electric field strength in oxide and air.
- The critical fields of oxide and air are not guaranteed to be higher than channel material (Ga₂O₃)

Fabrication Process Flow



Device Structure:

- 200 nm Ga₂O₃ epitaxial layer on SI substrate.
- EPI layer grown by ozone MBE.
- Targeted Doping = $2 \times 10^{17}/\text{cm}^3$
- 20nm gate SiO₂ by ALD+ 350nm field plate SiO₂ by PECVD+ 50nm top field plate SiO₂ by ALD.

Ohmic Contact:

- SOG Doping technique [4]
- 20nm-Ti/ 70nm- Au.
- BCl₃/Ar RIE treatment- 1 min.
- RTA: 470°C 1min.

Trench Etch:

- Selective CF₄/O₂ synergic etch under 2mT pressure.
- Al₂O₃ etch stop layer is used to precisely define gate oxide.

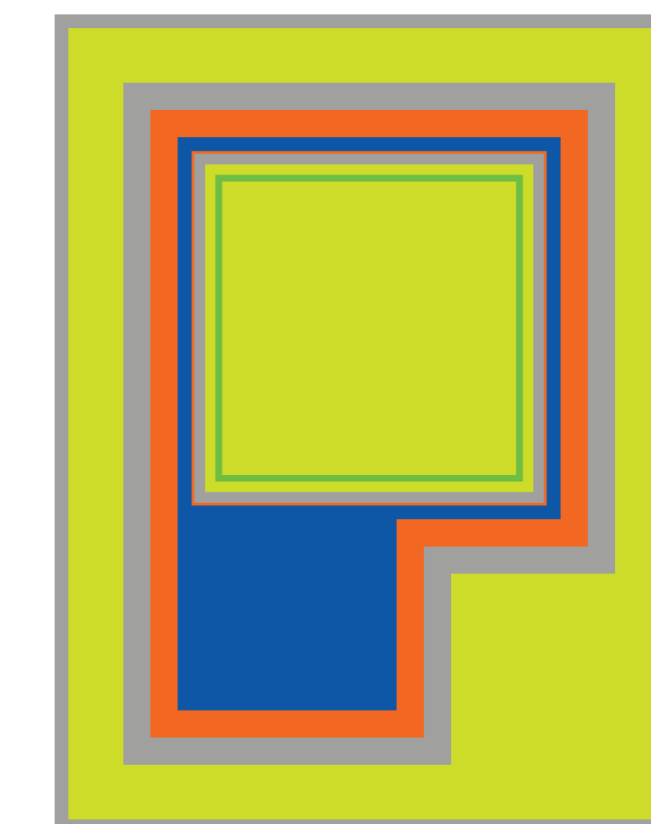


Fig. 3. Top View schematic of the device.

IV Characteristics

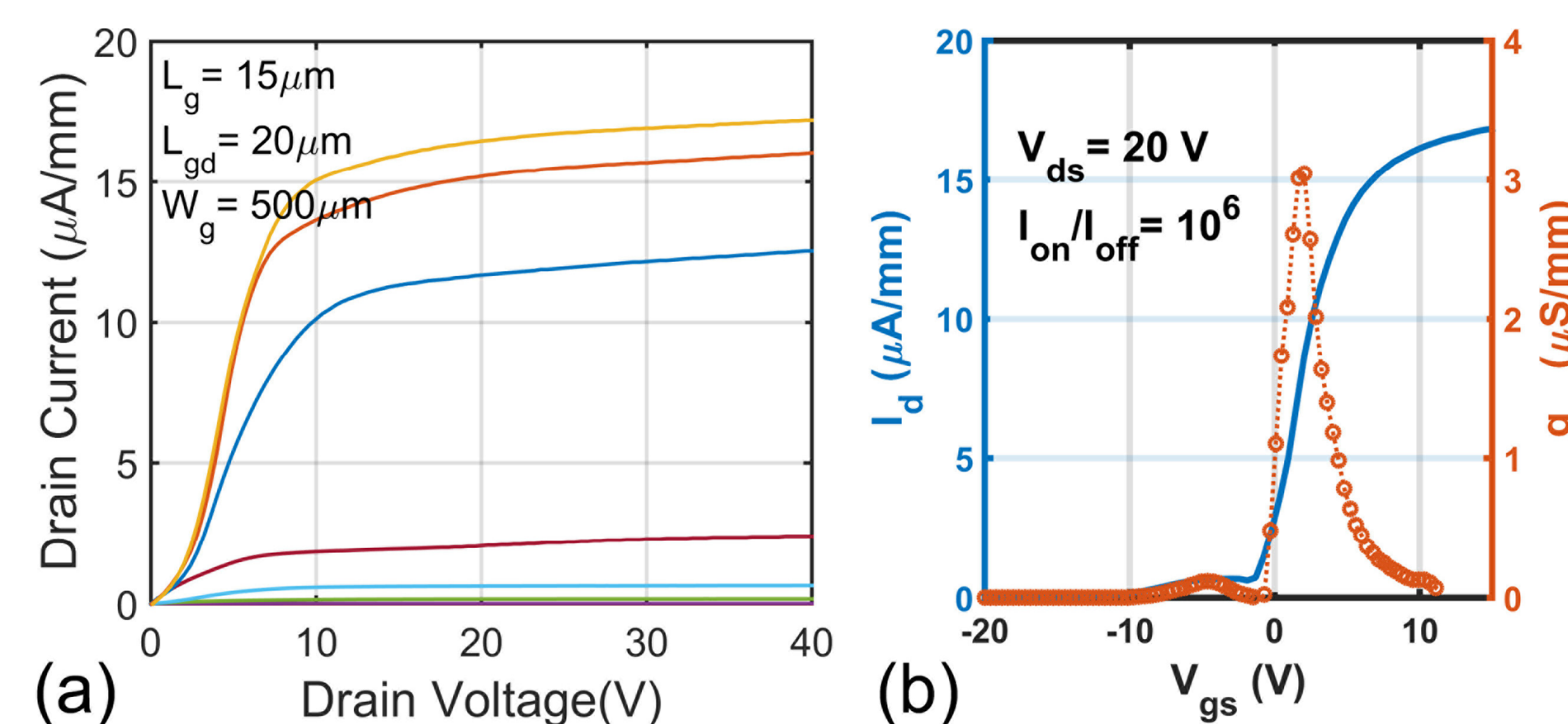


Fig. 4. (a) Output characteristic and (b) Transfer characteristic of a typical field-plated MOSFET.

- Post drive-in-annealing(SOG process) N_d (doping density) $\sim 1.5 \times 10^{16}/\text{cm}^3$.

Breakdown Characteristics

- V_{BR} of non-field-plated and field-plated devices are very similar around 350V.
- Air breakdown near the gate drain region most likely caused catastrophic breakdown of device.
- V_{BR} increased from 350V to ~ 700 V for both non-field-plate device and field-plated device.

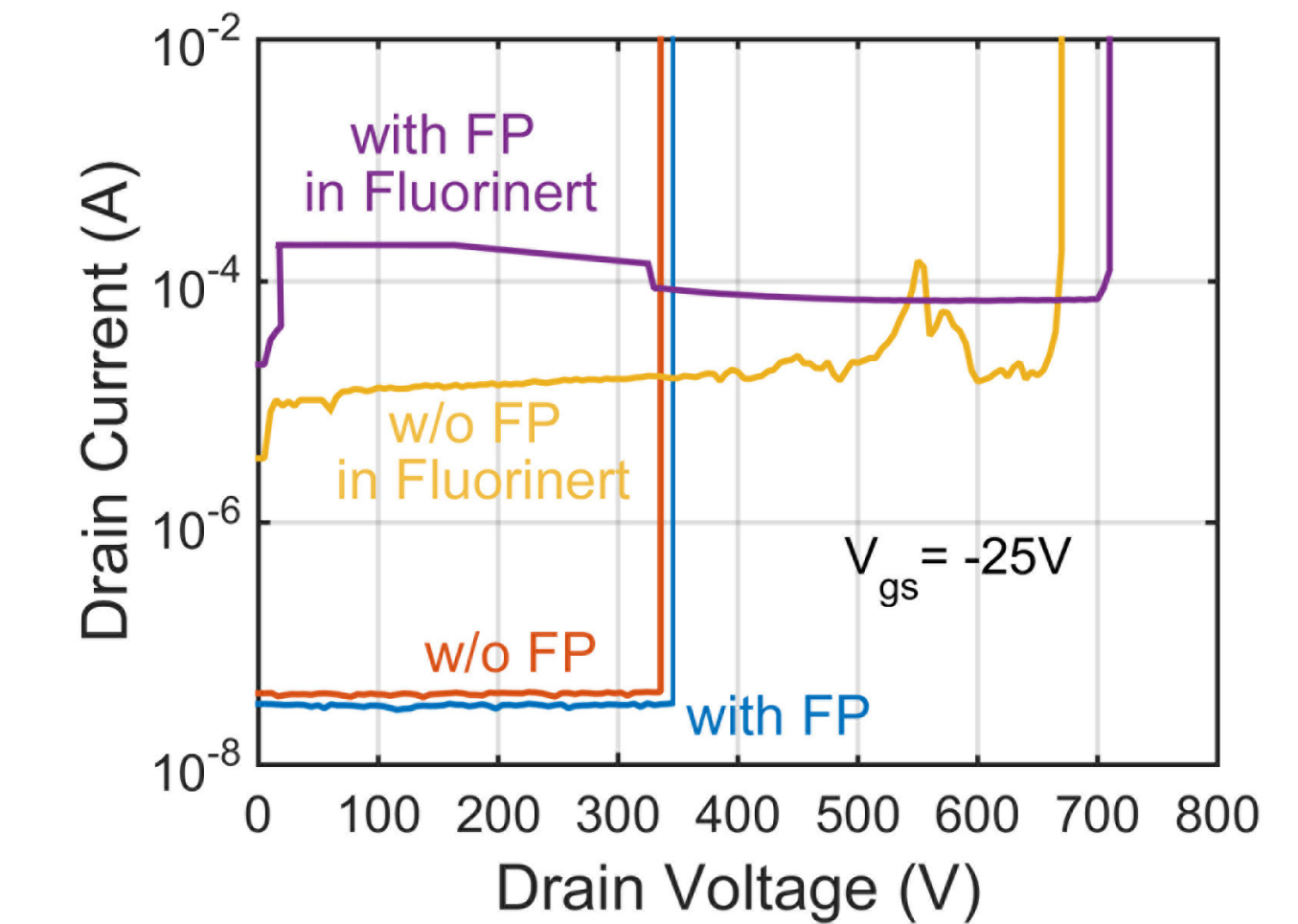


Fig. 5. Breakdown characteristic of four device with $L_{gd} = 20\mu\text{m}$ and with different field plate and measurement configurations.

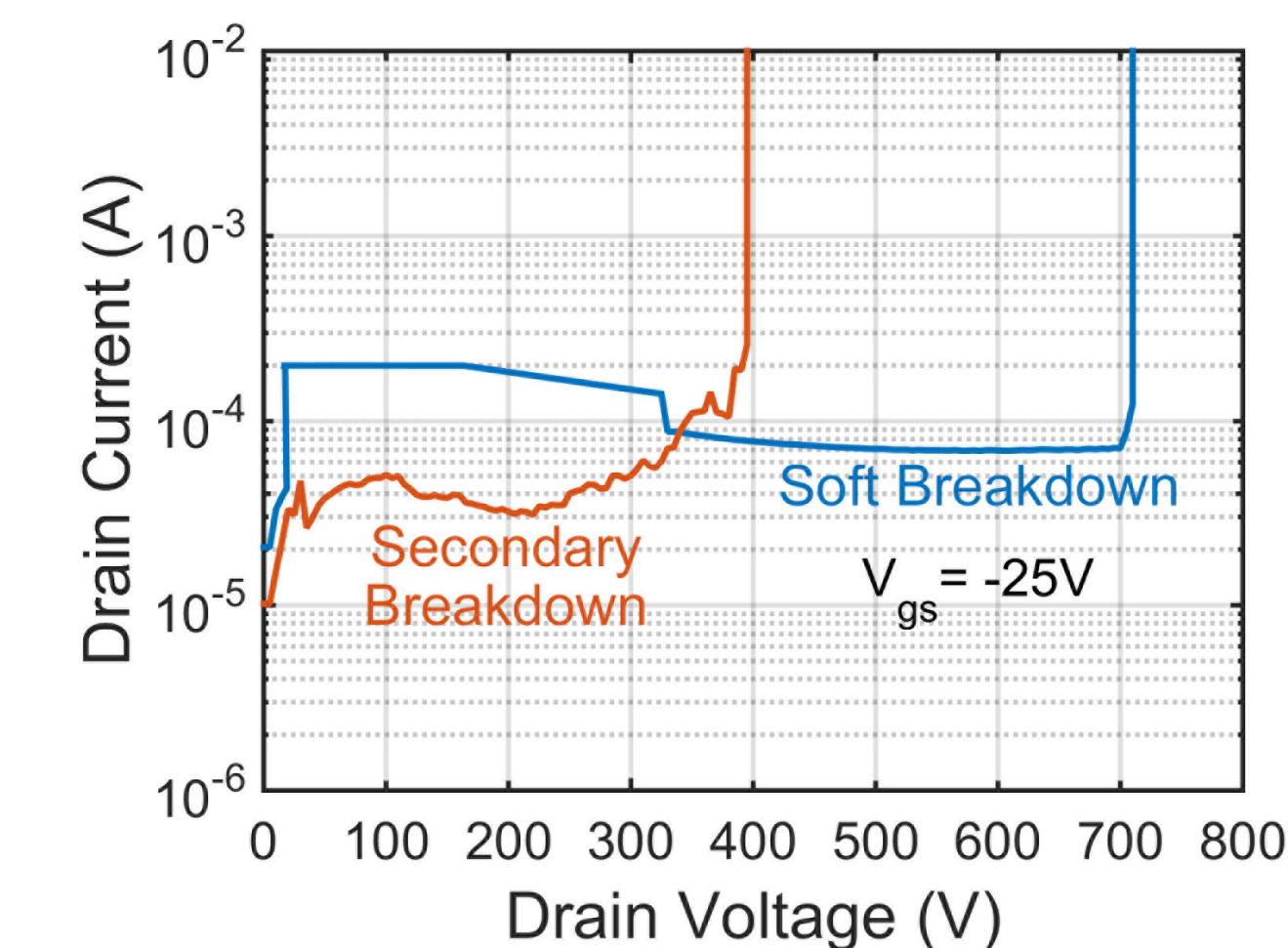


Fig. 6. Non-destructive breakdown characteristic, which happens when drain current compliance is set low ($\leq 1 \mu\text{A}$) and measured in fluorinert.

- When the drain compliance is set low ($\leq 1\mu\text{A}$), secondary breakdown can be sometimes measured.
- 10 μA of extra current in all measurement may be introduced by an unknown surface conduction layer formed with Fluorinert.

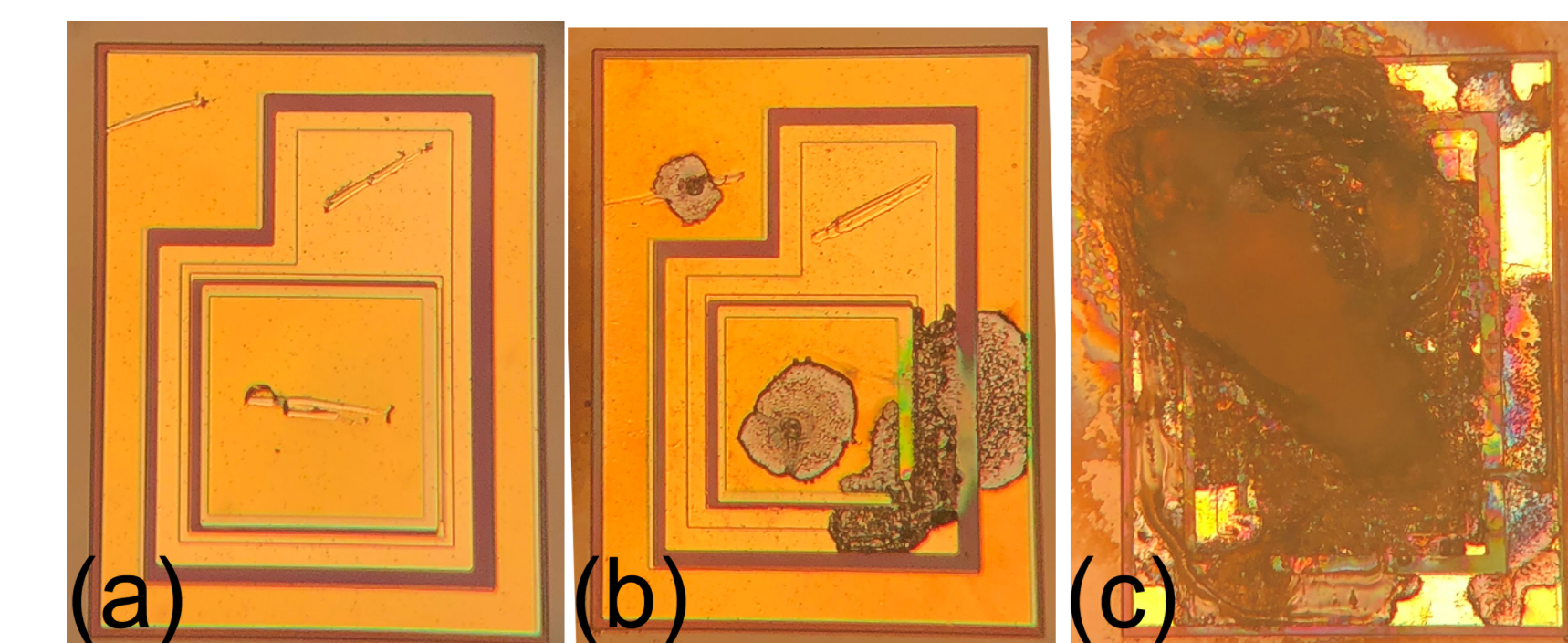


Fig. 7. Optical image of the MOSFET (a) while working, (b) after breakdown in air and (c) after breakdown in fluorinert with high compliance.

Conclusion and Future Work

- ✓ Verified the pre-mature breakdown in the air.
- ✓ The 710V V_{BR} is still caused by extrinsic path most likely in Fluorinert.
- ✓ Demonstrated a viable optimization pathway to higher breakdown Ga₂O₃ MOSFET.
- Improvement over ambient breakdown.
- Field-plate structural design for field re-distribution.

References

- [1] M.H. Wong et al., IEEE- EDL, vol. 37, p. 212, (2016). [2] H. Zhou et al., Appl. Phys. Lett, vol. 111, p. 092102 (2017). [3] K.D Chabak et al., IEEE- EDL, vol. 39, p. 67, (2018). [4] K. Zeng et al., IEEE- EDL, vol. 38, p. 513, (2017)