Single Sided and Double Sided Silicon MicroStrip Detector R&D

Tariq Aziz

Tata Institute, Mumbai, India

SuperBelle, KEK

December 10-12, 2008

Indian Effort   Mask Design at TIFR, Processing at BEL

Single Sided - 11 Sets of 32 strips with different strip width and pitch

Single Sided – 1024 strips with fixed strip width and pitch

Double-Sided with single metal contact

Double-Sided with double metal contact

Wafers with different crystal orientations

All on 4-inch n-type bulk wafer

First Batch

Specifications for Prototype Single Sided Silicon Microstrip Detector

Wafer : n type Silicon, 4inch Diameter, 300 micron thickness, FZ type

Orientation : <111>

Resistivity : 5 Kohm-cm

No. Of Independent sets of detectors : 11

Type of implantation for strips : p+

No. strips per set : 32

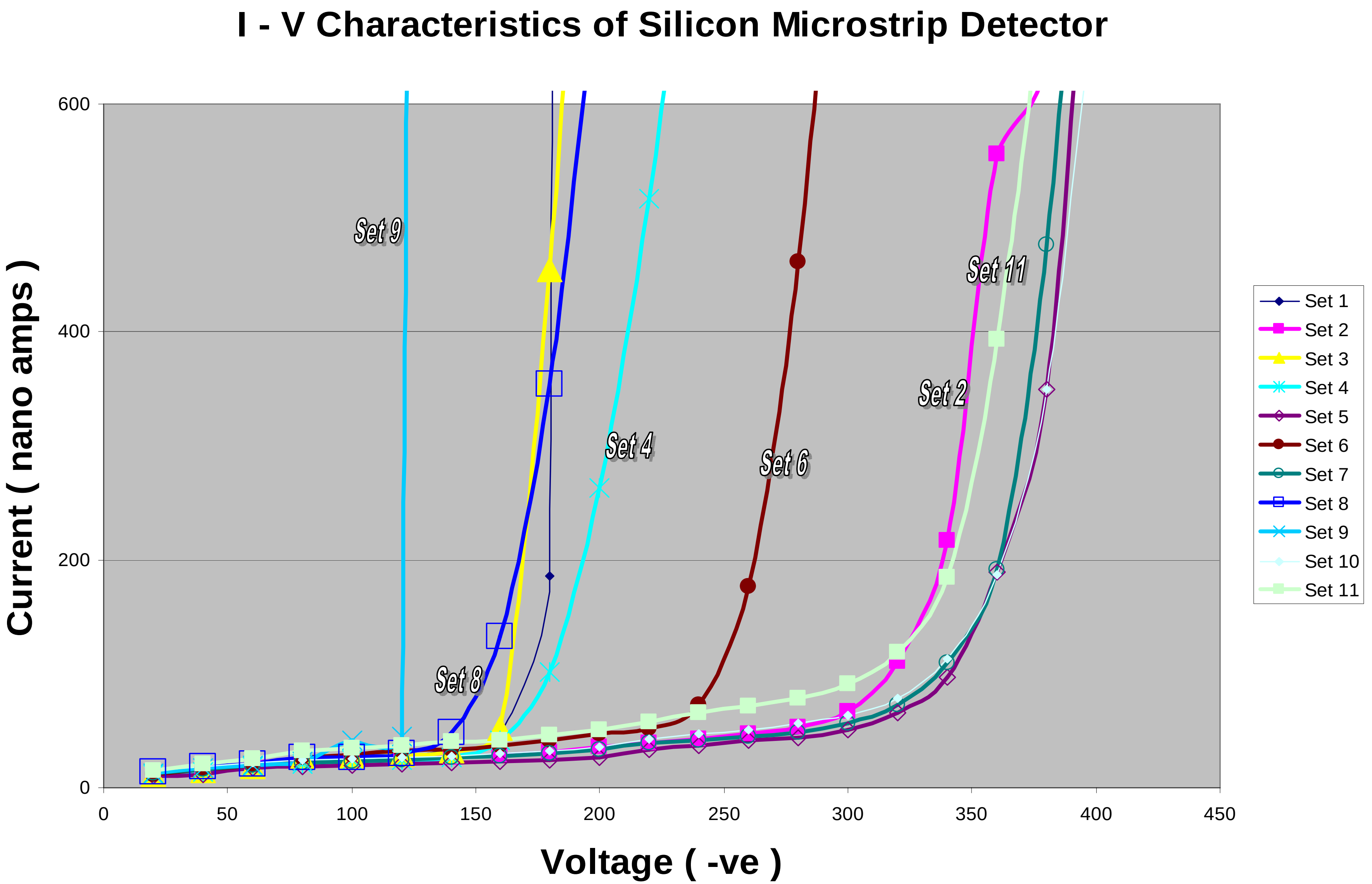
Polysilicon resistor value: 2 to 4 Megaohms

Dark Current (at 100V reverse voltage) max : 5 Microamps

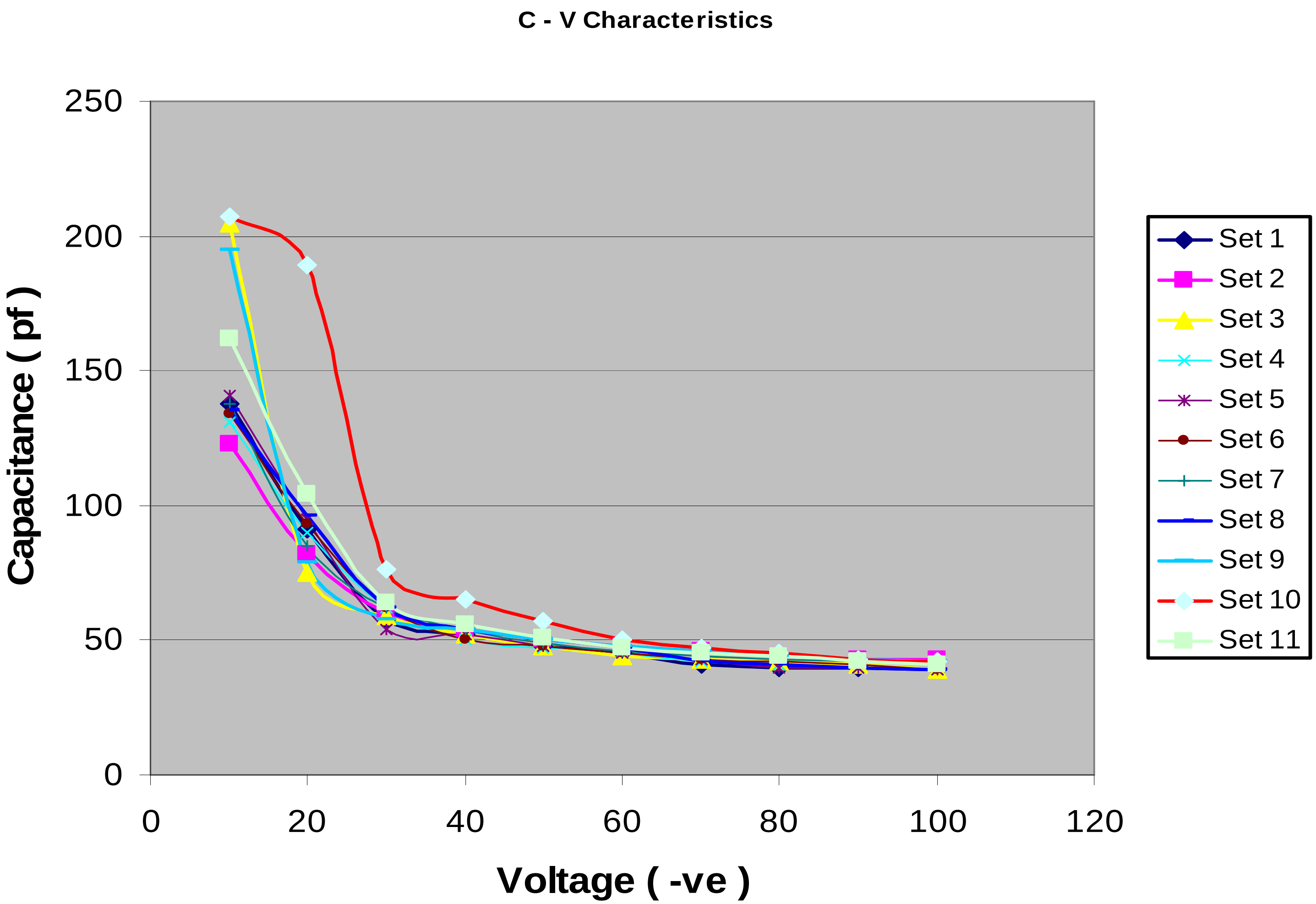
Silicon Micostrip P+ Implant Details

Set No.	Strip length (um)	width(um)	Pitch(um)	No. of strips
1	74734	12	65	32
2	74734	48	73	32
3	74734	12	80	32
4	74734	20	80	32
5	74734	35	80	30
6	74734	25	100	32
7	74734	35	100	32
8	74734	25	120	32
9	74734	35	120	32
10	74734	48	120	30
11	74734	25	135	32

I – V Characteristics



C – V Characteristics



Second Batch

Development of Single and Double Sided Silicon microstrip Detector

First Processing Cycle

Specifications of Double Sided Silicon microstrip Detectors

Wafer orientation : <100> FZ
Resistivity : 10k to 20k ohm cm
wafer thickness : 300 microns
Poly silicon value : > 5 Mega ohms

P side :

Number of strips : 1024
coupling capacitance : 160 pf
P+ strip width : 50 microns
Pitch : 75 microns

N side :

Number of strips : 512
coupling capacitance : 90 pf
N+ strip width : 12 microns
Pitch : 50 microns
Structure : ATOLL

Double sided silicon detector
Specifications continued

Wafer crystal orientation : < 100 >,Type: FZ

Wafer thickness : 300 µm , Size : 4 inch

Resistivity : > 5 Kohm-cm

Breakdown voltage : > 300V

Polysilicon resistor value : > 4 Megaohms

Total Dark current : <= 2 microamps @ 100V

Number of Dead Strips < 1%

Area : 79600 x 28400

Effective Area : 76800 x 25600

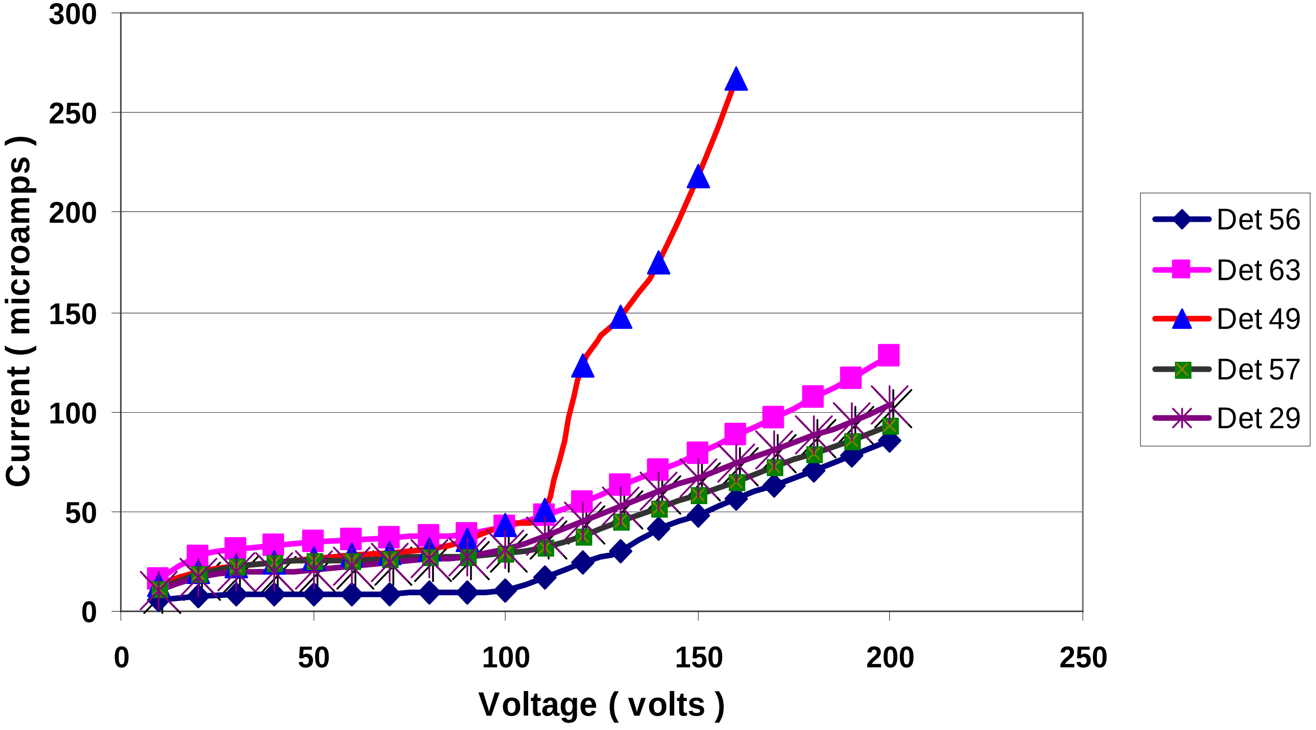
Detectors Produced :

1) SSD - 5 No's
2) DSSD – SL - 10 No's
3) DSSD – DL - 10 No's

First Process Cycle

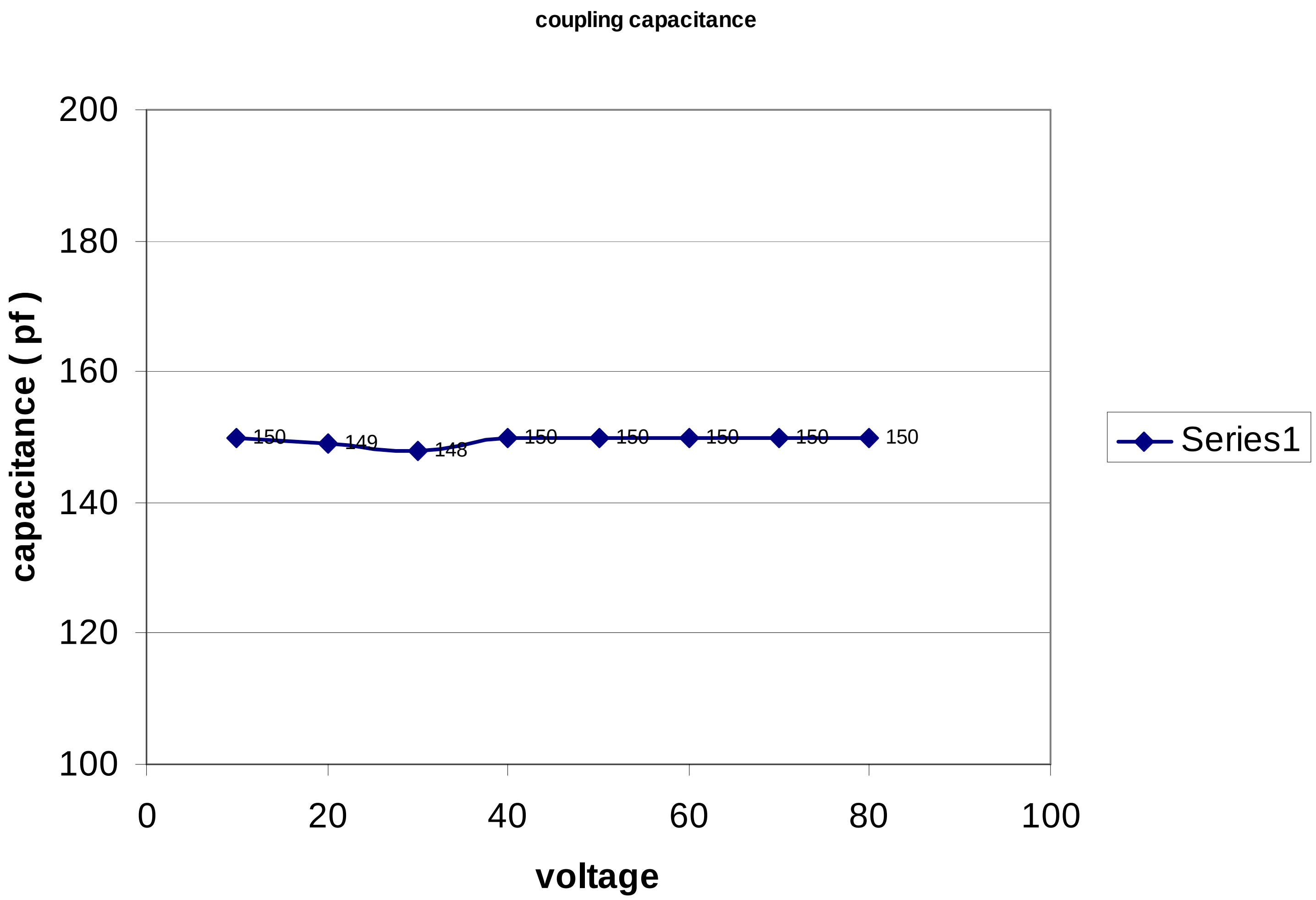
I – V Characteristics

Single sided detector <100 >



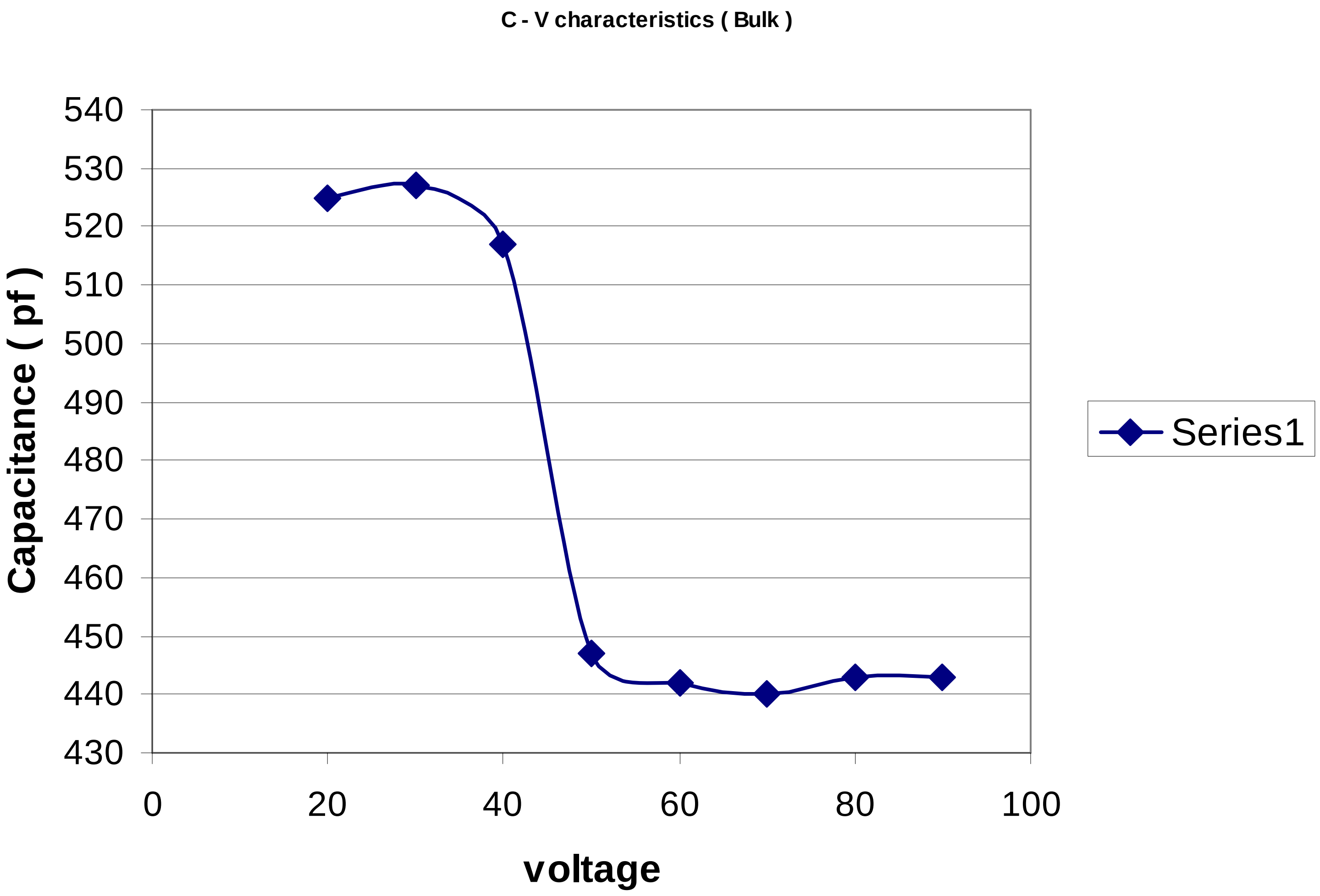
Leakage current higher than expected
BEL need to modify process parameters

Coupling capacitance



Spec- 160 pf Reasonably close, Need to do better

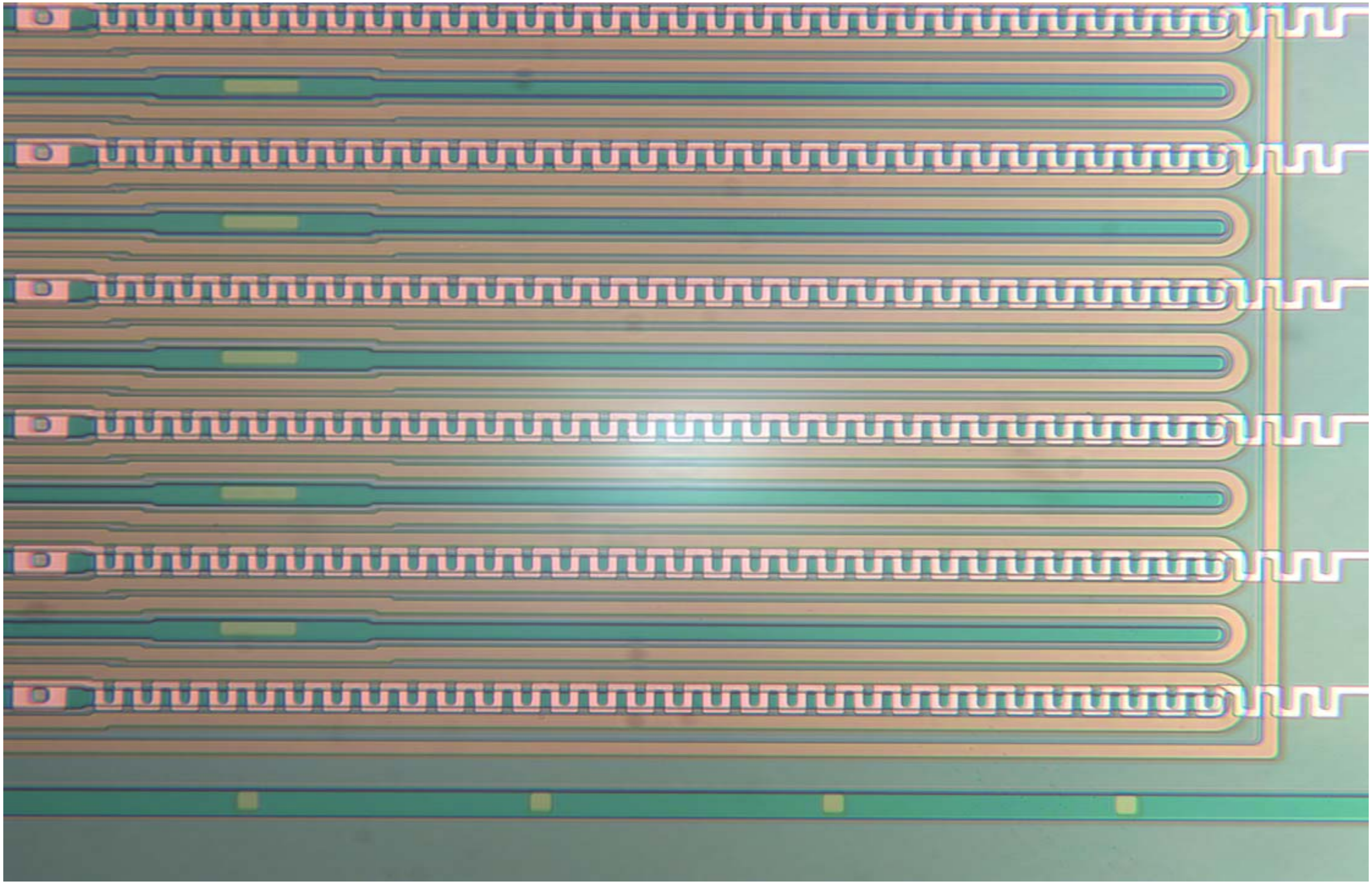
C – V characteristics



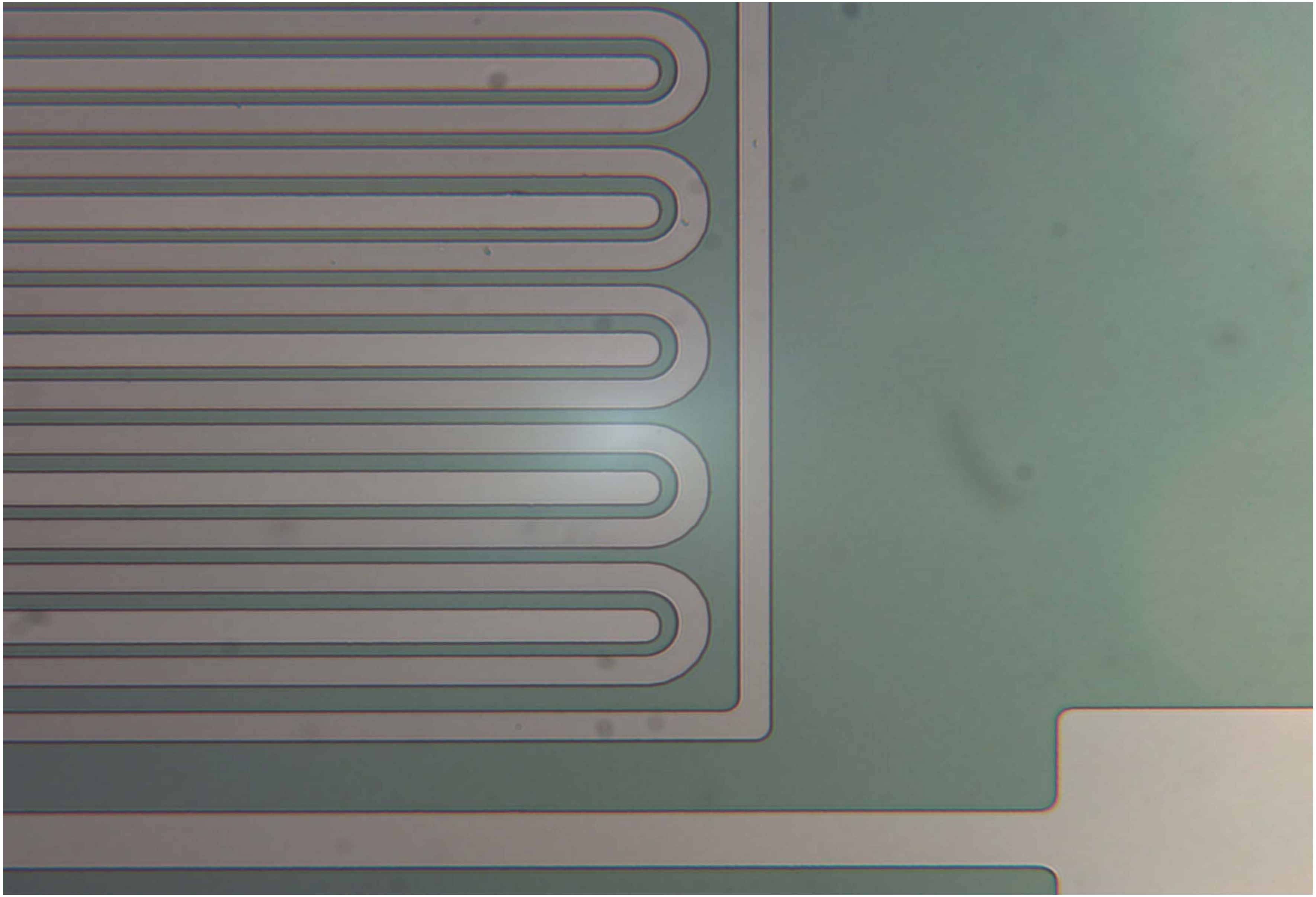
Higher than expected, Need to optimize process parameters

Double Sided

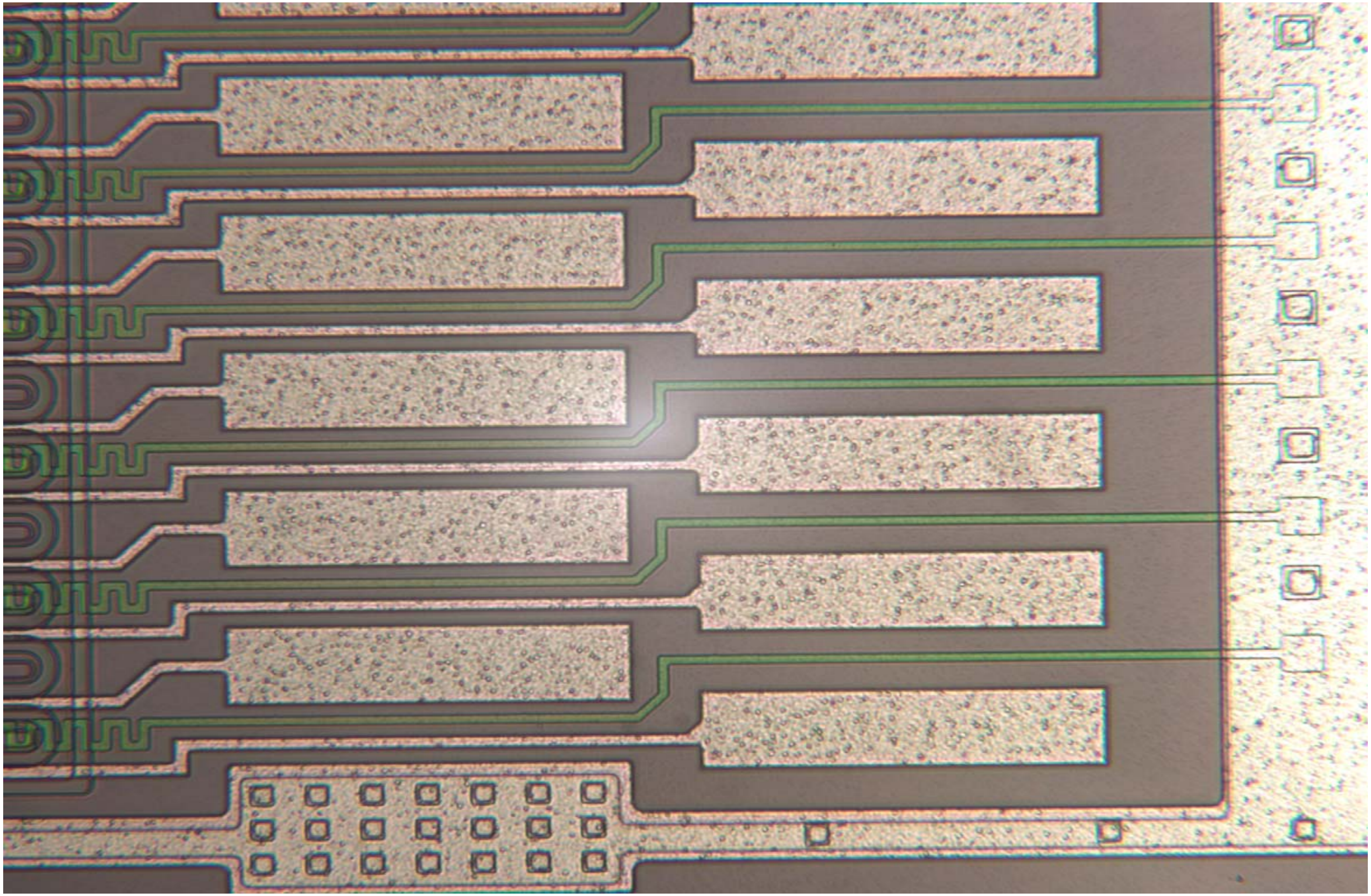
Photo N – Side Polysilicon resistors



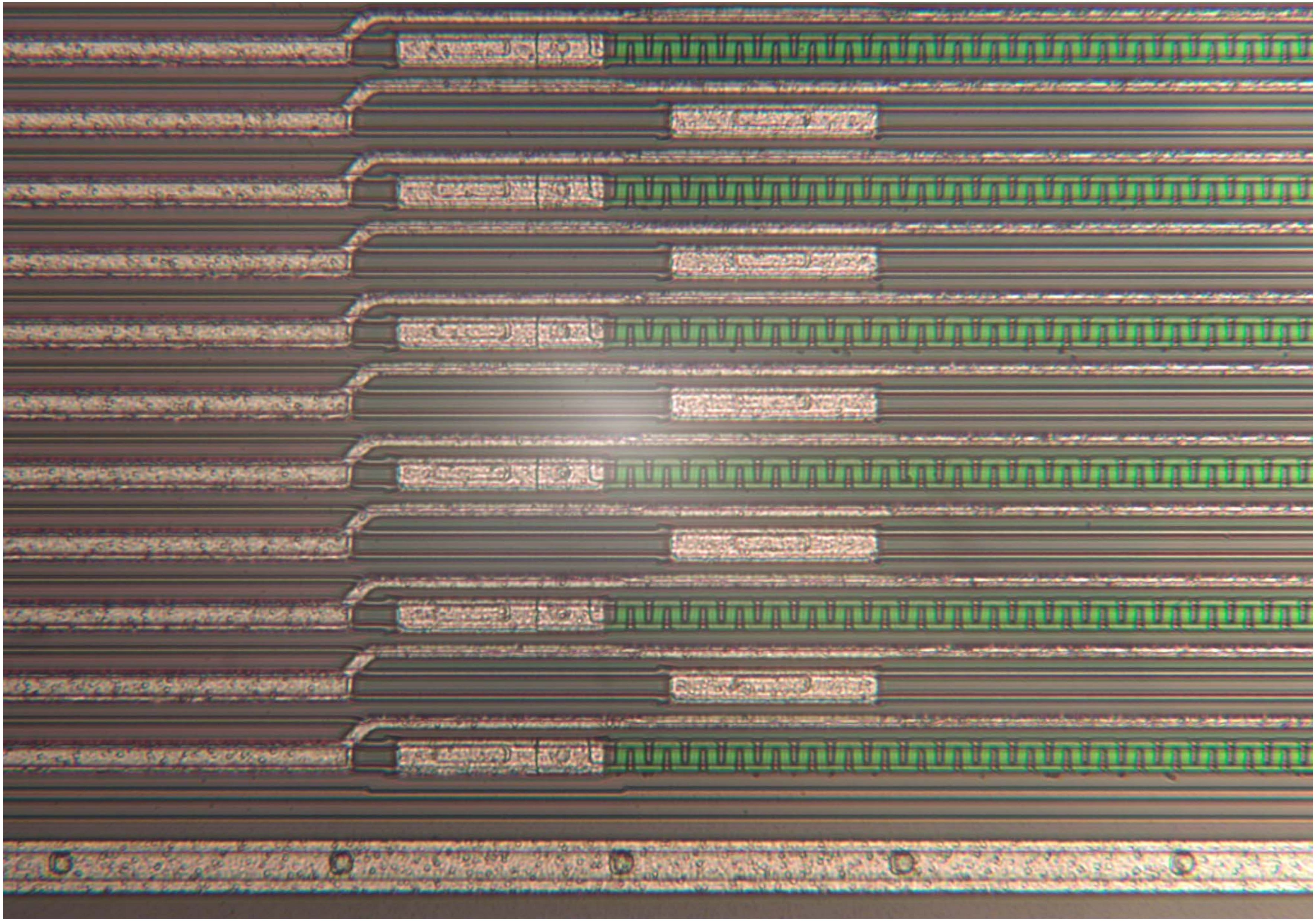
N – side ATOLL structure



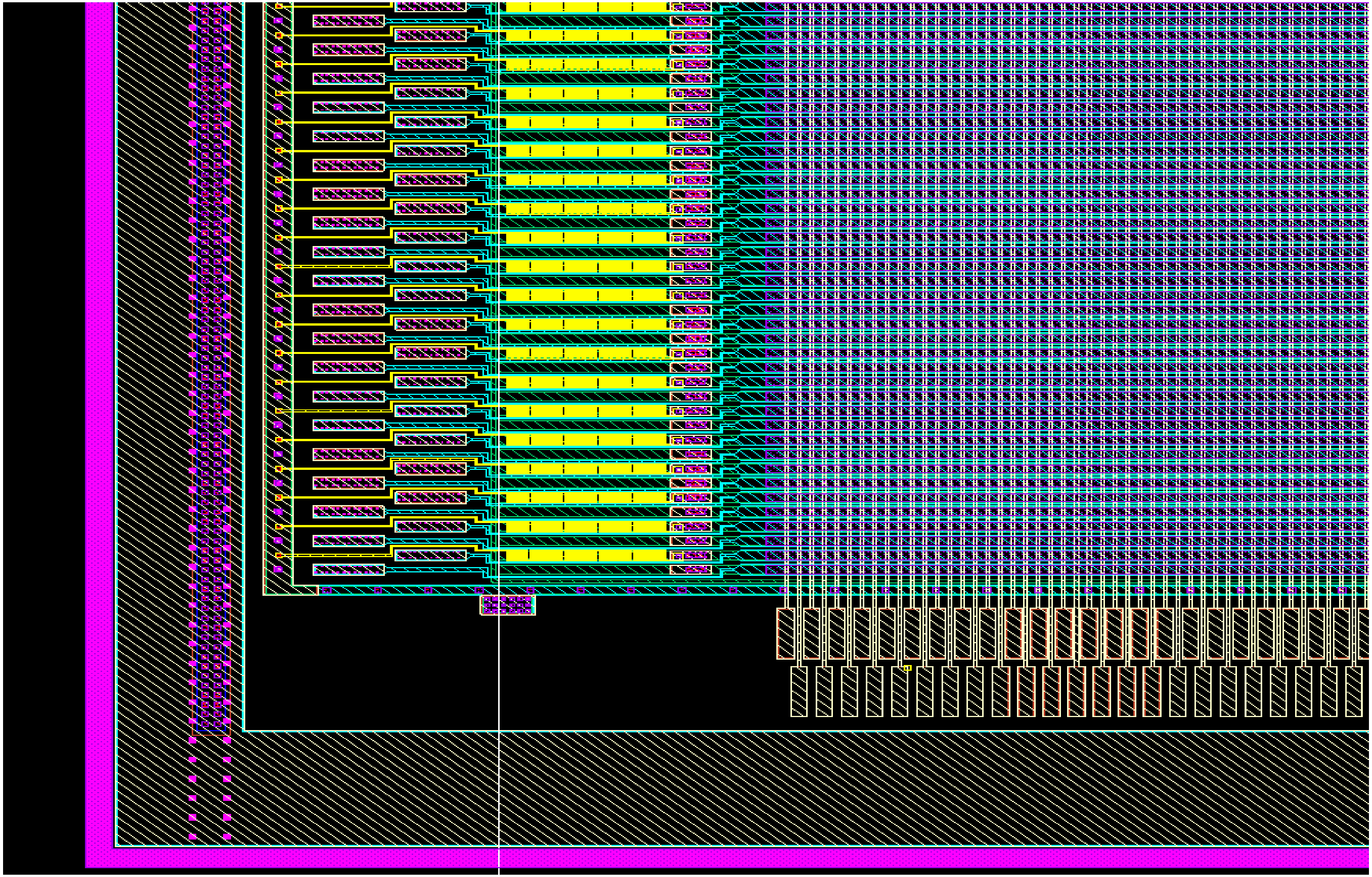
N - Side AC pads



N – Side DC pads



P –side design with all masks



P – side single metal AC pads

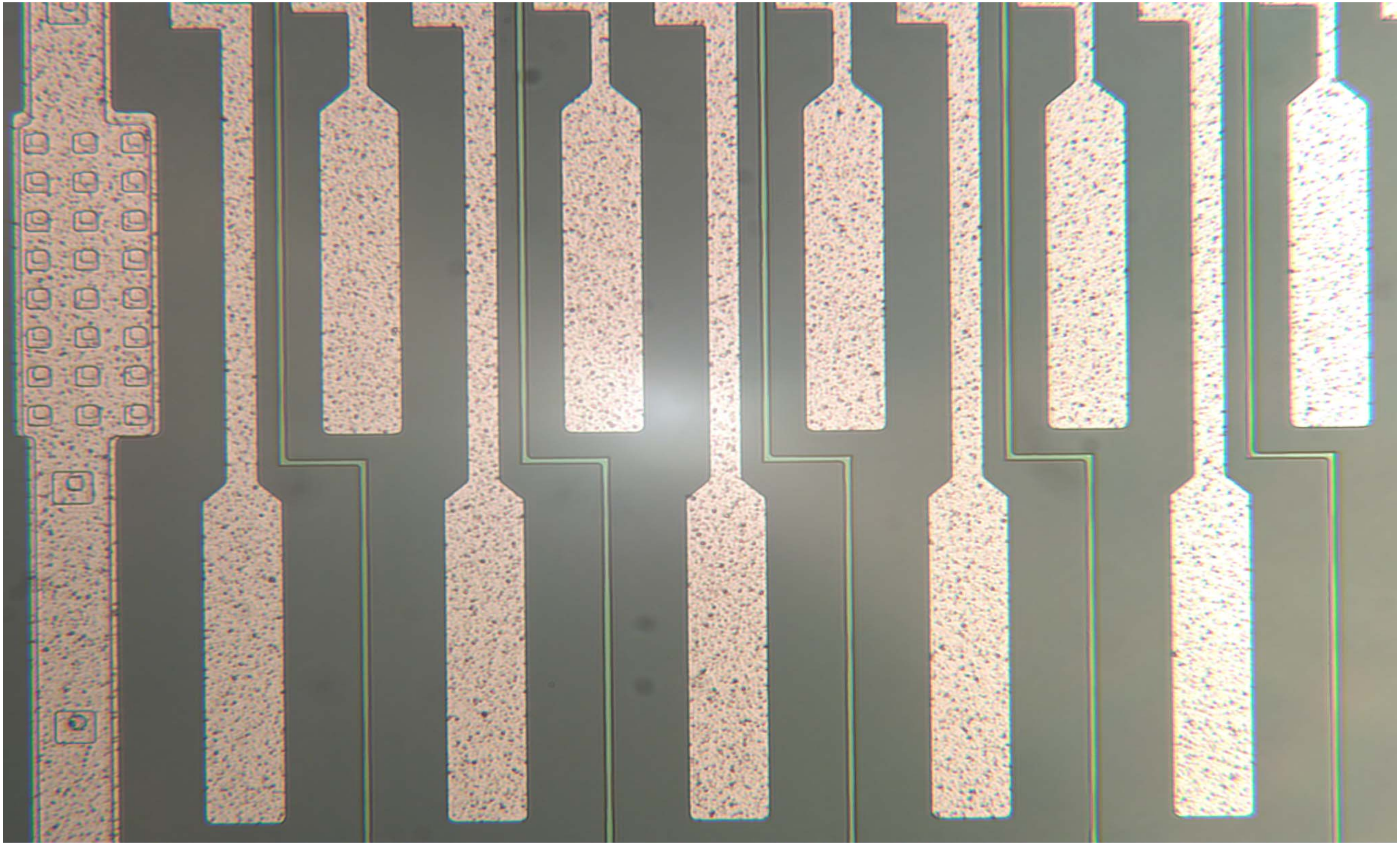
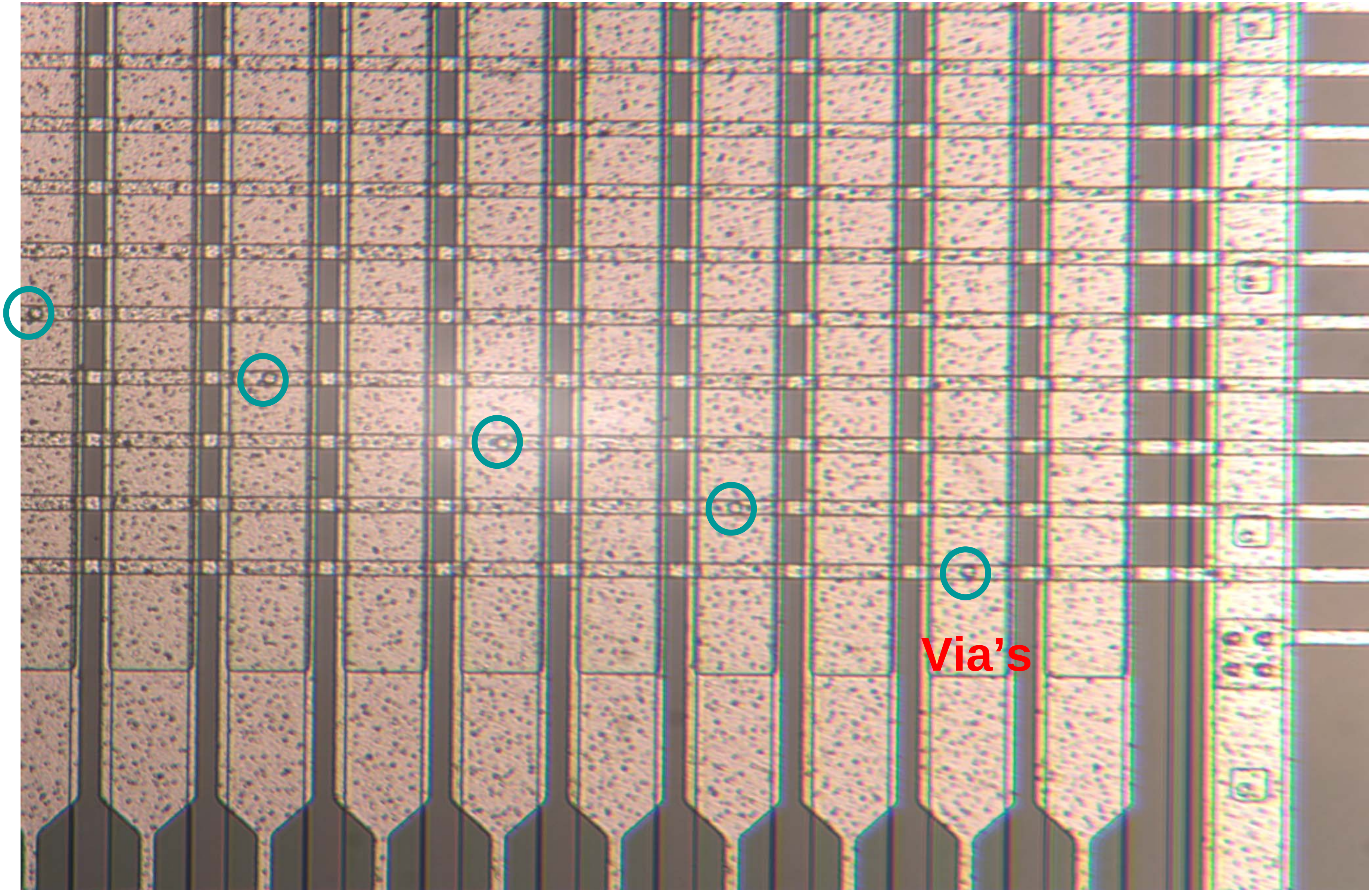
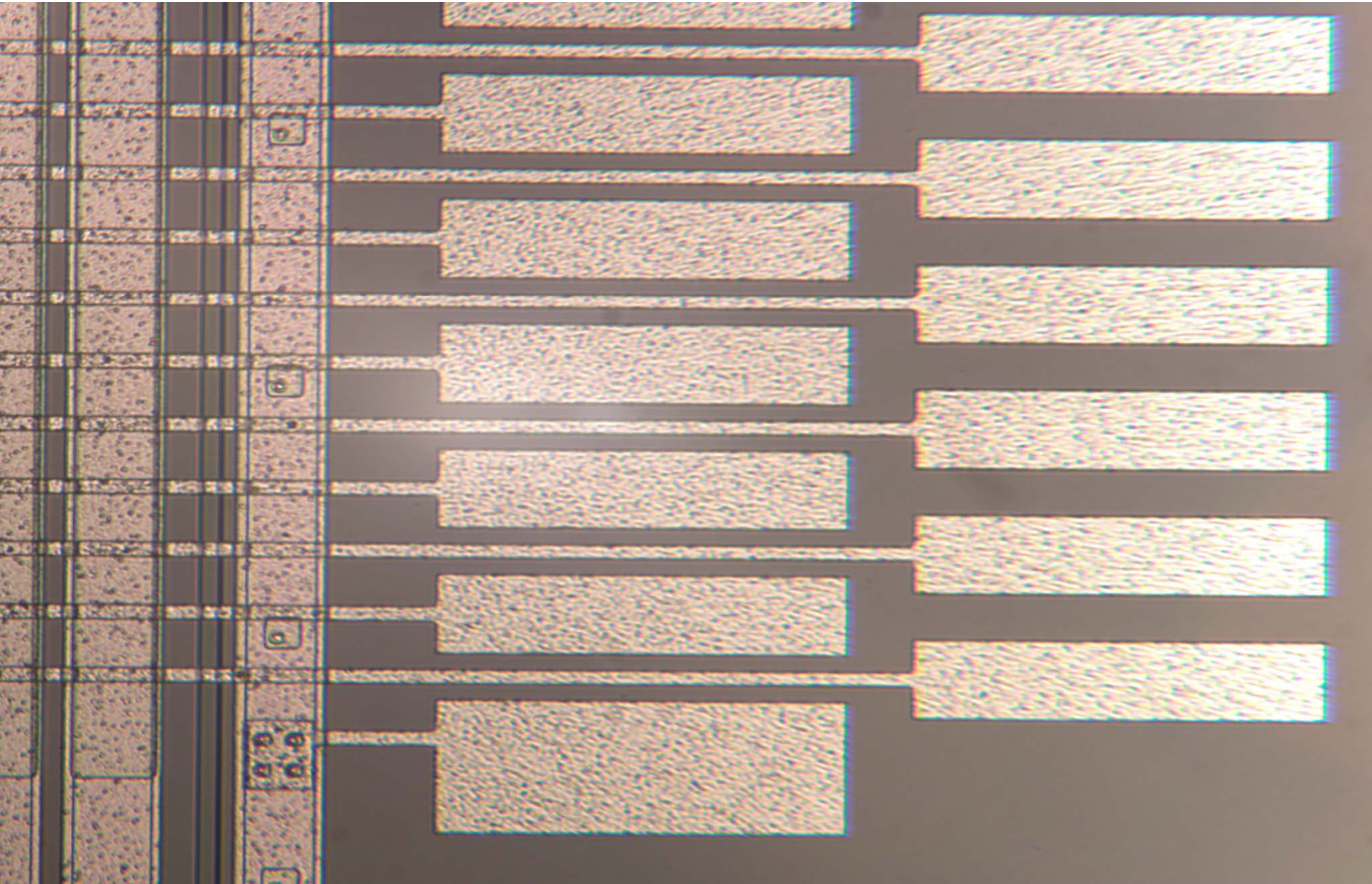


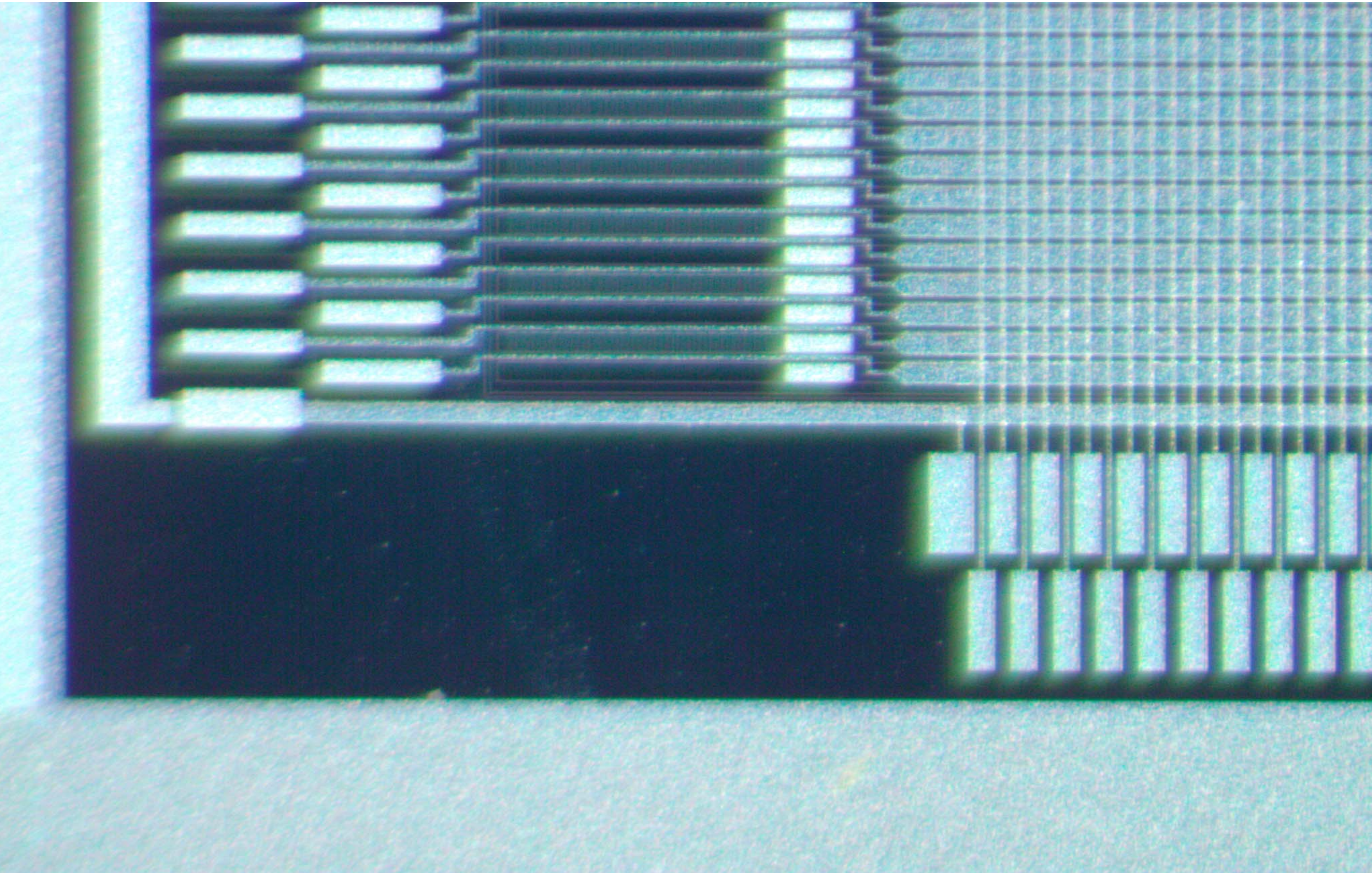
Photo of P - side Via's and Metal 2



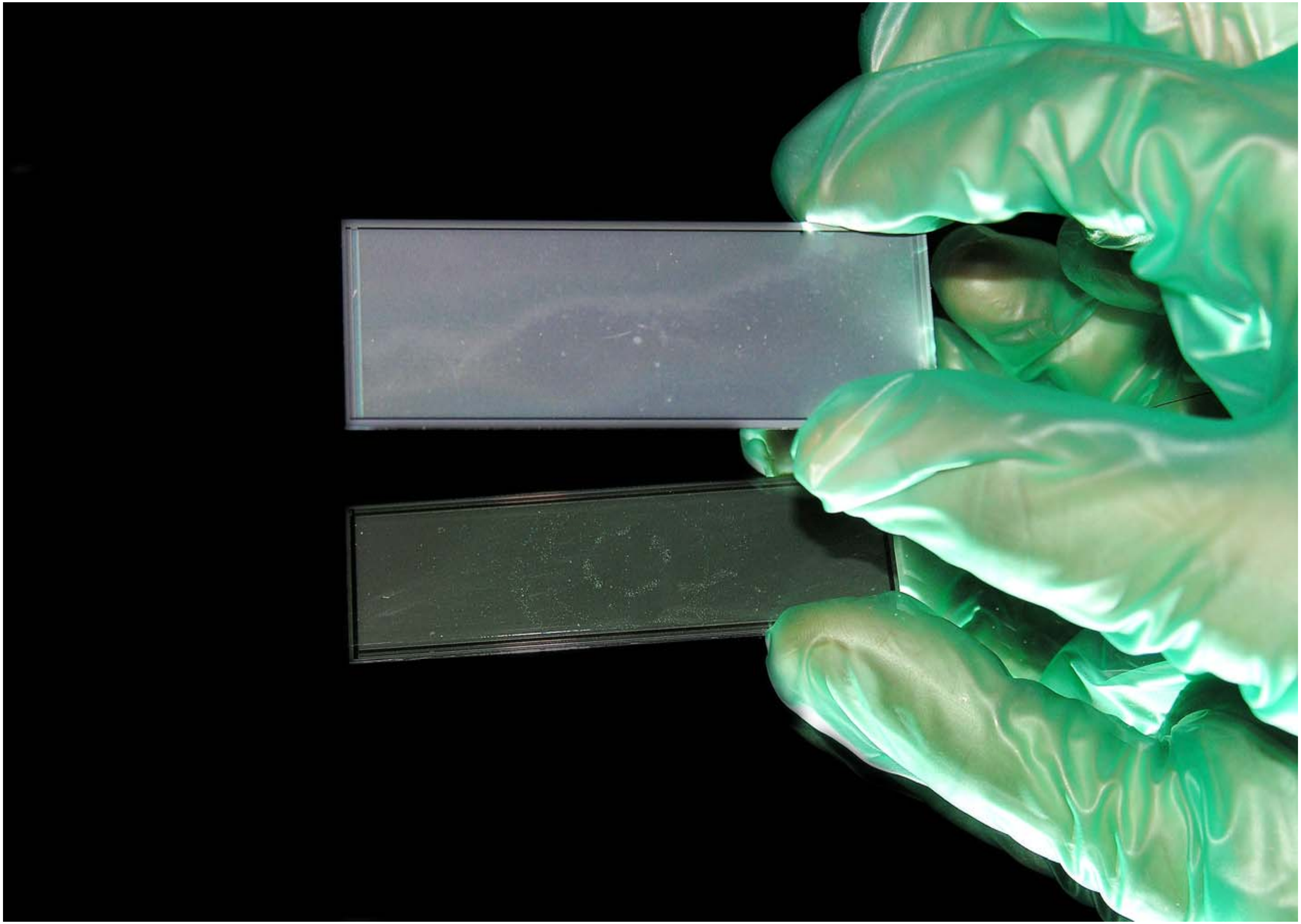
P – side AC pads after double metal



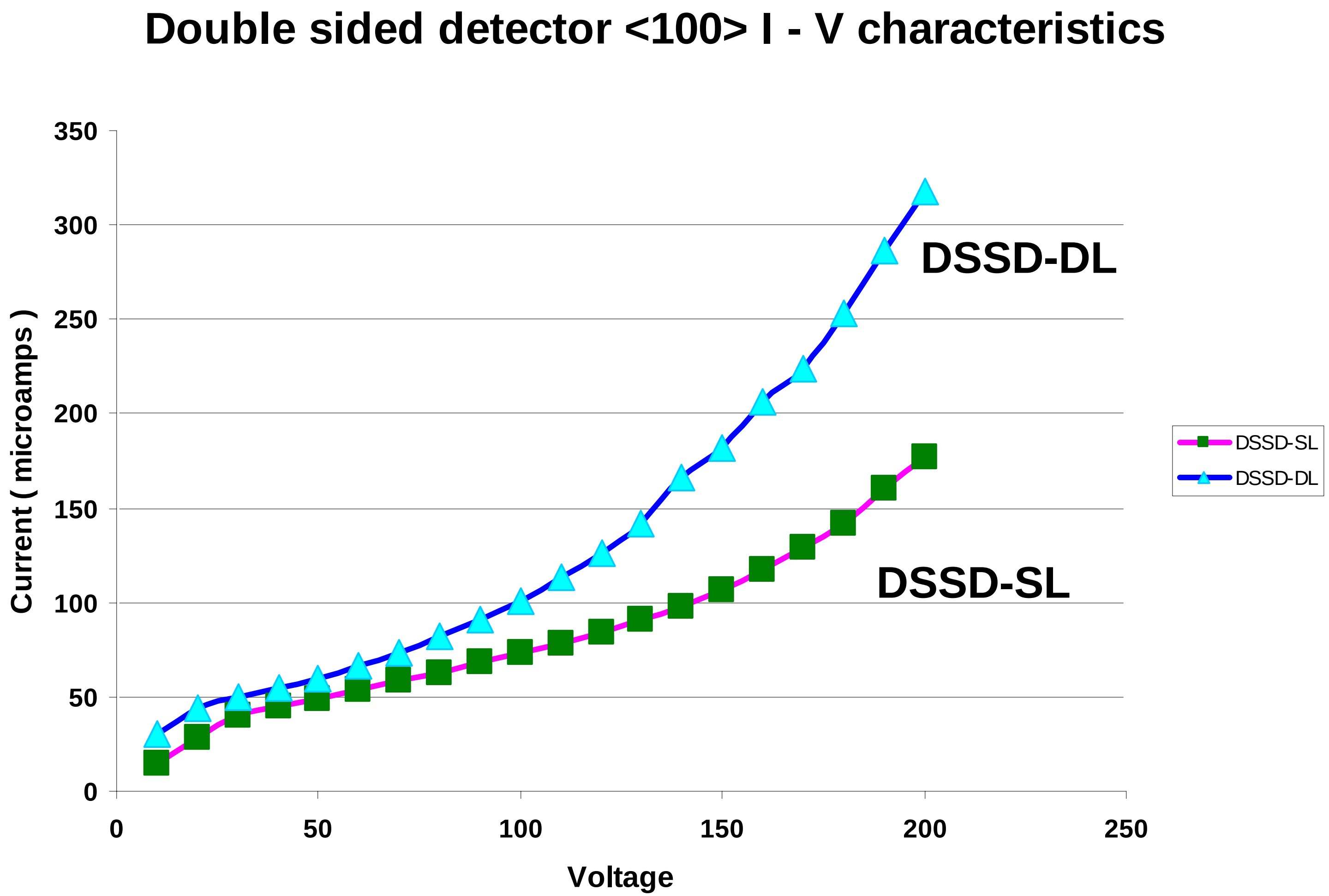
P – side double metal structure



Double sided silicon detector photo



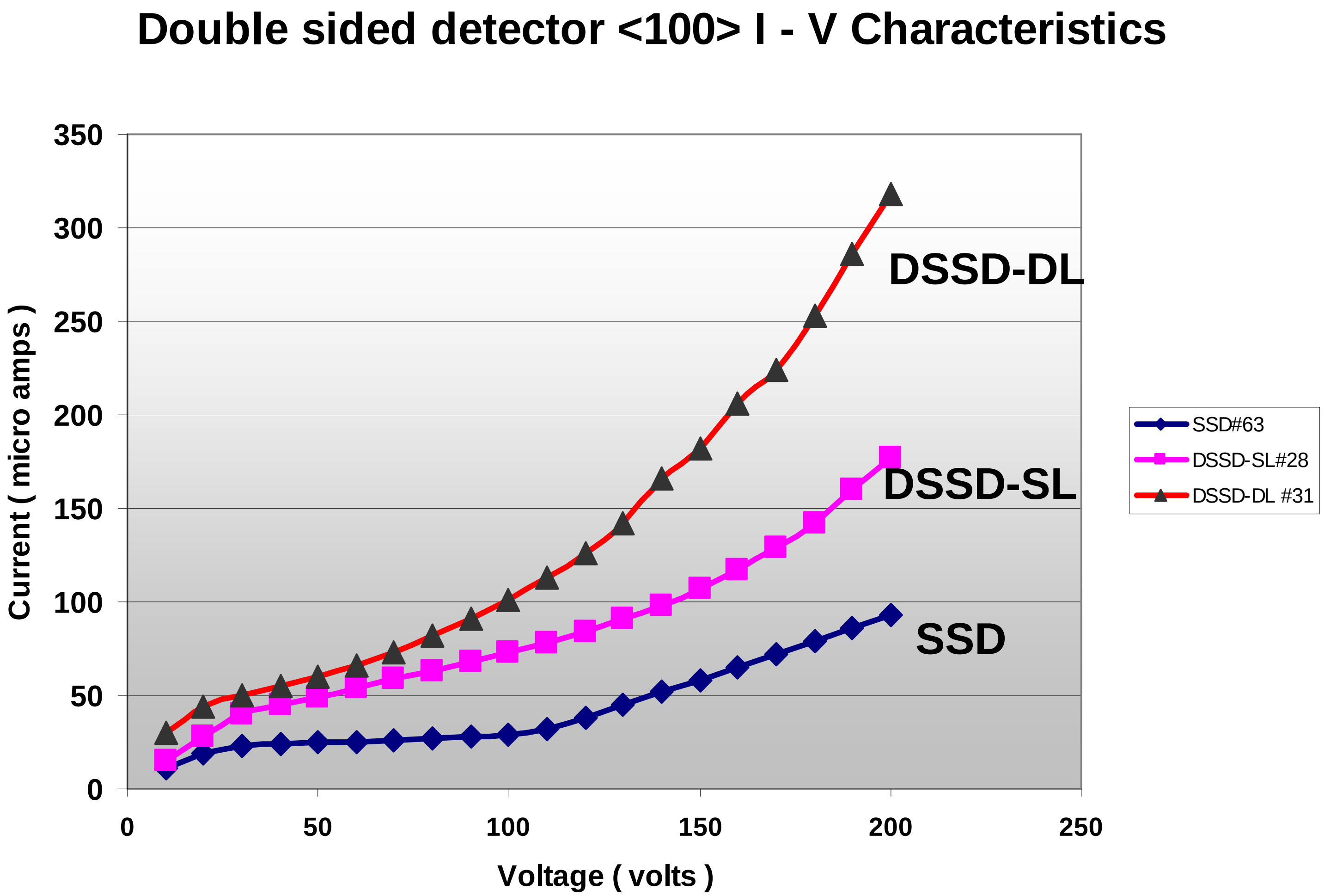
I – V characteristics of Double sided silicon Microstip detectors



Leakage current significantly higher than expected

First Process Cycle

I – V Comparision of single sided and double sided detectors



First Process Cycle

Third Batch

Development of single sided silicon microstrip detector

Number of detectors developed : 5

Wafer orientation	**: <111> FZ (earlier 100)**
Resistivity	**: 9k to 12k ohm cm**
wafer thickness	**: 300 microns**
Poly silicon value	**: > 5 Mega ohms**
Number of strips	**: 1024**
coupling capacitance	**: 160 pf**
P+ strip width	**: 50 microns**
Pitch	**: 75 microns**
Dead strip fraction	**: < 1%**

I – V characteristics of single sided detectors with different poly-values

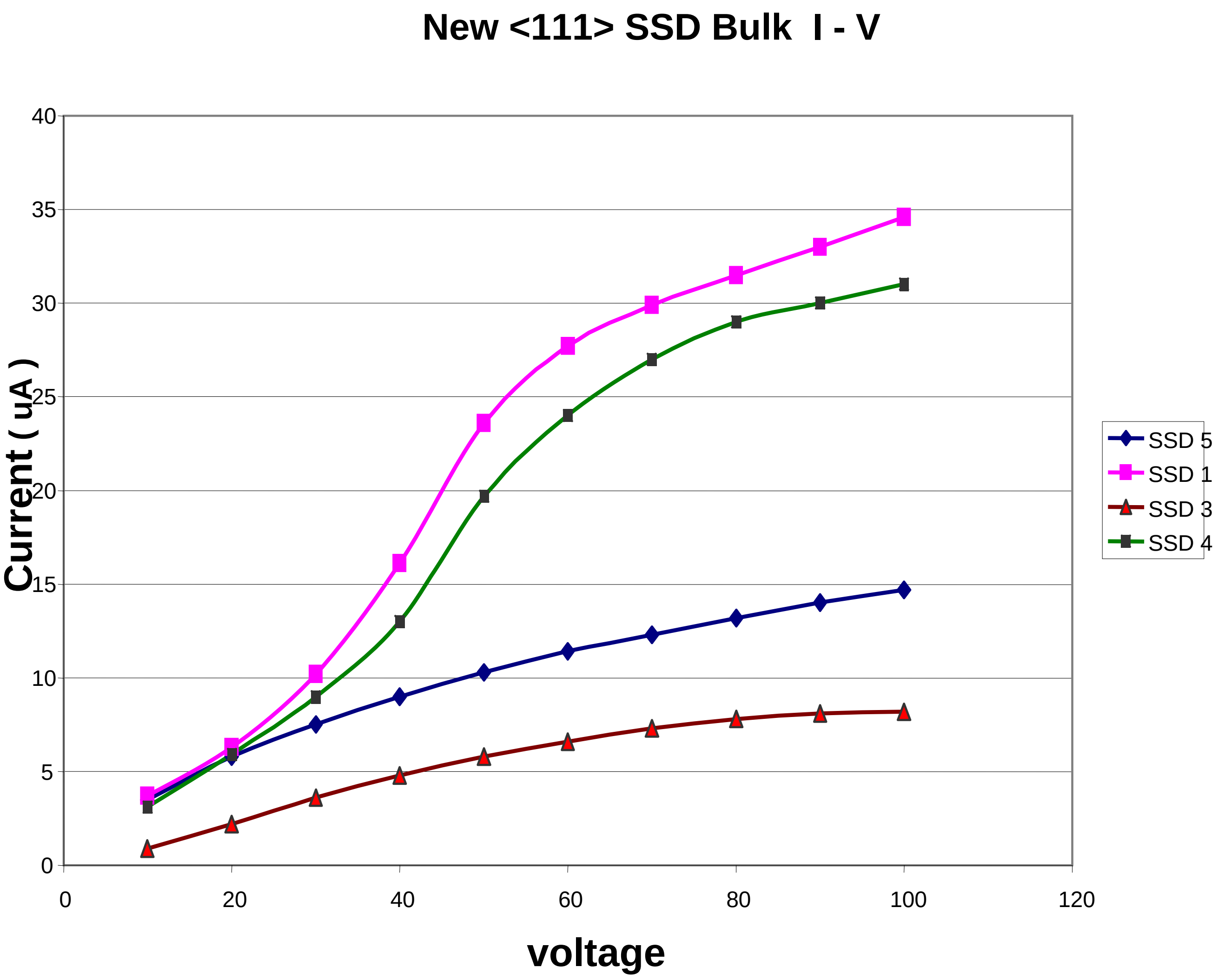
Poly-values Achieved :

SSD # 1 20 Mega ohms

SSD # 3   9 Giga ohms

SSD # 4   30 Mega hms

SSD # 5   26 Mega ohms



Fourth Batch

Under Development

Single sided silicon detector development with low resistivity of 2 to 4k ohm - cm

Expect first cycle by December end

If we see better results compared to high resistivity then go for DSSD as well

Remarks

DSSD Mask Design concept seems fine

Double Metal contact works

Leakage current and Capacitance on higher side

Since this is first cycle, hope better results at the end of 5th cycle in about a year

Pin-holes better than before, Need to do still better

Extra Slides

DOUBLE SIDED SILICON MICRO STRIP DETECTORS

Wafer crystal orientation : < 100 >
Type : FZ
Wafer thickness : 300 μm
Size : 4 inch
Resistivity : > 5 Kohm-cm
Breakdown voltage : > 300V
Polysilicon resistor value : > 4 Megaohms
Total Dark current : <= 2 microamps @ 100V
Area : 79600 x 28400
Effective Area : 76800 x 25600

N side :

Number of strips : 512

- Pitch : 50
- N+ strip width : 12
- N+ strip length : 76800
- P stop with ATTOL structure

AC pads will be available on both sides of the strips.

Polyresistors will be placed for one strip on the left side and the adjacent strip on the other side.

Proving pad (N – sub)

P side :

Number of strips : 1024

Number of Readout strips : 512

Pitch : 75

P+ strip width : 50

P+ strip length : 25600

Readout strips will be 512 only for both double metal structure as well as without double metal structure

AC pads will be available on both sides of the strips but reading will be alternate strips only

With double metal structure readout will be 512 strips

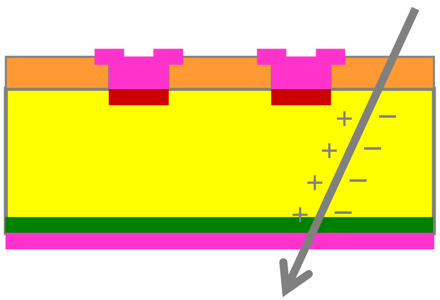
Polyresistors will be placed for one strip on one side and the adjacent strip on the other side.

AC pad accessibility of the strips will be available with double metal structure and as well as without double metal structure (provision for bonding with kepton cable)

Proving pad (N – sub) and serial number of strips on both sides

Silicon strip devices: Principle of operation

- Basic motivation: charged particle position measurement
  - **Use ionization signal left behind by charged particle passage**



  - **In a solid semiconductor, ionization produces electrons-hole pairs. For Si need 3.6 eV to produce one e-h pair. In pure Si, e-h pairs quickly recombine ⇒ need to drift the charges to electrodes … but how?**

Construction of detector

- **Sensor design choices**

  Sensor design must first follow physics requirements, still many choices:

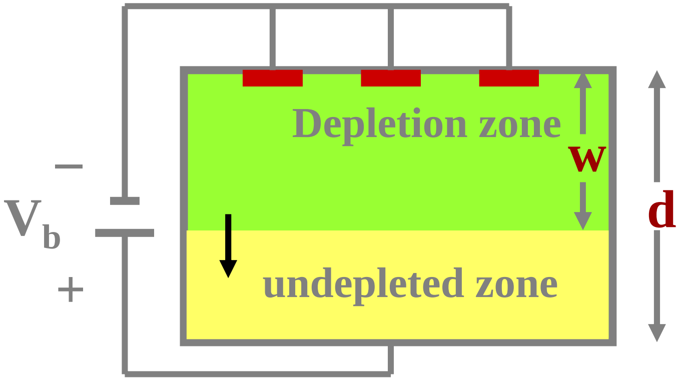
  - **Geometrical shape**
  - **Thickness**
  - **Read-out and implant pitch**
  - **p or n bulk silicon, resistivity**
  - **Double-sided or single-sided**
  - **Type of biasing structure**
  - **AC or DC coupling**
  - **Double-metal read-out**

In many cases there are conflicting design trade-offs between these choices. One finds that economics (limited project budget) often forces decision direction. Examples of trade-offs:

Choice	Pro	Con
Double-sided sensor	Less material for two read-out coordinates	Processing cost about 3x that for single-sided
500μm thickness	More signal	Multiple scattering and material budget are more

Principle of operation

- **Properties of the depletion zone**
  - **Depletion width is a function of the bulk resistivity , charge carrier mobility μ and the magnitude of the reverse bias voltage V_b:**



$$w = \sqrt{2\varepsilon\rho\mu V_b}$$

where ρ = 1/qμN for doped materiel and N is the doping concentration (q is always the charge of the electron)

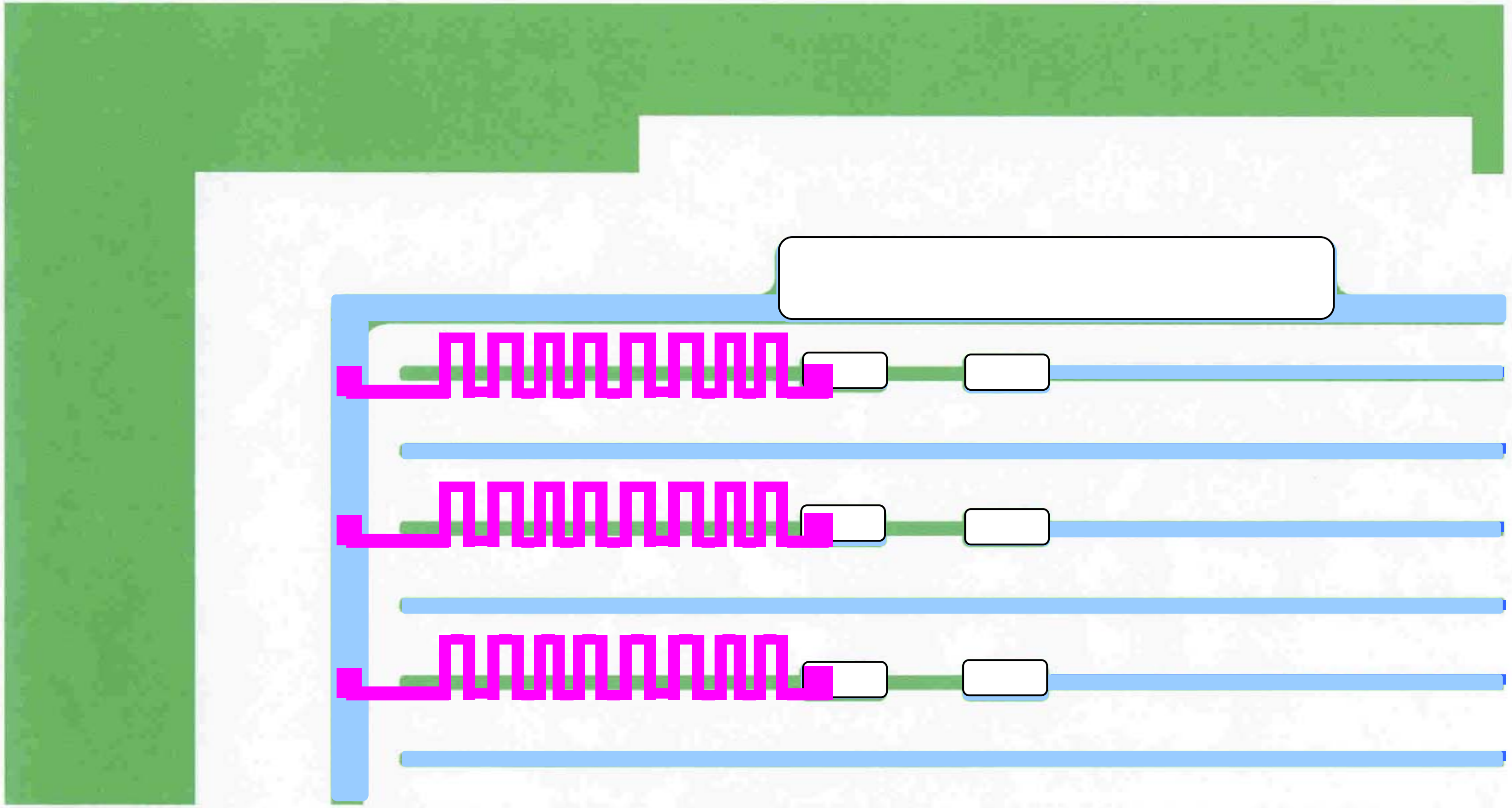
- **The voltage needed to completely deplete a device of thickness d is called the depletion voltage, V_d**

$$V_d = d^2 / (2\varepsilon\rho\mu)$$

- **Thus one needs a higher voltage to fully deplete a low resistivity material.**
- **One also sees that a higher voltage is needed for a p-type bulk since the carrier mobility of holes is lower than for electrons (450 vs 1350 cm²/ V·s)**

MASK DESIGNS

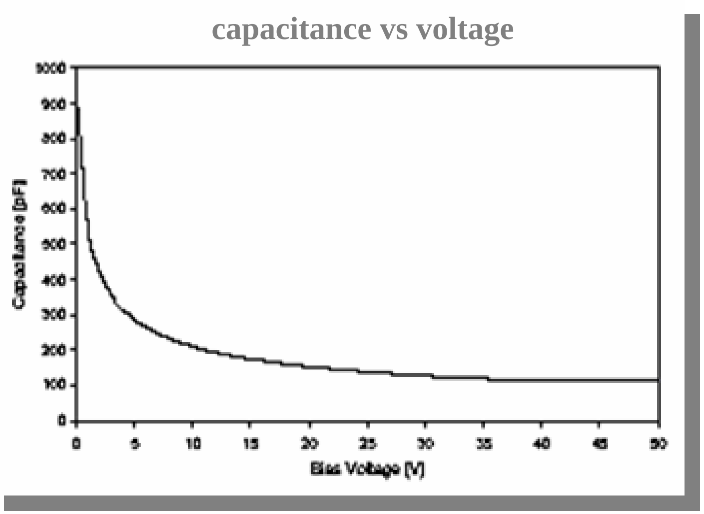
Mask 1 : p+
Mask2 : Capacitor (SiO_2)
Mask3 : Polycontact opening
Mask4 : Polyresistor
Mask 5 : Opening Contacts over dc pad, bias pad
Mask 6 : Metal
Mask 7 : Protective layer



Principle of operation

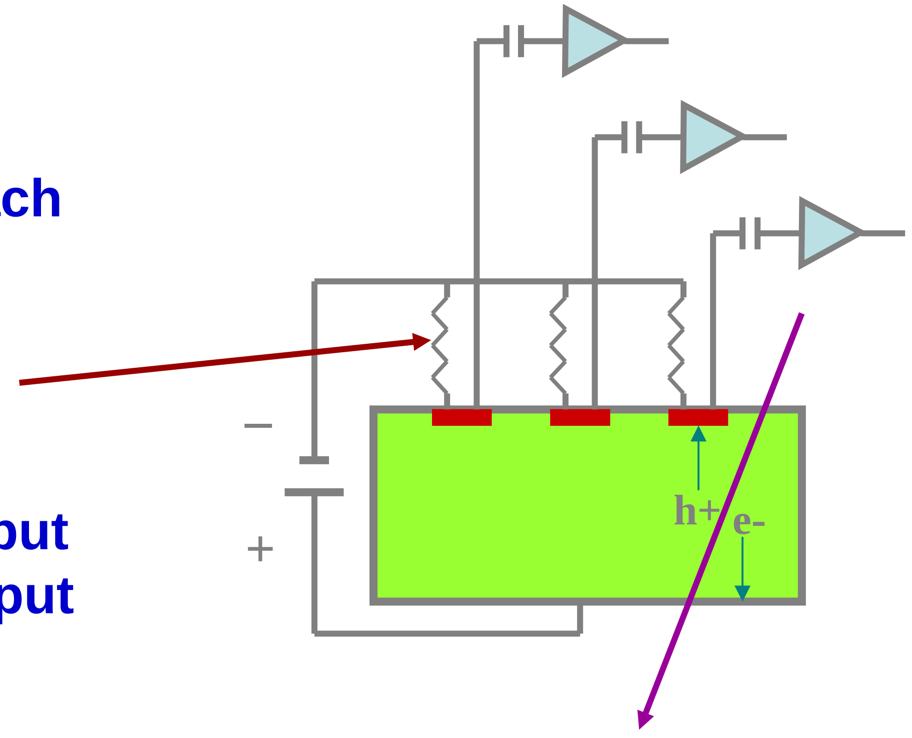
- **Properties of the depletion zone (cont)**
  - **The capacitance is simply the parallel plate capacity of the depletion zone. One normally measures the depletion behaviour (finds the depletion voltage) by measuring the capacitance versus reverse bias voltage.**

$$C = A\sqrt{\varepsilon / 2\rho\mu V_b}$$



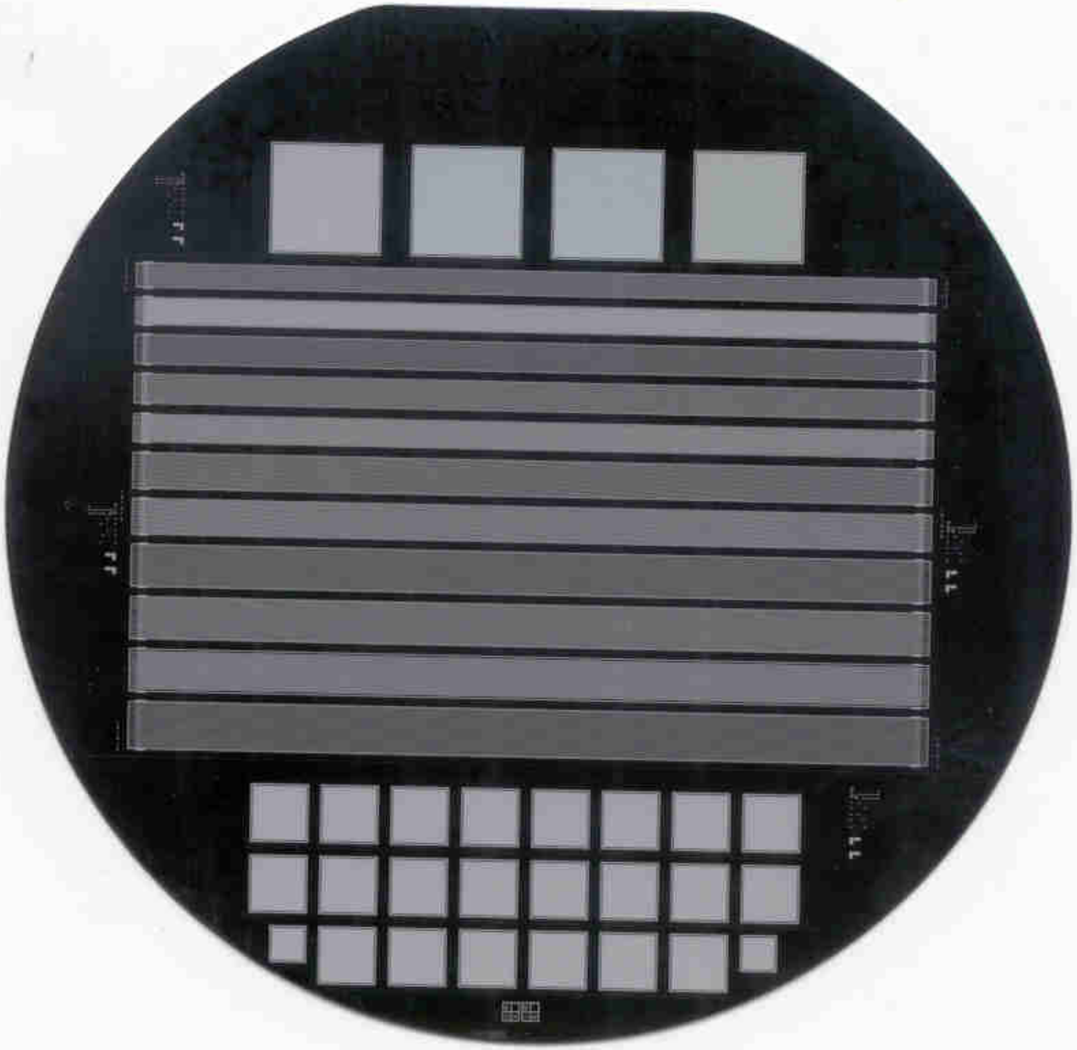
Principle of operation

- **Charge collection**
  - **Need to isolate strips from each other and collect/measure charge on each strip ⇒ high impedance bias connection (resistor or equivalent)**
  - **Usually want to AC couple input amplifier to avoid large DC input currents**
  - **Both of these structures are often integrated directly on the silicon sensor. Bias resistors via deposition of doped polysilicon, and capacitors via metal readout lines over the implants but separated by an insulating dielectric layer (SiO_2).**



Minimum ionizing particle generates approximately 23000 electron – hole pairs in 300micron silicon detector

ProtoType Silicon Microstrip Detector



Geometry： 76mm * 47mm