Co-funded by the European Union

MINISTRY OF EDUCATION, YOUTH AND SPORTS

FZU Institute of Physics of the Czech Academy of Sciences

ATLAS ITk

Low dose gamma irradiation study of ATLAS ITk MD8 diodes

M. Mikeštíková[a,*], V. Fadeyev[b], P. Federičová[a], P. Gallus[c], J. Kozáková[a], J. Kroll[a], M. Kůtová[a], J. Kvasnička[a], P. Tůma[a], M. Ullan[d], Y. Unno[e]

[a] Institute of Physics, Czech Academy of Sciences, Na Slovance 2, 18200 Prague 8, Czech Republic

[b] Santa Cruz Institute for Particle Physics (SCIPP), University of California, Santa Cruz, CA 95064, USA

[c] UJP PRAHA a.s., Nad Kamínkou 1345, 156 10 Prague – Zbraslav, Czech Republic

[d] Instituto de Microelectrónica de Barcelona (IMB-CNM), CSIC, Campus UAB-Bellaterra, 08193 Barcelona, Spain

[e] Institute of Particle and Nuclear Study, High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Motivation:

- Results from previous studies of gamma-irradiated diodes show that bulk current increases linearly with total ionizing dose (TID), while surface current saturates [1]. Unfortunately, the minimum TID in that study was 66 Mrad, making it impossible to determine at what TID surface current saturates. Studies of gamma-irradiated main bare sensors, ATLAS18 [2] and sensors on modules [3] showed a steep increase in total current already at low TIDs.
- This study shows detailed measurements of total, bulk, and surface currents in MD8 diodes after multiple low-dose gamma irradiations.
- The study also explores the dependence on temperature and annealing.

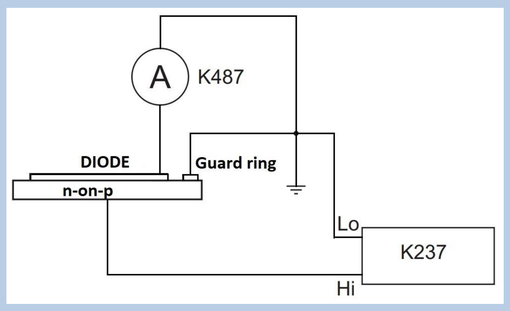
Samples:

- n^+-in-p float zone diodes MD8 from the ATLAS18 production wafers:
  - MD8 with p-stop implant between Bias (BR) and Guard Rings (GR) – MD8p
  - regular MD8 without p-stop – MD8

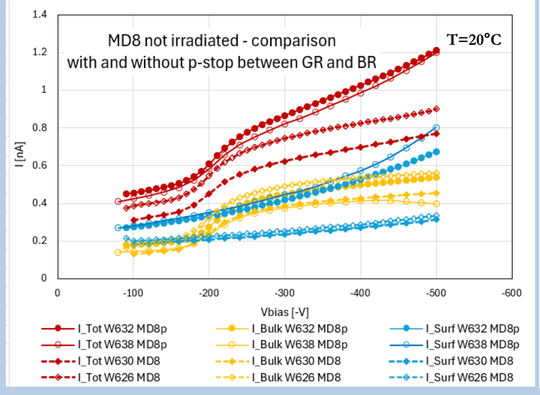
Irradiation:

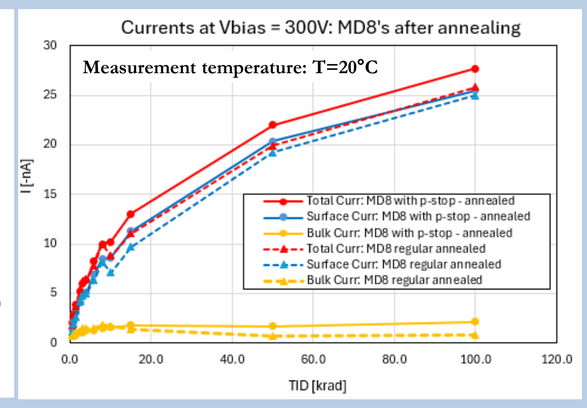
- Samples irradiated by ^{60}Co gamma
- **TID: 14 doses 0.5 – 100krad**
- Temperature < 35 °C
- Dose rate: 1.60 krad/min (up to 8 krad) and 8.5 krad/min (from 10 to 100 krad) in Si
- Dose rate uncertainty: <5%
- Irradiation in **Charge Particle Equilibrium box** according to ESA/SCC Basic Spec. No. 22900
  - Dose enhancement from low-energy scattered radiation is minimised by producing electron equilibrium
  - Uniform distribution of energy deposited in samples is ensured

Bulk, surface and total currents before and after irradiation:



- Great care was taken to properly determine bulk current flowing through active volume of diode **(I_{bulk})** bounded by guard ring and surface current dominating outside of this guard ring **(I_{sur})**
- Setup enables readings of total and bulk currents.
- Surface current is obtained as $I_{sur} = I_{tot} - I_{bulk}$.

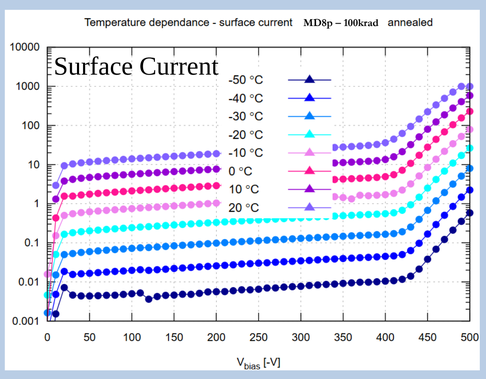


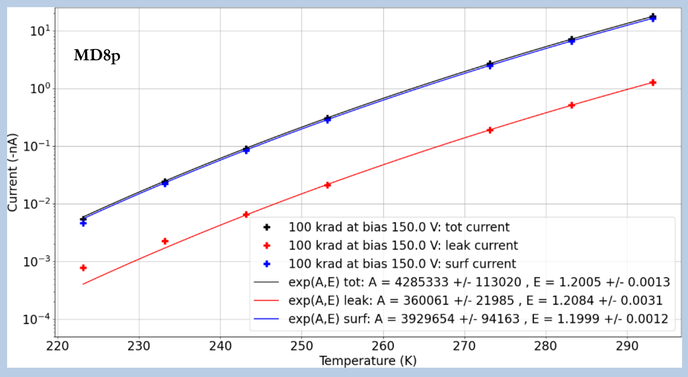


- Before irradiation of MD8 diode, bulk and surface currents are comparable in magnitude.
- Surface current is slightly larger in diodes with p-stop between BR and GR than in regular diodes.
- After irradiation, the surface current increases significantly even at the low TID.
- Bulk current remains relatively stable up to measured TID of 100 krad.

Temperature dependence of Total, Surface and Bulk currents after gamma irradiation

- Temperature dependence of current generated in Si bulk is summarized in [4] for proton and neutron irradiated silicon.
- In this study temperature dependence of total, surface and bulk currents after gamma irradiation were studied.





Temperature dependence of currents was measured in range -50°C - +20°C in MD8p diode and fitted by $I(T) = AT^2\exp(-\frac{E}{2kT})$, where k *is* Boltzmann constant ($k = 8.617 \times 10^{-5}$ eV·K^{-1}) with free parameters A and activation energy E for total, surface and bulk currents.

MD8p	E_{TOT}[eV]	E_{BULK}[eV]	E_{SURF}[eV]	A_{TOT}[nA/K²] x 10^6	A_{BULK}[nA/K²] x 10^6	A_{SURF}[nA/K²] x 10^6
10krad	1.209	1.192	1.211	2.101	0.166	1.951
50krad	1.184	1.172	1.185	2.281	0.137	2.148
100krad	1.201	1.208	1.200	4.285	0.360	3.930

Assumption:

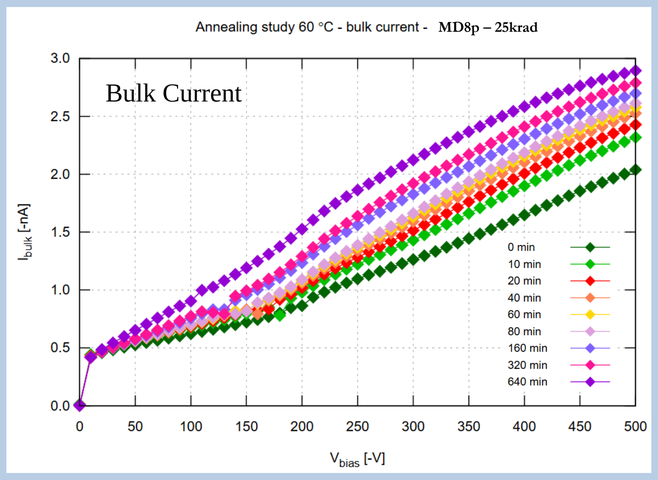
- E may differ for I_{BULK}, I_{SURF}, and I_{TOT} due to presence of the SiO_2 layer in surface.
- E may vary with dopant concentration. However, no significant change in radiation formed defects in bulk is expected after low gamma doses.

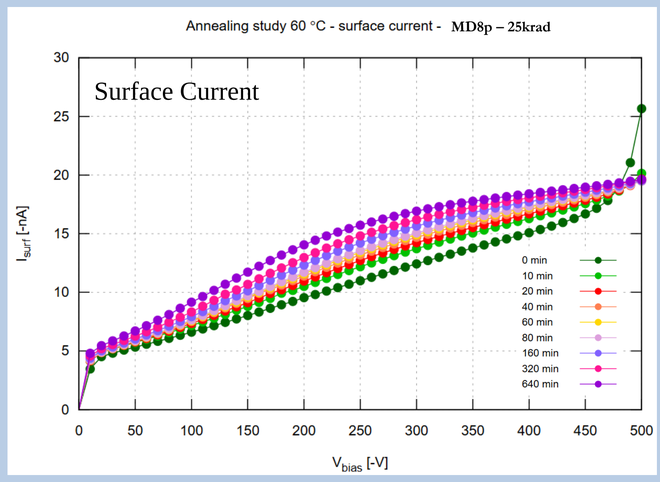
Results:

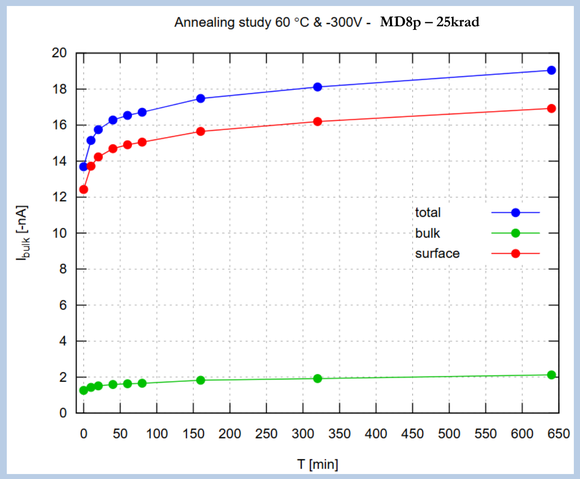
- No differences in activation energy were observed in temperature dependence fit for total, surface, and bulk currents.

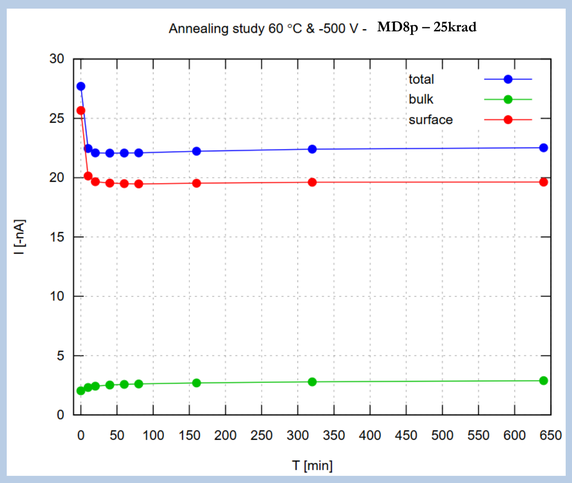
Annealing at 60°C:

- MD8 diode irradiated to 25krad underwent controlled annealing at 60°C for 10, 20, 40, 60, 80, 160, 320, and 640 minutes.
- Bulk current is slightly increasing with increasing time of annealing at 60°C
- The surface current at 480V has no annealing. Annealing is decreasing the soft-breakdown at higher voltage?





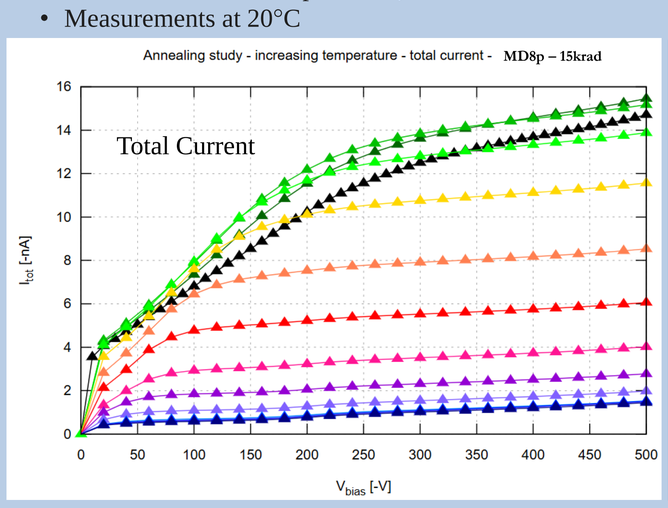


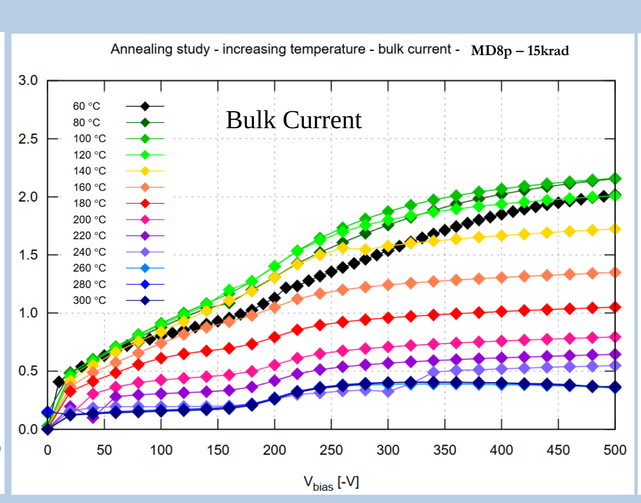


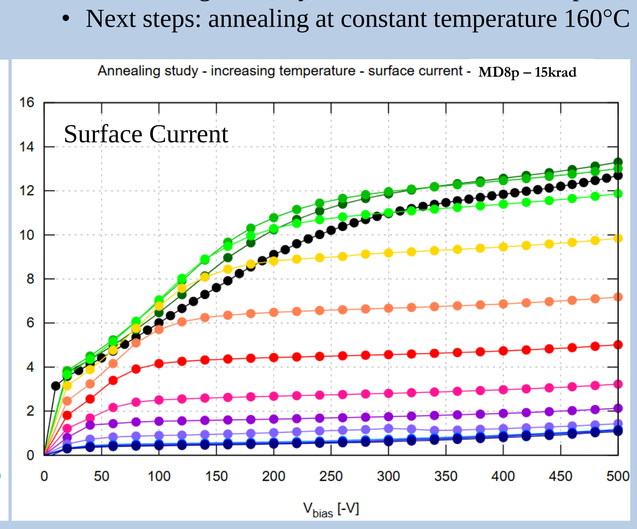
Annealing at increasing temperature 60°C - 300°C:

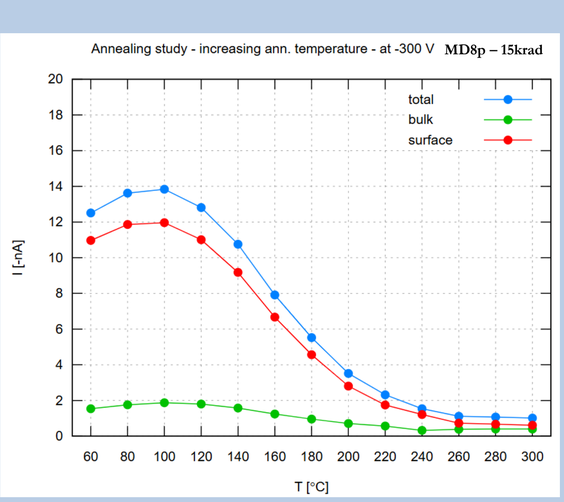
- MD8p diode irradiated to 15krad underwent annealing for 80 minutes at 60°C and after that isochronal annealing for 20 min at different temperatures, between 80 °C and 300 °C. Temperature was increased in steps of 20 °C.
- Measurements at 20°C

- Total, bulk, and surface currents show a slight increase up to 100°C, but at higher temperatures, currents decrease significantly, and return to levels comparable to those before irradiation
- Next steps: annealing at constant temperature 160°C









Conclusions:

- **Pre-Irradiation:** The bulk and surface currents are comparable in magnitude.
- **Post-Irradiation**: Total, bulk, and surface currents increases with increasing TID. At low TIDs, increase in total current is primarily driven by increase in surface current.
- No differences in activation energy for total, surface, and bulk currents were observed in temperature dependence fit for MD8 diodes.
- **Annealing at 60°C:** Total, bulk, and surface currents show a slight increase with annealing time.
- **Anneling at higher temperatures:** Total, bulk, and surface currents measured in full depletion conditions increase slightly for annealing temperatures up to 100°C. At temperatures > 100°C, all three currents decrease significantly, returning to levels comparable to pre-irradiation values. Radiation-induced defects in both bulk and surface, caused by gamma irradiation, seems to be completely annealed at high temperatures.

Acknowledgement:

This work was supported by the European Structural and Investment Funds and the Czech Ministry of Education, Youth and Sports of the Czech Republic via projects LM2023040 CERN-CZ and FORTE - CZ.02.01.01/00/22_008/0004632 and by the US Department of Energy, grant DE-SC0010107.

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PIXEL2024, Strasbourg, France, Nov 18th – Nov 22nd, 2024