Ioffe Physical Technical Institute

Saint Petersburg Electrotechnical University "LETI"

Impact of bulk generation current on operation of floating rings in silicon detectors

E. Verbitskaya, V. Eremin, N. Safonova*

Ioffe Physical-Technical Institute of Russian Academy of Sciences
St. Petersburg, Russia

**also Saint-Petersburg Electrotechnical University "LETI", St. Petersburg, Russia*

16 RD50 Workshop
Barcelona, May 31 – June 2, 2010

Outline

- Motivation
- Experimental
- Results on potential distribution between the floating rings of VTS and I-V characteristics of interring gaps
- Physical model of potential distribution controlled by carrier injection
- Influence of detector parameters on potential distribution

Conclusions

Motivation

Current subjects of Ioffe team: ***<u>specified at 15 RD50 workshop</u>***

- Strip detector performance at SLHC: very high fluences and enhanced bulk generated current →
  (14&15 RD50: Avalanche multiplication in CCE, segment isolation)

- Development of operational model for:
  - current terminating structure (CTS, edgeless detectors) (13 RD50)
  - voltage terminating structure (VTS) (16 RD50)

- Noise performance of spectroscopic strip detectors (GSI, Darmstadt)

Motivation

Goal: stabilization of I-V characteristics at high voltage operation:

- stabilization of ring potentials
- reduction of electric field near the sensitive p^+-n junction

Known methods: facets, doping (active edge), floating rings (VTS)

VTS: floating rings around pad electrode that extend towards chip periphery:

developed for

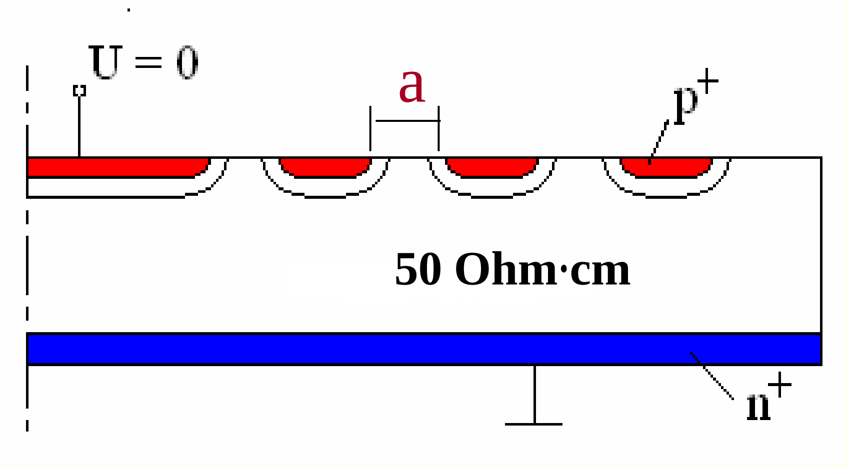
High V and power Si devices:
diodes, thyristors

- low ρ (10–100) Ohm·cm;
- deep gradual p-n junction (tens μm);
- high current (mA)

Detectors – principal difference in:

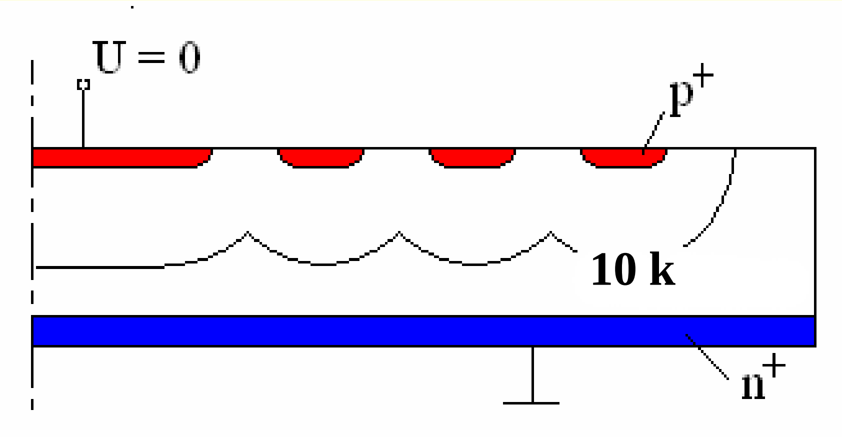
- high ρ (1–20) Ohm·cm;
- shallow abrupt junction (≤1 μm);
- low current (nA/cm^2/100 μm)
- **radiation hardness of VTS!?**

Electrostatic model of potential distribution



a – gap width

Low ρ

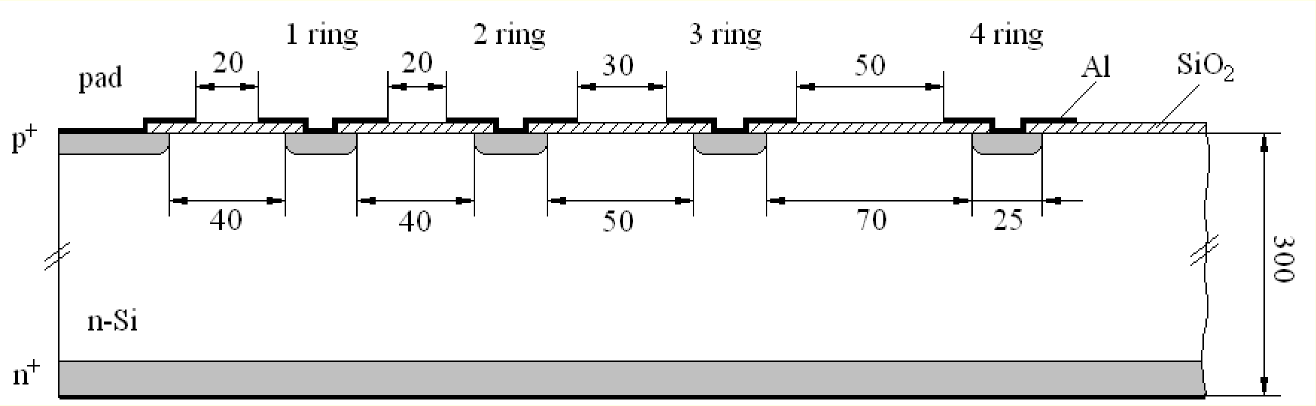


High ρ

At $V_{pad} = 0$ and $\varphi_c = 0.6$ V: SCRs of the rings should be connected and potentials of the rings the same – **fails** - disagrees with experiment!

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Experimental



Our standard test structure:
p^+-n-n^+
4 floating rings

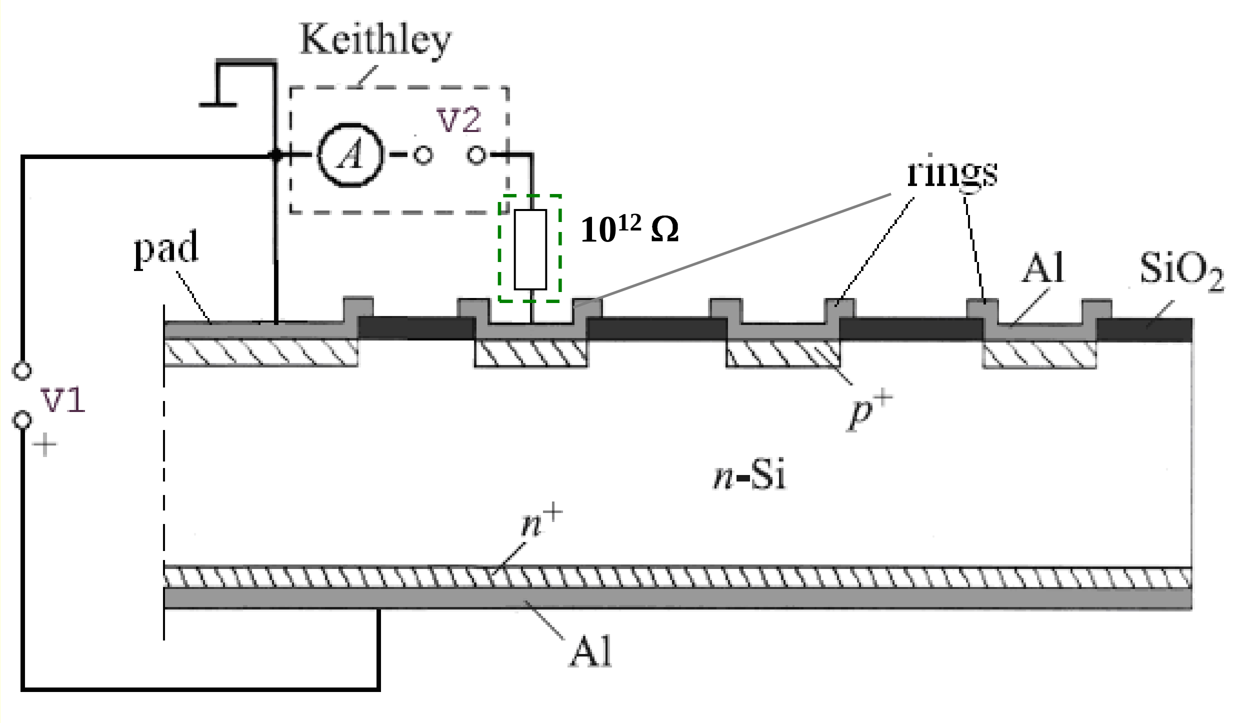
group	sample	number of rings	*d* (μm)	n-Si	U_{fd} (V)	ρ (kΩ·cm)
I	1	4	300	FZ Topsil	12	24.6
	2	4	300	FZ Wacker	65	4.5
	3	4	300	CZ Okmetik	230	1.3
II	4	8	300	FZ Topsil	80	3.7
	5	8	300	FZ Topsil	80	3.7
	6	8	**1000**	FZ Topsil	**160**	20
	7	8	**1000**	FZ Topsil	**160**	20

Experimental

Measurement:

potential of the rings

I-V characteristics of the gaps

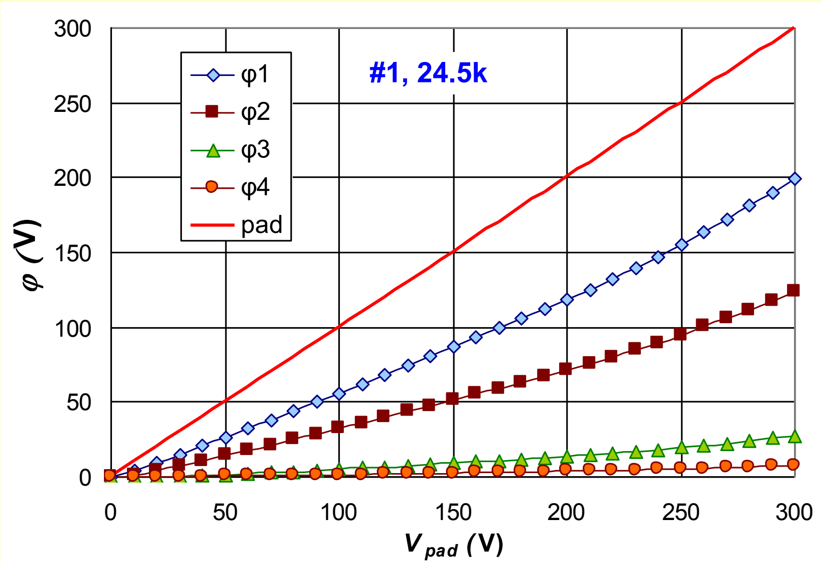


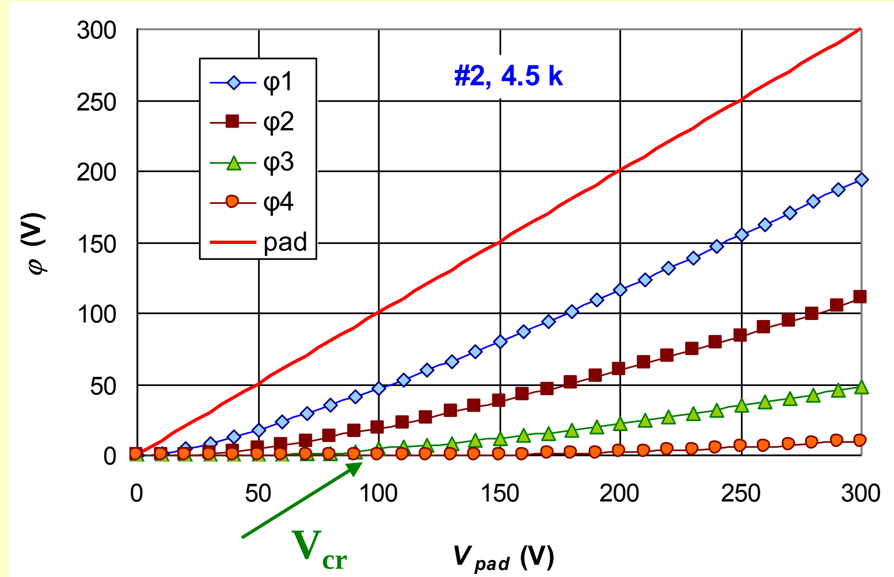
Gaps:
pad-ring,
interring

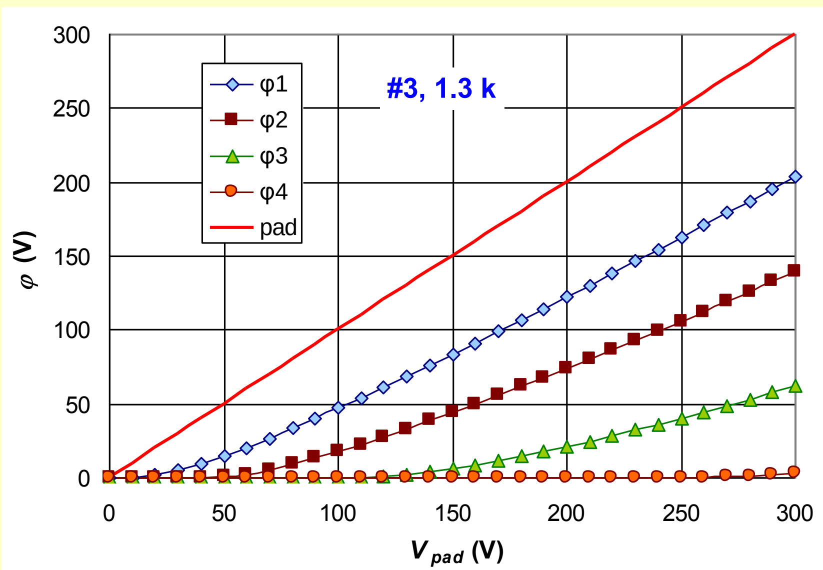
E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Potential distribution in VTS

different ρ





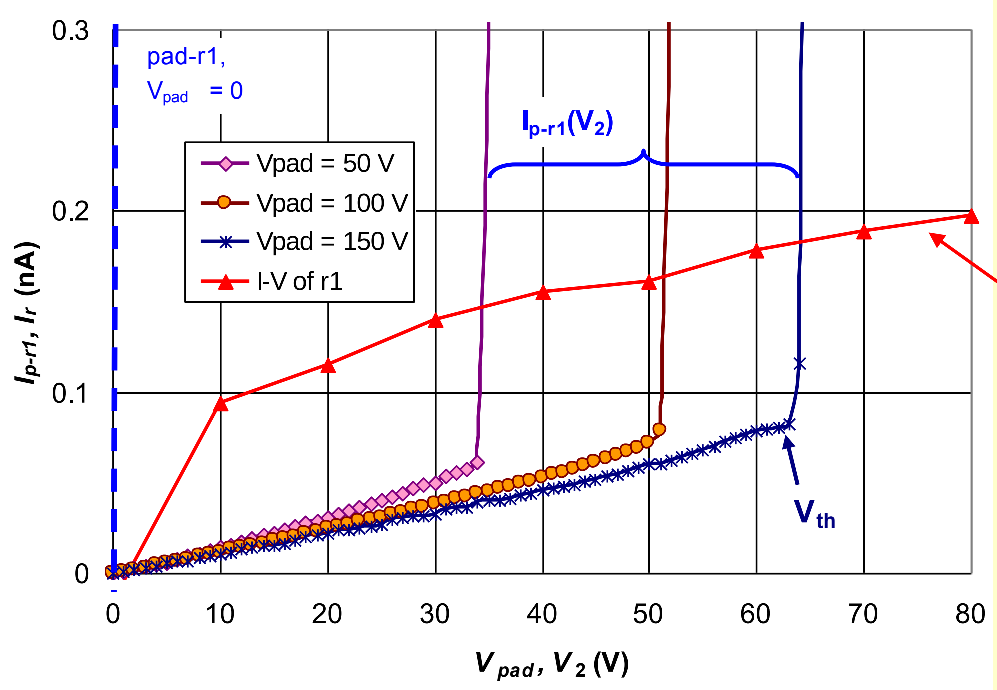


φ starts to rise at $V_{pad} = V_{cr}$

V_{cr} ↑ as ρ ↓

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

I-V characteristics of the gaps



Gap pad-r1

ρ = 4.6 k

$I_{p-r1}(V_2)$ - current in the gap (offset extracted)

V_2 – bias voltage applied to the gap

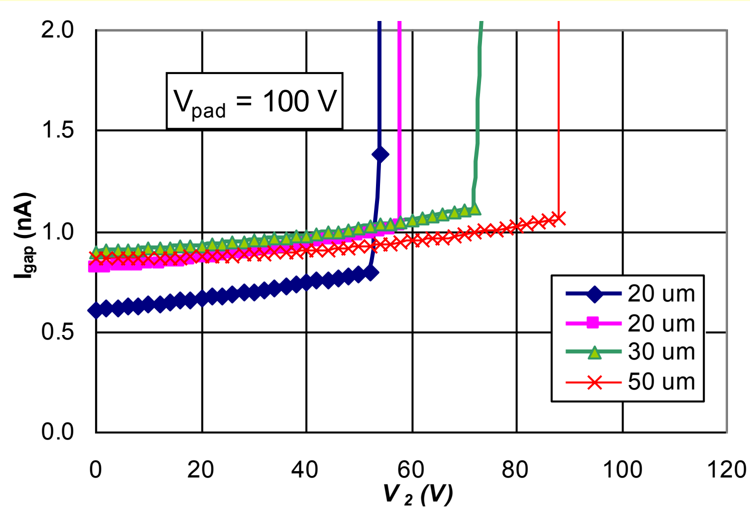
Red – I-V of r1

Two regions in $I_{pad-r1}(V_2)$:

Low current (leakage in the gap)

<u>Sharp rise</u> of the current at V_2 = V_{th} – **threshold voltage**

- injection current between p-n junctions

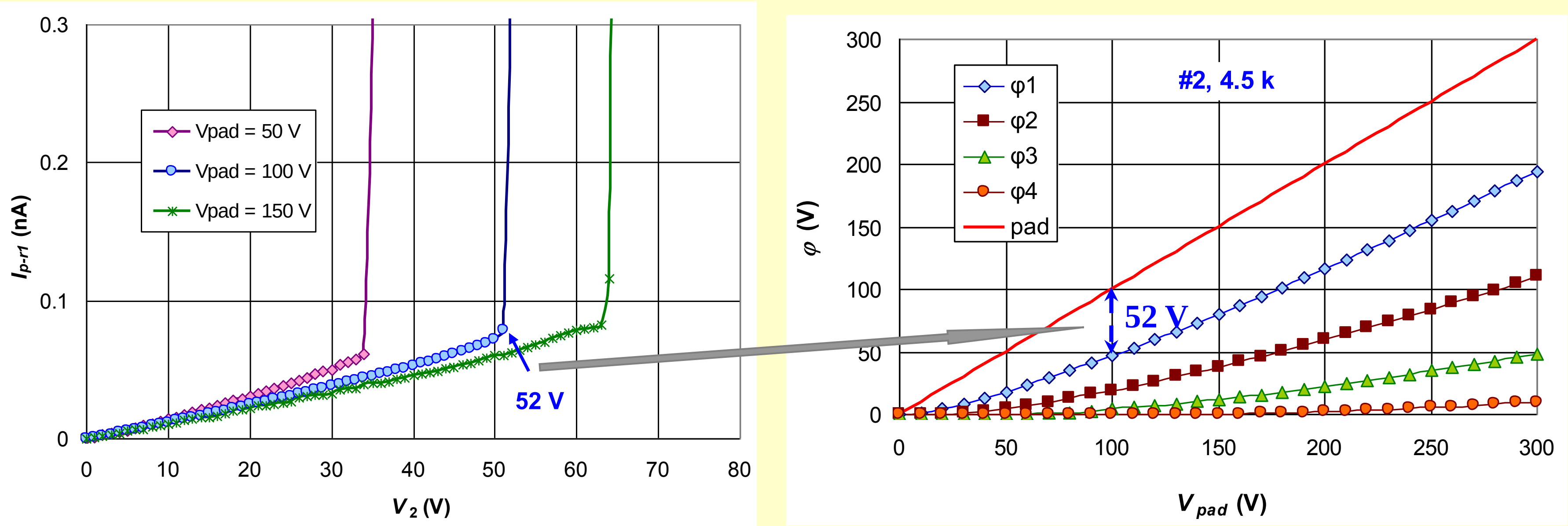


V_{th} depends on interring gap width *a*:

V_{th} ↑ as interring gap width *a* ↑

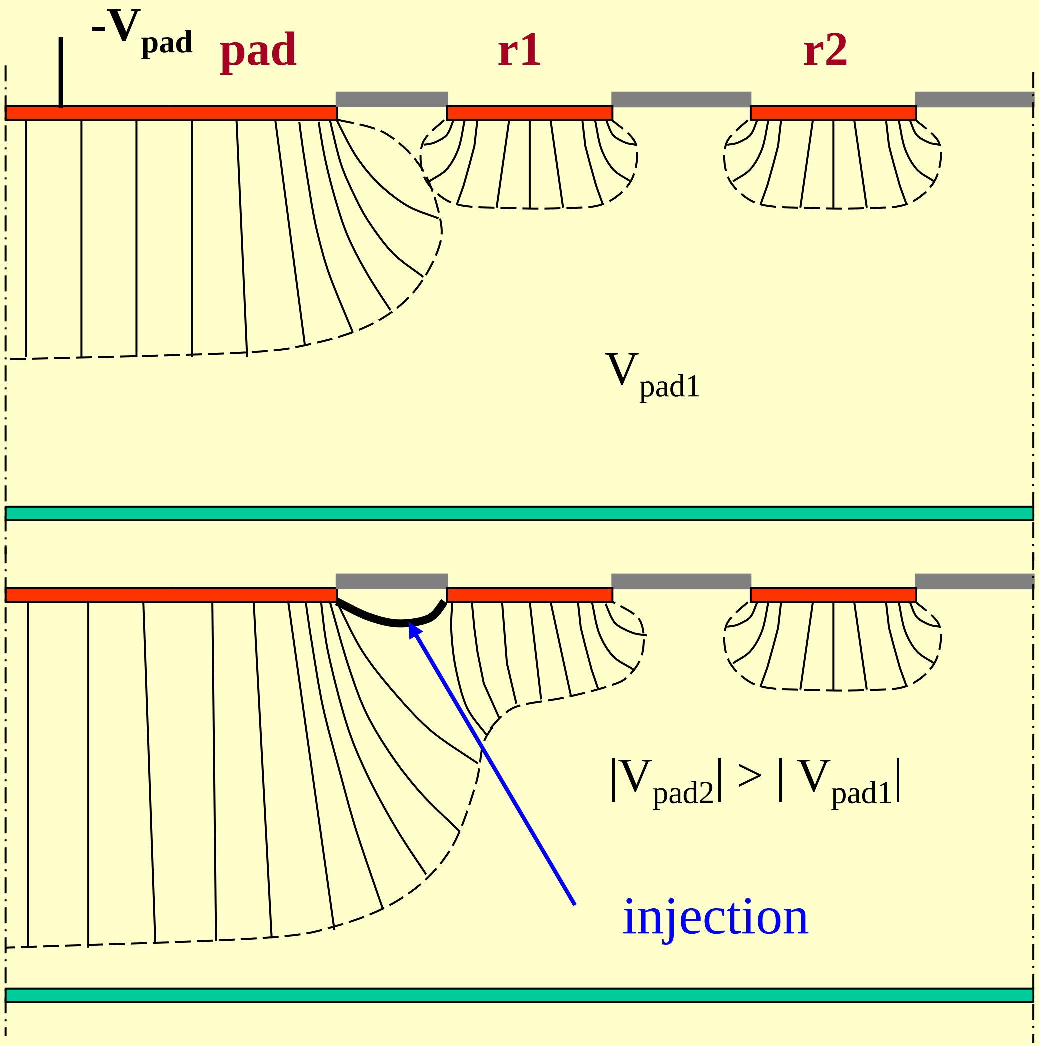
E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Potentials at the rings



- Potential difference at the gap equals to the threshold voltage V_{th} at which injection starts →
- Potential distribution between the rings is governed by injection current in the gap (forward biased junction operated at high lateral field))

Injection model of potential distribution



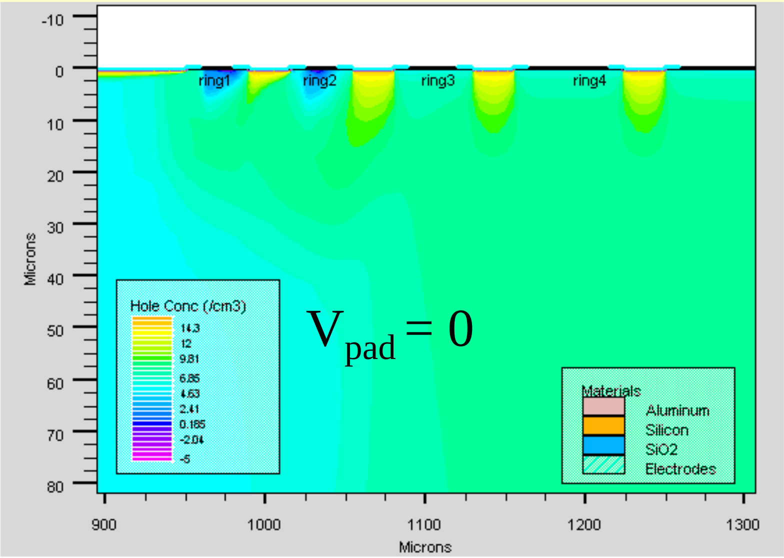
Potential stabilization:
hole transfer to the ring
+ hole injection in the gap

Criteria for potential stabilization at the ring –

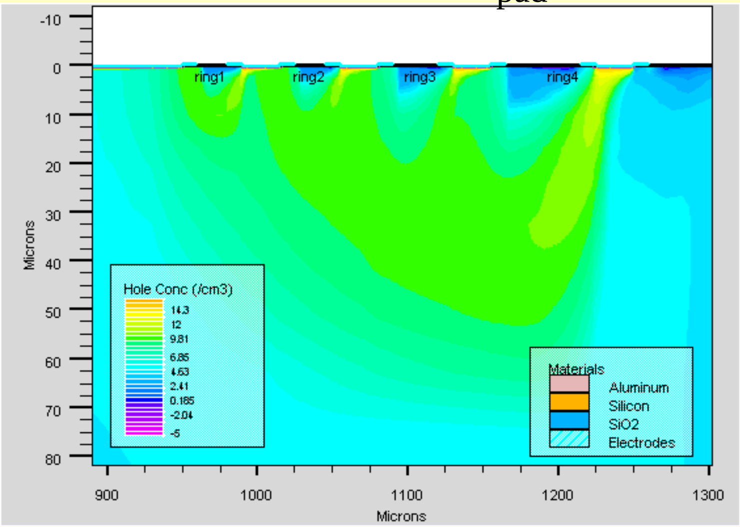
- trajectory between the rings for hole injection from the ring with lower negative potential;
- low leakage in the gap: $I_{leak} < I_{gen}$ near the ring (individual for rings, less sensitive gap pad-ring - maximum I_{gen} near pad; interface properties)

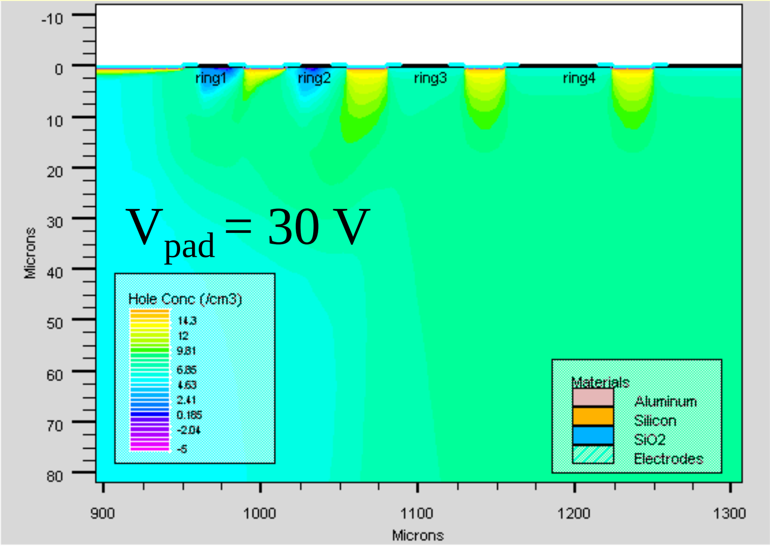
E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Distribution of holes in the gaps



V_{pad} = 300 V





As V_{pad} increases,
holes are extracted inside the gaps

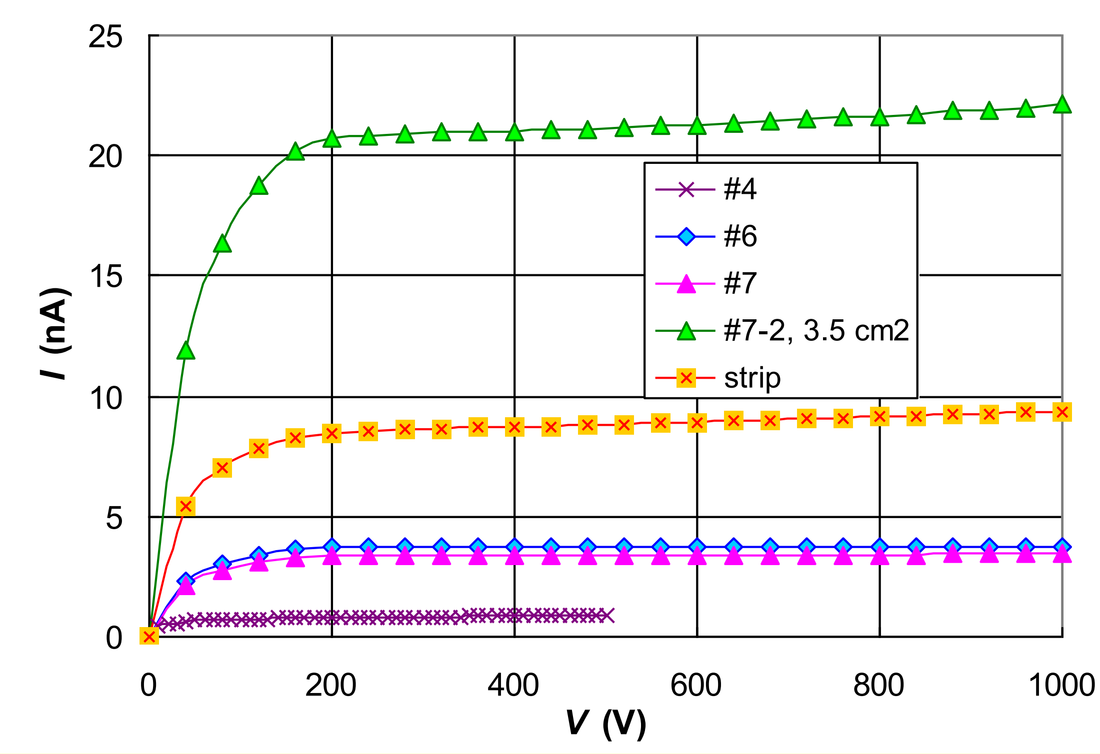
Needed for detailed description – Q at the interface, topology of rings

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Detectors with 1 mm thickness: I-V characteristics

d = 1 mm; ρ = 20 k; V_{fd} = 160 V; **V_{max} = 1000 V**

VTS with 8 rings



4: d = 300 μm; I ≈ 1 nA

others: 1 mm

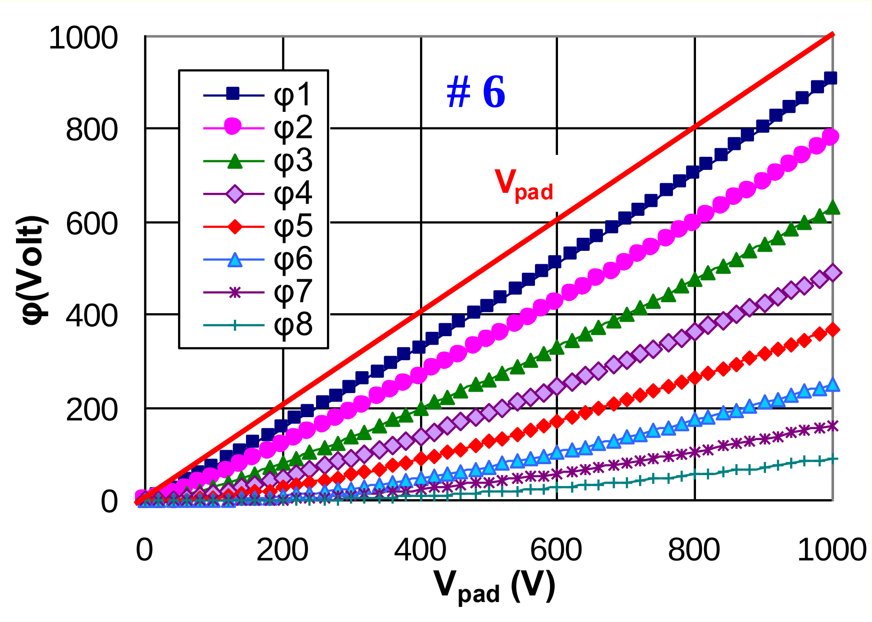
6, 7: I ≈ 3.5 nA

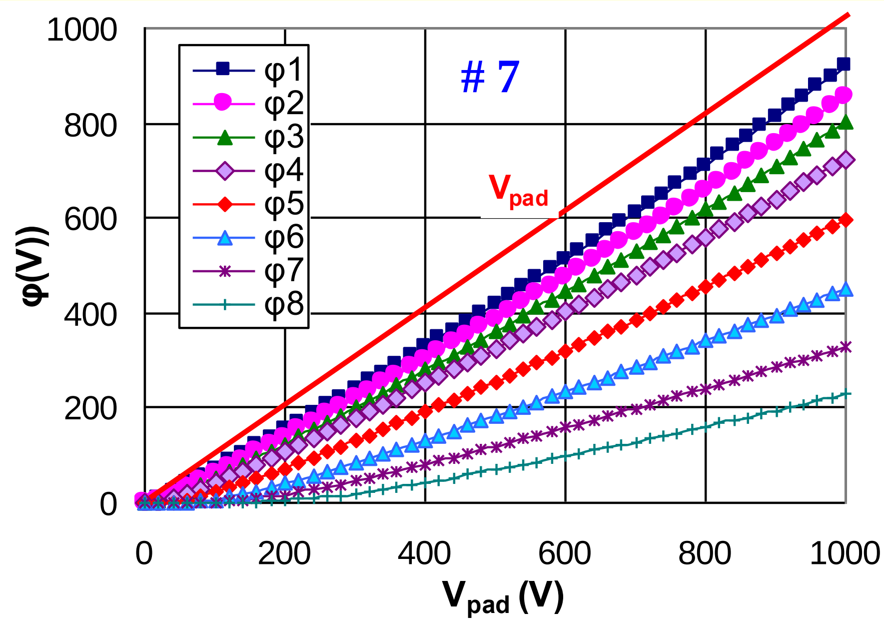
Bulk generation current proportional to detector thickness

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Detectors with 1 mm thickness
Potential distribution

d = 1 mm; ρ = 20 k; V_{fd} = 160 V; V_{max} = 1000 V VTS with 8 rings





Detectors with 1 mm thickness: topology with 8 rings allows reduction of the electric field near sensitive p-n junction – main task!

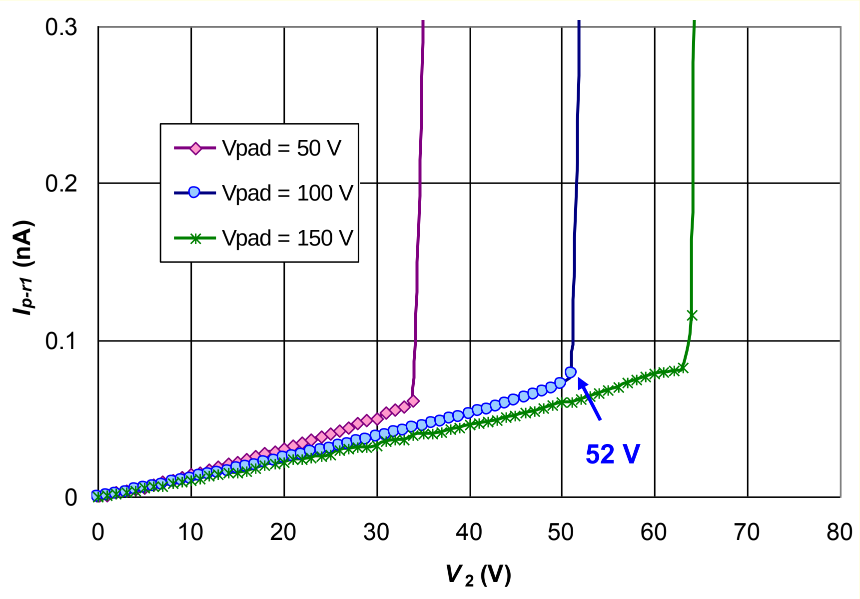
Distribution is controlled by VTS design

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Predictions for irradiated detectors

p-on-n

Before SCSI



✔**High current (irradiation, illumination) cannot change potentional distribution – key point for radiation hardness)**

Beyond SCSI:

Double peak electric field

+ active base -

♦ low field near p^+, and high F at n^+

♦ holes are captured by deep levels and affect electric field distribution

Predictions for irradiated detectors

n-on-p

floating rings at n^+ side
The same mechanism of potential distribution
via injection current in the gap at high and low radiation fluence

Difference: injection current of electrons, electrons are captured by deep levels and affect electric field distribution

E. Verbitskaya et al., 16 RD50 Workshop, Barcelona, May 31-June 2, 2010

Future studies

- various VTS design
- parameterization of potential
- development of engineering approach
  for calculation of potential distribution
- study of irradiated detectors

Conclusions

1. Potential stabilization is controlled by hole injection current in the gap (new model)

2. The factors that define potential distribution between floating rings are:
   - low leakage in the gap (interface);
   - Si resistivity: at lower ρ larger V_{pad} is needed for potential dividing;
   - gap width a.

3. Model of potential stabilization due to injection current is valid for irradiated detectors and insensitive to resistivity.

4. Practical importance:
Pad and strip test detectors with 1 mm thickness and operational bias up to 1 kV processed →
low dark current, lower electric field near sensitive p-n junction.

Acknowledgments

This work was made in the framework of RD50 collaboration
and supported in part by:

- RF President Grant # SS-3306.2010.2
- Fundamental Program of Russian Academy of Sciences on collaboration with CERN

Thank you for attention!