3D DETECTORS AT VTT

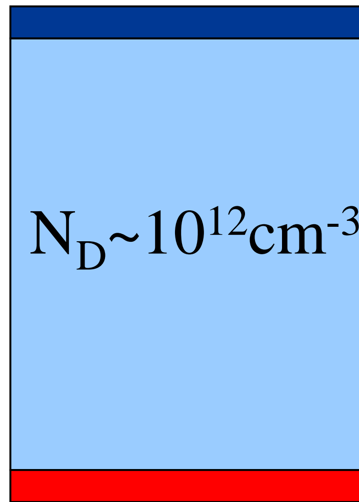
VERY FIRST RESULTS / S. ERÄNEN & J. KALLIOPUSKA

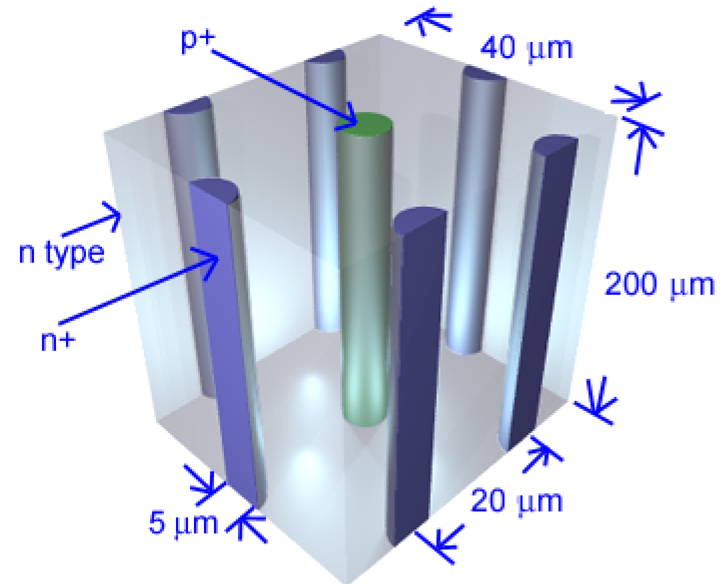
3D DETECTORS @ VTT
CERN, APRIL 2004

OUTLINE

- 3D DETECTORS: GENERAL
- NEW STRUCTURES &LAYOUTS
- BENEFITS OF SEMI 3D STRUCTURES
- PROCESS SEQUENCE
- PHOTOGRAPHS
- ELECTRICAL: IV, LEAKAGE, ILLUMINATION, CV & DEPLETION, BREAKDOWN, SCRIBING DAMAGE
- RADIATION MEASUREMENTS
- SIMULATIONS
- CONCLUSIONS
- CONTINUATION

2D (PLANAR) TO 3D DETCTORS

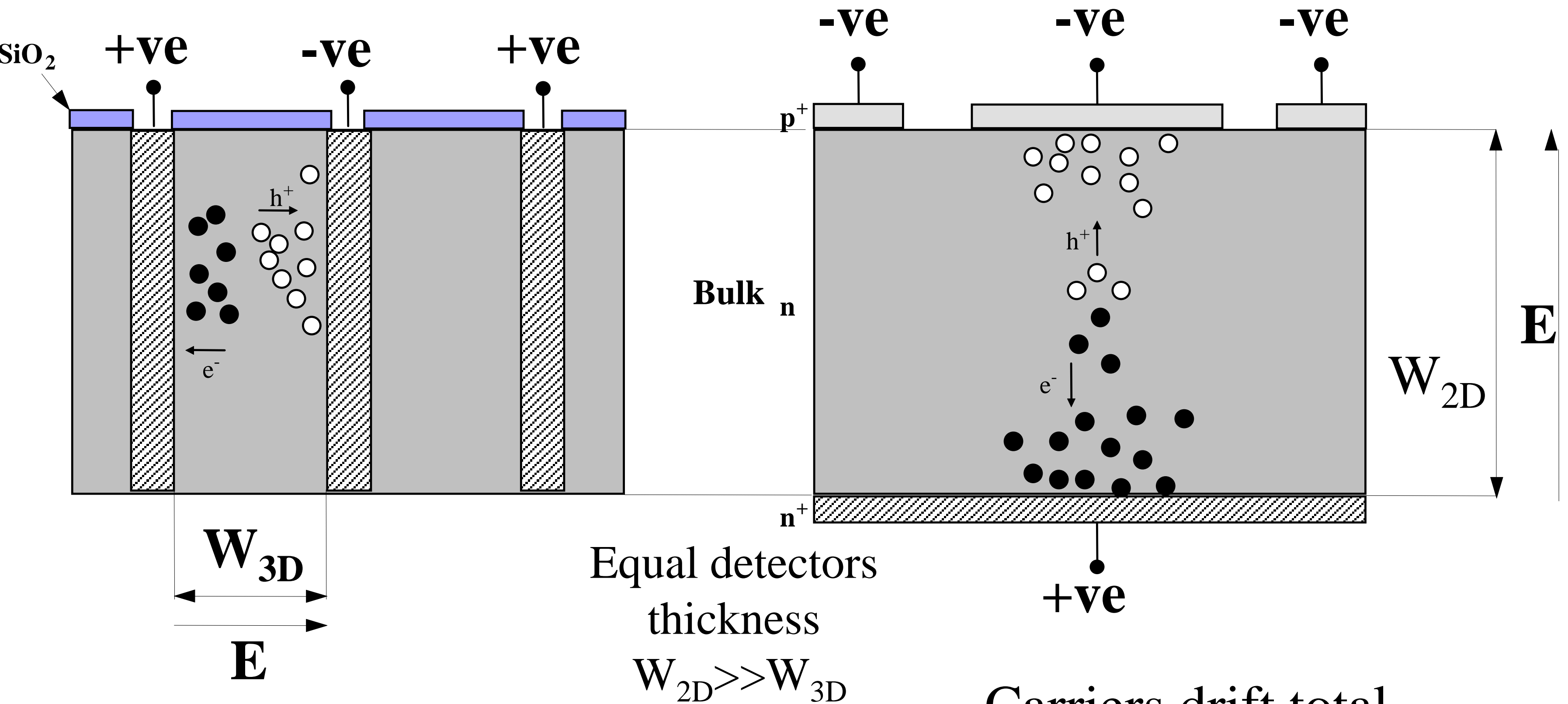




PLANAR: STRIP OR PIXEL

Parker et al @ 1997

- application areas: high energy physics experiments and (medical) imaging
- the real advantage of 3D detectors is the ability to build structures, that operate at lower bias voltages. This implies the possibility to use in the detector fabrication large area CZ-Si wafers, which are also believed to offer a more radiation tolerant devices as compared to those fabricated on the FZ-silicon
- speed of charge collection
- spatial resolution
- narrow dead area at the edges



Carriers swept horizontally
Travers short distance between electrodes

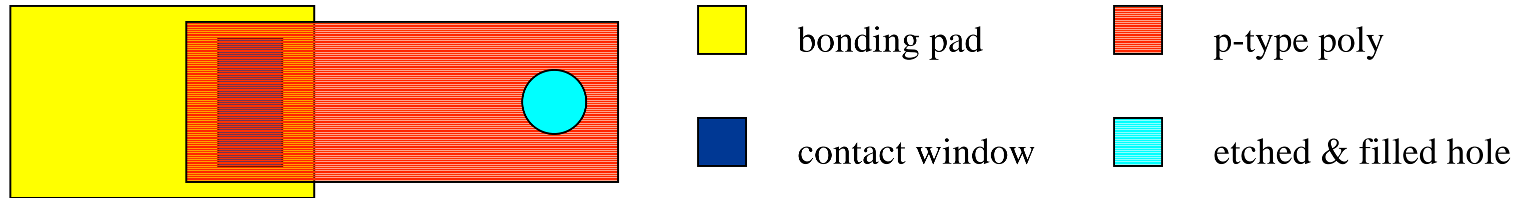
Carriers drift total thickness of material

Proposed by S.Parker, Nucl. Instr. And Meth. ***A 395*** *pp. 328-343(1997).*

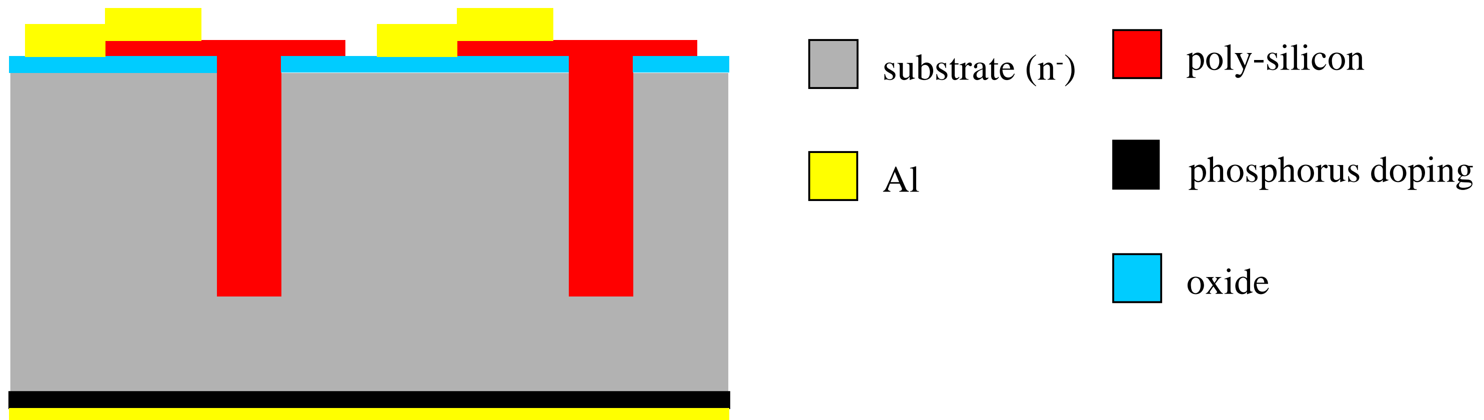
VTT

NEW (SEMI 3D) STRUCTURES

1. PIXEL DETECTOR

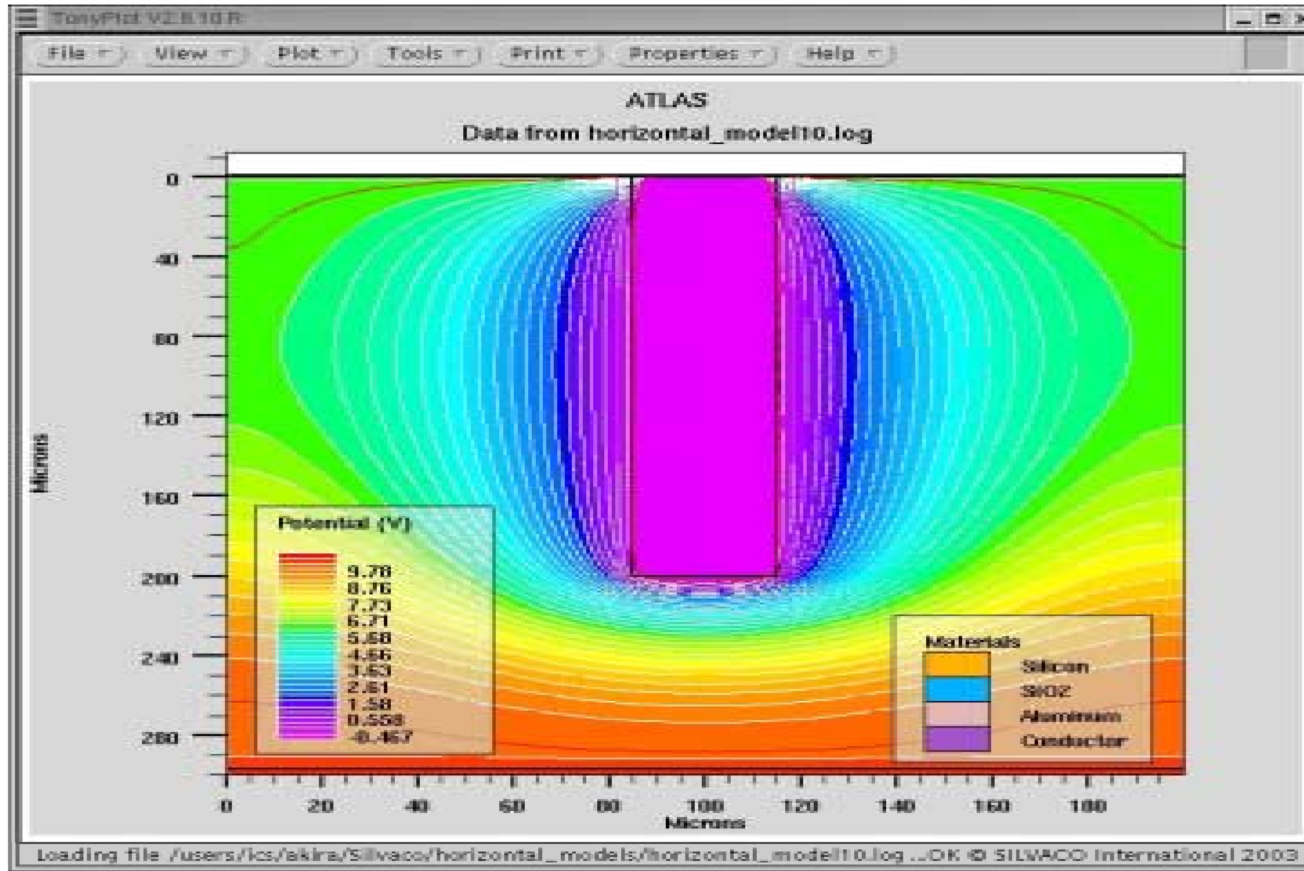


• principled cross section of two adjacent pixels (scale not correct)



NEW (SEMI 3D) STRUCTURES

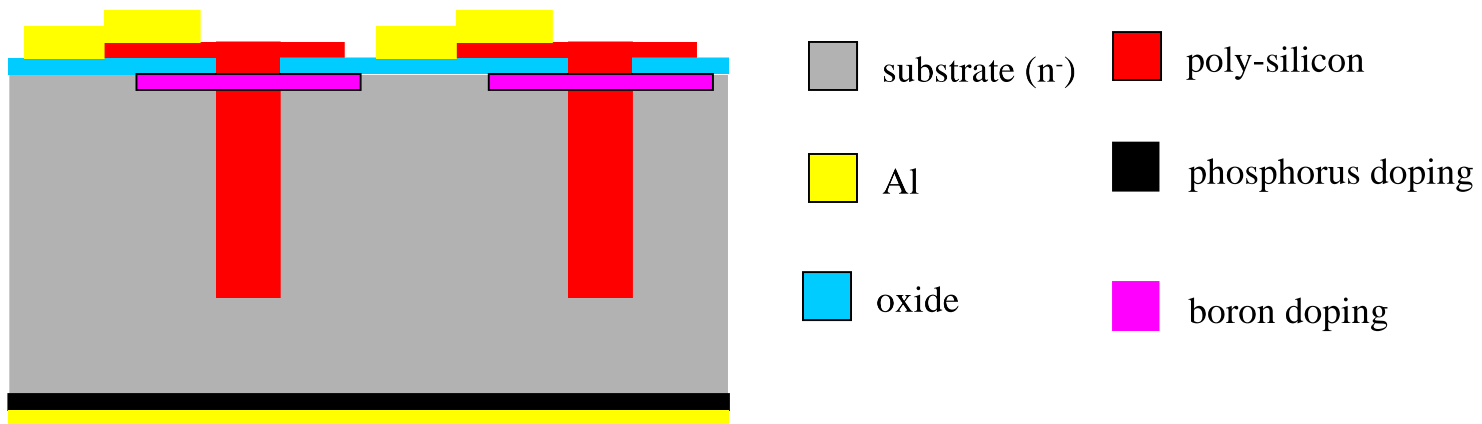
SIMULATION EXAMPLE



SURFACE CHARGE !

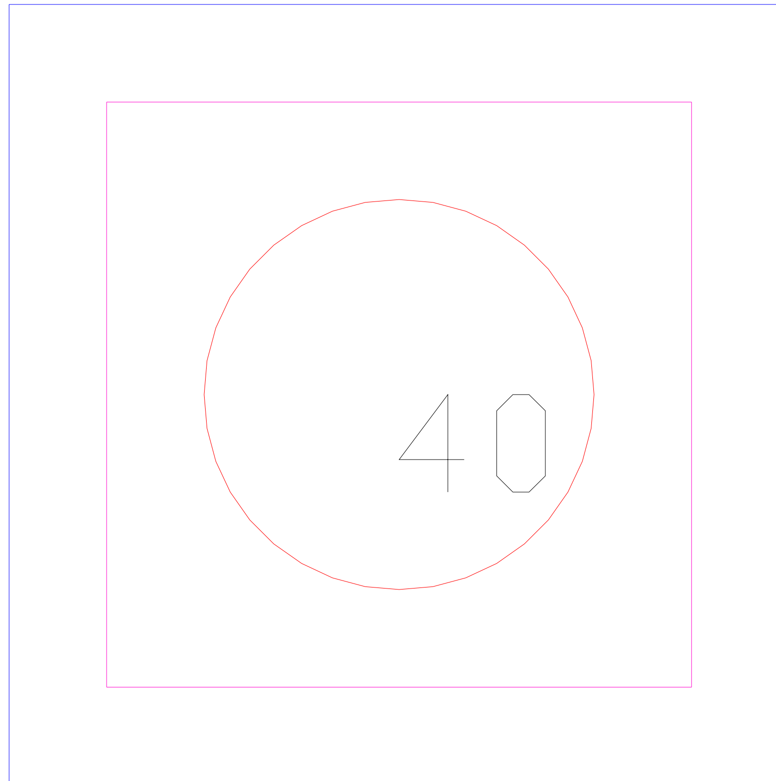
NEW (SEMI 3D) STRUCTURES

SURFACE IMPLANT IN ORDER TO IMPROVE DEPLETION



NEW (SEMI 3D) STRUCTURES

PIXEL LAYOUT



NEW (SEMI 3D) STRUCTURES

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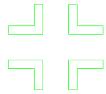

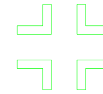

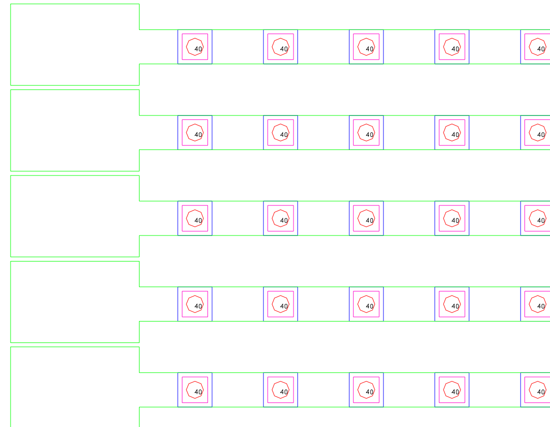

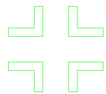

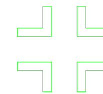

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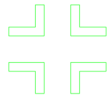
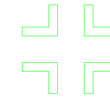
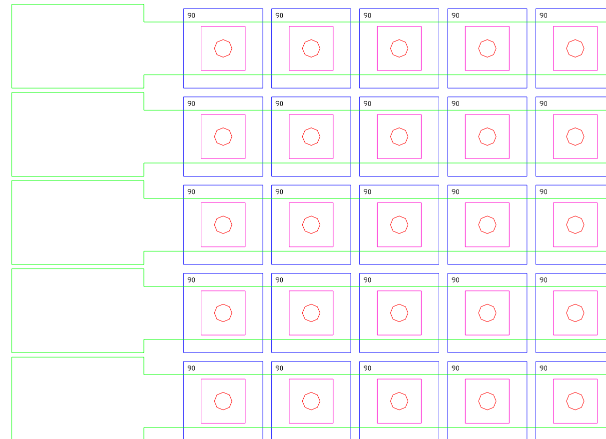
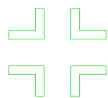
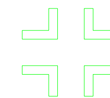




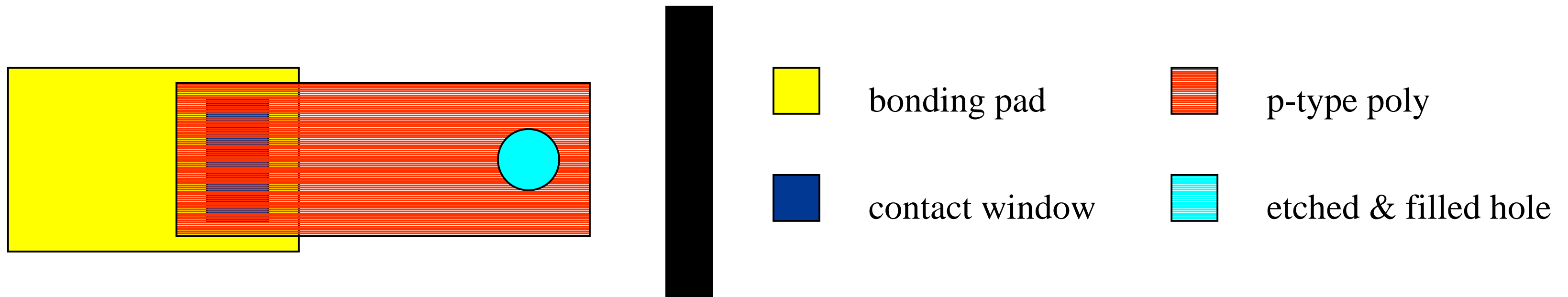






NEW (SEMI 3D) STRUCTURES

2. ACTIVE EDGE PIXEL DETECTOR



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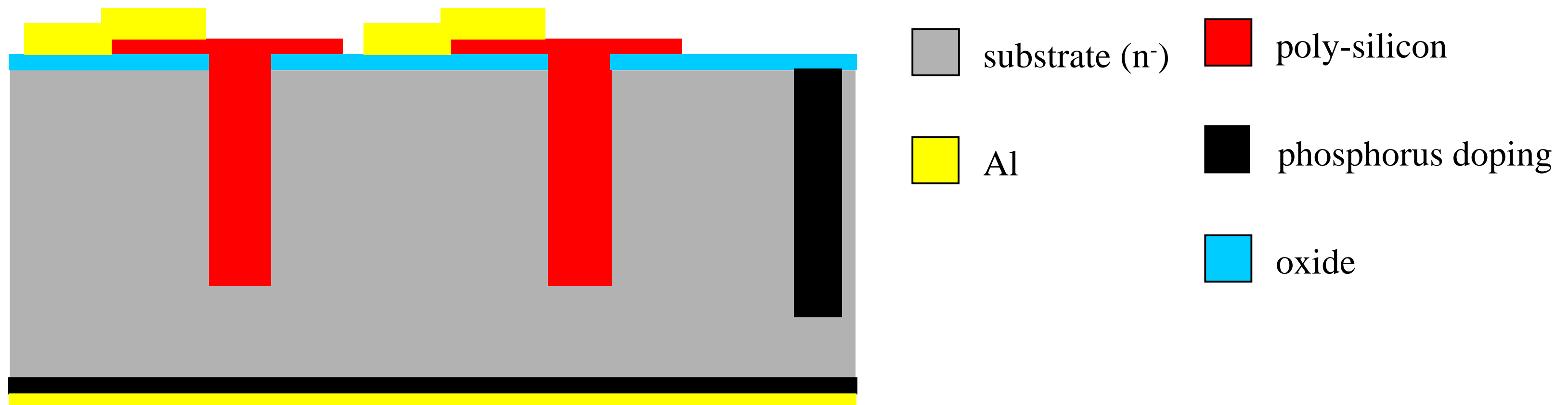
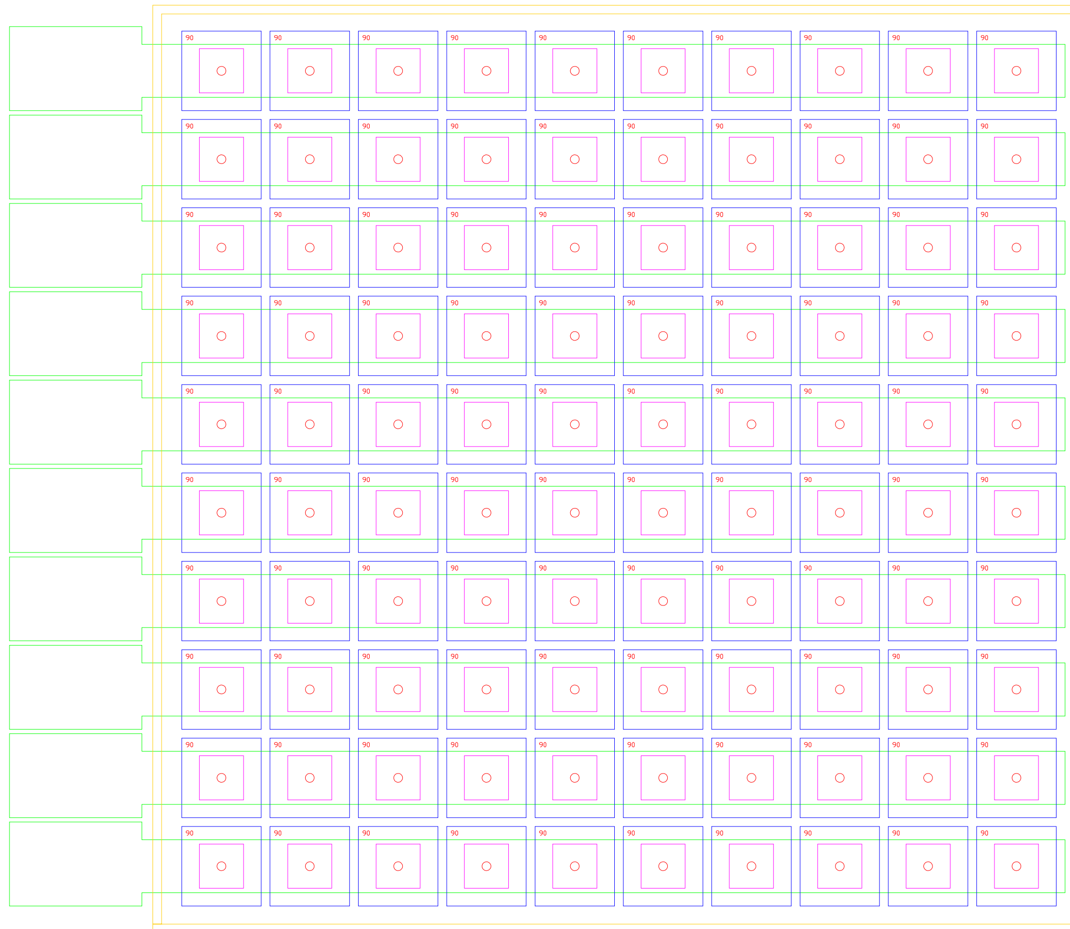


NEW (SEMI 3D) STRUCTURES

2. ACTIVE EDGE PIXEL LAYOUT



PIXEL DETECTOR: STRUCTURES

STRUCTURES:

- HOLE DIAMETER 10 & 20 MICRONS --> ETCH DEPTH 150 & 200 MICRONS
- PITCH 100 & 200 MICRONS
- SURFACE IMPLANT 40, 90, 100 & 190 MICRONS
- AREA 1*1 cm^2 & 2*2 cm^2 (10000 PIXELS)+ SMALL STRUCTURES

NEW (SEMI 3D) STRUCTURES

BENEFITS

- FABRICATION PROCESS NOT TOO COMPLICATED
- BULK SILICON WAFERS (CZ TOO)
- SPATIAL RESOLUTION
- TUNABILITY OF THE VERTICAL DOPING PROFILES
- SMALL DEPLETION VOLTAGE
- FAST SIGNAL CHARGE COLLECTION
- READ-OUT PITCH AND DEPLETION VOLTAGE INDEPENDENT
- LARGE AREA DETECTORS DEMONSTRATED

PIXEL DETECTOR: PROCESS

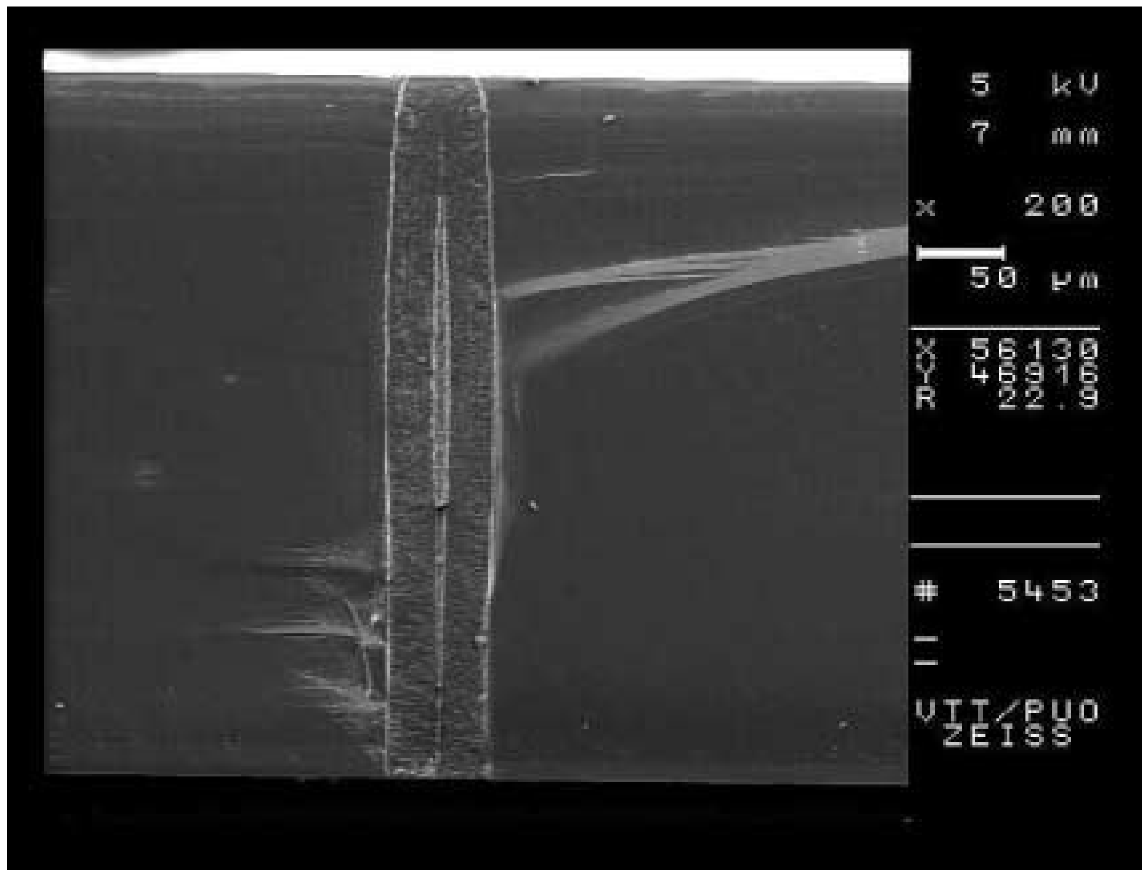
- n-type wafer, CZ & FZ, 300 microns thickness
- oxidation
- masking step to define the hole positions — first mask
- etch silicon to the desired depth
- grow p-type poly
- fill the holes and planarize (CMP or etch back)
- open oxide and implant — second mask
- diffusion & activation
- contact windows — third mask
- sputter aluminum
- metal pattern — fourth mask
- NOTE: MASKLESS BACKSIDE PROCESSES EXCLUDED FROM THE FLOW

4 MASKS NEEDED - COMPLEXITY COMPARABLE TO PLANAR DETECTORS

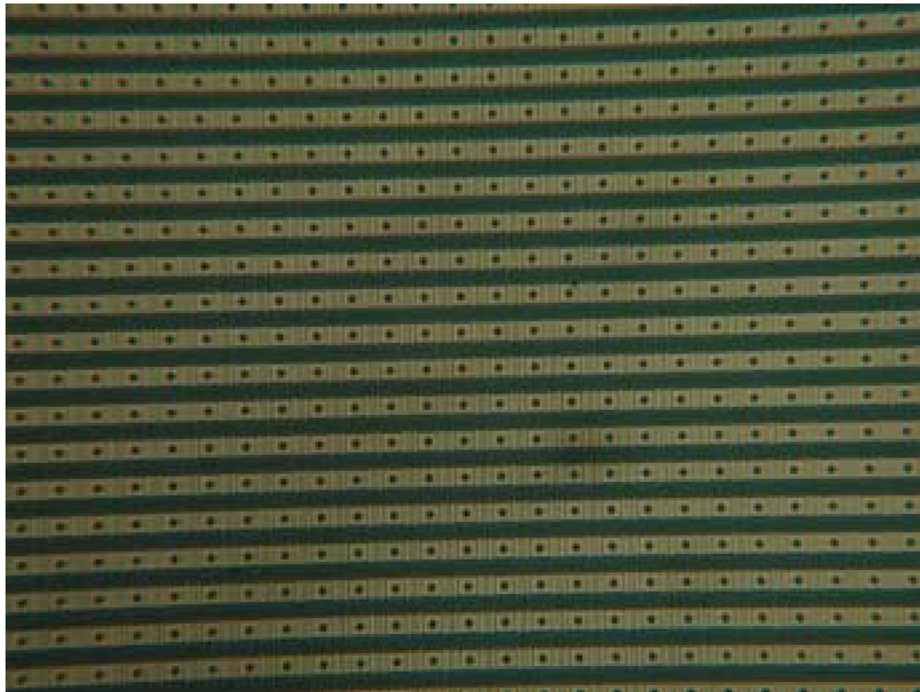
ACTIVE EDGE WILL ADD ONE MASK STEP AND POLYSILICON STEP INTO FLOW

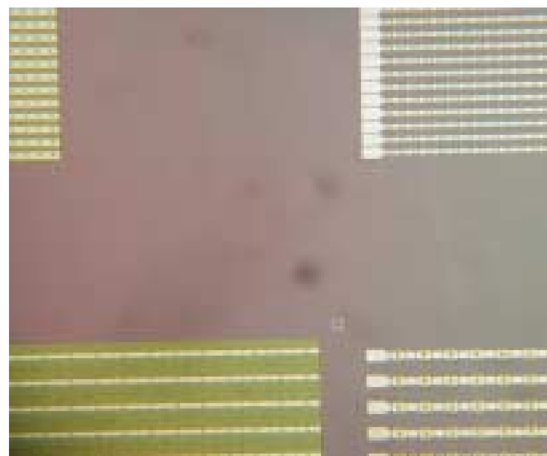
PIXEL DETECTOR: PROCESS

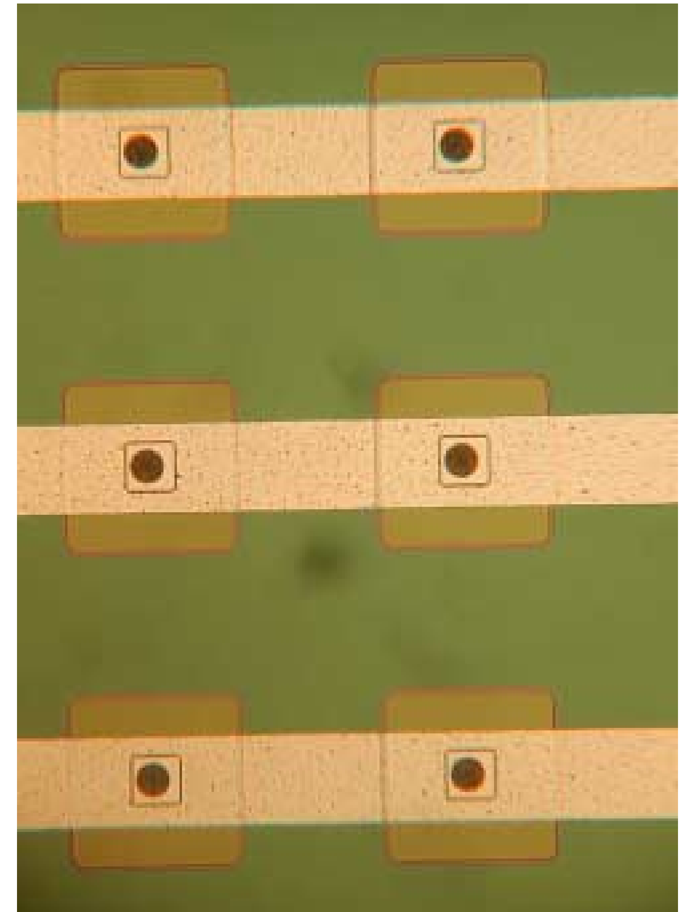
- ICP-ETCHING & LPCVD POLYSILICON GROWTH
- POLYSILICON: IN-SITU DOPED & FAST GROWTH RECIPE (40 nm / min)



PIXEL DETECTOR: PHOTOGRAPHS

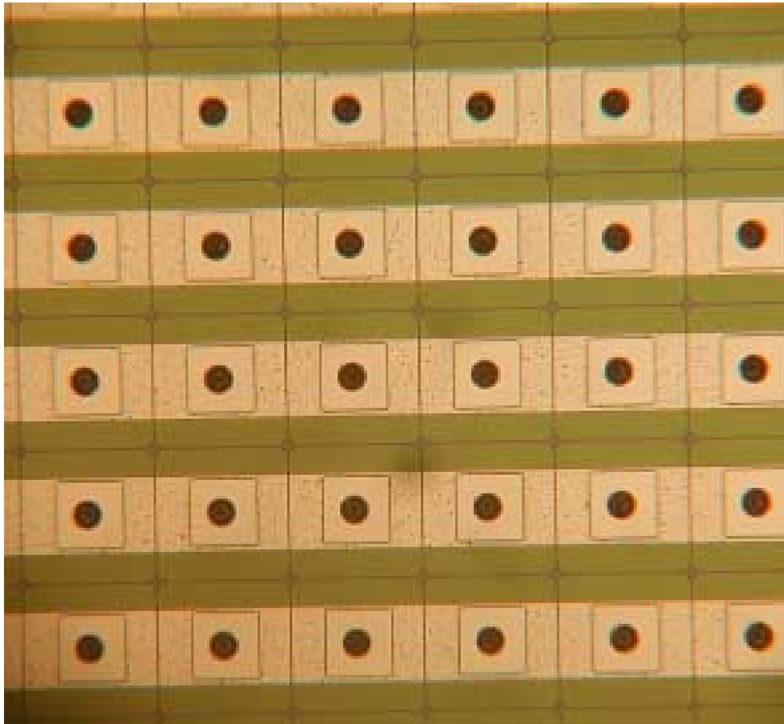


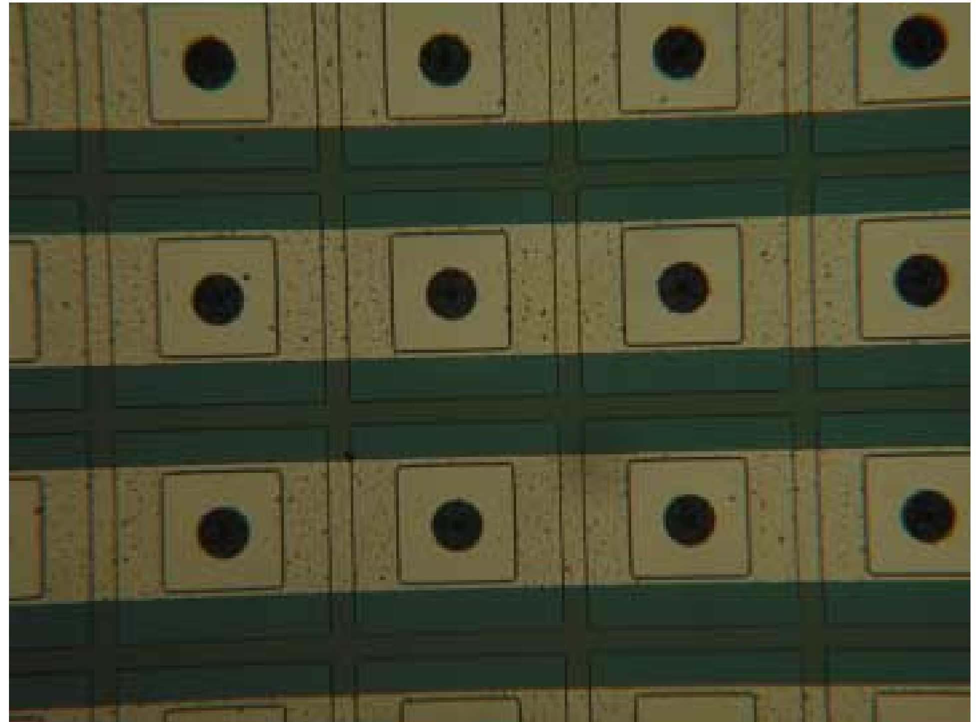




VTT

PIXEL DETECTOR: PHOTOGRAPHS





VTT

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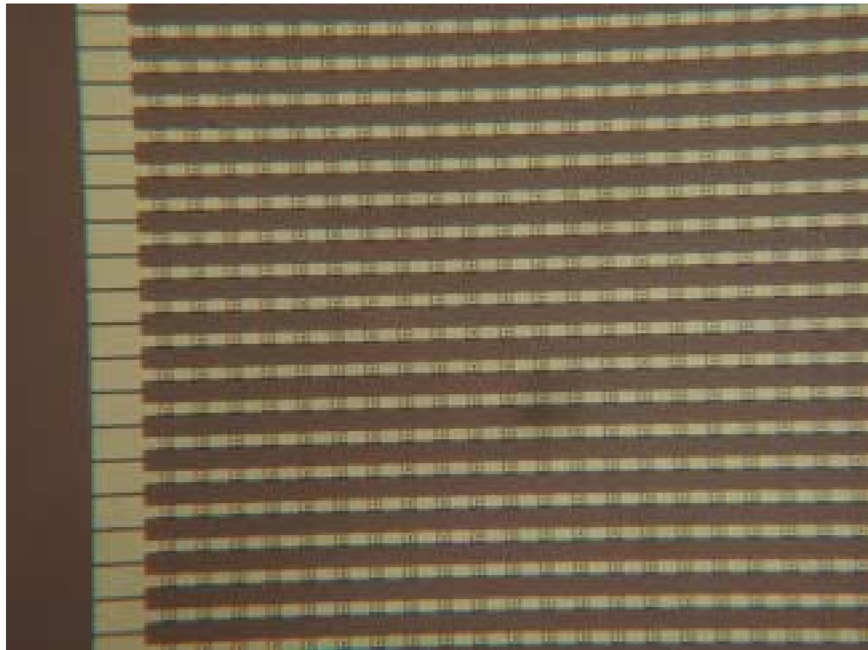

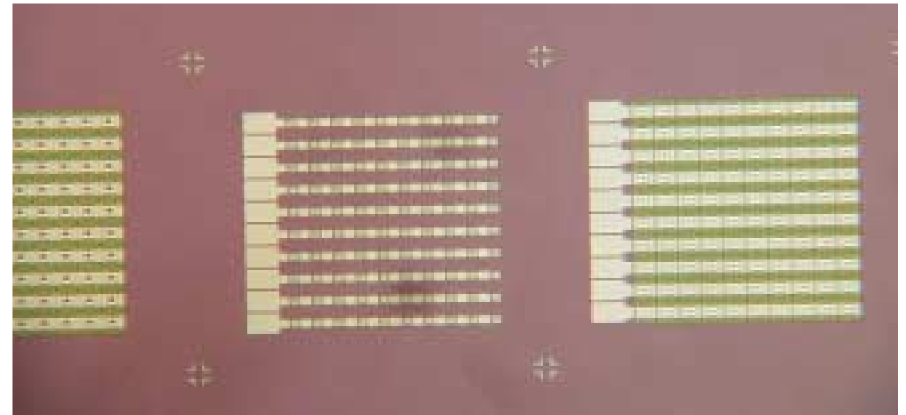

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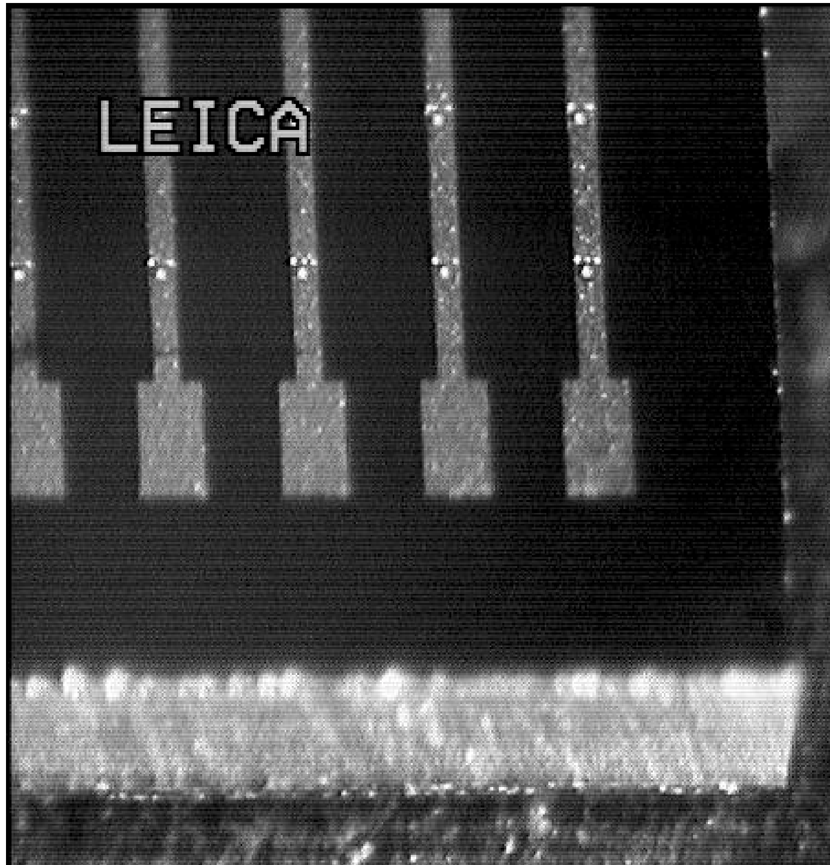
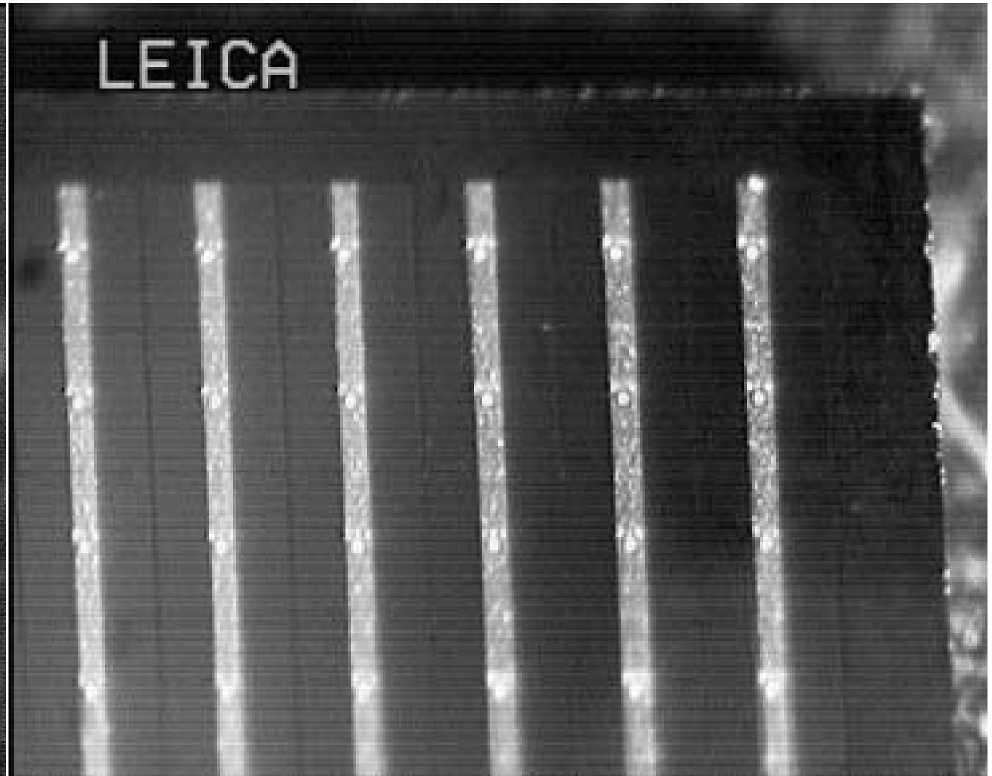
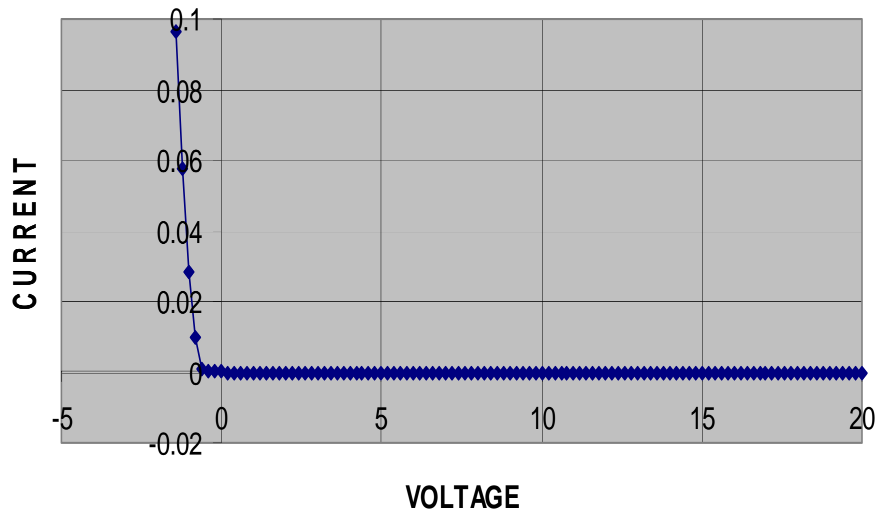


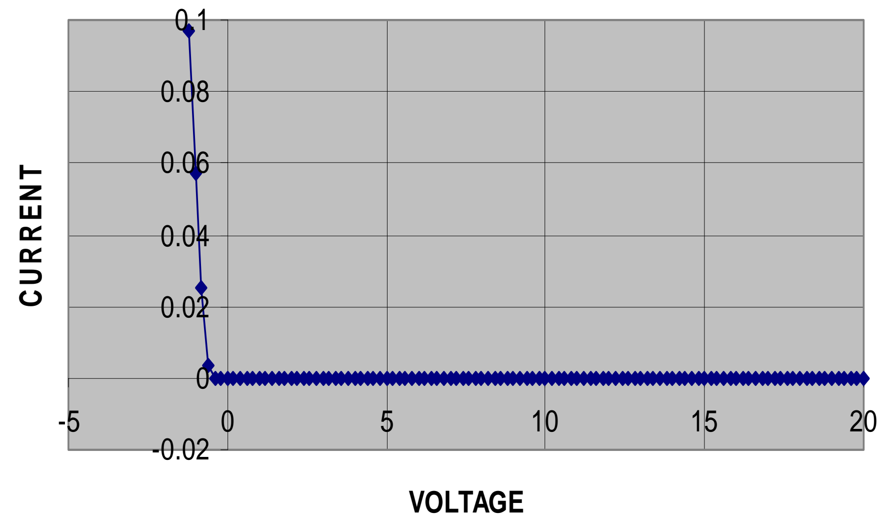


SCRIBING DAMAGE !!

PIXEL DETECTOR: ELECTRICAL

1. DIODE CHARACTERISTICS





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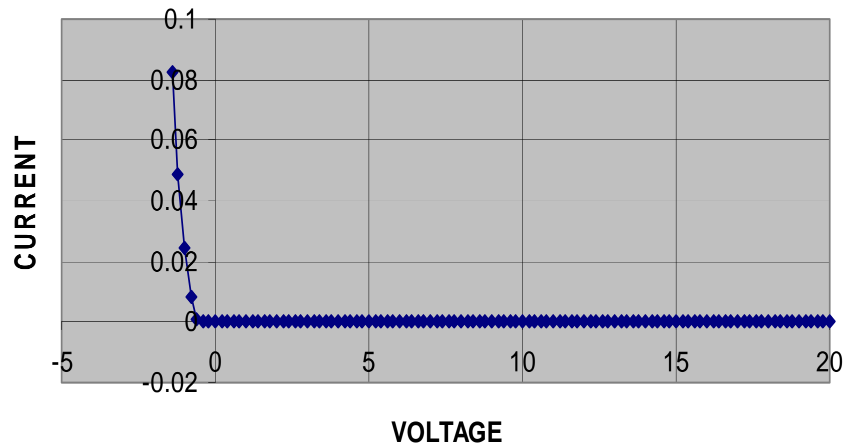
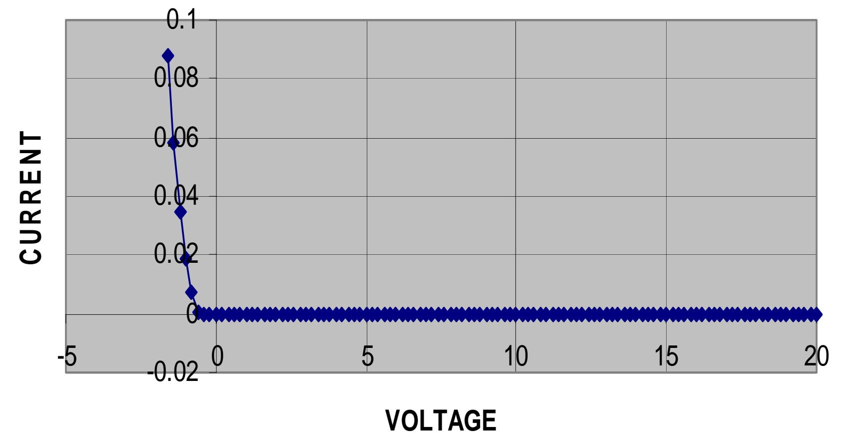
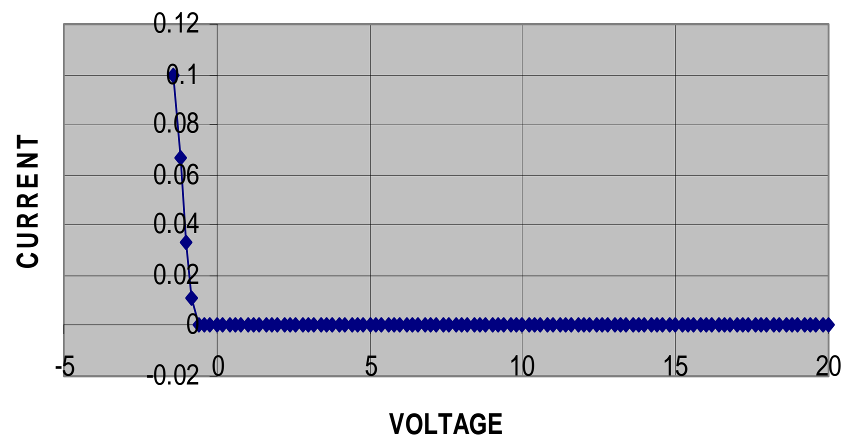
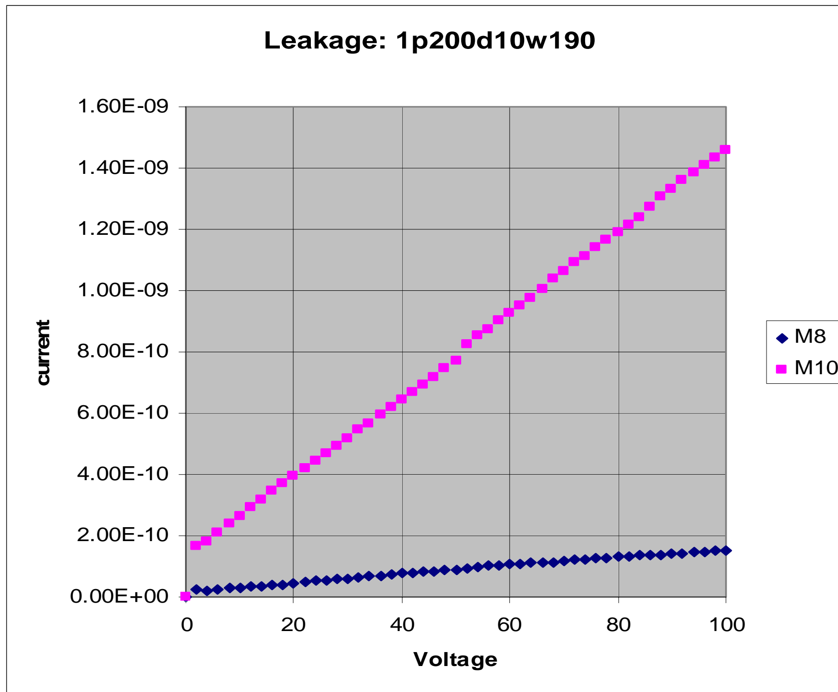


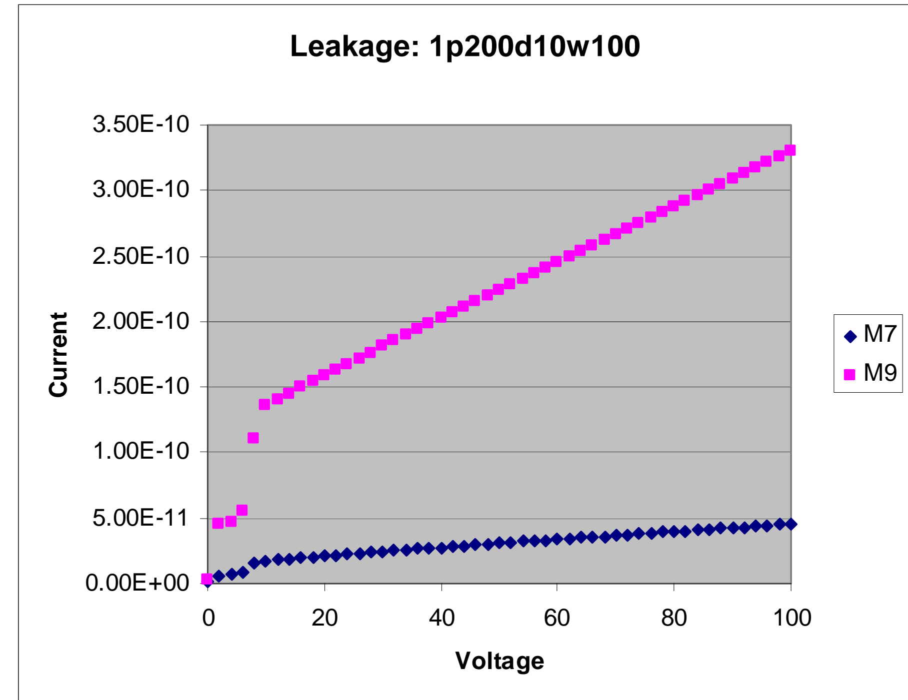




PIXEL DETECTOR: ELECTRICAL

2. LEAKAGE CURRENT





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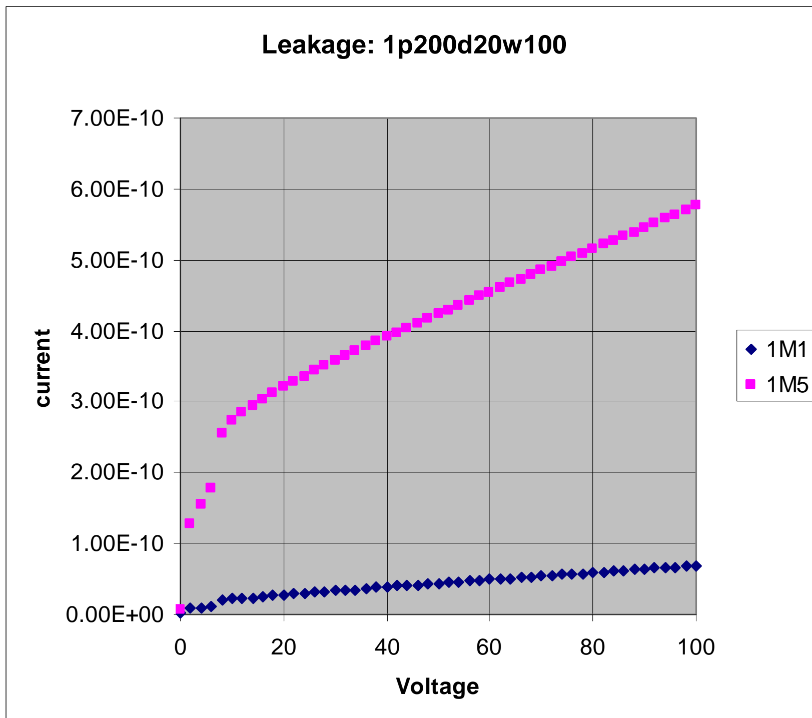

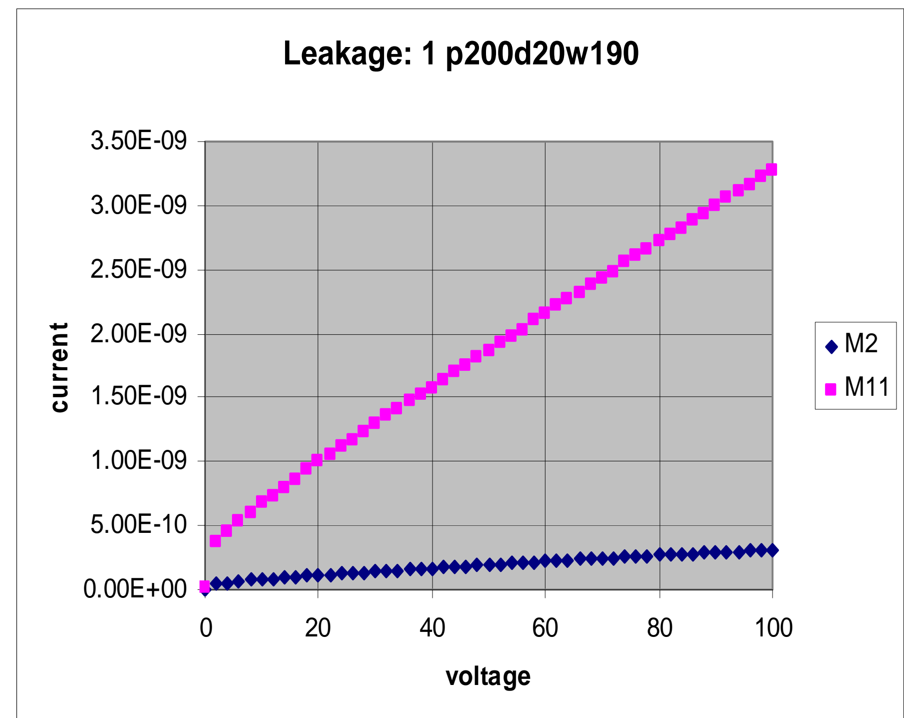

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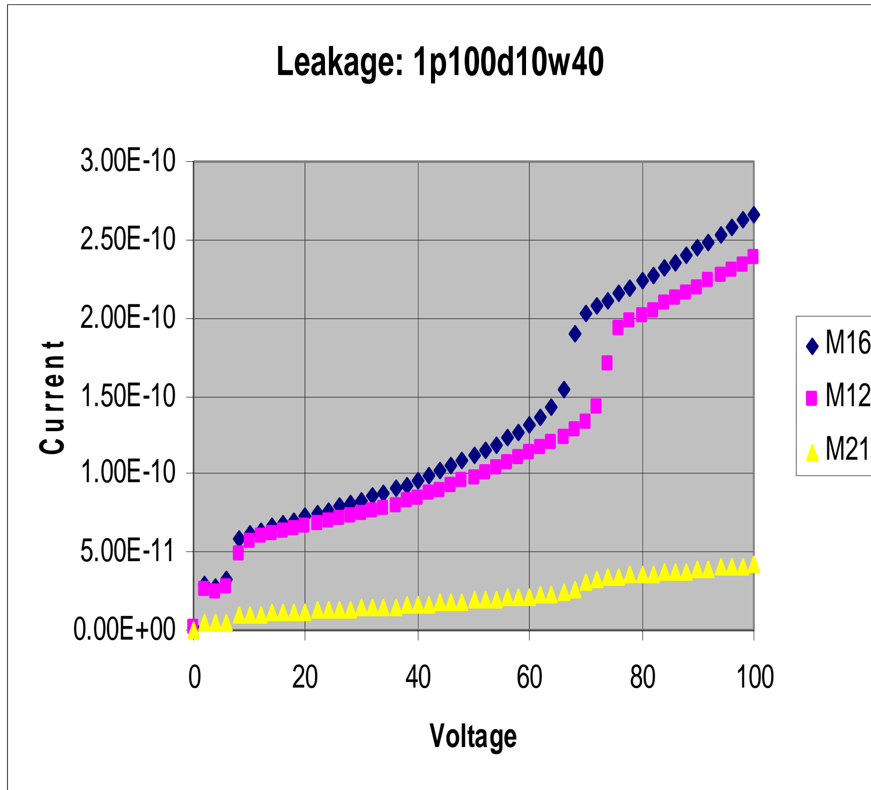

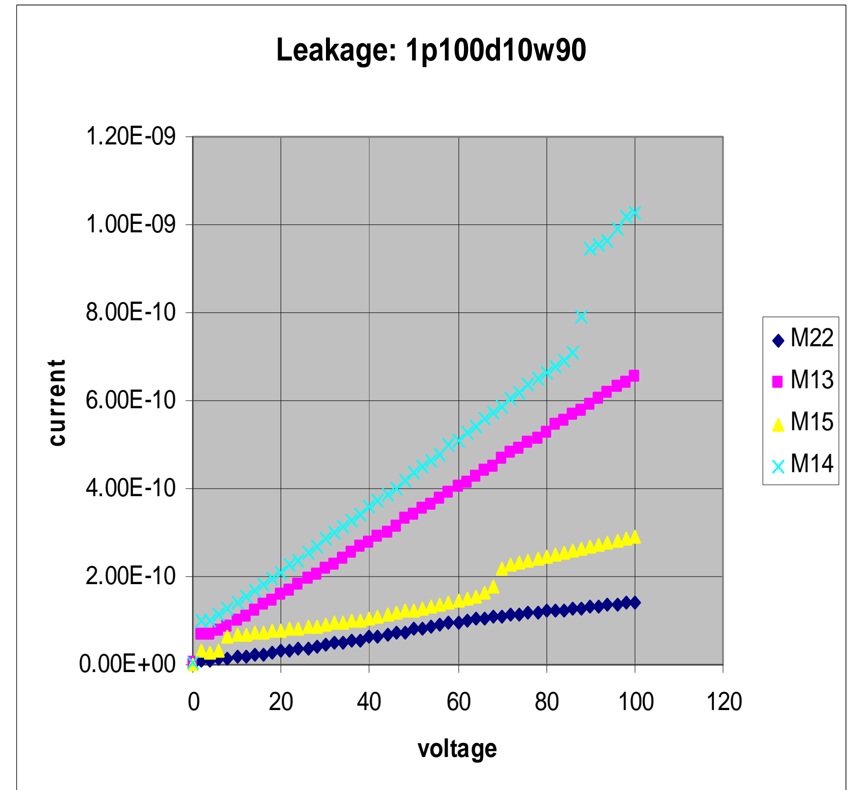

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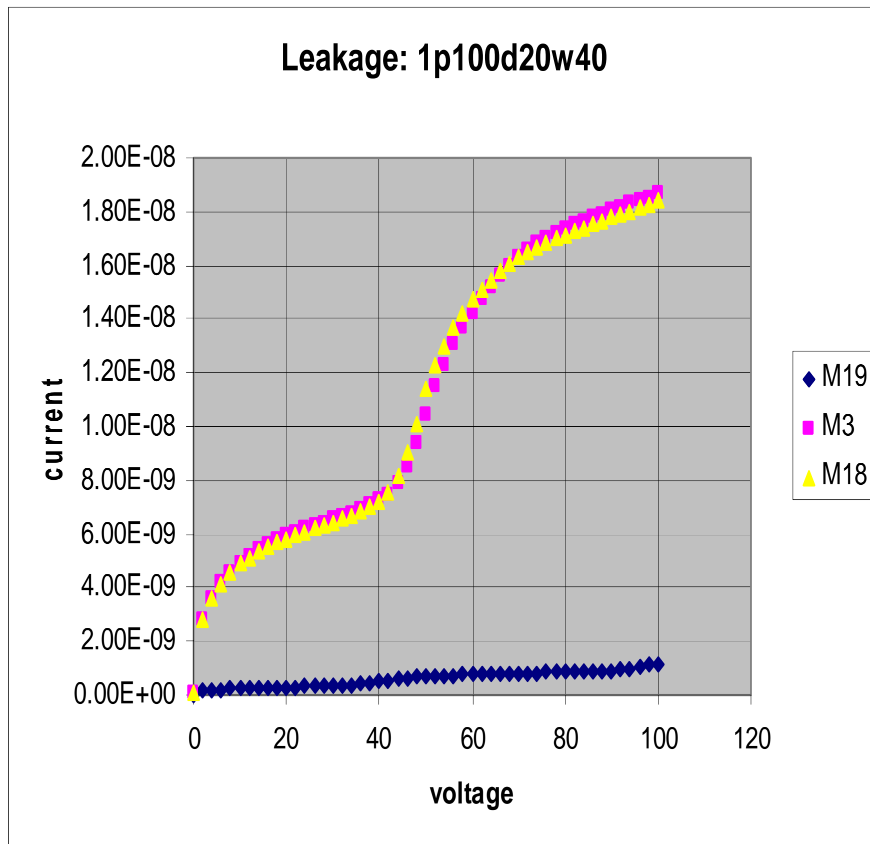

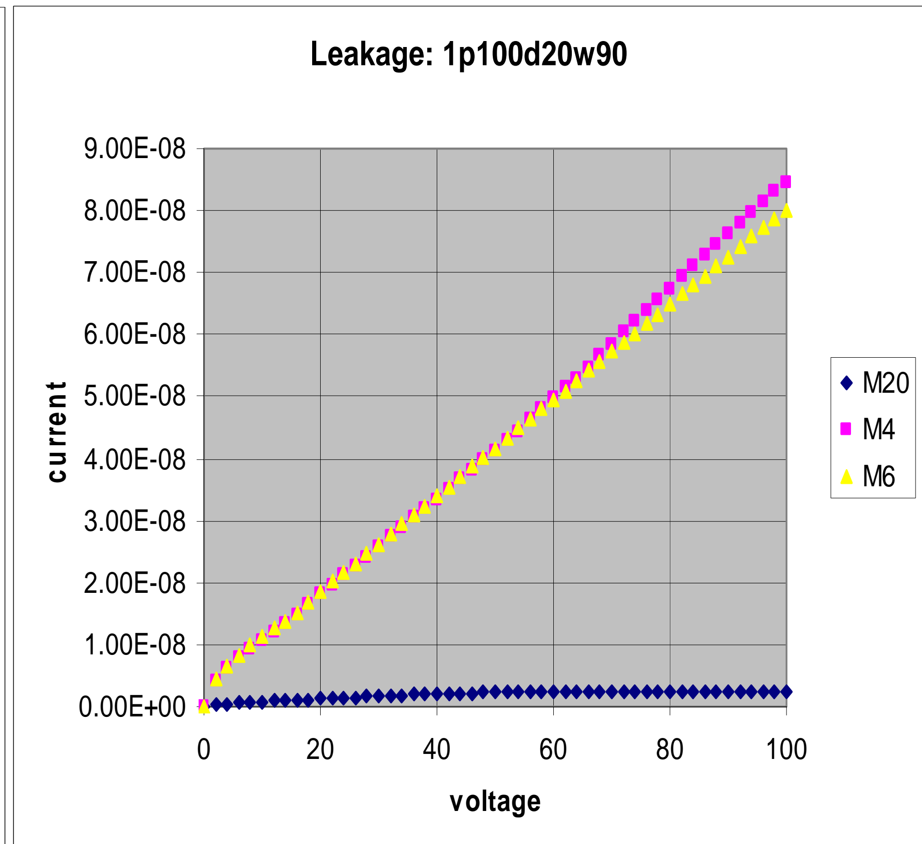

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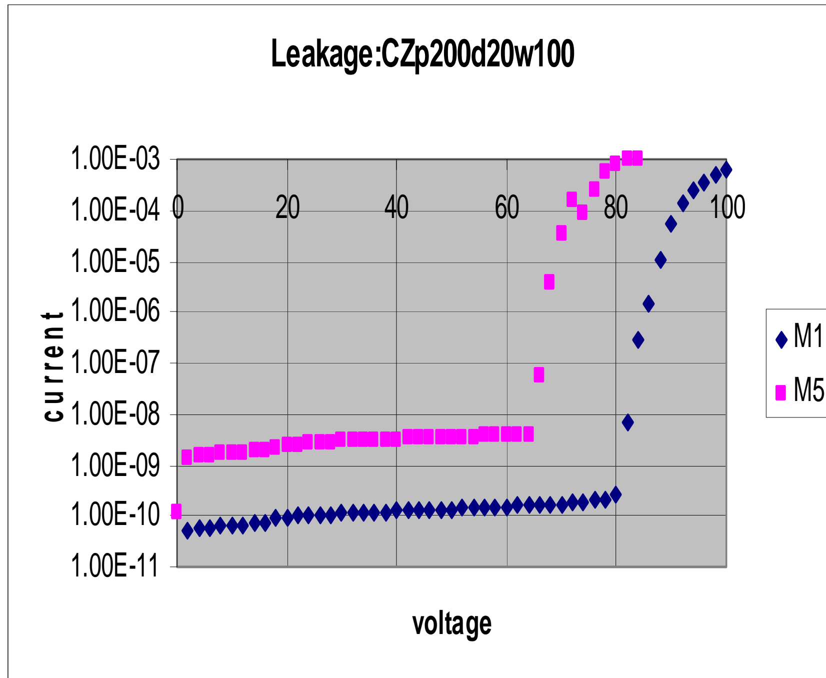

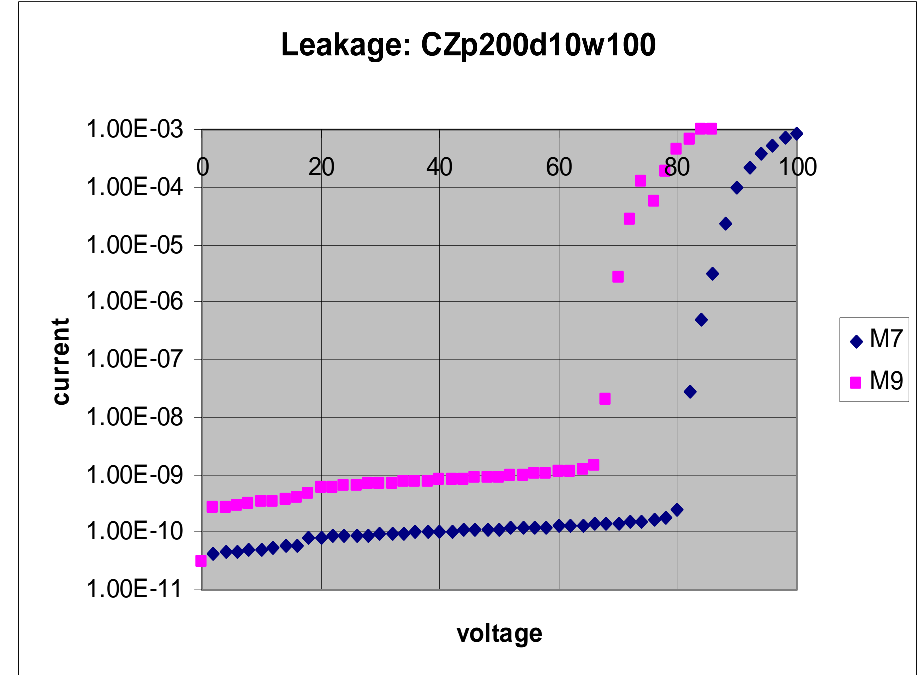

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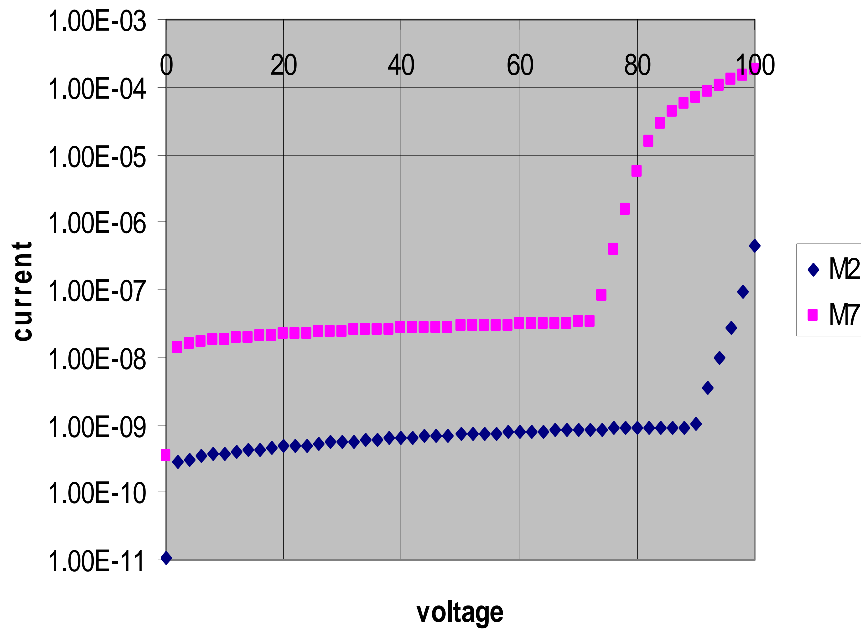

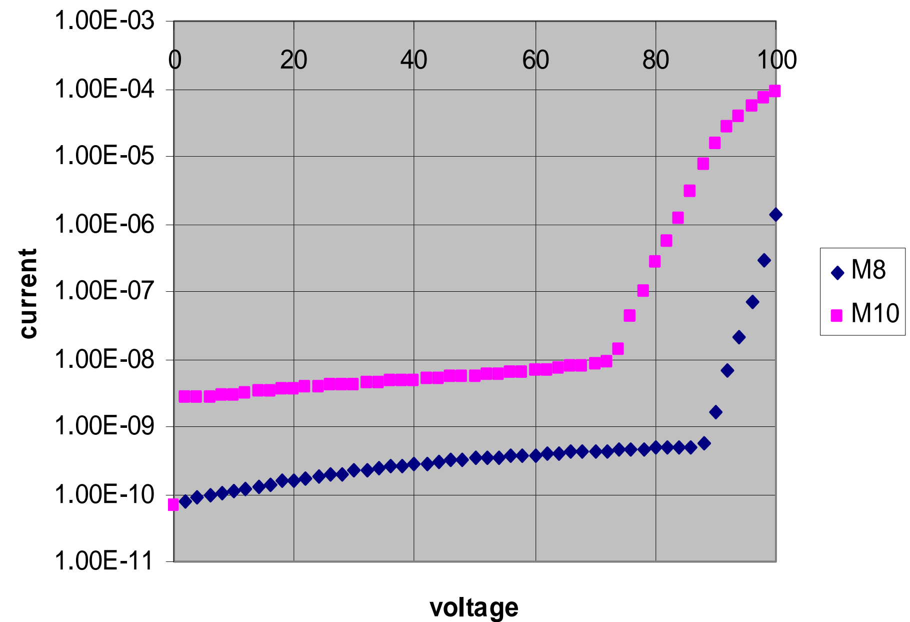

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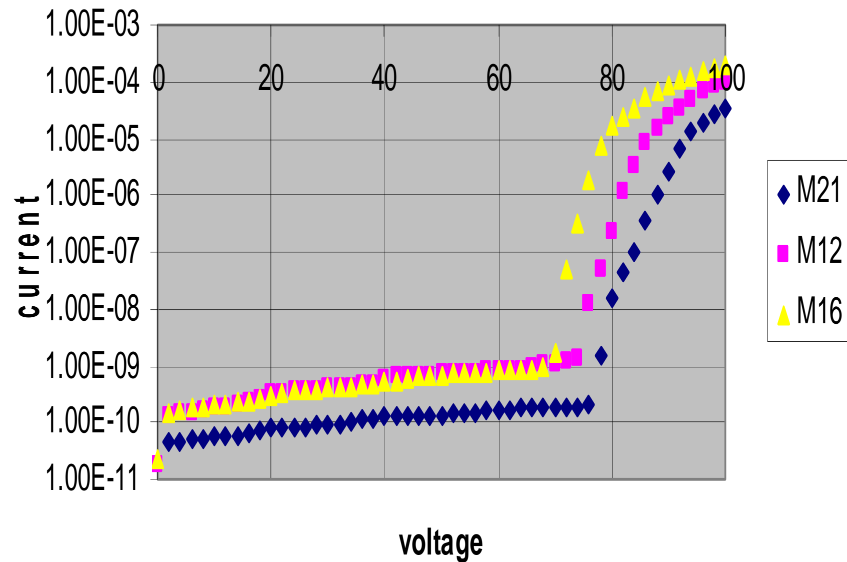

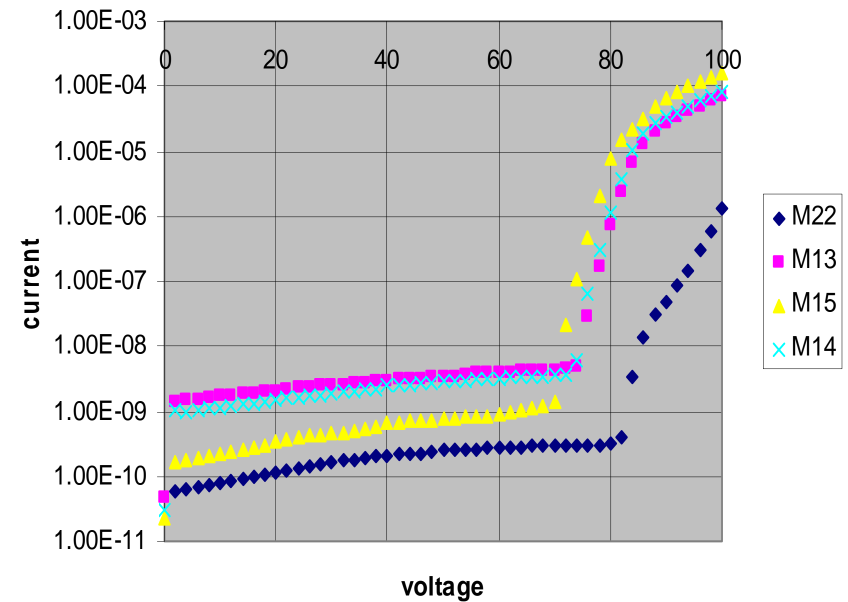

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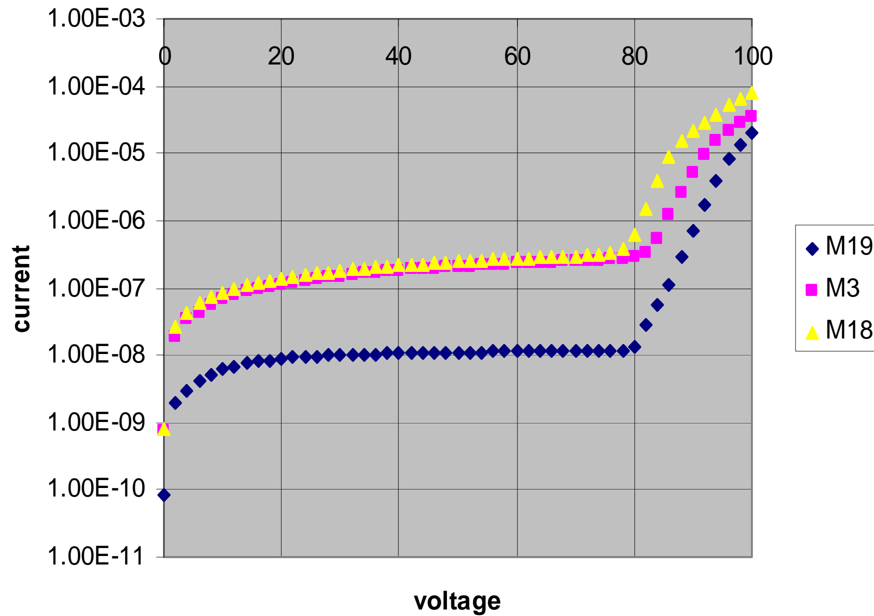
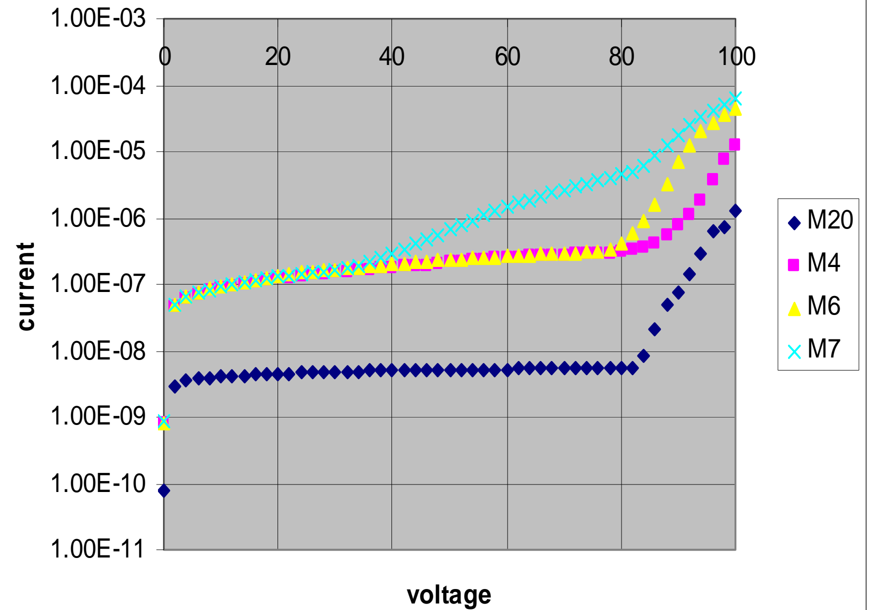




PIXEL DETECTOR: ELECTRICAL

Leakage: conclusion

FZ

- p = 200: small pixels (d10w100) show good performance
- p= 100: d10w40 best → d10 recommended
- d10 better than d20

- ”10x rule” holds between 10x10 and 100x100 matrixes
- kinks on the curves – no understanding

CZ

- p = 200: small pixels (d10w100) show good performance
- p = 100: d10w40 best of all
- d20 bad results

•FZ / CZ

•FZ always better even below breakdown

PIXEL DETECTOR: ELECTRICAL

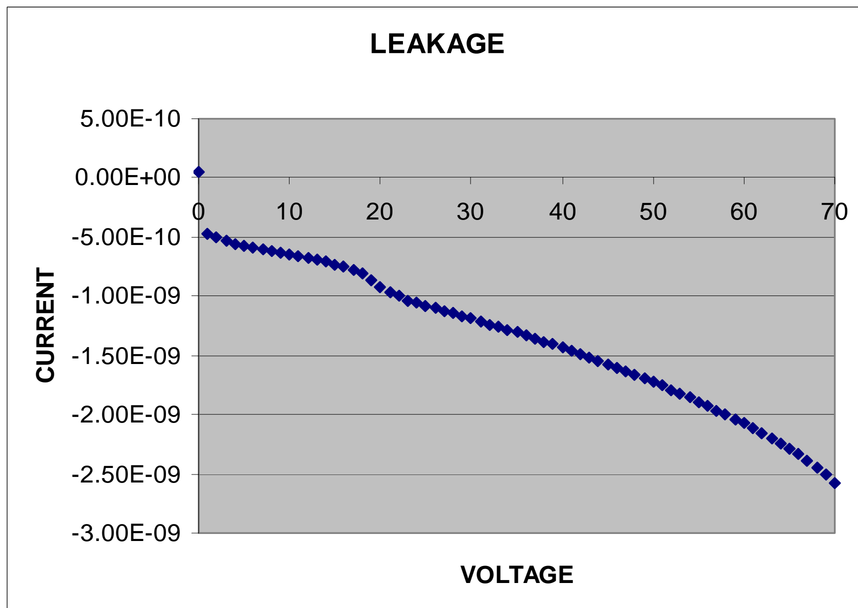
3. BREAKDOWN

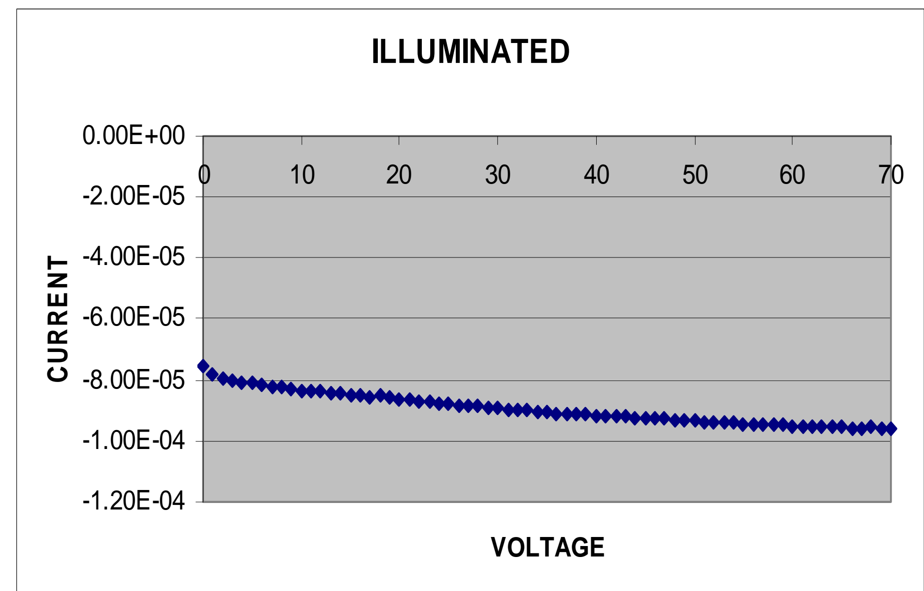
WAFER	STRUCTURE	DEVICES	BD VOLTAGES
FZ	P200D10W100	M7, M9	140 V, 140 V
FZ	P200D10W190	M8, M10	> 200 V
FZ	P200D20W100	M1, M5	120 V, 140 V
FZ	P200D20W190	M11	> 200 V
FZ	P100D10W40	M12, M16, M21	162 V, 142 V, 152 V
FZ	P100D10W90	M13, M14, M15, M22	> 200 V, > 200 V, 138 V, 182 V
FZ	P100D20W40	M3, M18, M19	164 V, 160 V, 178 V
FZ	P100D20W90	M4, M6, M20	> 200 V, > 200 V, 182 V
FZ	DIODES	P#	> 200
CZ	P200D10W100	M7, M9	80 V, 66 V
CZ	P200D10W190	M8, M10	88 V, 76 V
CZ	P200D20W100	M1, M5	80 V, 64 V
CZ	P200D20W190	M11	90 V
CZ	P100D10W40	M12, M16, M21	72 V, 70 V, 76 V
CZ	P100D10W90	M13, M14, M15, M22	74 V, 74 V, 70 V, 82 V
CZ	P100D20W40	M3, M18, M19	80 V, 82 V, 78 V
CZ	P100D20W90	M4, M6, M20	84 V, 82 V, 80 V
CZ	DIODES	P#	120 V… 140 V

PIXEL DETECTOR: ELECTRICAL

4. LIGHT ILLUMINATION

DEVICE: 11M5 (P200D20W100)





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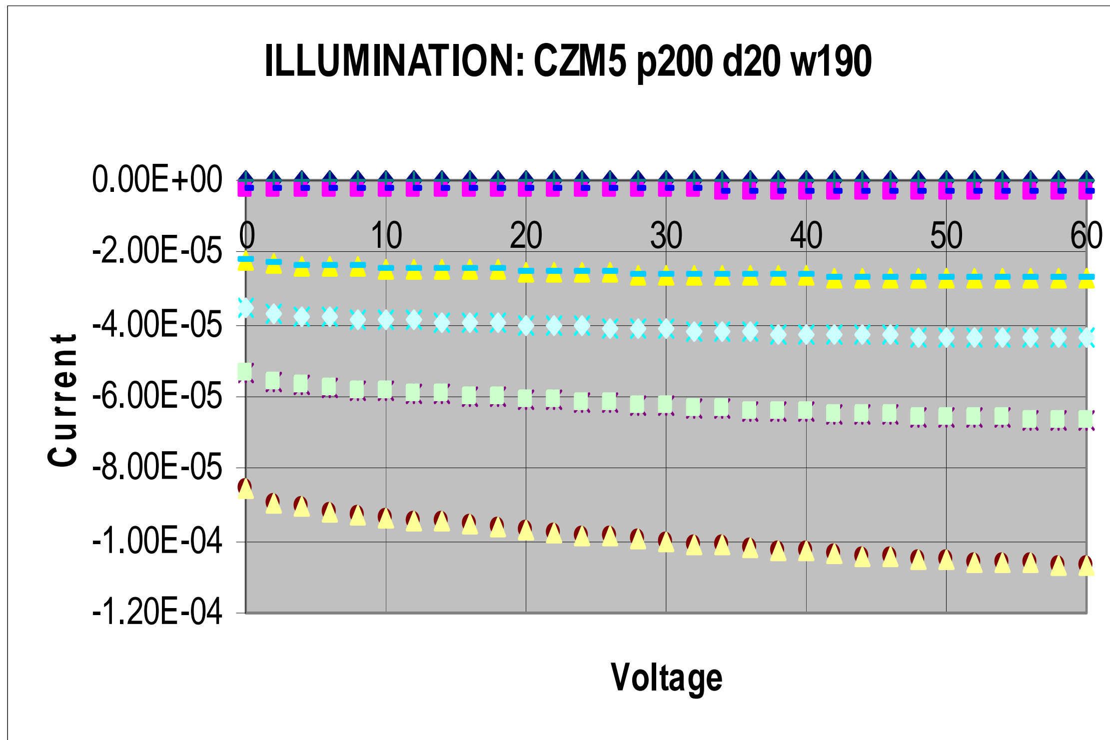
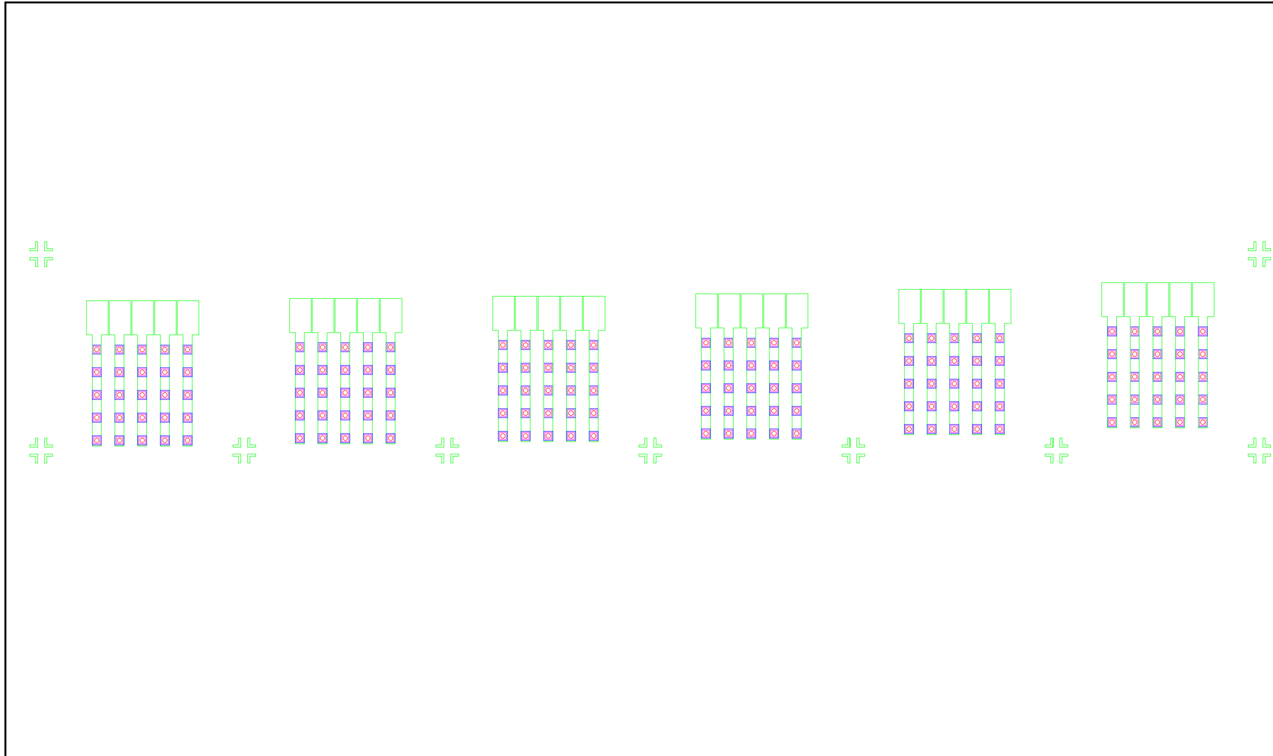


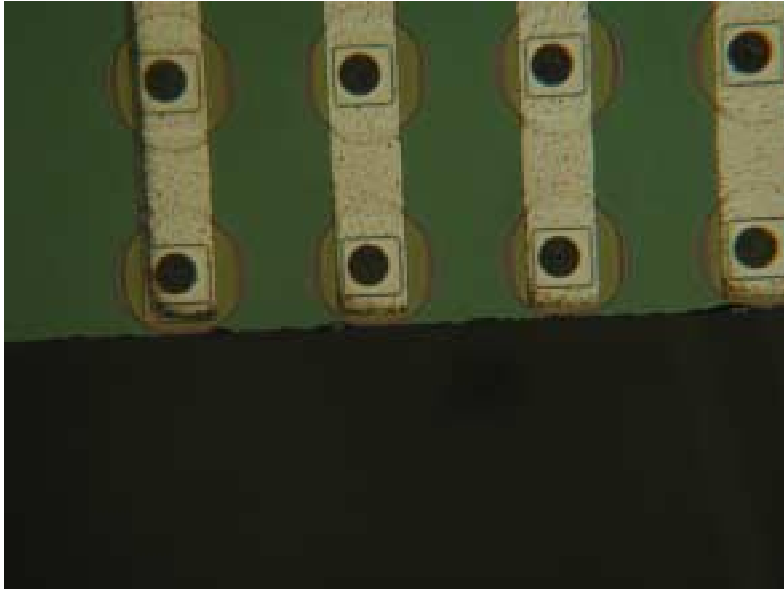
PIXEL DETECTOR: ELECTRICAL

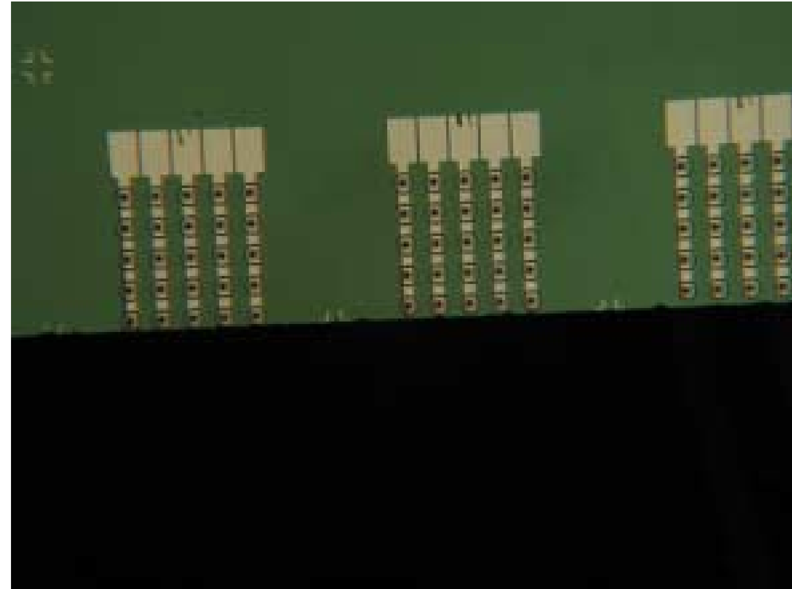
5.EDGE / SCRIBING DAMAGE

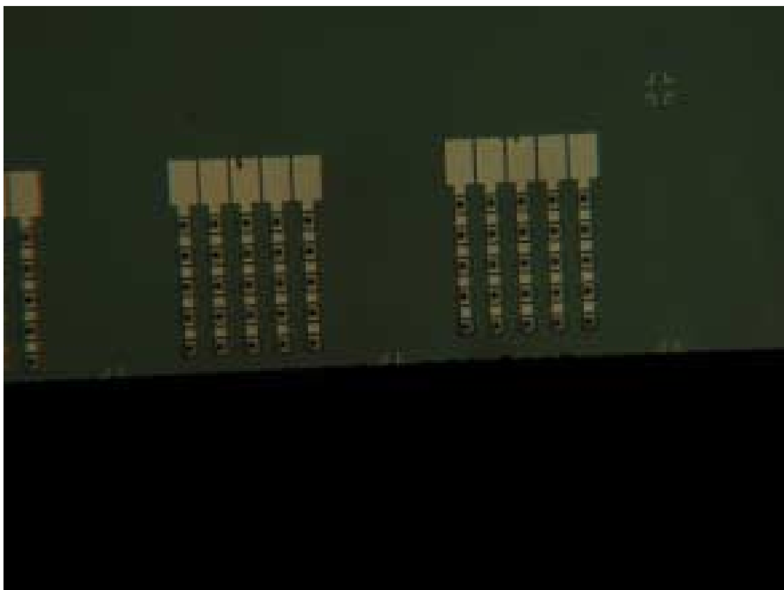


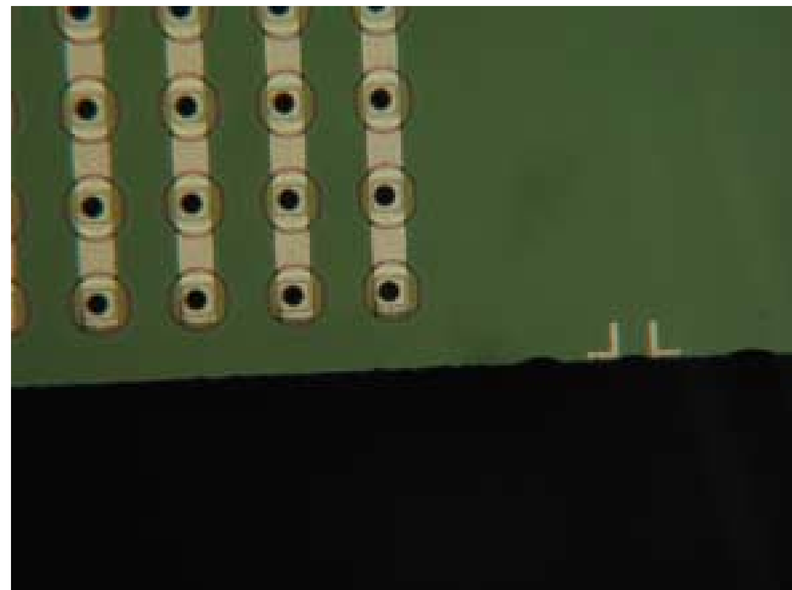
Distance to scribe line:20, 50, 70, 80, 90 & 100 microns

PIXEL DETECTOR: ELECTRICAL

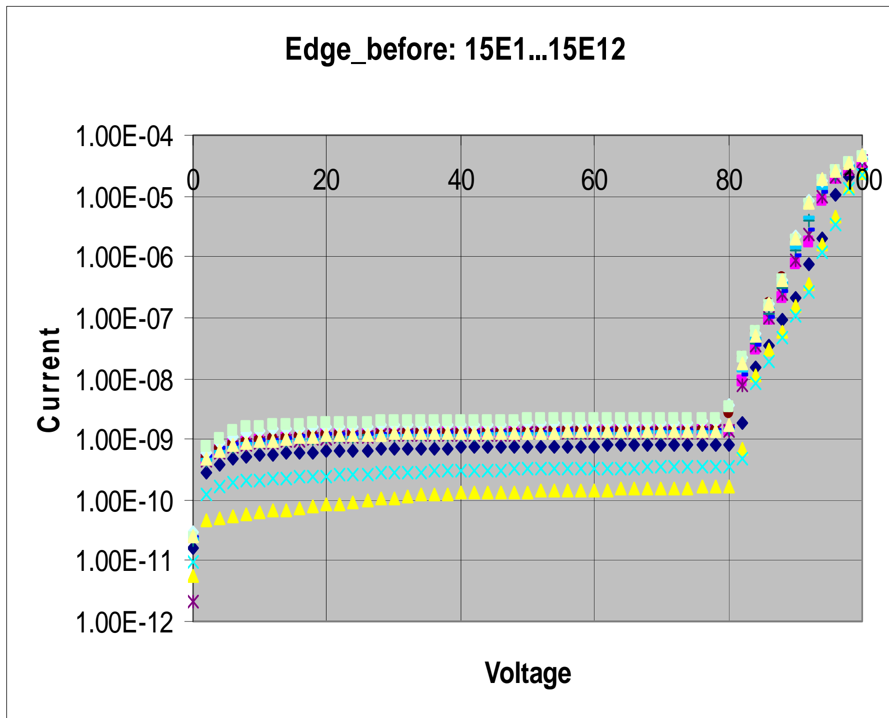


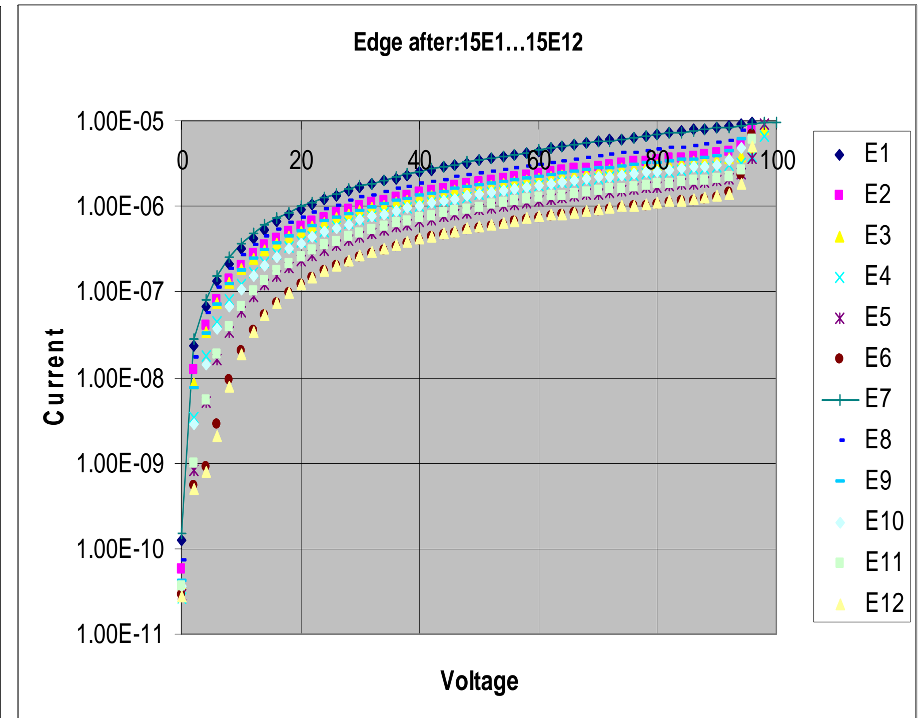






PIXEL DETECTOR: ELECTRICAL





Problems with scribing damage (even with edge doping?)! Alternative scribing ?

PIXEL DETECTOR: ELECTRICAL

6.CAPACITANCE

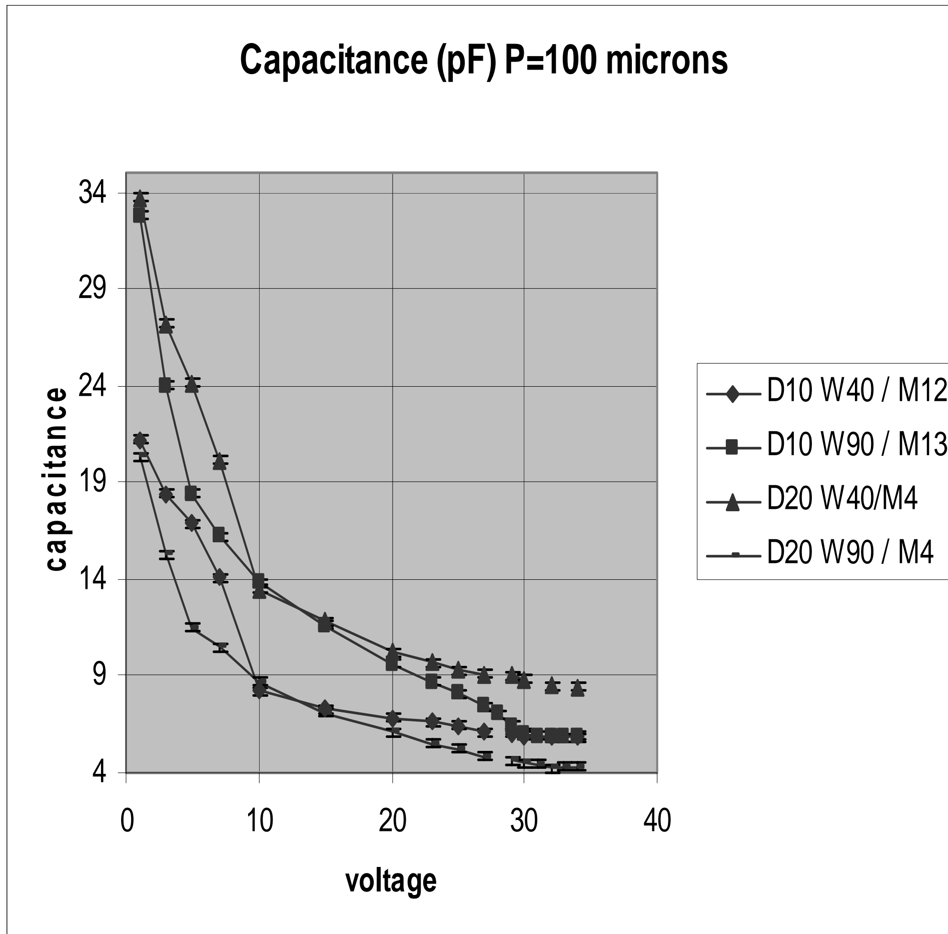
- 100 pixels in parallel

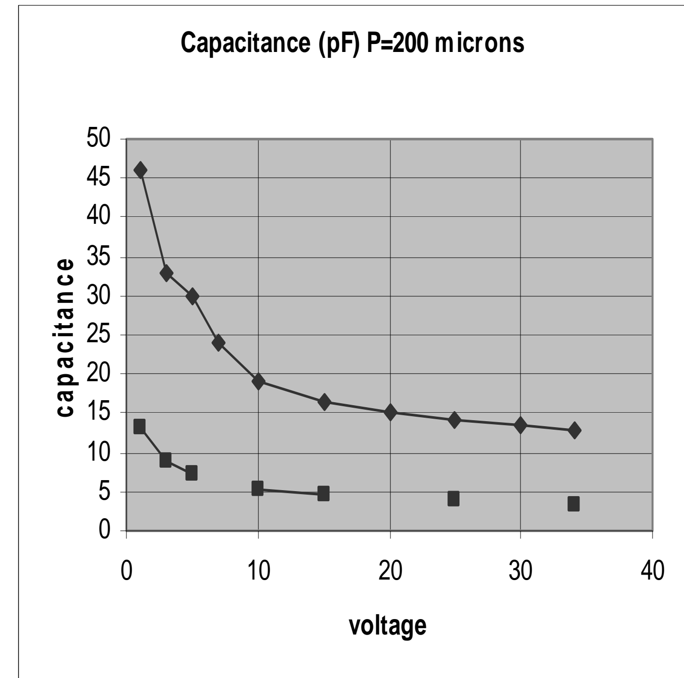
	CAPACITANCE / pF (10 kHz / 50 mV)			
	P =100			
voltage	D10 W40 / M12	D10 W90 / M13	D20 W40/M4	D20 W90 / M4
1	21.2	32.8	33.7	20.3
3	18.4	24	27.2	15.3
5	16.9	18.4	24.1	11.5
7	14.1	16.2	20.1	10.5
10	8.2	13.8	13.5	8.7
15	7.3	11.6	11.8	7.1
20	6.8	9.6	10.2	6.1
23	6.6	8.7	9.7	5.5
25	6.4	8.1	9.3	5.2
27	6.1	7.4	9.1	4.8
28		7		
29	6	6.4	9	4.6
30	5.9	6	8.8	4.5
31		5.9		4.4
32	5.9	5.8	8.5	4.2
33		5.8		4.3
34	5.9	5.8	8.4	4.3

CAPACITANCE / pF (10 kHz / 50 mV)		
P =200		
voltage	D20 W190 / M11	DIODE
1	46	13
3	33	8.8
5	30	7.1
7	24	
10	19	5.4
15	16.3	4.7
20	15.1	
25	14.3	3.8
30	13.4	
34	12.7	3.4

- FOR P = 100 MICRONS CAPACITANCE SATURATION ABOVE 30 VOLTS (?)

PIXEL DETECTOR: ELECTRICAL



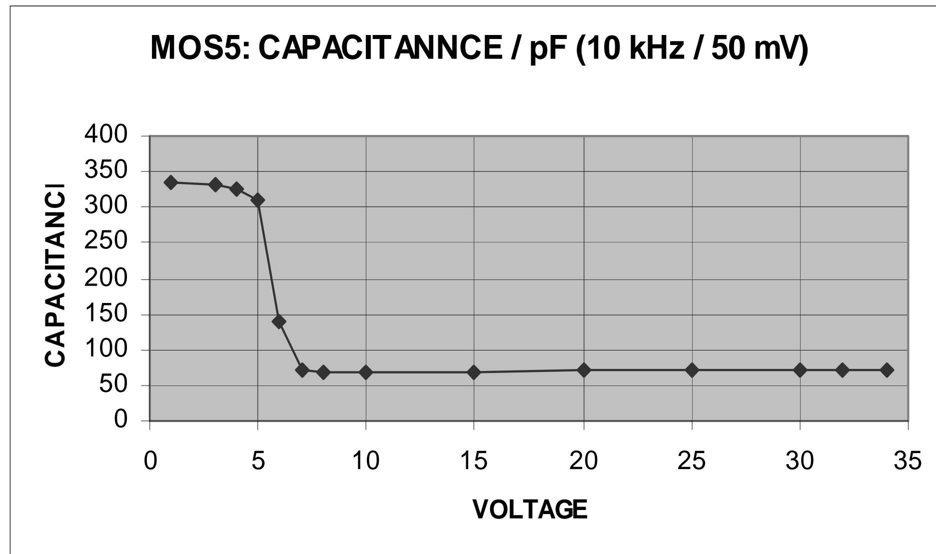


PIXEL DETECTOR: ELECTRICAL

PARALLEL MOS-CAPACITANCE

3X3 mm^2 MOS CAPACITOR

MOS CAPACITANCE/ pF (10 kHz / 50 mV)		
voltage	MOS5	
1	335	
3	332	
4	326	
5	309	
6	140	
7	72	
8	67	
10	67	
15	69	
20	70	
25	71	
30	71	
32	71	
34	71	

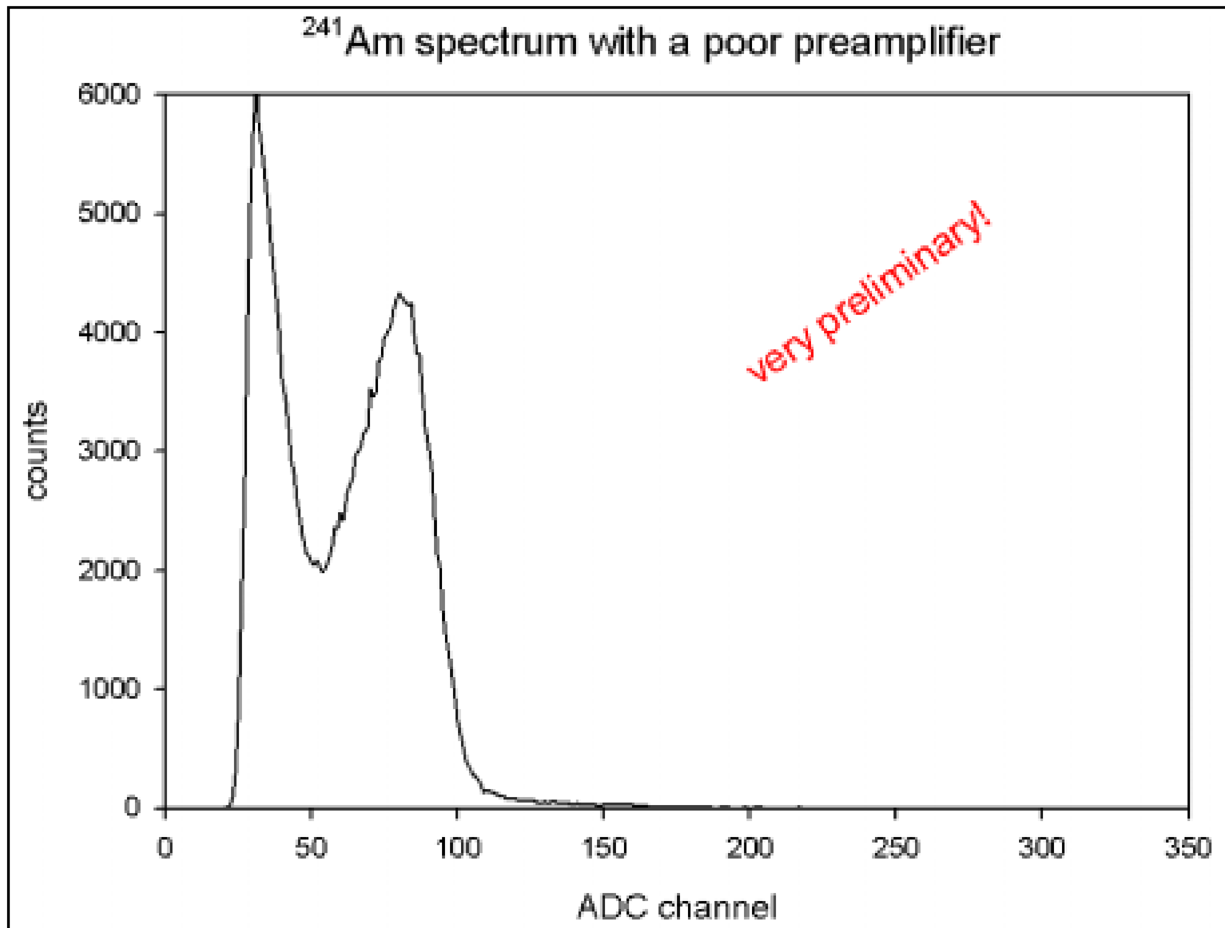


FLAT CHARACTERISTICS IN THE PIXEL CAPACITANCE SATURATION REGION

PIXEL DETECTOR: ELECTRICAL

7.RADIATION MEASUREMENTS

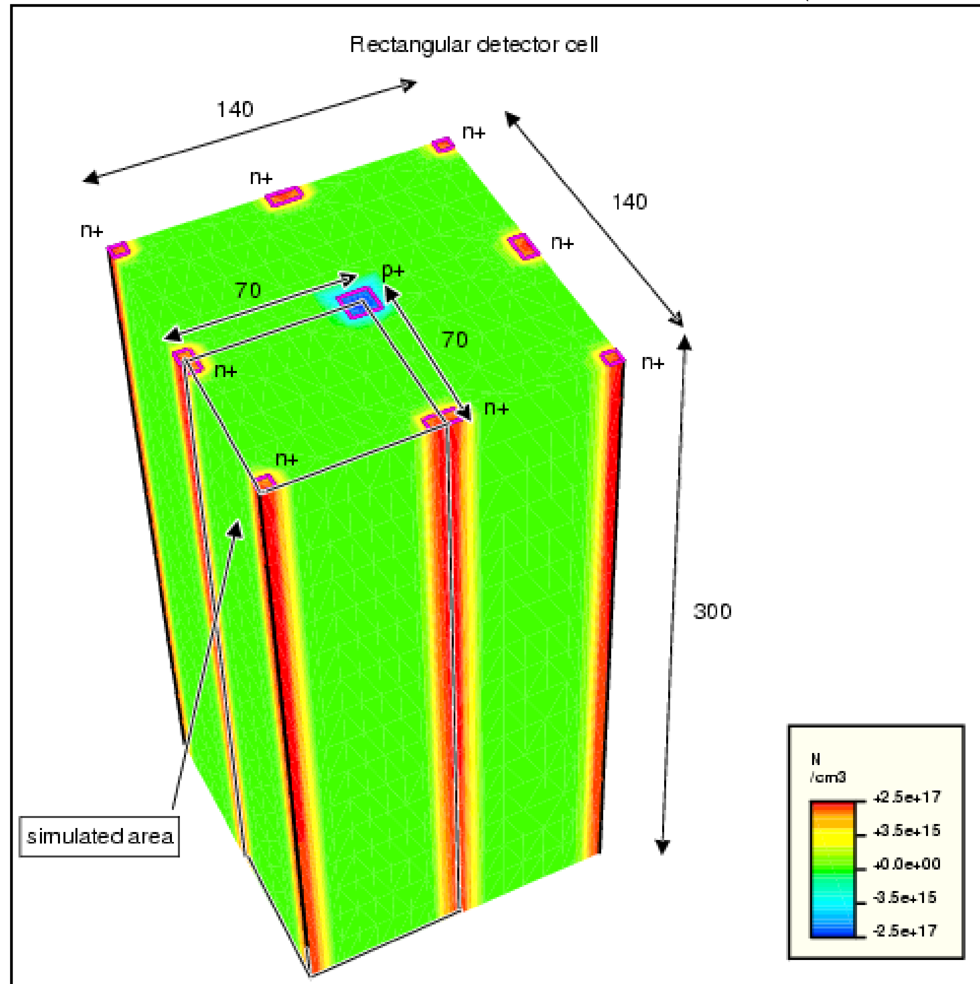
- Am-241 by K. Kurvinen & M. Eräluoto @ HU



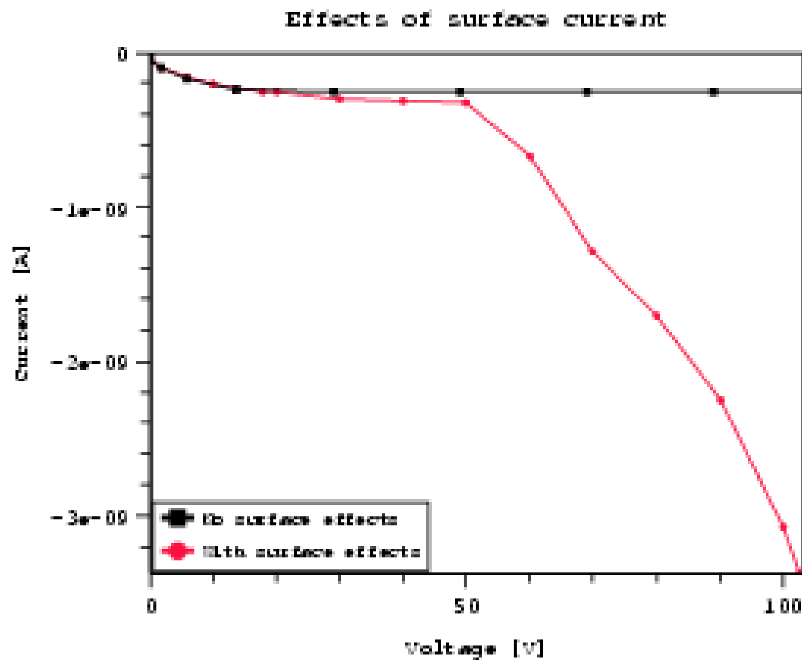
PIXEL DETECTOR: SIMULATIONS

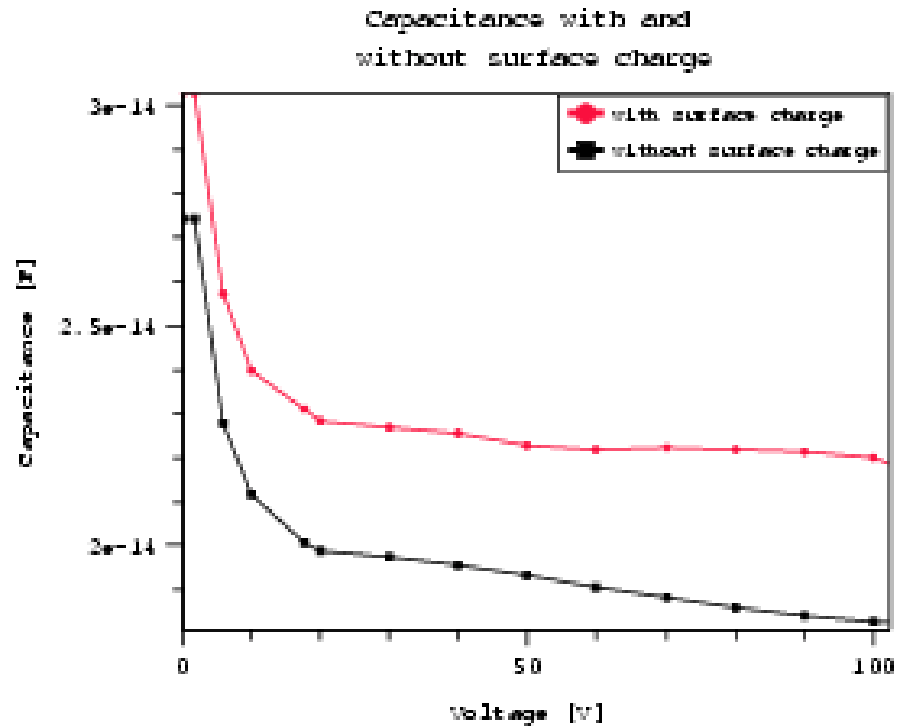
8. 3D TRANSIENT (MIXED MODE) SIMULATIONS

- MADE BY J. KALLIOPUSKA USING ISE-TCAD (&SILVACO TOOLS)

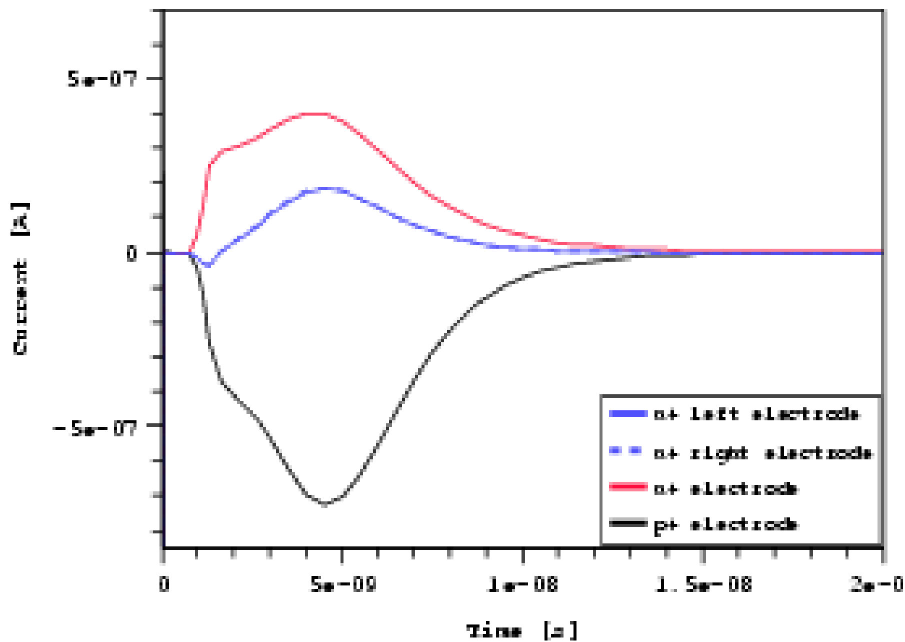


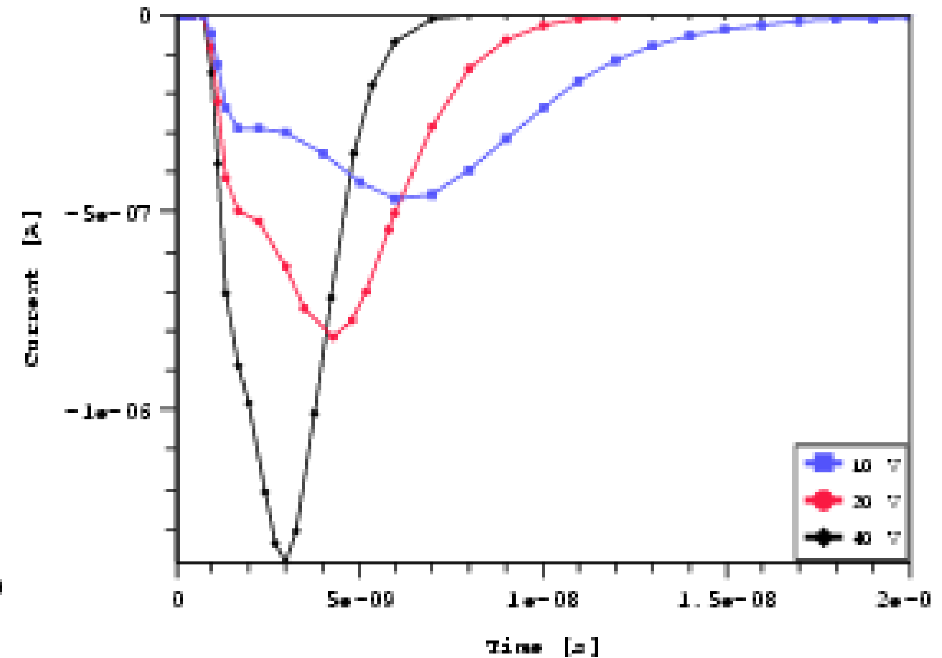
PIXEL DETECTOR: SIMULATIONS



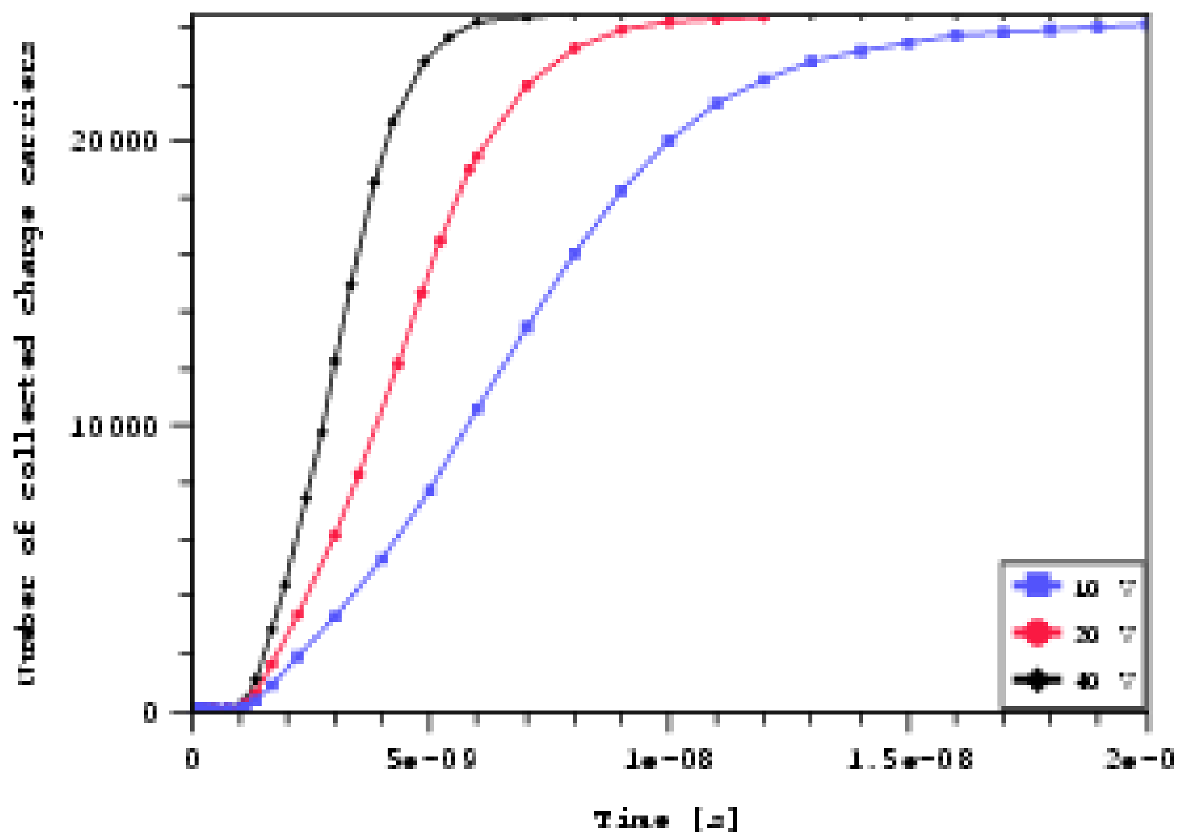


PIXEL DETECTOR: SIMULATIONS

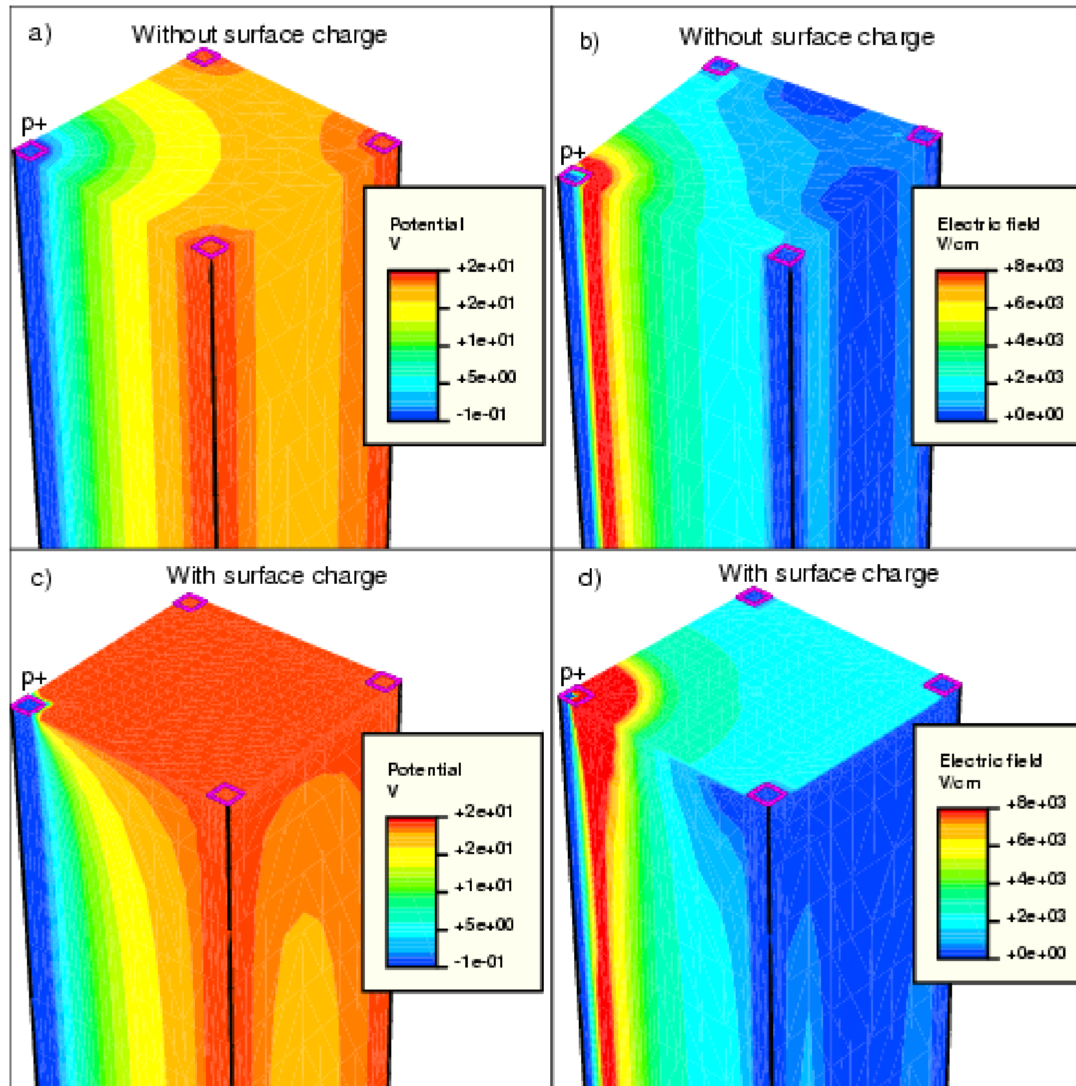




PIXEL DETECTOR: SIMULATIONS



PIXEL DETECTOR: SIMULATIONS



PIXEL DETECTOR: CONCLUSIONS

- NEW TYPE OF 3D DETECTOR INTRODUCED
- LARGE AREA DEVICES READY FOR RADIATION MEASUREMENTS
- FABRICATION PROCESS: MOST OF PROBLEMS SOLVED - FINE TUNING NEEDED
- 3D TRANSIENT (MIXED MODE) SIMULATIONS
- ELECTRICAL CHARACTERIZATION:
    - IV & LEAKAGE OK
    - BREAKDOWN > 100 V (WAFER TYPE DEPENDENT)
    - CV OK
    - DEPLETION AT 30 V FOR 300 MICRON WAFER & 100 MICRON PITCH
    - PROBLEMS WITH NARROW EDGES / SCRIBING

PIXEL DETECTOR: CONTINUATION

- TESTS WITH RADIATION SOURCES
- COMPLETION OF ELECTRICAL CHARACTERIZATION
- RADIATION HARDNESS MEASUREMENTS (RD50 / J. HÄRKÖNEN)
- 3D SIMULATIONS OF NEW 3D STRUCTURE
- SECOND FABRICATION RUN:
    - DESING BY APRIL 30, 2004 - PROCESS BY JUNE 30, 2004
    - NEW TEST STRUCTURES
    - ACTIVE EDGE / EDGE DOPING
    - PIXEL DESIGN FOR MEDIPIX2 READOUT-CHIP
    - OTHER IDEAS

END