Punch-through Protection of SSDs in Beam Accidents

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with
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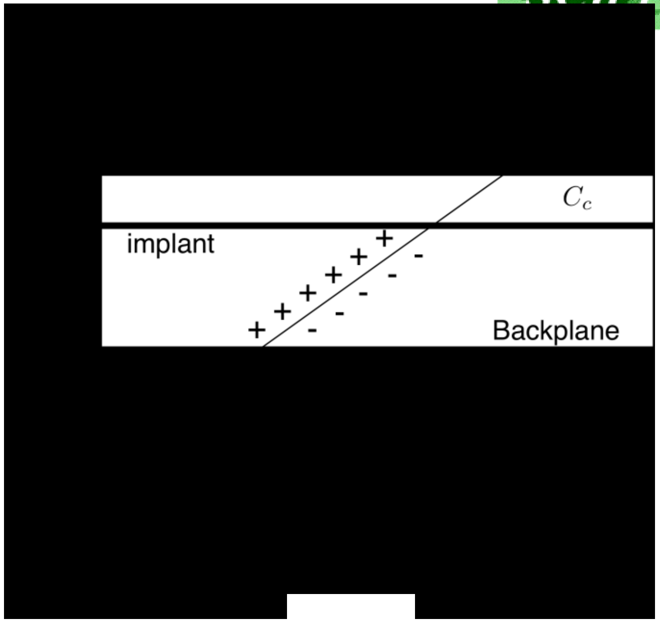
- Large Voltages on Readout Implants in Beam Accidents
- Punch-through Protection against Large Voltages on Implants
- Simulation of Field-breakdown with an IR Laser
- Explanation of large voltages: DC 4-R Model
- Role of Implant Resistance

Damage from Beam Losses to AC-coupled SSD



- ALEPH at LEP observed break-down of the coupling capacitors on AC-coupled SSD in a beam accident. The Al readout trace of AC coupled sensors are held at ground by the readout ASIC.
- We proposed that this was due to the breakdown of the field inside the sensor when the deposited charge made the sensor conductive. At that point, the bias voltage can reach into the sensor bulk and can impart large voltages to the implants.
- To check this, we used IR lasers to mimic the beam loss and we indeed observed large voltages on the implants

T. Dubbs et al., IEEE Trans. Nuclear Science 47, 2000:1902 – 1906.

- The reach-through (punch-through) effect was considered an elegant and effective way to limit the voltages on the implants. Special punch-through protection (PTP) structure can be designed where the geometrical layout determines the voltage limits on the implants.

J. Ellison et al., IEEE Trans. Nuclear Science, 36, 1989: 267 - 271.

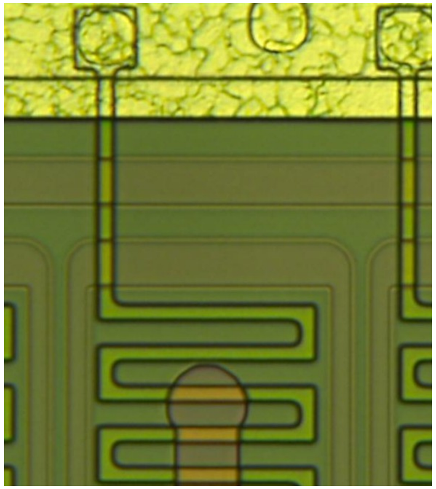
- PTP structures were implemented in the p-on-n SCT sensors.
- But the PTP structure in SCT sensors were shown not to guarantee protection against large voltages across the coupling capacitors when IR laser pulses were used.

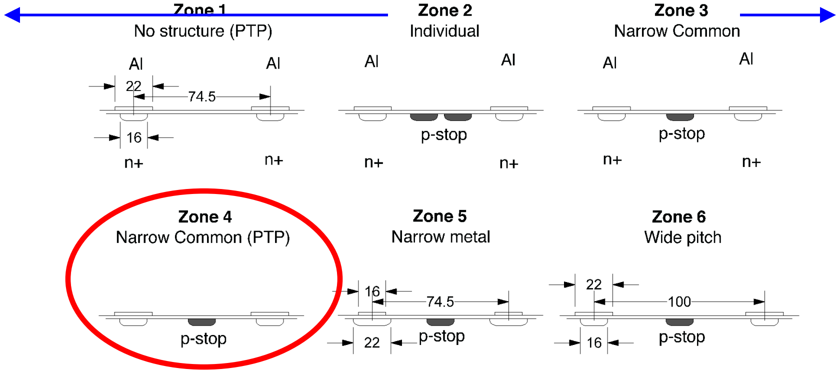
K. Hara, et al., Nucl. Instr. and Meth. A 541 (2005) p. 15-20.

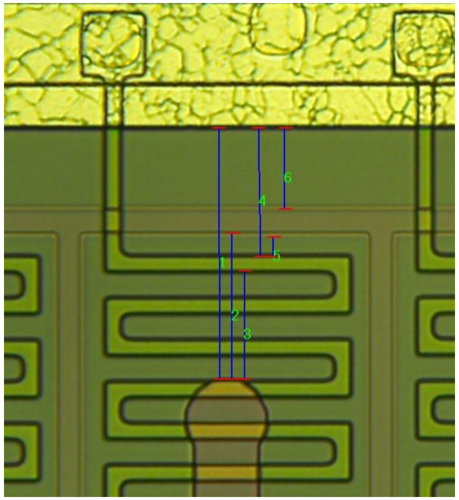
PTP in Upgrade Sensors ATLAS07

N-on-P full-size sensors and “mini’s” to investigate PTP (in Zone 4A-4D) Y. Nobu, et al., NIMA A (2010)doi:10.1016/j.nima.2010.04.080

No PTP structure

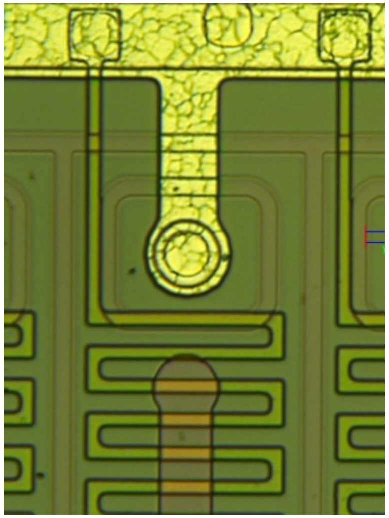




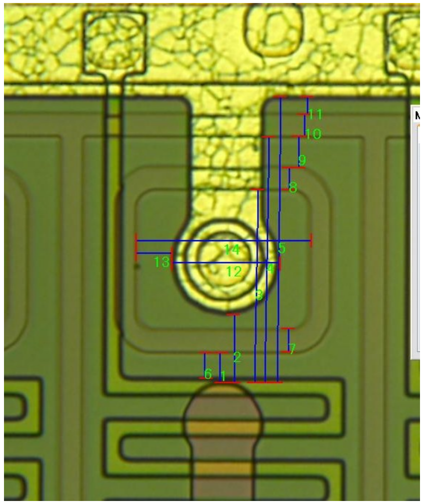


PTP structures

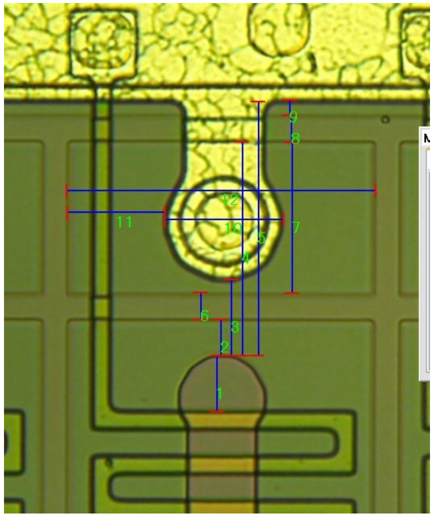
BZ4A



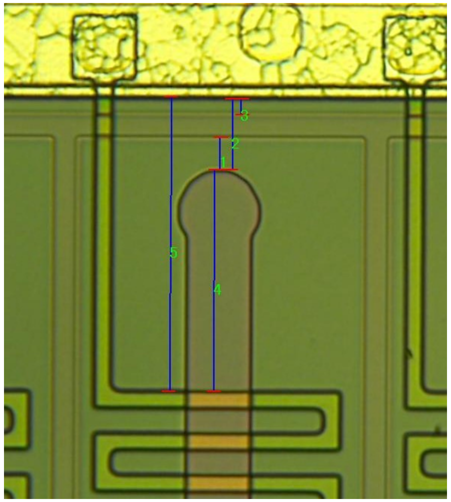
BZ4B



BZ4C



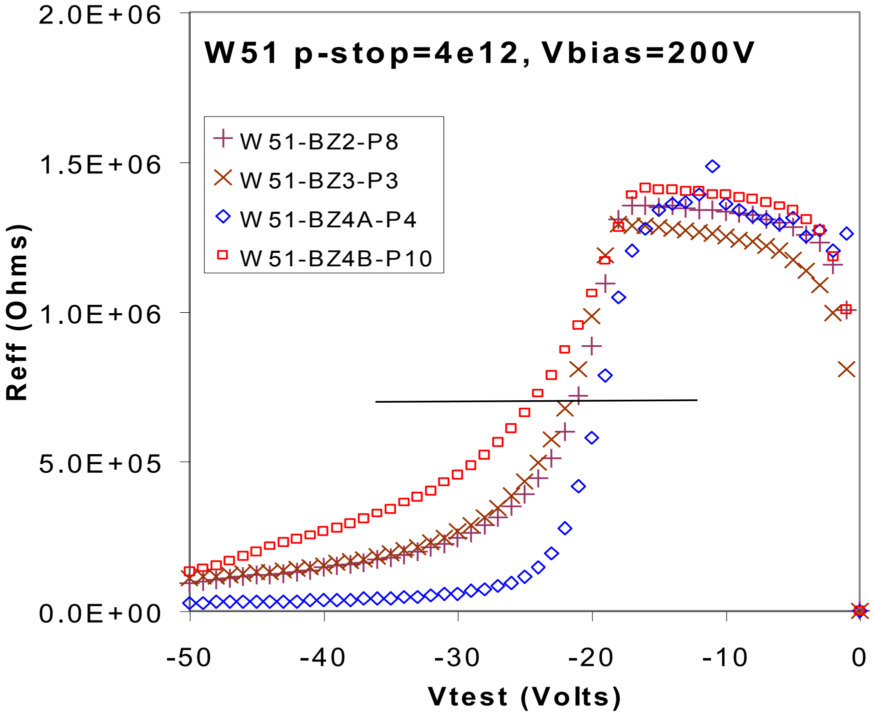
BZ4D



PTP Structure Effectiveness

- The effectiveness of PTP structures is determined in DC i-V measurements between the strip and the bias ring. One measures the “integral” effective resistance R_{eff}, which is the bias resistor R_{bias} in parallel to the PTP resistor R_{PTP}.
- The measure of the effectiveness of the PTP structure is the punch-through voltage V_{PT} , defined as the voltage at which

  $R_{PTP} = R_{bias}$, i.e. $R_{eff} = 0.5^* R_{bias}$.
- The PT voltage V_{PT} was measured to be a few 10’s of Volt.



S. Lindgren, et al., NIM A (2010) doi:10.1016/j.nima.2010.04.094

But:
V_{PT} shows very little variation with the dimension of the PTP structure (channel length L):

	L [μm]	V_{PT}
BZ4A	21	20
BZ4B	21	24
BZ2 / BZ3	75 / 67	21

Testing Large Implant Voltages with Laser

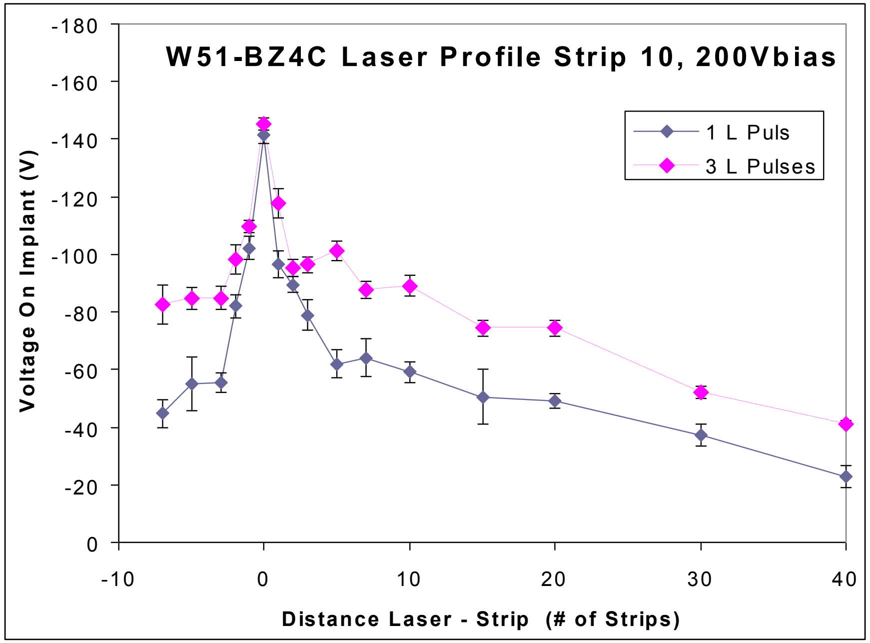
T. Dubbs et al., IEEE Trans. Nuclear Science 47, 2000:1902 – 1906.

- Alessi IR cutting laser deposits large amounts of charge inside the detector which collapses the field(>10^{10} e/h pairs ~ 10^6 MIPs ~ 1 Rad / pulse).
- Intensity given by number of laser triggers ~ 4 μsec apart (we used up to 3).

- Bias ring is held to ground
- Voltage on a DC pad and/or AC pad are read via an high impedance voltage divider into pico-probe or digital scope.
- DC pad reflects biasing of strips,
- AC pad reflects instantaneous collected charge (~ depleted region)

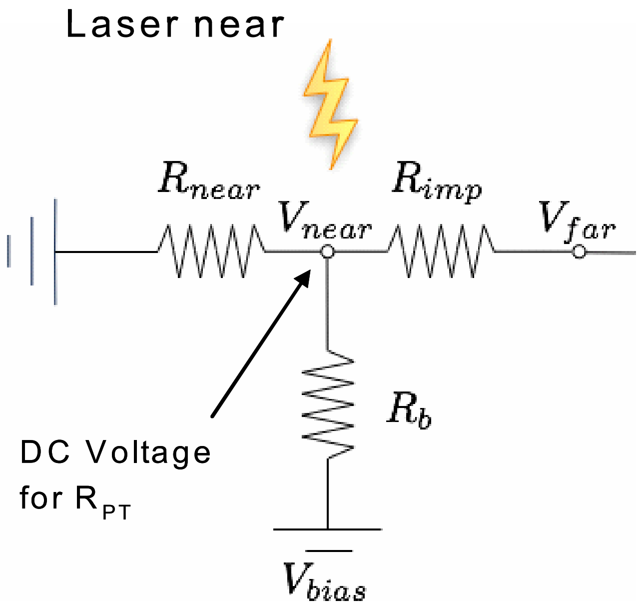
- Laser spot ~ 10 μm, but large DC voltages extend over few mm.

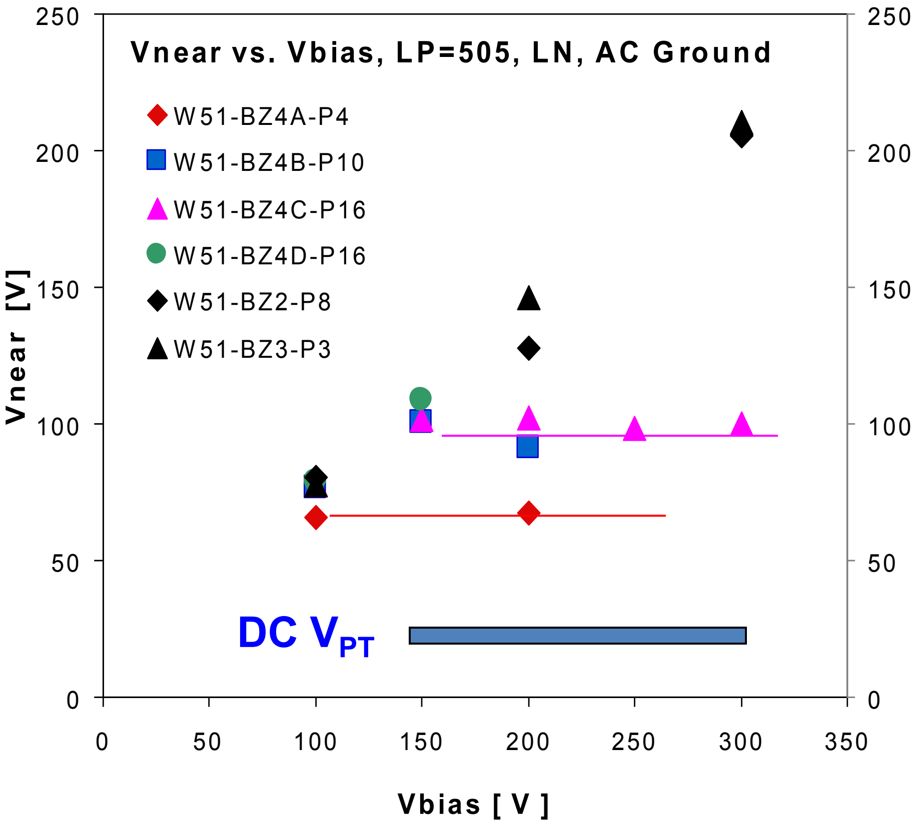
- Peak voltage independent of laser intensity, and AC grnd/floating



Voltages on strips are large, much larger than DC V_{PT} , comparable to bias voltage.

Laser implant voltages near R_{PT} vs. Bias





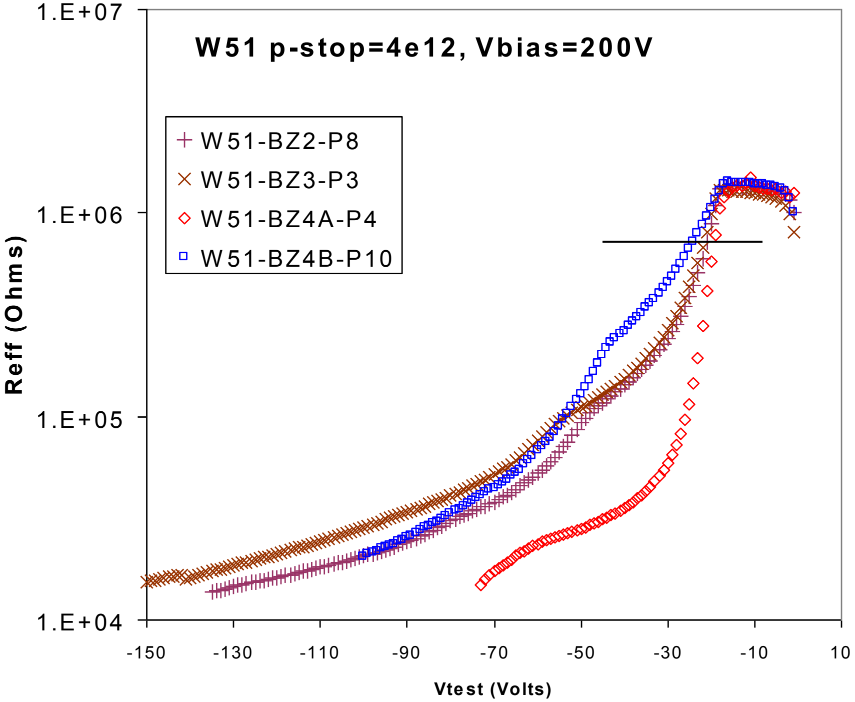
**At high bias voltages, implant voltages for PTP structures saturate.
But the ones without PTP structures do not saturate
(even though DC VPT were very similar)**

Can this be reconciled with the DC voltage dependence of R_{PT} ?

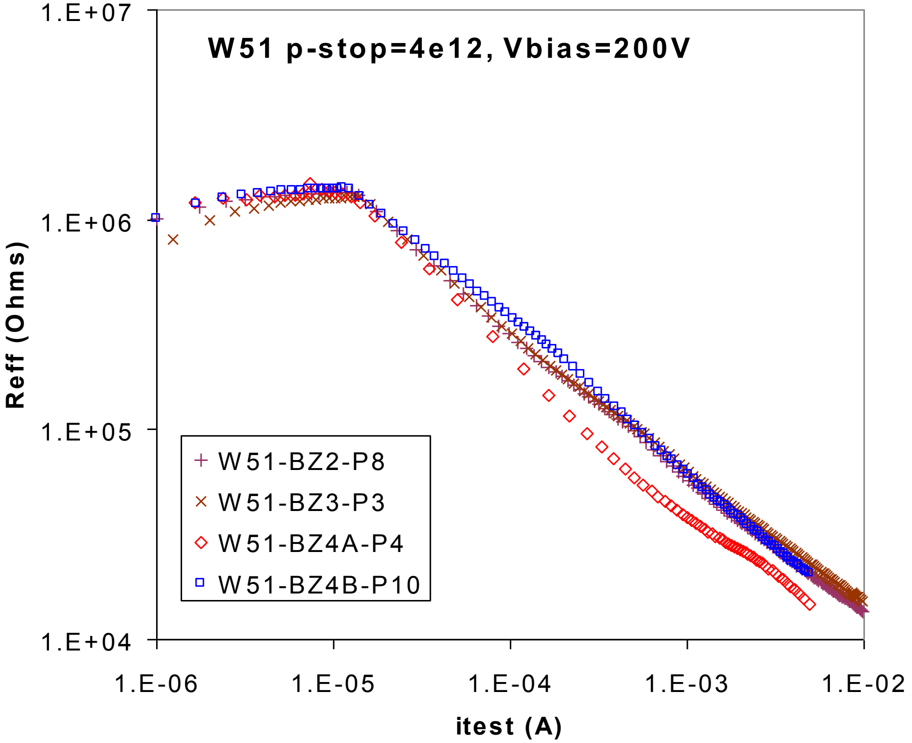
DC Characteristics of PTP Structures

Extend the DC measurements to larger voltages and currents.

R_{eff} vs. V_{near}



R_{eff} vs. PT current i_{PT}



R_{PT} never becomes a short
R_{eff} = 20 kΩ reached at different voltages for different structures.
Strip Voltage depends on resistance of bulk and implant.

$R_{eff} \sim 1/ i_{PT}$

Independent of structure!

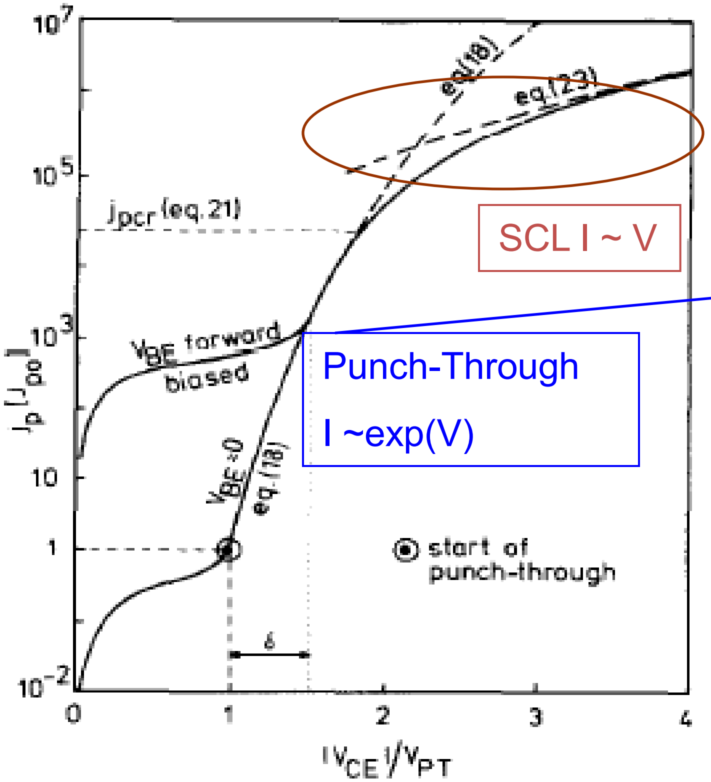
R_{eff} = 10 kΩ reached at current of about 10 mA .

Space-Charge Limitation in PTP Structures

J.I. Chu, G. Persky, and S.M. Sze, J. Appl. Phys., Vol. 43, No.8, August 1972

J. Lohstroh et al.
Solid-State Electronics.
Vol. 24, No. 9, pp. 805-814, 1981

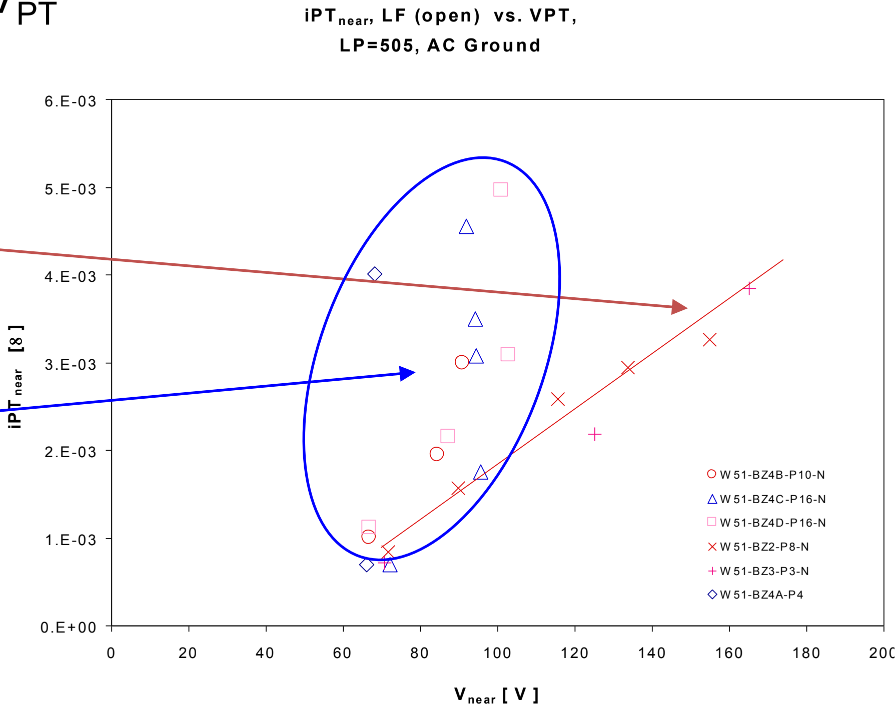
I_{PT} vs. V_{PT}



SCL I ~ V

Punch-Through

I ~exp(V)

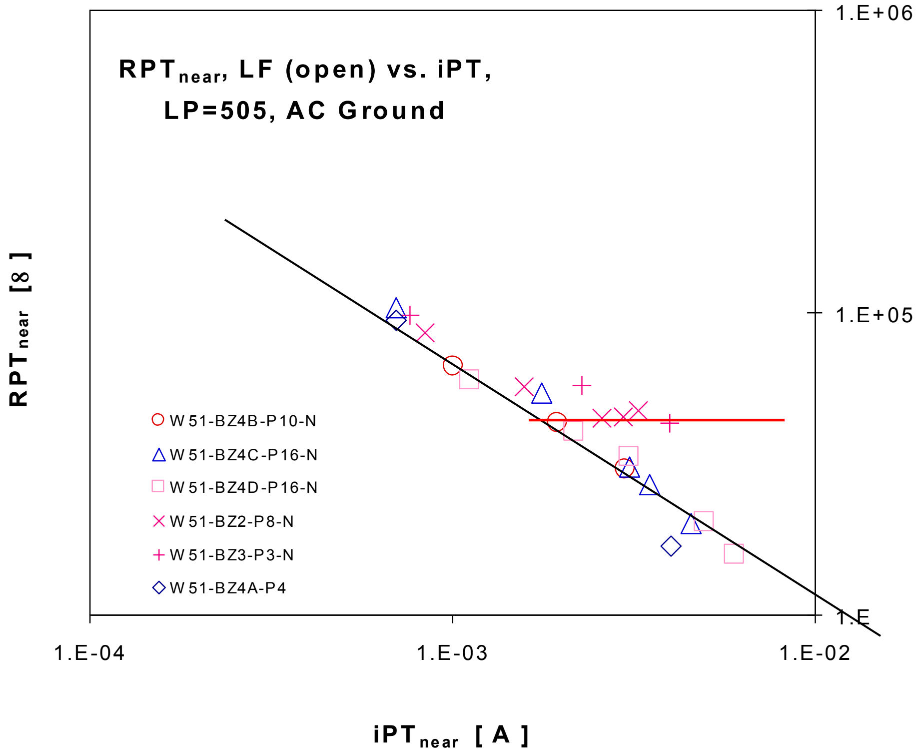


iPT_{near}, LF (open) vs. VPT, LP=505, AC Ground

Punchthrough Region: I_{PT} ~ exp(V), R_{pt} ~ $1/i_{PT}$, V_{PT} saturates

SCL Region: i_{PT}~ V, Rpt ~ const1/i_{PT}+const2, R_{PT} saturates

More evidence for SCL



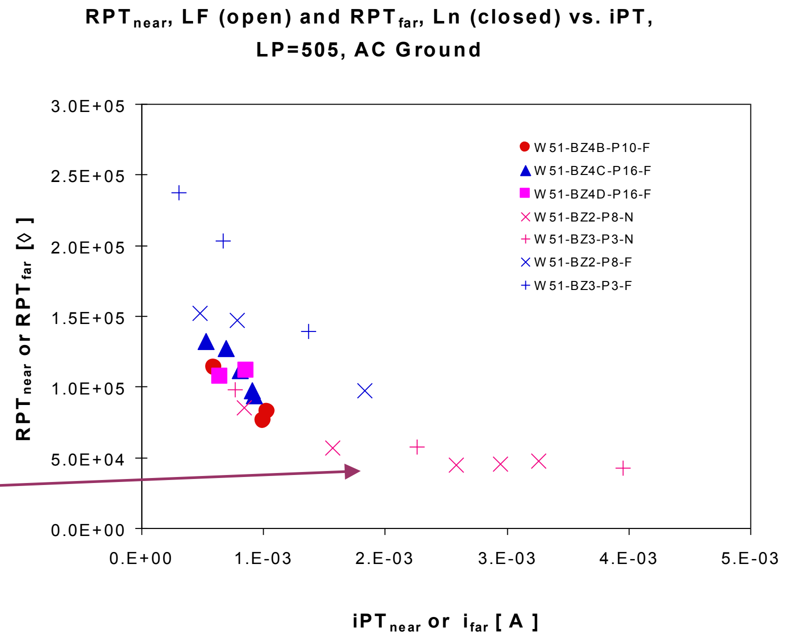
$R_{PT} \sim 1 / i_{PT}$

for all PTP structures,

…but saturation of R_{PT} at ~ 40kΩ

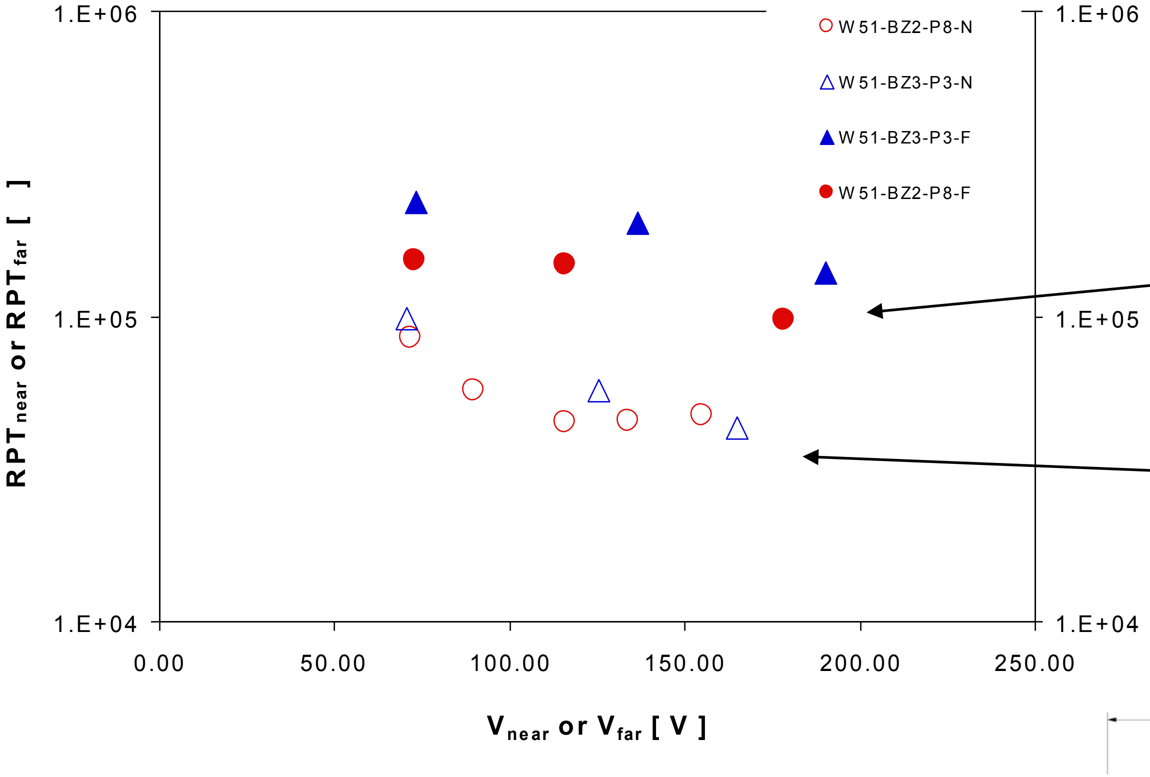
for BZ2 and BZ3

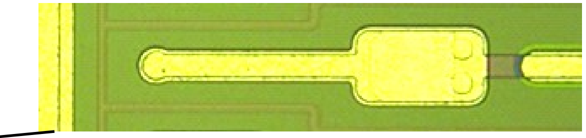
SCL Region: $R_{PT} \sim \text{const1} / i_{PT} + 40\text{k}\Omega$

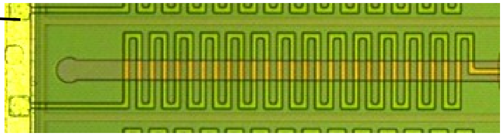


Comparison between R_{PT}(near) and R_{PT}(far)

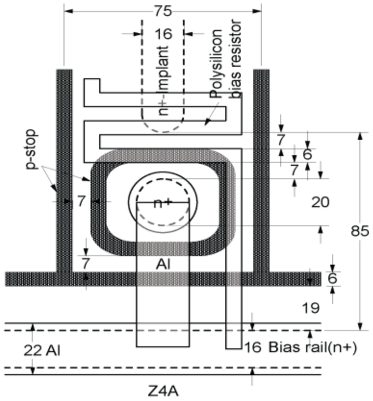
RPT_{near}, LF (open) and RPT_{far}, Ln (closed) vs. VPT,
LP=505, AC Ground

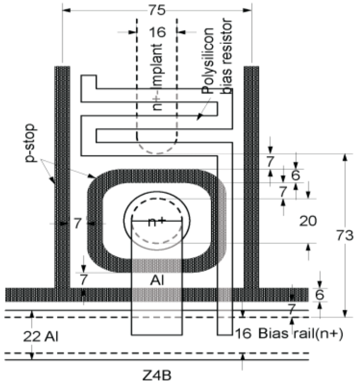






Difference of “identical” near and far resistances in BZ2 and BZ3:
Strong gate effect of the Poly bias resistor (c.f. FOXFET)
Also: in BZ4A the Poly resistor has the best channel coverage



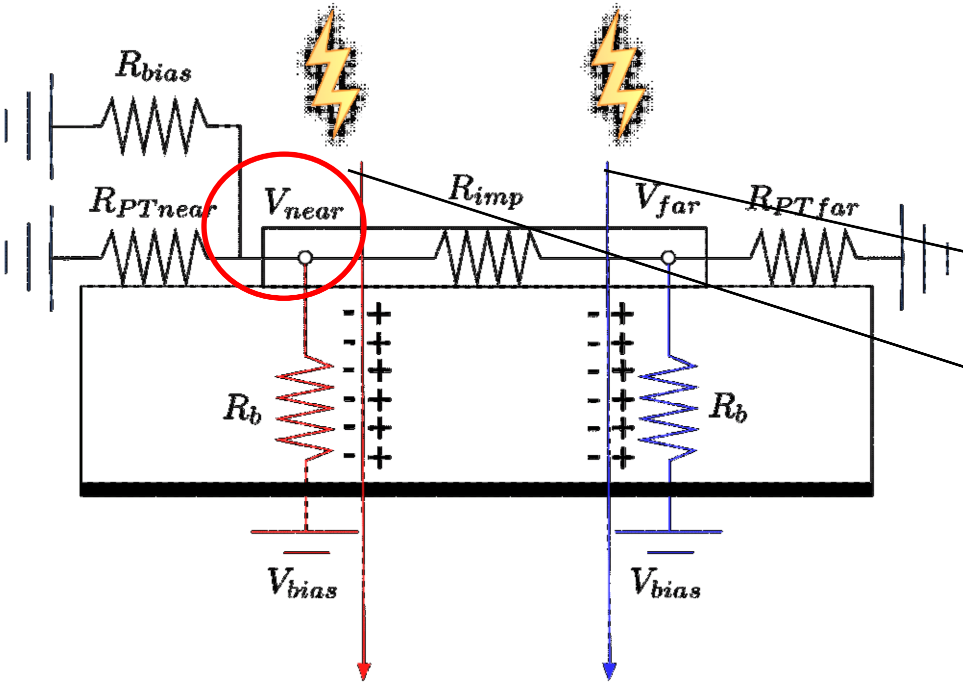


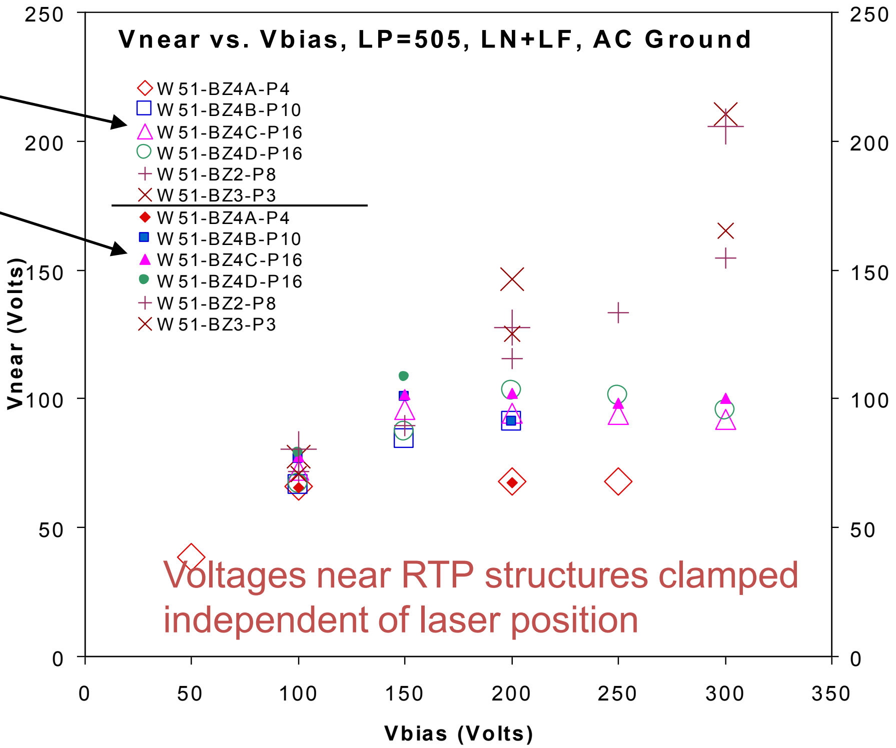
Propose a DC “4R” Model

- After breakdown of field inside the sensor, deal with DC resistor chain only

$R_{PTnear} = R_{eff}(R_{PTnear}, R_{bias})$
$R_{PTfar} = R_{PT}$ on the far end of the strip, $R_{PTfar} > R_{PTnear}$
R_{imp} = Resistance of implant 15kΩ/cm
R_{bulk} = Bulk Resistance

To check 4R Model:
Fire laser both near and far.
Measure both V_{near} and V_{far}
Calculate $V_{near} = V_{far} - R_{immp} * I_{near}$





Voltages near RTP structures clamped independent of laser position

Current regulates the punch-through resistance through
$R_{PT} \sim 1 / i_{PT}$
What about bulk resistance?

Bulk Resistance

One more parameter after breakdown:

Bulk resistance measured consistently $R_b \approx 15\ k\Omega$ (independent of the current)

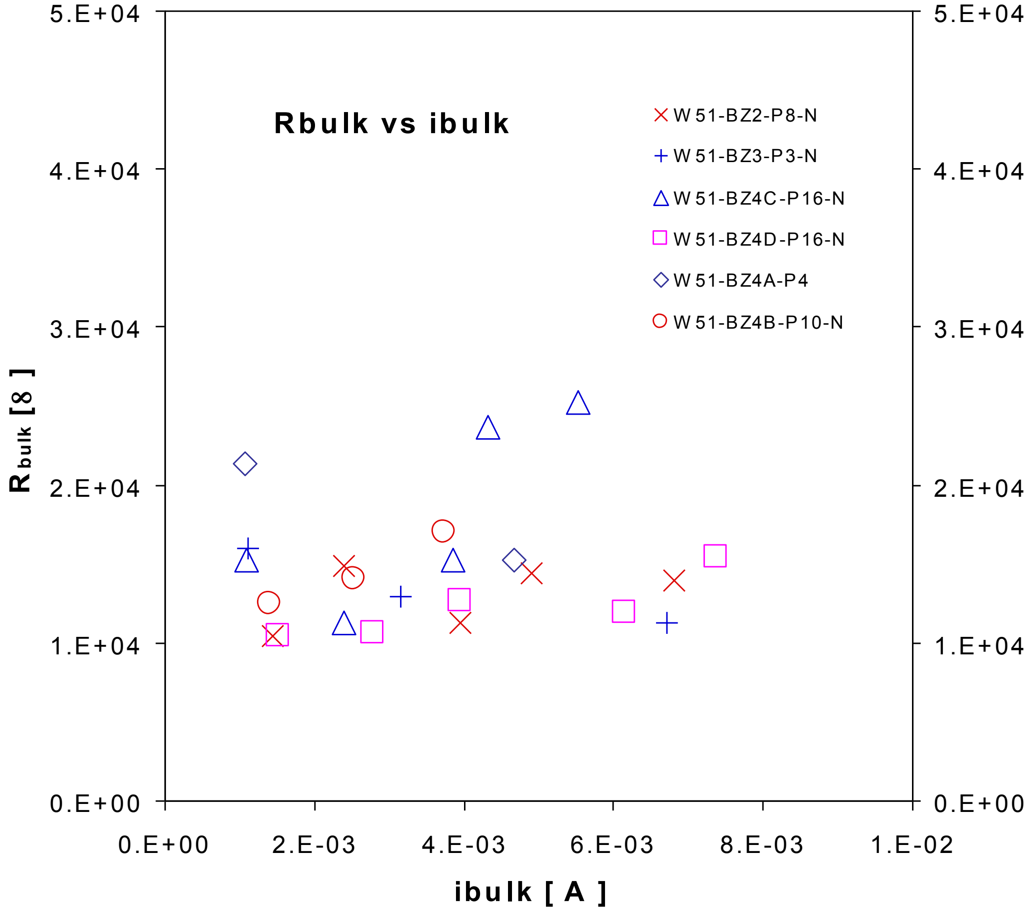
An approximately constant bulk resistance

$R_b \approx 15\ k\Omega$

and a PTP resistance depending on the inverse of the current

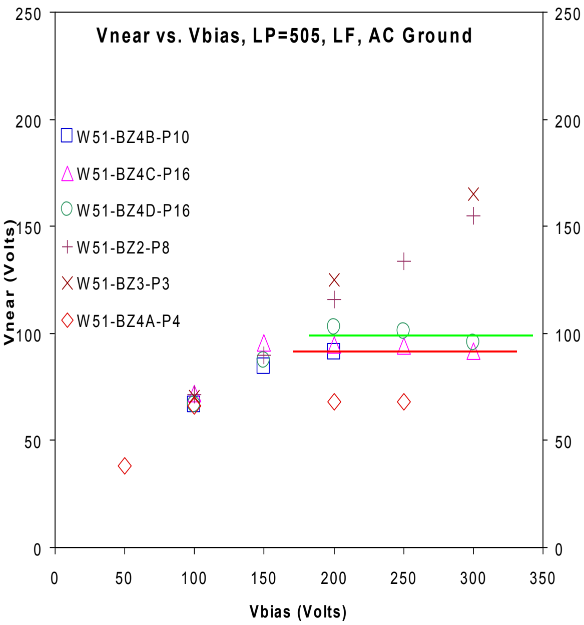
$R_{PT} \sim 1 / I_{PT}$

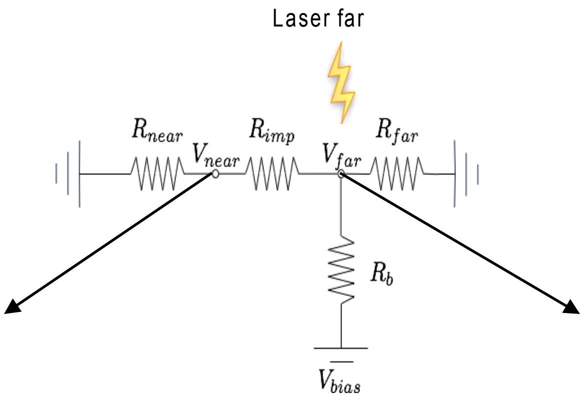
can explain the saturation of the PTP voltages.



Effect of Finite Implant Resistance R_{imp}

Fire laser at the far end of the 1 cm strip, measure both V_{near} and V_{far}



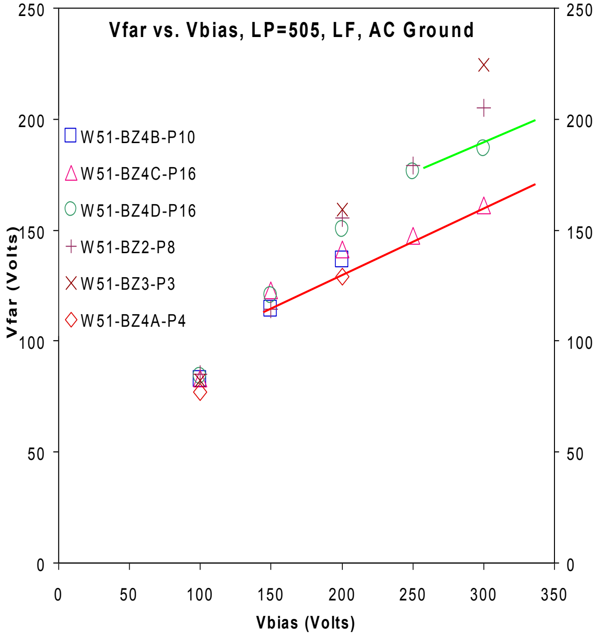


$V_{far} > V_{near}$

Saturation in V_{near}

No saturation in V_{far}

RTP structure not effective for V_{far}



Limitation of application of PTP structures: finite R_{imp}

Implant Voltages do not saturate at high bias voltages, if finite implant resistance R_{imp} isolates PTP structure from breakdown region.

Conclusions

- An IR cutting laser simulates the beam accident conditions: large Q, collapsing E-field.

- Field breakdown size ~ 0.5 mm, with a much larger area with partial breakdown .

- Voltages on the implants V > V_{PTP} (DC), due to finite R_{PTP}.

- The observed voltages can be explained by 4 resistor DC model :
  R_{PTP}(near), R_{PTP}(far), R_{bulk} , $R_{implant}$.

- For PTP structures, the voltage near the laser V_{PTP}(laser, near) saturates.
  Then R_{PTP} ~20kΩ; I ~ 5 -10 mA.

- Saturation voltage V = 50 – 100V

- R_{PTP} ~ 1 / i_{PT}, while R_{bulk} ~15kΩ. For no PTP structure, R_{PTP} saturates at ~ 40kΩ (SCL region)

- $R_{implant}$ is very important: the present value, ~15 kΩ/cm, can effectively isolate the collapsed field from the PTP structure, increasing voltages on the implants by 100's of volts => need low $R_{implant}$!

- The effect of the R-C biasing network at the backplane will be studied next.

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