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Single-Event Burnout in Vertical β-Ga_2O_3 Diodes with Pt/PtO_x Schottky Contacts and High-k Field-Plate Dielectrics

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Introduction

Gallium Oxide (Ga_2O_3) is a wide-bandgap material (4.9 eV) with 8 MV/cm breakdown field [1]. Ga_2O_3 devices have higher breakdown voltage, lower on-state resistance and higher switching speed comare to other wide band gap counterparts which makes It a perfect choice for space and defence applications. However, Ga_2O_3 Schottky barrier diodes (SBDs) are susceptible to single event burnout (SEB) as seen in [1-2]. Structural improvements have been made since to improve the radiation hardness of β-Ga_2O_3 SBDs [3]. Improved devices show higher breakdown voltage significantly more SEB tolerance than the previous structure evaluated in [1].

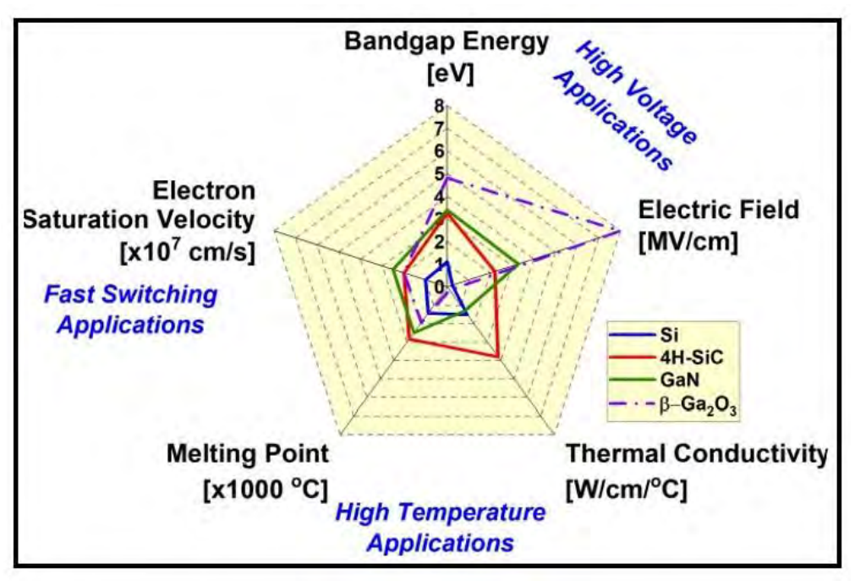

Fig. 1: Comparison of β-Ga_2O_3 properties with other materials

Improved structures & SEB tolerance

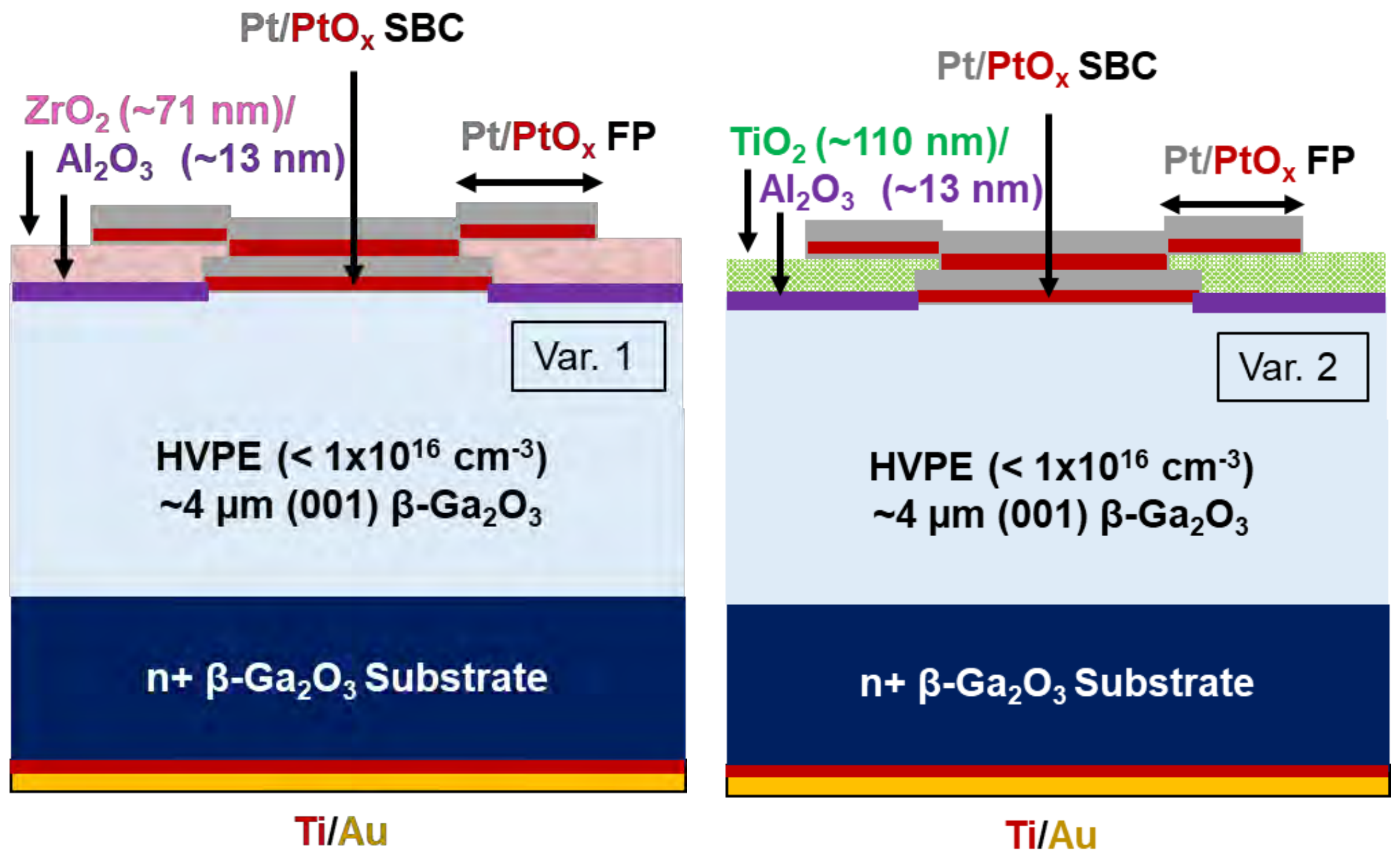

Fig. 2. Schematic diagram of vertical HVPE β-Ga_2O_3 Schottky barrier diode (SBD) with a 4 µm HVPE epitaxial layer on a highly doped substrate with Pt/PtOx Schottky barrier contact. Variant 1 (Var. 1) has ZrO_2/Al_2O_3 dielectric and variant 2 (var. 2) has TiO_2/Al_2O_3 dielectric under the FP. The SBDs are circular diodes of 200 µm diameter with 40 µm FP

- ☐ Sn-doped (001) Ga_2O_3 substrate
- ☐ Low-doped
- ☐ (~7-8×10^{15} cm^{-3}) HVPE epitaxy with 4 µm thickness
- ☐ PtOx Schottky metal
- ☐ High-k dielectric materials under Field plates with thin Al_2O_3 underneath

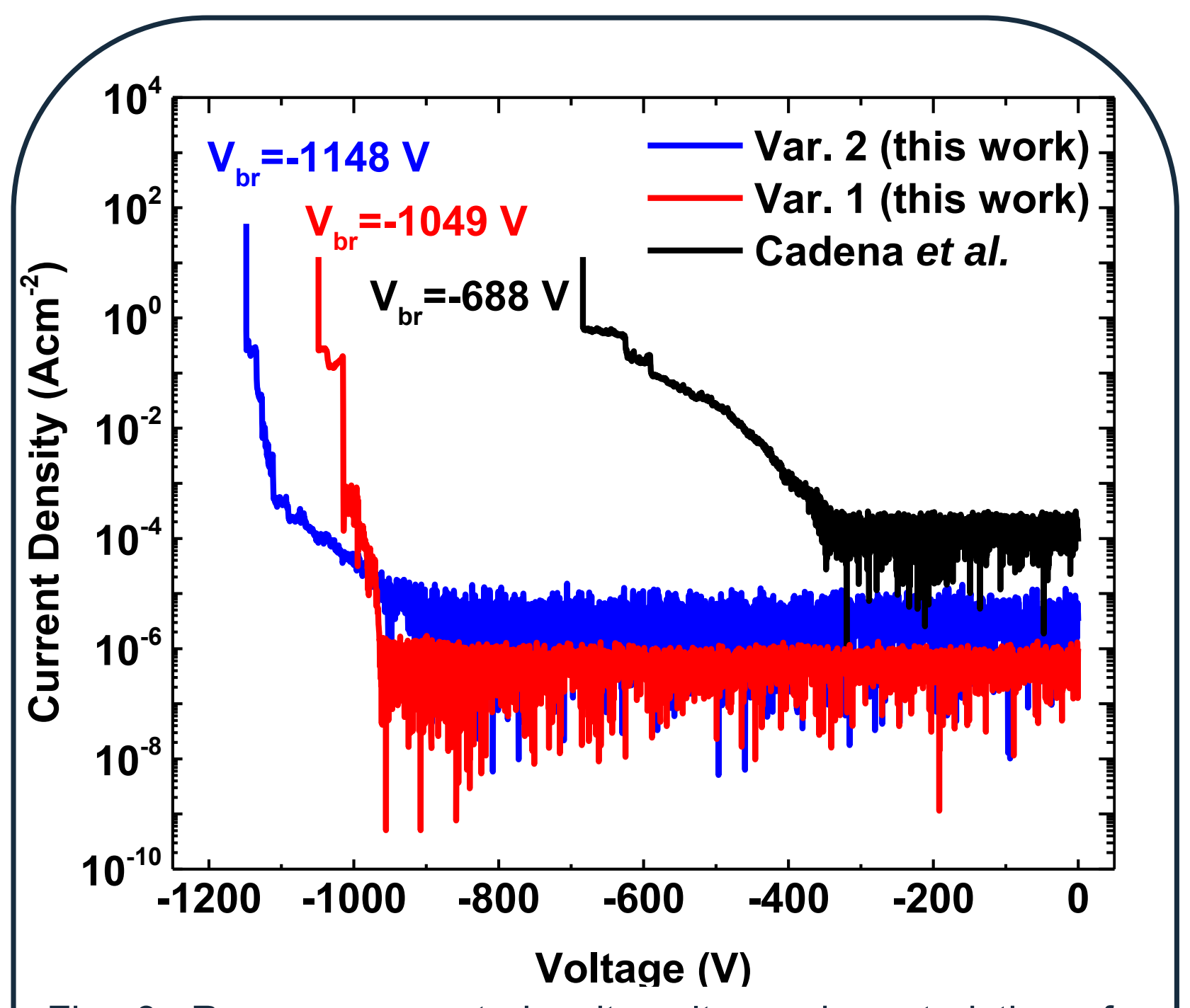

Fig. 3. Reverse current density-voltage characteristics of vertical β-Ga_2O_3 SBDs from previous work and this work (Vars. 1 and 2).

Device performance:

- ☐ Higher SBH helps reducing tunneling leakage.
- ☐ Field plate SBDs (this work) perform better than no-field plate ones.
- ☐ High-k dielectric under field plate provide better field management.
- ☐ TiO_2 further improves devices performance than ZrO_2.

Optical images of SEB damage:

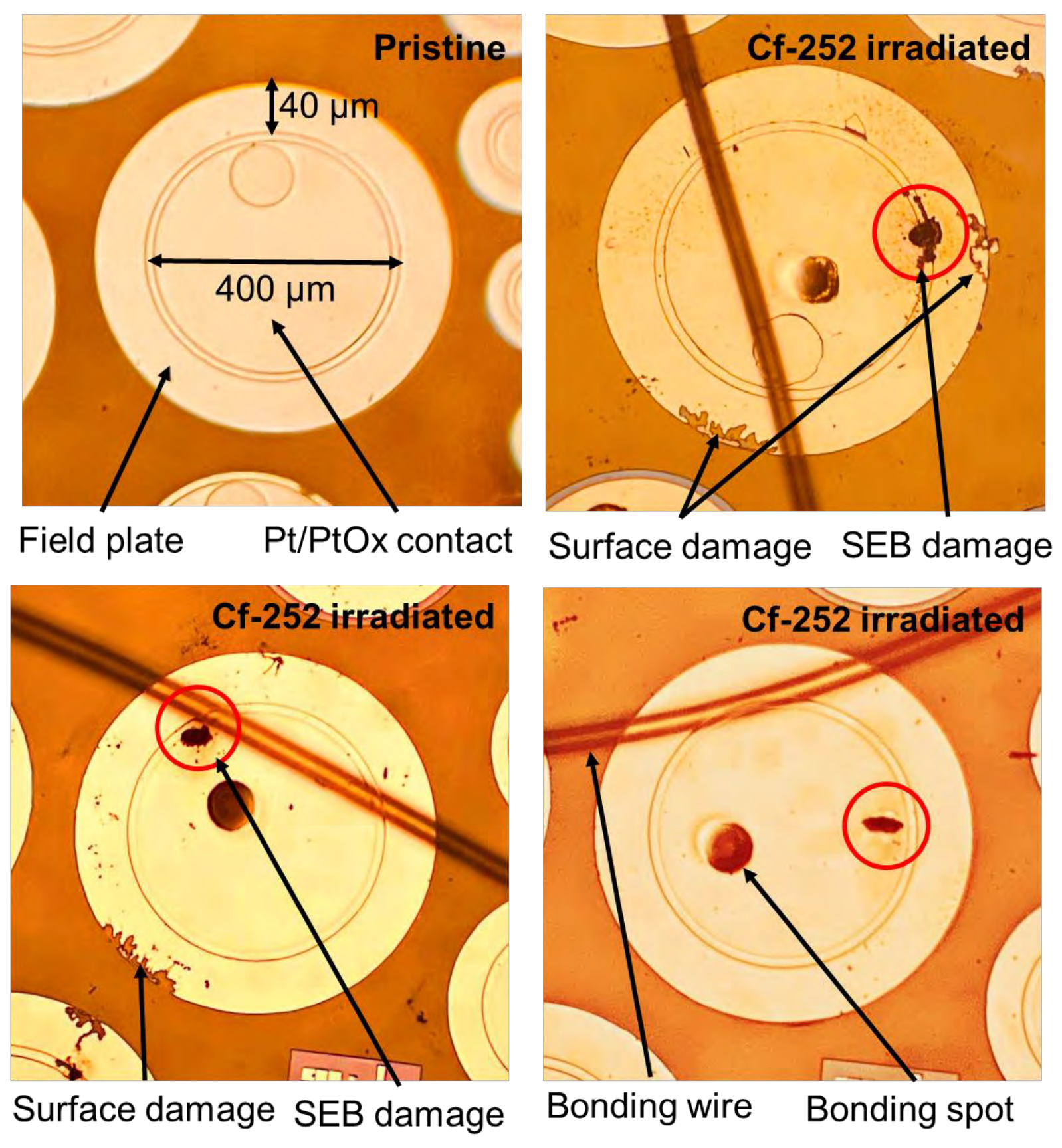

Fig. 4. Optical image of (a) pristine β-Ga_2O_3 SBD and (b)-(d) Cf-252 irradiated SBD. The small ring at the top is an artefact of the mask, and does not reflect any changes in the underlying structure. The circular dark spots in (b)-(d) are the solder pad locations. Physical SEB damage (red circles) is clearly evident near the field plates in (b)-(d). Surface damage regions that are not associated with measurable device degradation or failure are also noticeable in (b)-(c).

Radiation response: Cf-252

- ☐ Cf-252, LET = 10-45 MeV cm^2/mg, Range = 3-10 µm
- ☐ SBDs were reverse-biased for 30 min without radiation, then 30 min with radiation. The sequence was repeated until the device failed with Cf-252
- ☐ **SEB threshold avg. ~400 V (Var. 2 has a slightly higher avg.)**

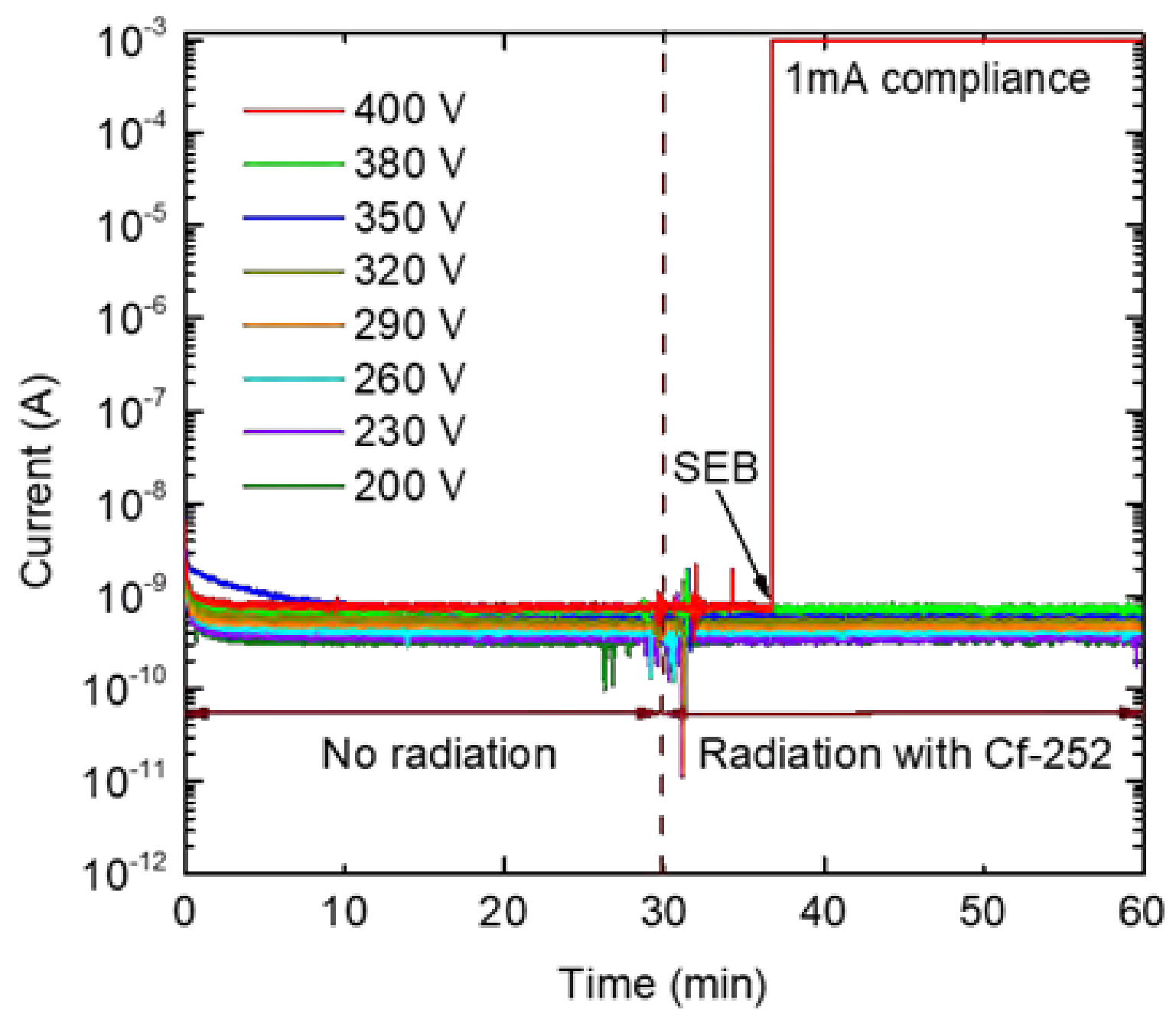

Fig. 5. Current vs. time for a β-Ga_2O_3 SBD (Var. 1) during Cf-252 irradiation under 200 V to 400 V reverse bias with a 30 V or 20 V increase in magnitude each time. The irradiation begins at 30 minutes. SEB is observed at 400 V.

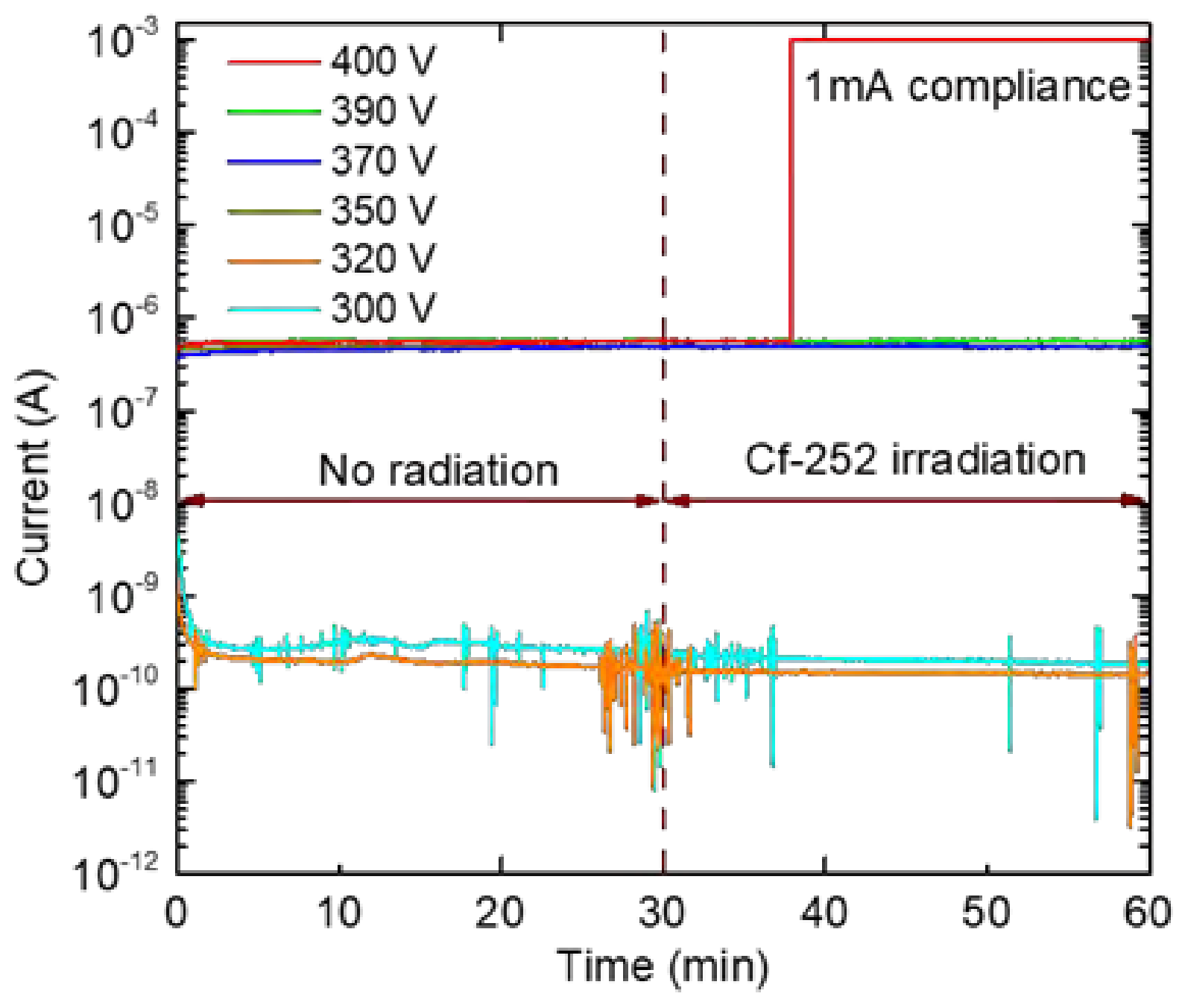

Fig. 6. Current vs. time for a β-Ga_2O_3 SBD (Var. 2) during Cf-252 irradiation under 200 V to 400 V reverse bias with a 30 V or 20 V increase in magnitude each time. The irradiation begins at 30 minutes. SEB is observed at 400 V.

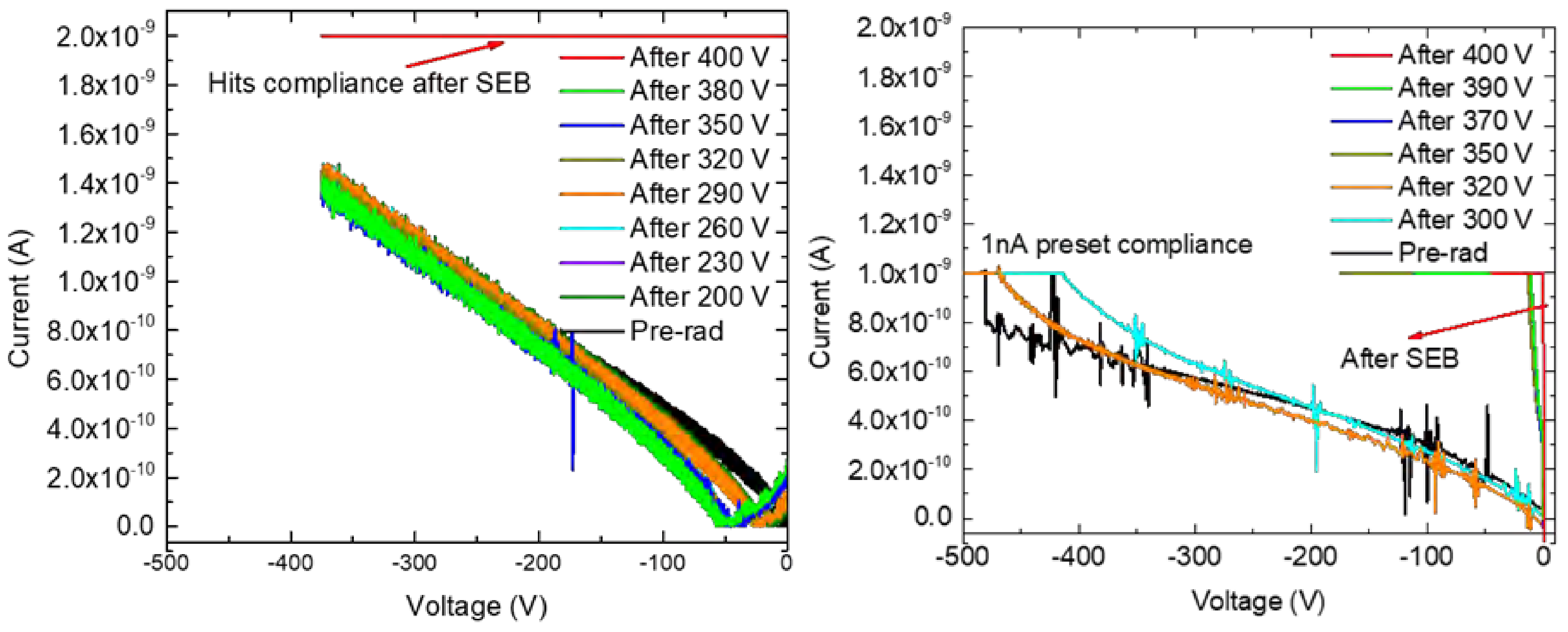

Fig. 7. Reverse bias *I-V* curves before and after the Cf-252 stress/irradiation cycles of Fig. 5 (Var. 1) and Fig. 6 (Var. 2). The part failed during the 400 V reverse bias irradiation for both cases.

Radiation response: Am-241

- ☐ 5.4 MeV Am-241, LET < 1 MeV cm^2/mg, Range > 10 µm
- ☐ Same test method as Cf-252
- ☐ **No degradation or damage up to electrical failure limit (in air)**

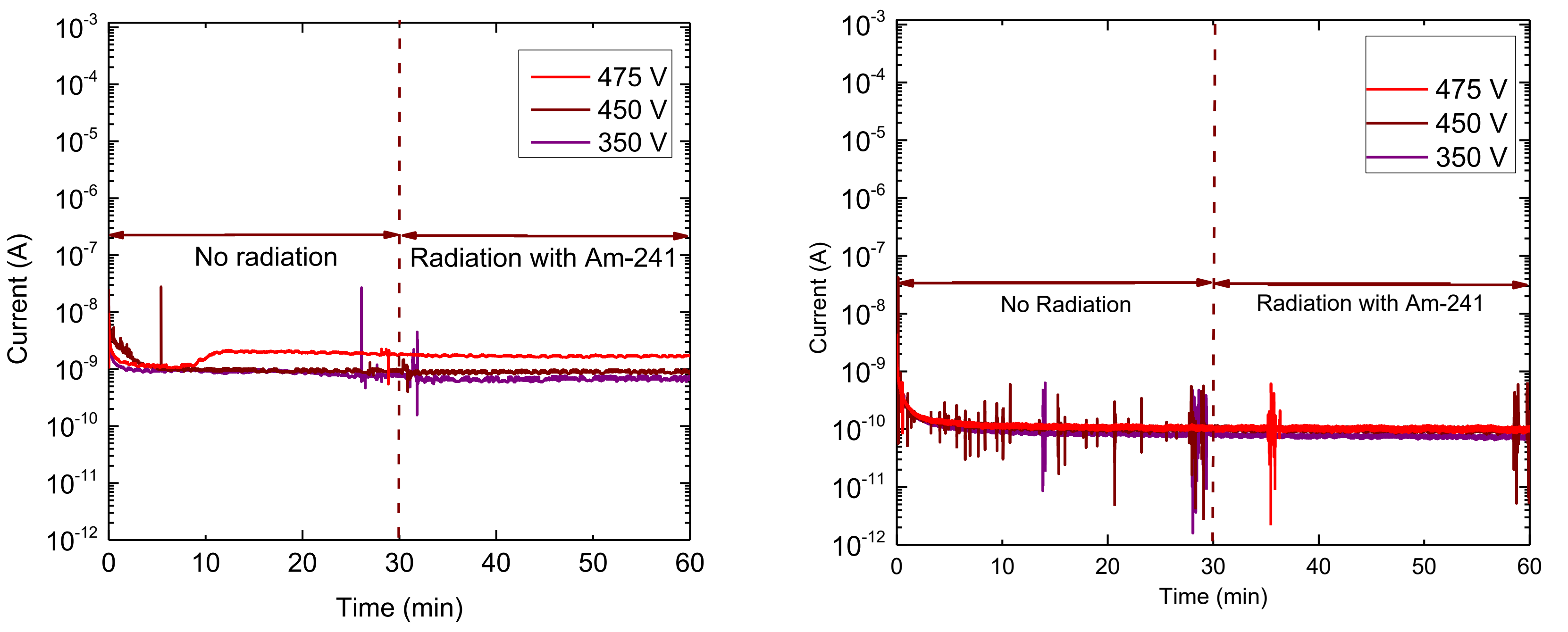

Fig. 8. Current vs. time for Var. 1 (left) and Var. 2 (right) β-Ga_2O_3 SBD for alpha-particle irradiation under reverse biases from 350 V to 475 V. The irradiation begins at 30 min. No significant effects on device response are observed.

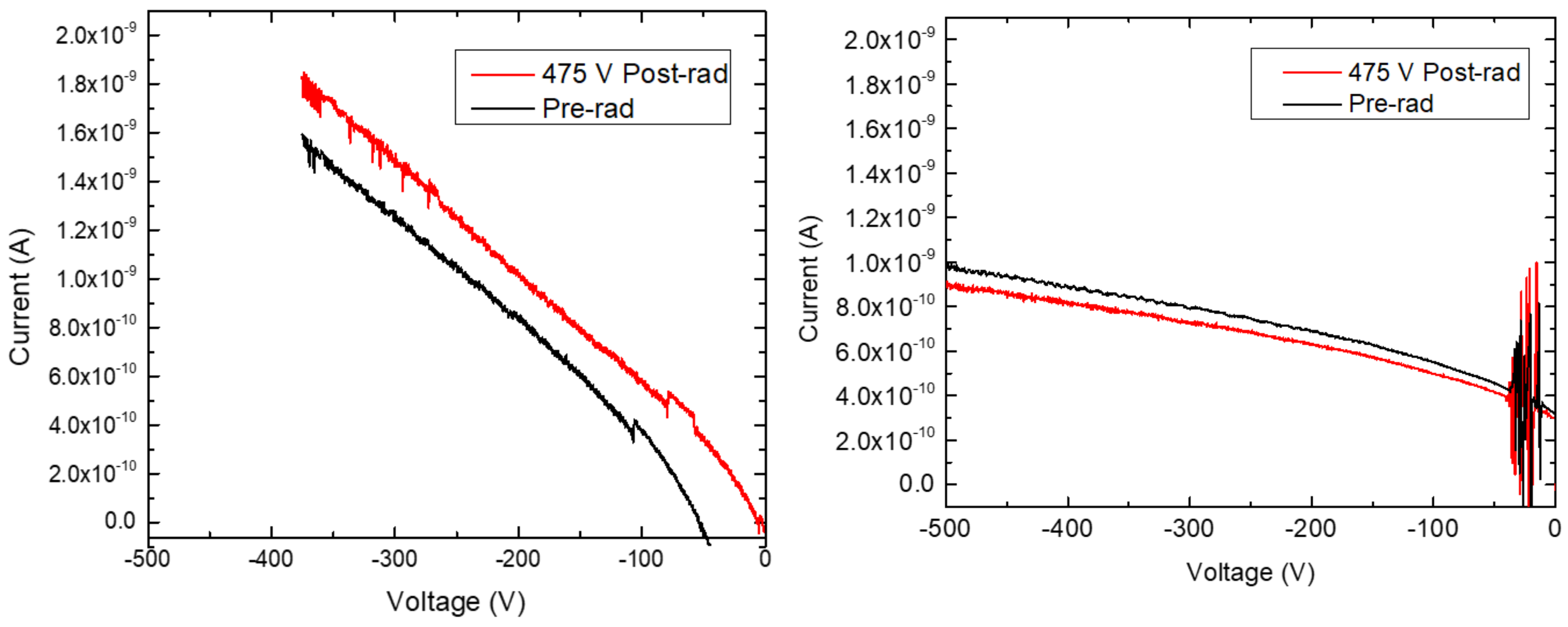

Fig. 9. Reverse bias *I-V* curves for a Var. 1 and Var. 2 β-Ga_2O_3 SBD before and after Am-241 alpha particle exposure up to a total fluence of 1.2 × 10^7 particles/cm^2. No significant changes are observed.

Conclusions

- ☐ Changes in metallization, field-plate dielectric, and edge-termination structures lead to improved reverse-breakdown characteristics and higher SEB threshold of β-Ga_2O_3 diodes.
- ☐ New variants are well resistant to alpha particle irradiation like the previous structure.
- ☐ Both process variants investigated in this work show improved SEB response to the devices of [1] for Cf-252 and short-range, heavy-ion irradiation.
- ☐ SEB damages occurring near the edge of the Schottky barrier contact making it the most vulnerable location of the device under ion irradiation

References

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[2] S. Islam *et al.*, *Dev. Res. Conf. (DRC)*, Santa Barbara, CA, USA, June 26-28, 2023
[3] E. Farzana *et al.*, *Apl. Mat.*, vol. 10, p. 1111041 (2022).