4D particle tracking with Resistive AC-Coupled Silicon Detectors (RSD)

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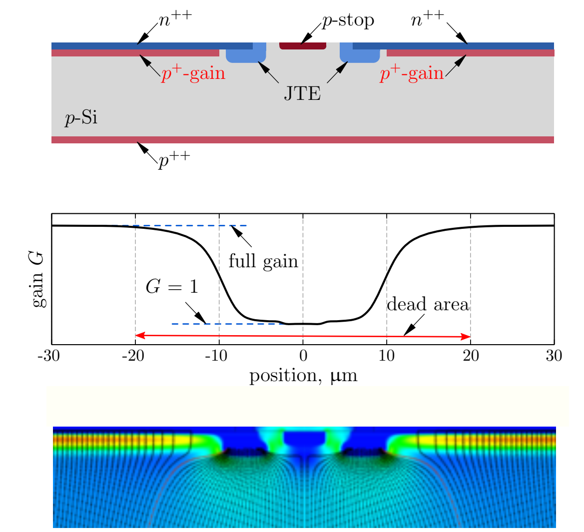
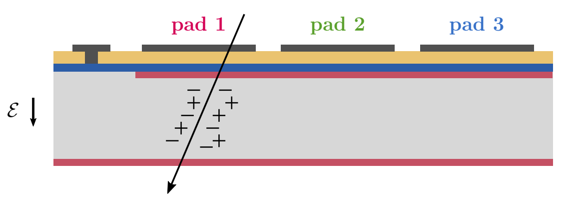
From LGAD to RSD

- To get rid of the dead area between pixels, as in standard LGADs, we implemented a new readout paradigm: the Resistive AC-Coupled Silicon Detector technology
- In RSD the readout is analogic, and no more binary, with bipolar signals
- RSD benefit from the good timing performances proper of LGADs, but with an increased capability to track particles in space: they are suitable for 4D tracking
- 100% fill-factor and analogic readout make possible to reconstruct the hit position with a precision ~2 orders of magnitude lower than the pad pitch





Development timeline

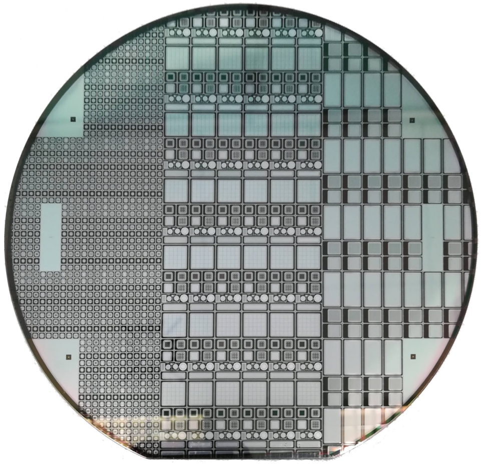
- The Resistive AC-Coupled Silicon Detector technology was first proposed for a proof of princicle in the CSN5 grant called RSD (PI: M. Mandurrino), in strong synergy with the UFSD project in Torino
- **First production** – submitted Jan **2019**
- Promising results and indication from RSD1
- Moreover, all the main signal properties are conserved in large-area RSD detectors
- **Second production** – submitted end of **2020**
- **What is missing?** – electrical tests at FBK, not yet arrived in Torino
- **Why perfect for Muon Collider?**

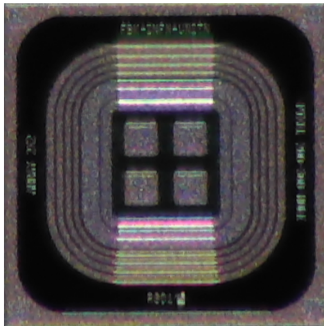
The first production: RSD1

Production layout and technological splits

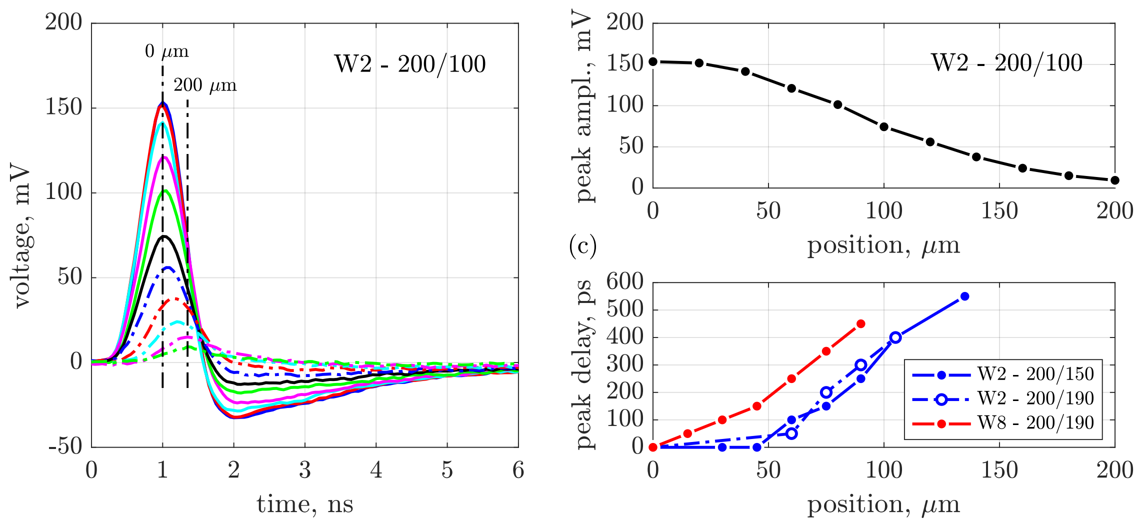
Split table of parameters implemented in RSD1 (2019)

wafer #	*n*-plus dose	*p*-gain dose	diel. thickness	substrate
1	B	0.92	Low	FZ
2	B	0.94	Low	FZ
3	B	0.94	Low	Epi
4	B	0.94	High	FZ
5	B	0.96	High	FZ
6	C	0.92	Low	Epi
7	C	0.94	Low	FZ
8	C	0.94	Low	FZ
9	C	0.96	Low	FZ
10	C	0.96	High	FZ
11	D	0.92	Low	FZ
12	D	0.94	Low	Epi
13	D	0.94	Low	FZ
14	D	0.96	High	Epi
15	D	0.96	High	FZ





RSD and 4D-tracking – RSD1



Correlation between hit position and signal amplitude/delay

Laser measurements

RSD1	Gain 12		Gain 17		Gain 24	
	σ_x [μm]	σ_t [ps]	σ_x [μm]	σ_t [ps]	σ_x [μm]	σ_t [ps]
100/70	3.2	17.6	2.8	15.3	2.5	13.9
200/100	8.6	31.1	6.2	22.3	-	-
200/190	17.9	58.7	14.3	62.6	8.8	59.9
500/200	27.3	45.7	20.6	34.6	20.6	32.6

The space/time resolution increase at high gain and small pad pitch/size

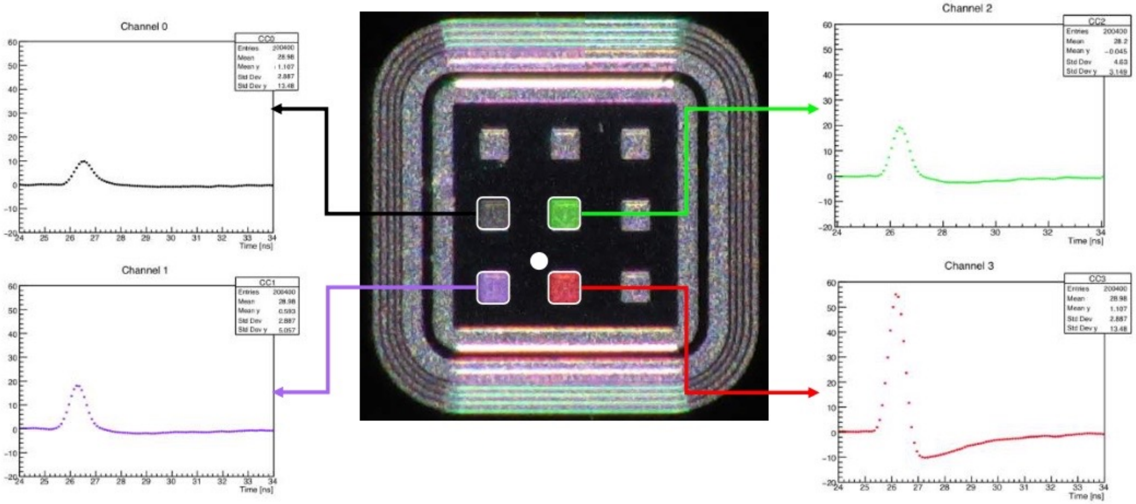
FNAL testbeam (RSD 200/100)

$\sigma_x = \sim 5\ \mu m$ and $\sigma_t = \sim 40$ ps

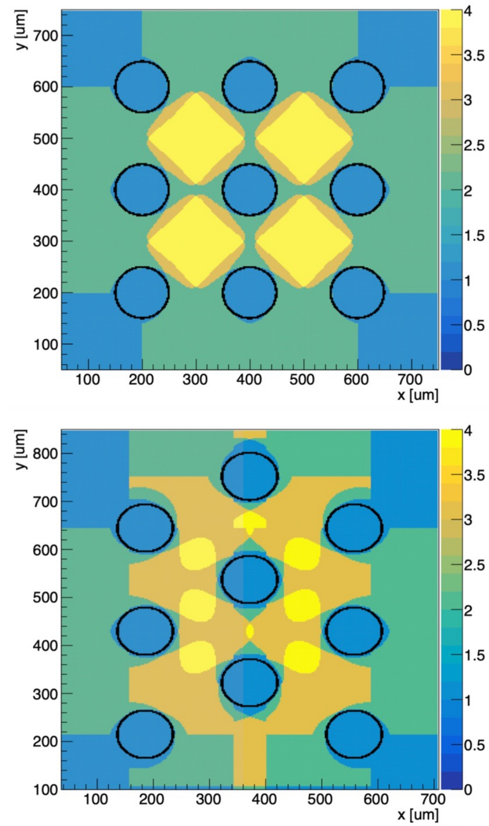
4D-tracking with RSD

Hit reconstruction

amplitude-weighted centroids



ML algorithms



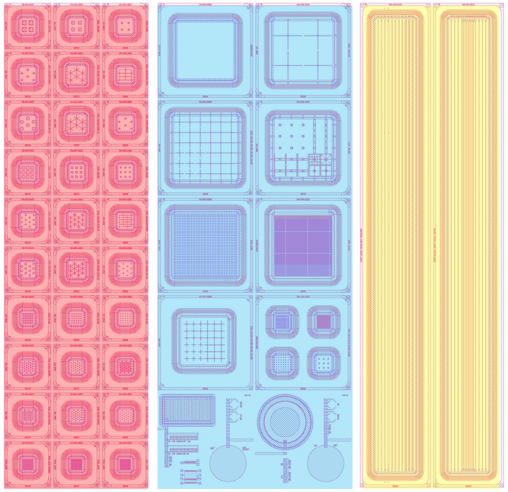
The second production: RSD2

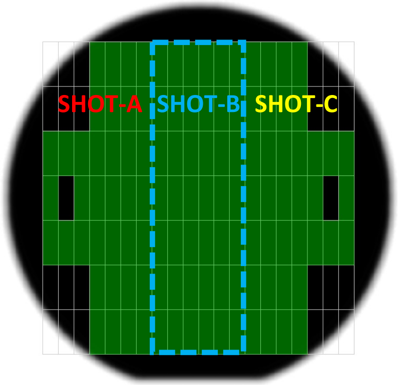
Production layout and technological splits

Split table of parameters implemented in RSD2 (2021)

wafer #	*n*-plus dose	*p*-gain dose	met. thickness	substrate	C
1	A	0.96	thick	FZ	N
2	A	0.96	normal	FZ	N
3	A	0.98	normal	FZ	N
4	A	1.00	normal	FZ	N
5	B	1.00	normal	FZ	N
6	B	1.00	normal	Epi	N
7	B	0.98	normal	FZ	N
8	B	0.96	normal	Epi	N
9	B	0.96	normal	Epi	N
10	B	0.96	normal	Epi	Y
11	C	0.96	normal	Epi	N
12	C	0.96	normal	Epi	Y
13	C	0.98	normal	FZ	N
14	C	0.98	normal	Epi	N
15	C	0.94	normal	FZ	N

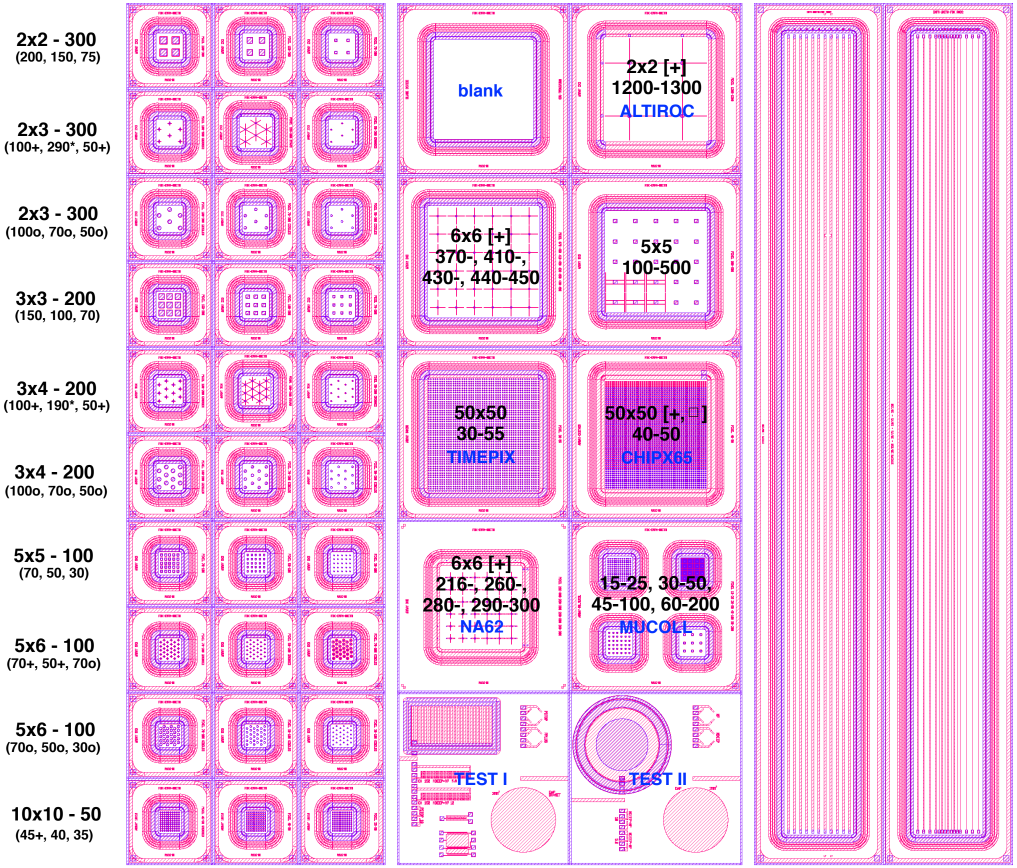
Low dielectric thickness
Epi: 45 μm / FZ: 55 μm





The second production: RSD2

Sensors layout



Testing campaigns

- **RSD1:**
  - measurements on irradiated structures
- **RSD2:**
  - $I(V)$ and $C(V)$
  - gain measurements
  - resistivity
  - signal properties
  - irradiation campaigns
  - test-beams

RSD for RD_MUCOL

Present RSD are designed and produced for different general purpose particle-physics experiments (**thick substrates, medium granularity, very low gain**)

RSD optimized for a muon collider need for:

- **low material budget** (thin handle wafers)
- the **optimal geometry** to comply with the physics requirements
- production of **large-area** detectors
- **radiation-hardness** studies

Costs for one RSD production at FBK:

- batch of **25 6-inches epitaxial wafers** and production under the **INFN-FBK collaboration framework**: **30 kEuro**

Selected references on RSD

- LGAD design: https://doi.org/10.1201/9781003131946 (Chapter 3)
- RSD design: http://dx.doi.org/10.1016/j.nima.2020.163479
- First RSD1 tests: http://dx.doi.org/10.1109/LED.2019.2943242
- FNAL testbeam: https://arxiv.org/abs/2007.09528

Thank you!

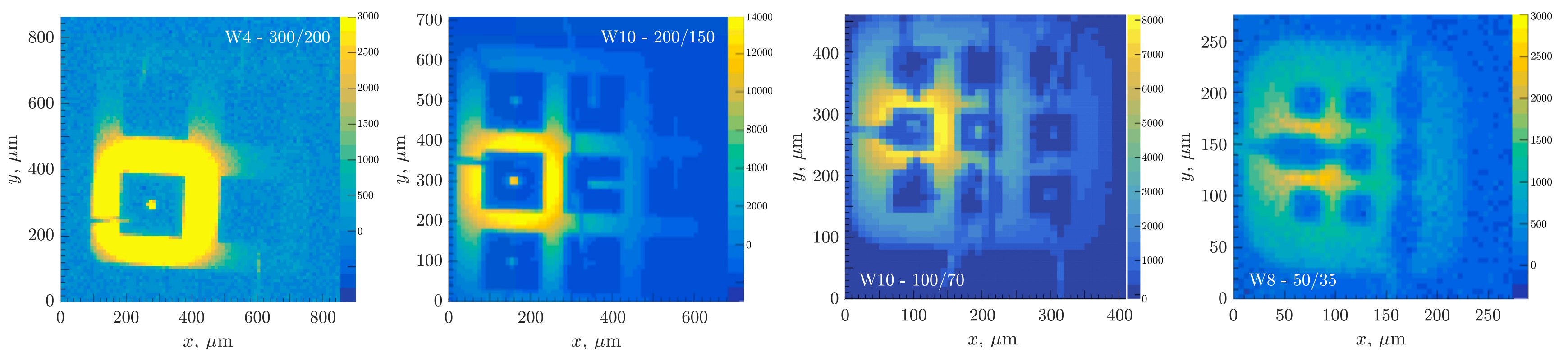
Backup

The first production: RSD1

Detector testing

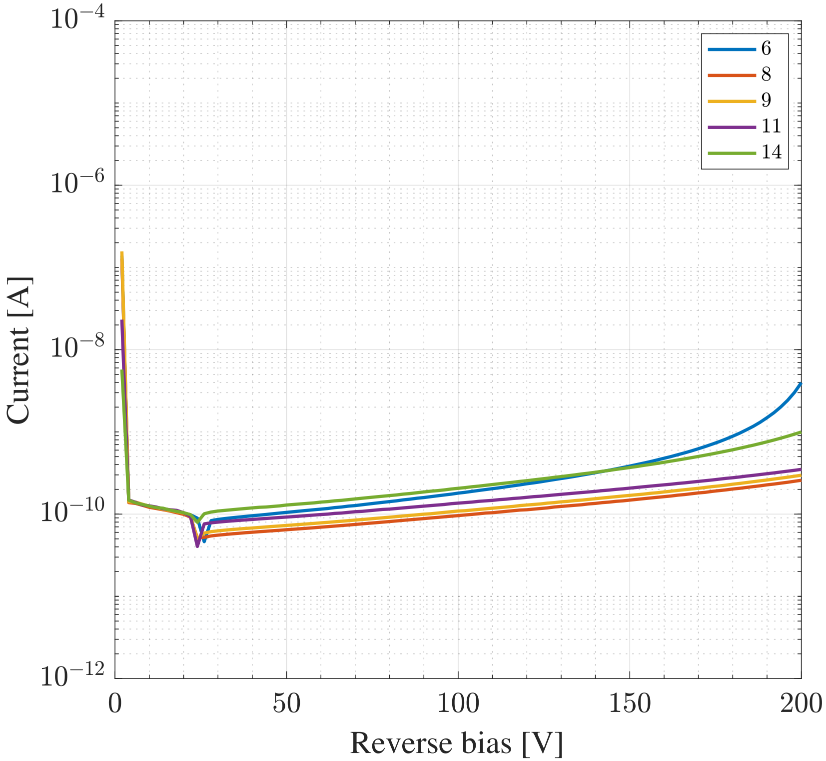
Electrical characterization campaigns on RSD1 have shown that FBK is able to reproduce the **optimal physical-technological parameters** we found at INFN through **numerical modeling** with high precision, reproducibility and homogeneity.

We also demonstrated to reach the challenging goal of producing (working) **100% fill-factor** Silicon detectors with **internal gain** and **high-segmentation level**:



The second production: RSD2

(Preliminary) electrical tests at FBK



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4	A	1.00	normal	FZ	N
5	B	1.00	normal	FZ	N
6	B	1.00	normal	Epi	N
7	B	0.98	normal	FZ	N
8	B	0.96	normal	Epi	N
9	B	0.96	normal	Epi	N
10	B	0.96	normal	Epi	Y
11	C	0.96	normal	Epi	N
12	C	0.96	normal	Epi	Y
13	C	0.98	normal	FZ	N
14	C	0.98	normal	Epi	N
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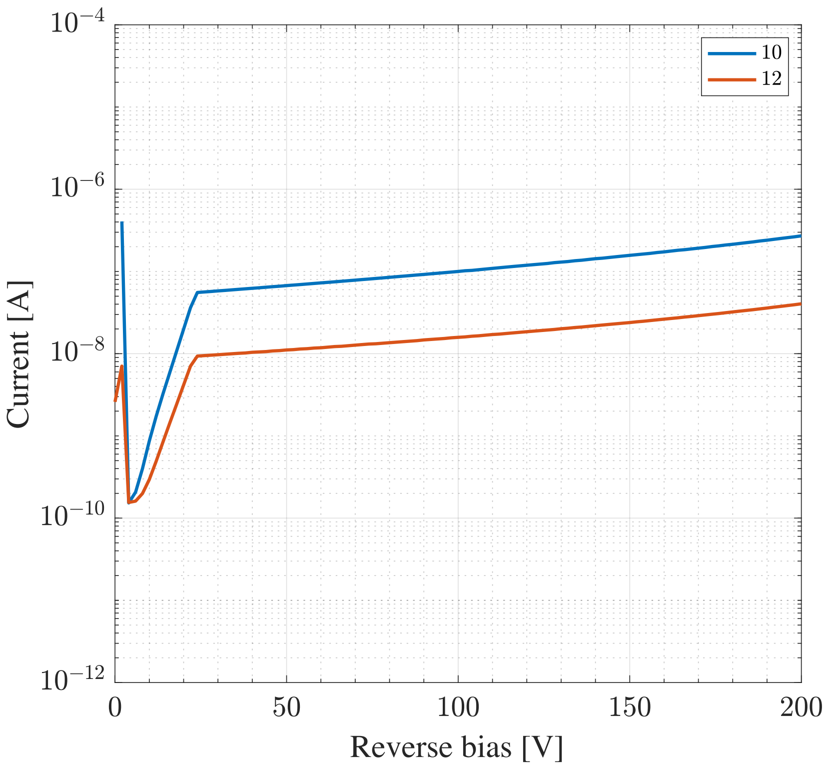

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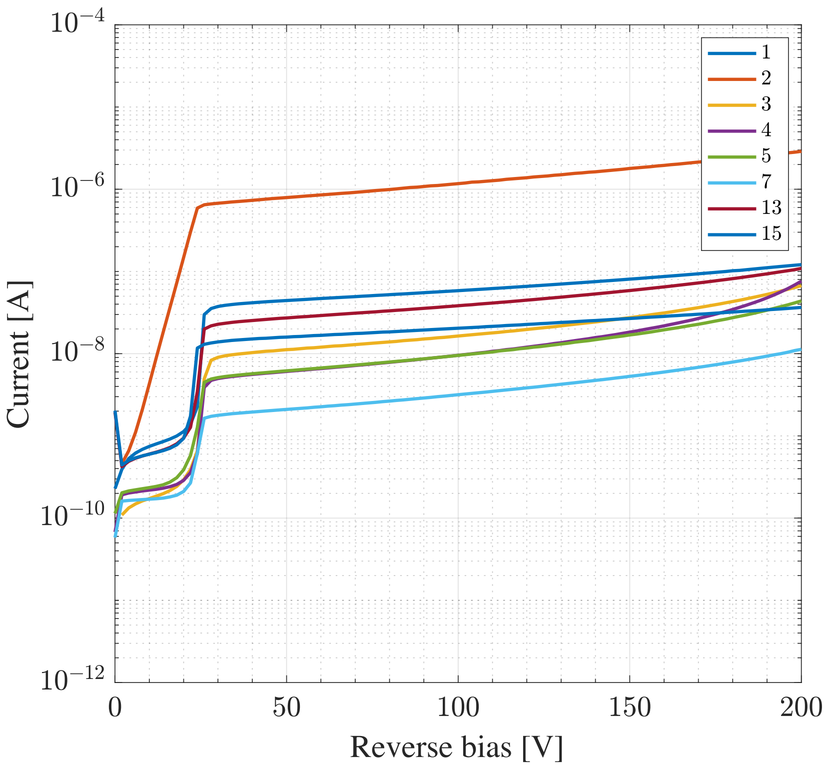

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