Wafer characterization

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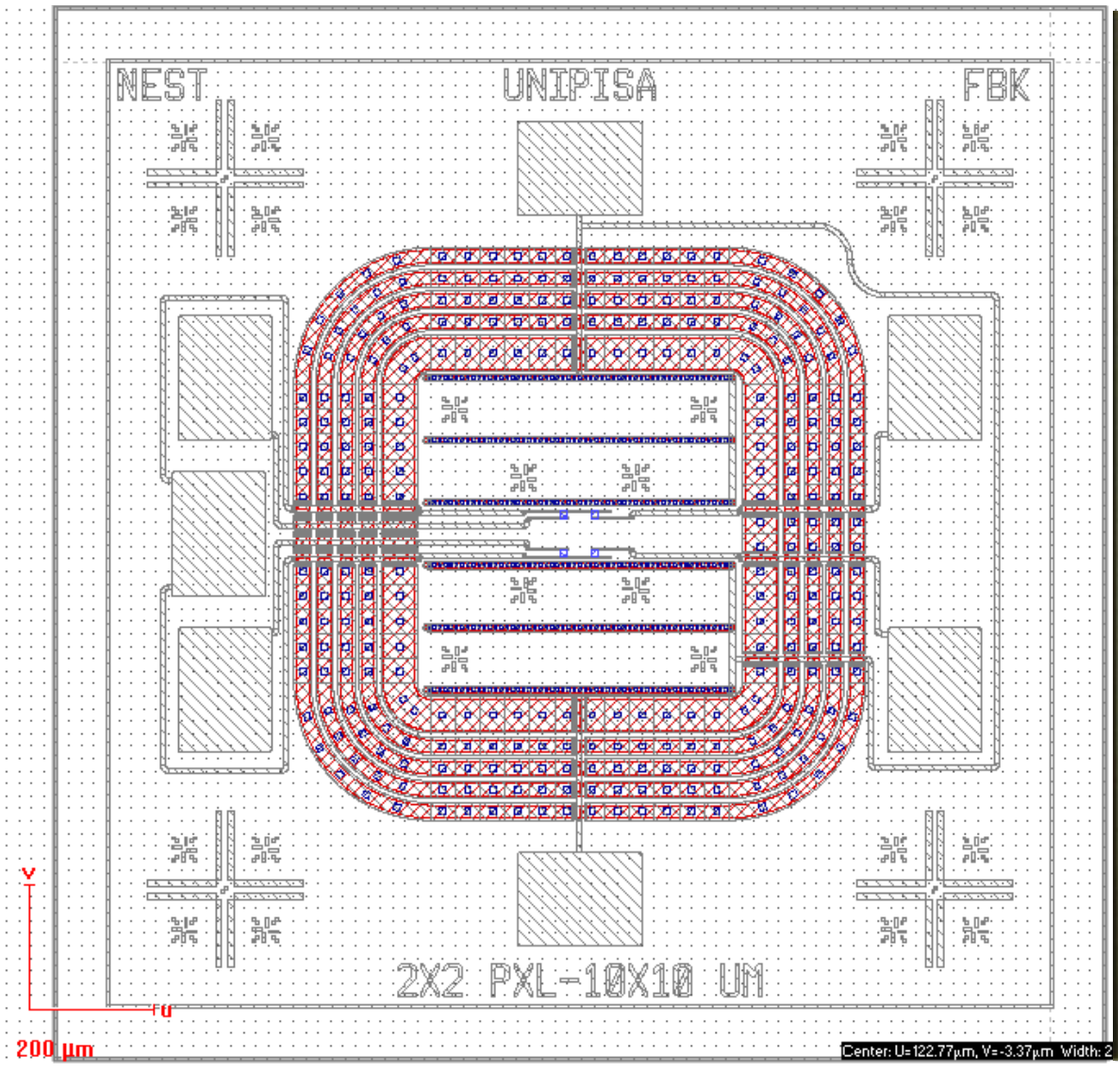
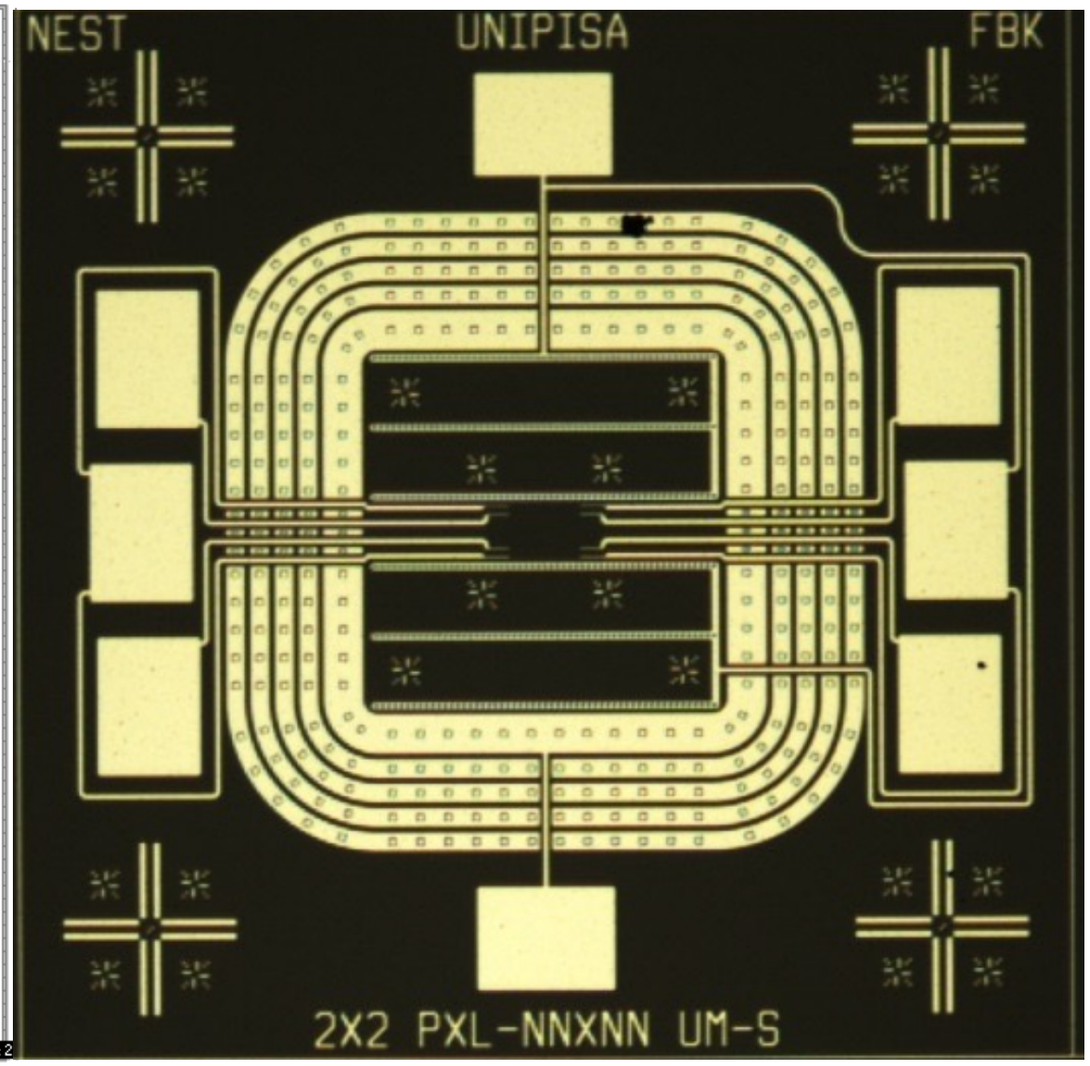
INFN Pisa, 26 January 2018

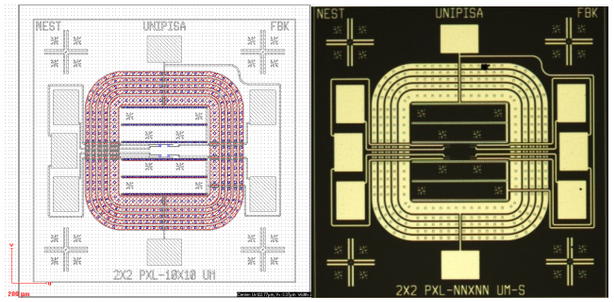
Project

- Test FBK sensor structures
- 2 FBK test structures
  - Diode
  - Gate controlled diode
- Test Instruments in Clean Room
- Optimize LabVIEW VIs for tests in February

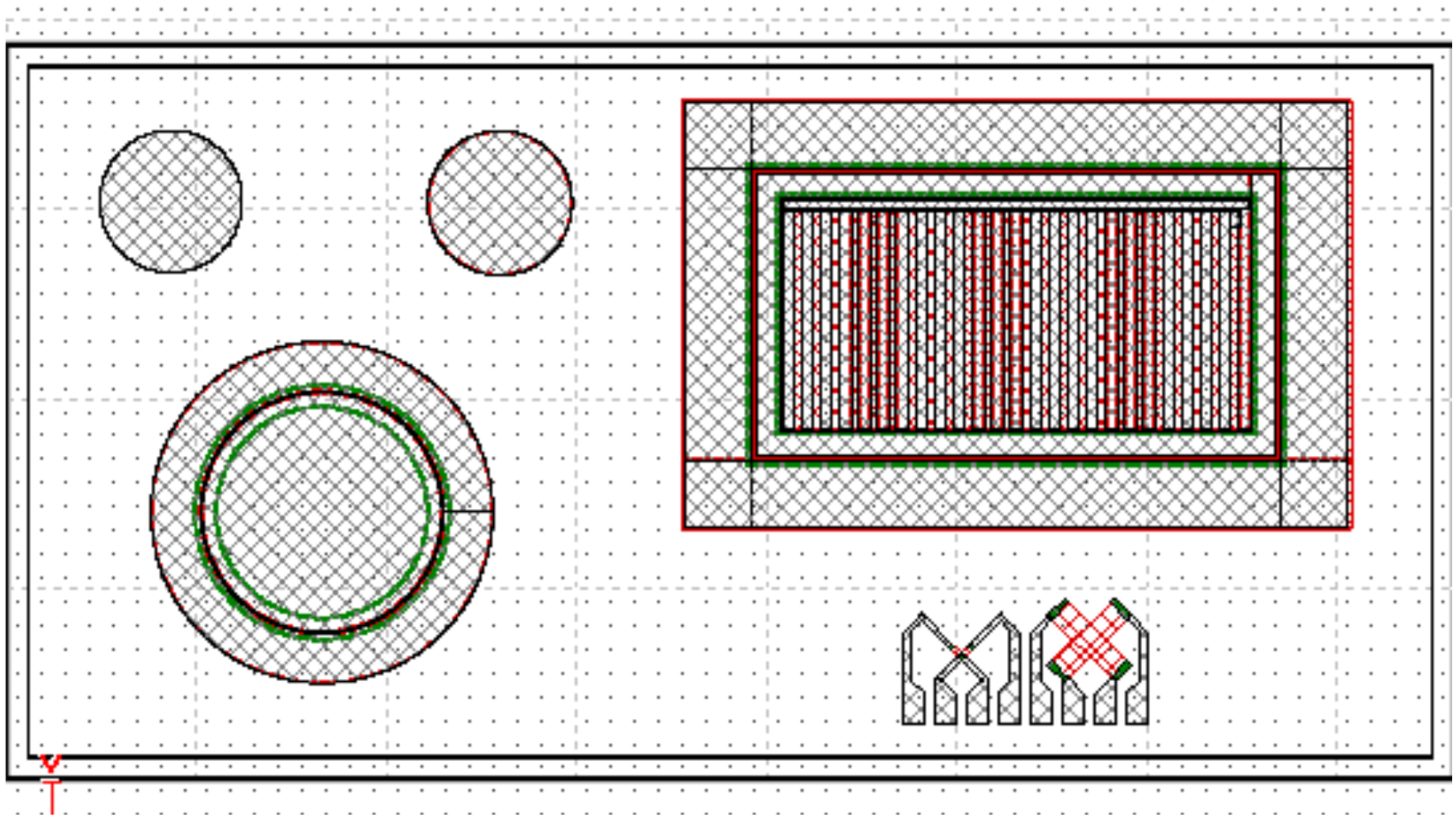
Project


NEST
UNIPISA
FBK
2X2 PXL-10X10 UM
200 µm
Center: U=122.77µm, V=-3.37µm Width: 2

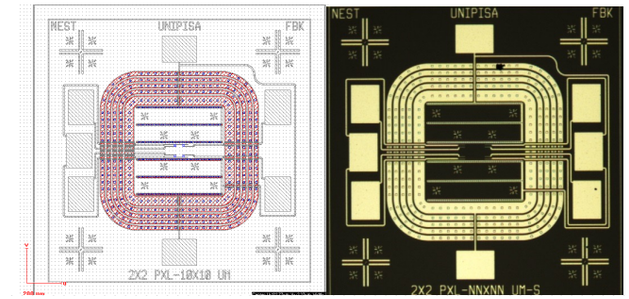

NEST
UNIPISA
FBK
2X2 PXL-NNXNN UM-S


NEST
UNIPISA
FBK
2X2 PXL-10X10 UM
NEST
UNIPISA
FBK
2X2 PXL-NNXNN UM-S

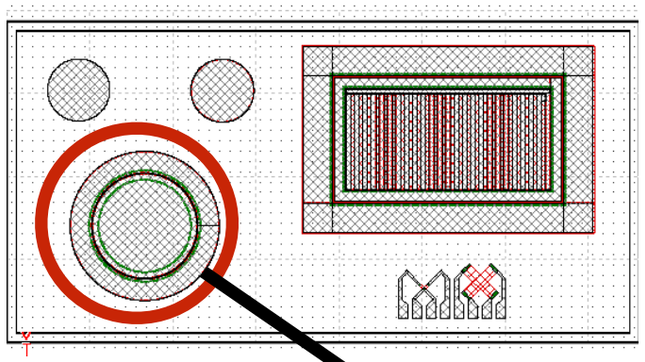
Project

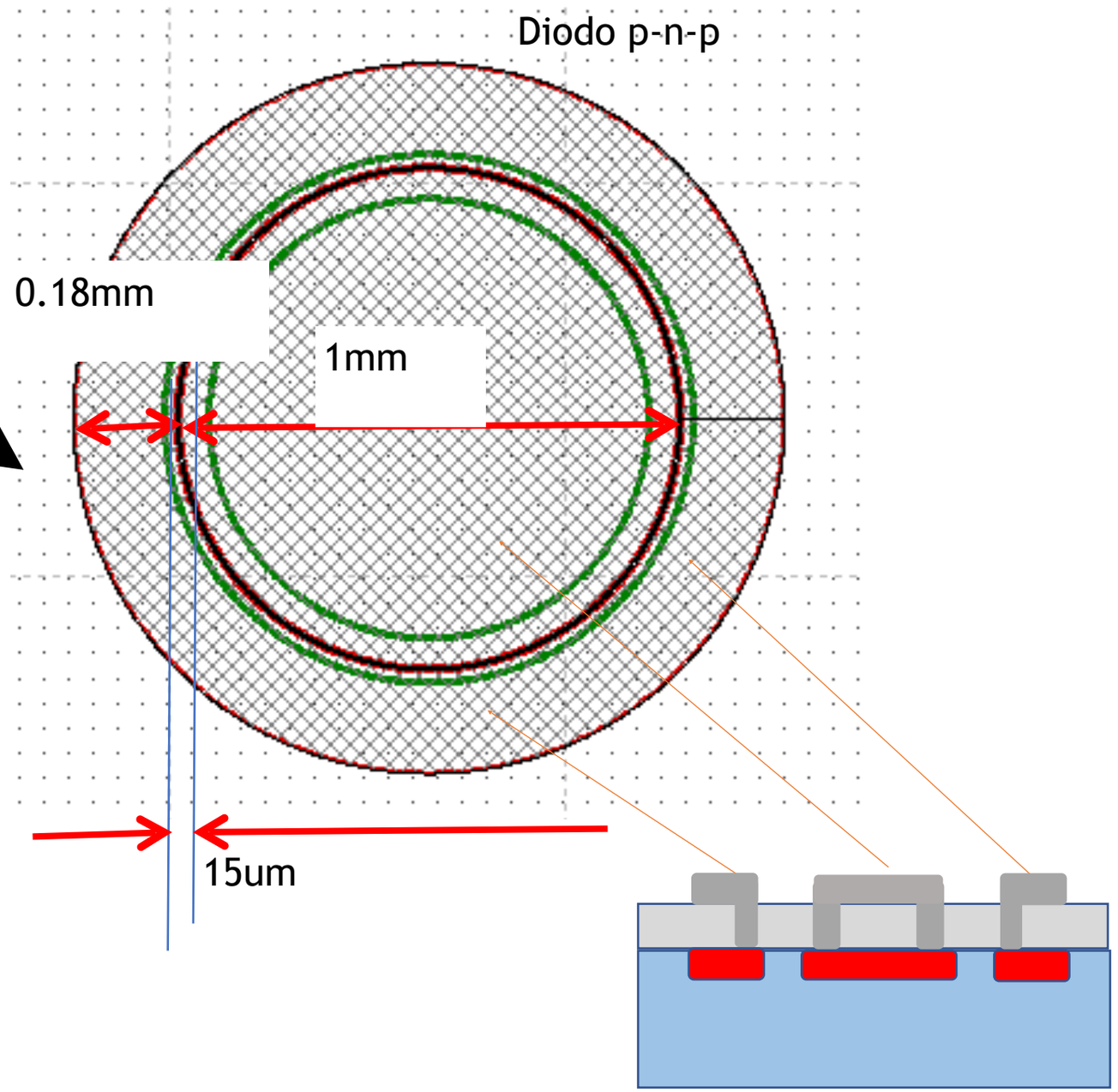


Project

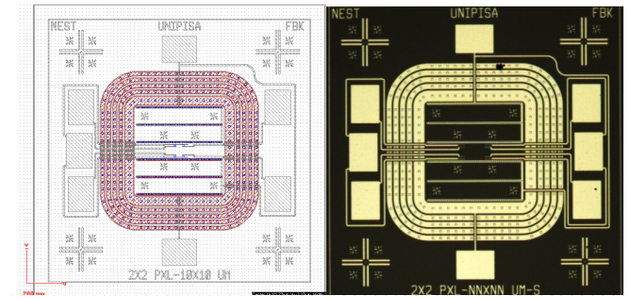

NEST
UNIPISA
FBK
2X2 PXL-10X10 UM

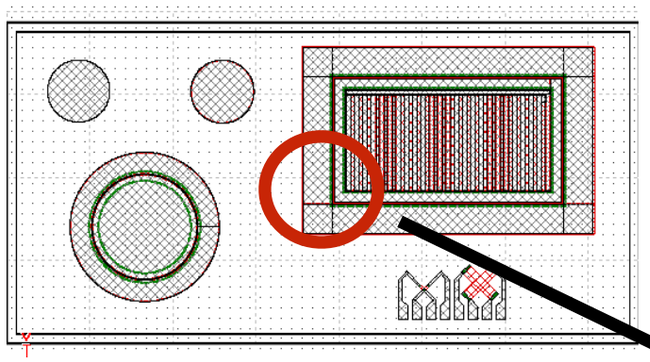
NEST
UNIPISA
FBK
2X2 PXL-NNXNN UM-S

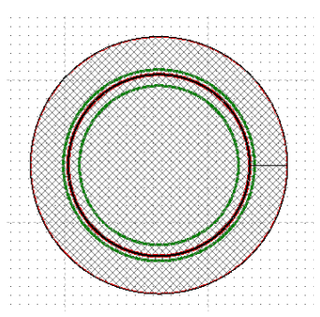


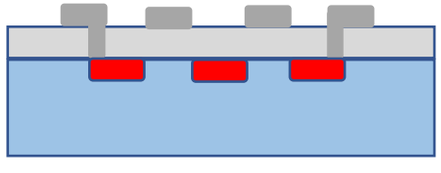

Diodo p-n-p
0.18mm
1mm
15um

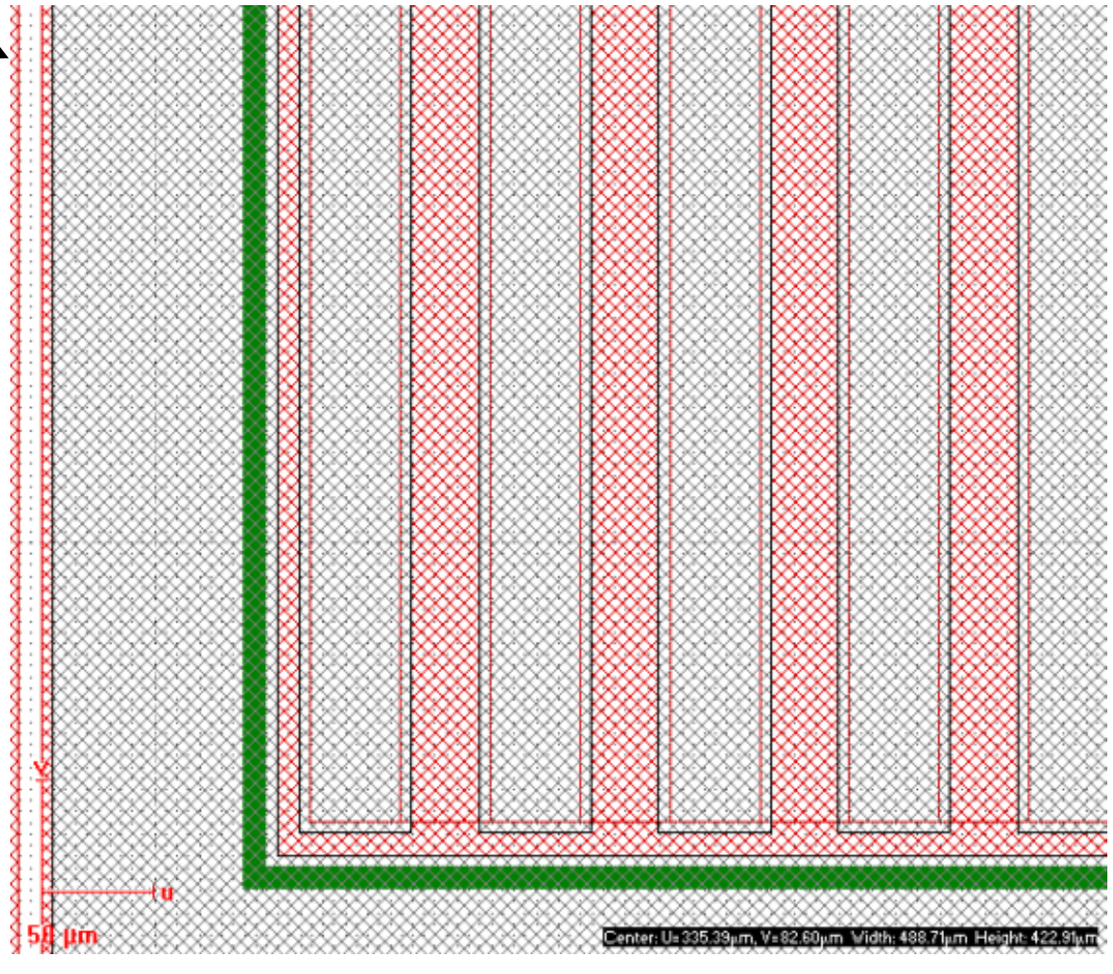
Project

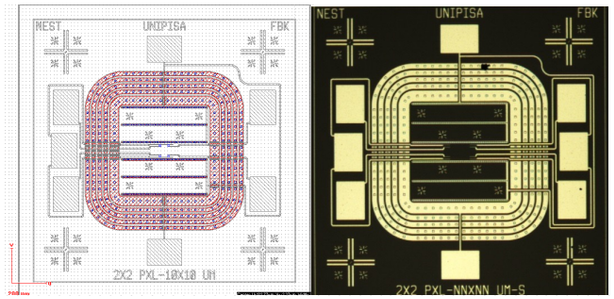

NEST
UNIPISA
FBK
2X2 PXL-10X10 UM
NEST
UNIPISA
FBK
2X2 PXL-NNXNN_UM-S

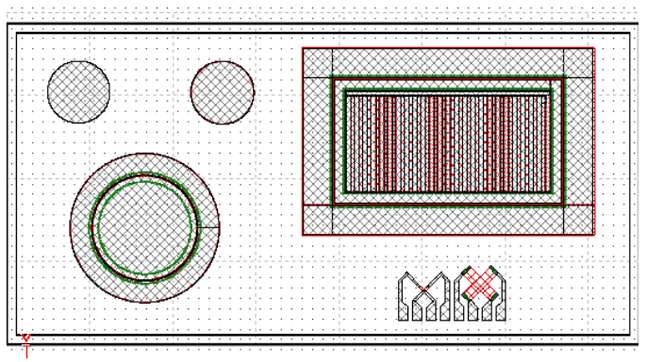


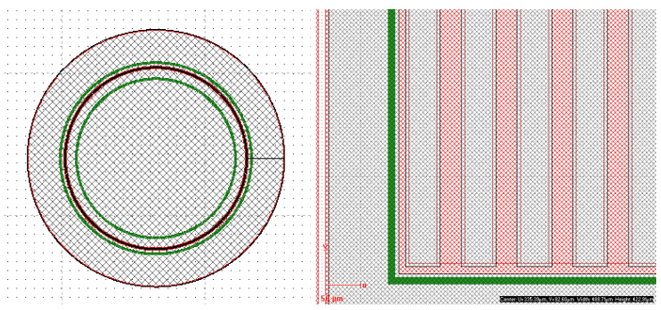




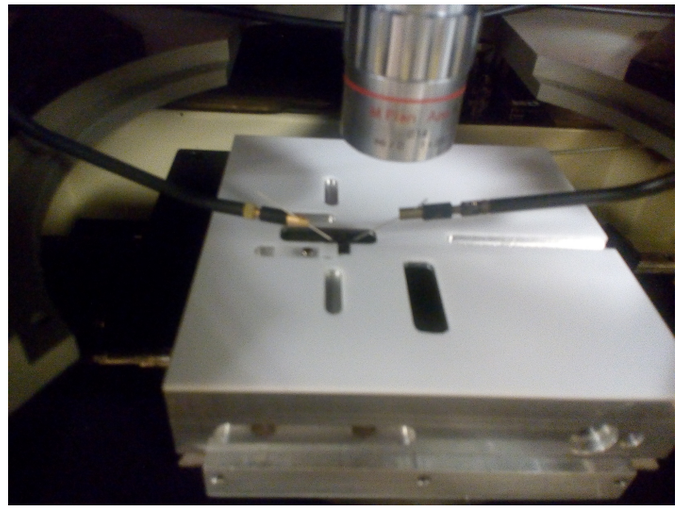

v
u
50 µm
Center: U=335.39µm, V=82.60µm Width: 488.71µm Height: 422.91µm

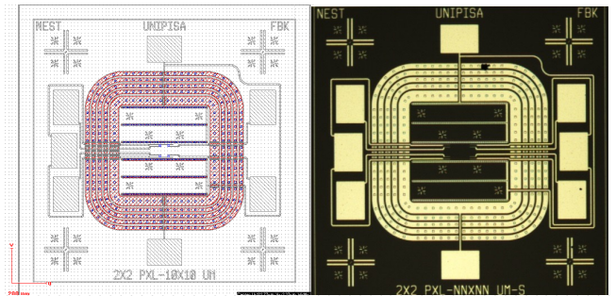

NEST
UNIPISA
FBK
2X2 PXL-10X10 UM
NEST
UNIPISA
FBK
2X2 PXL-NNXNN UM-S

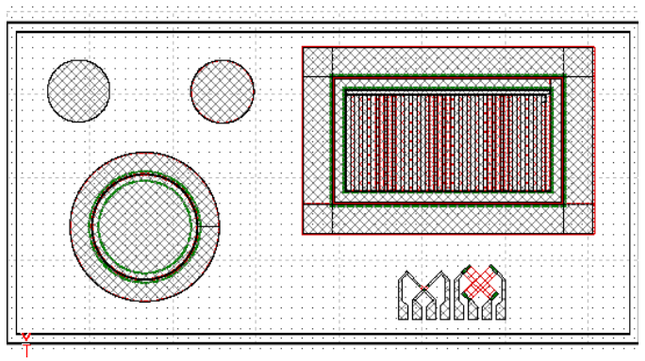


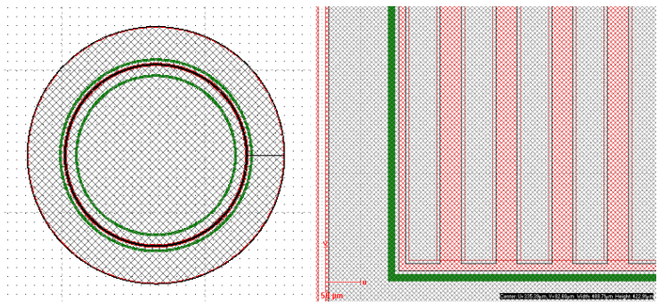


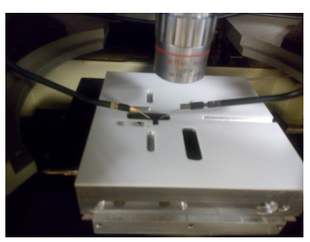
Project




NEST
UNIPISA
FBK
2X2 PXL-10X10 UM
NEST
UNIPISA
FBK
2X2 PXL-NNXNN UM-S





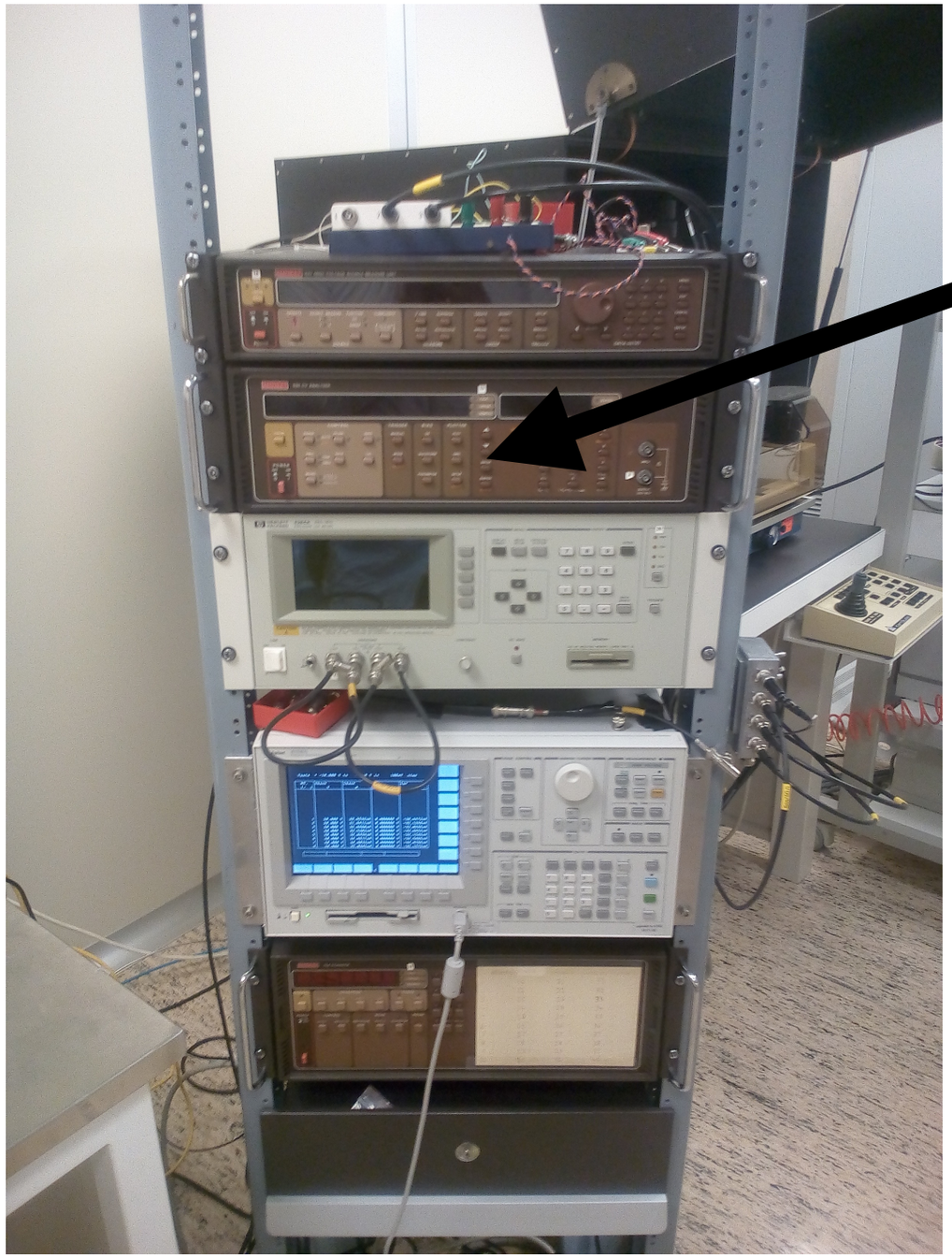


Project

Instruments

- KEITHLEY 590
  - CV Analyzer
- Agilent 4156C
  - Semiconductor Parameter Analyzer

Instruments



- KEITHLEY 590
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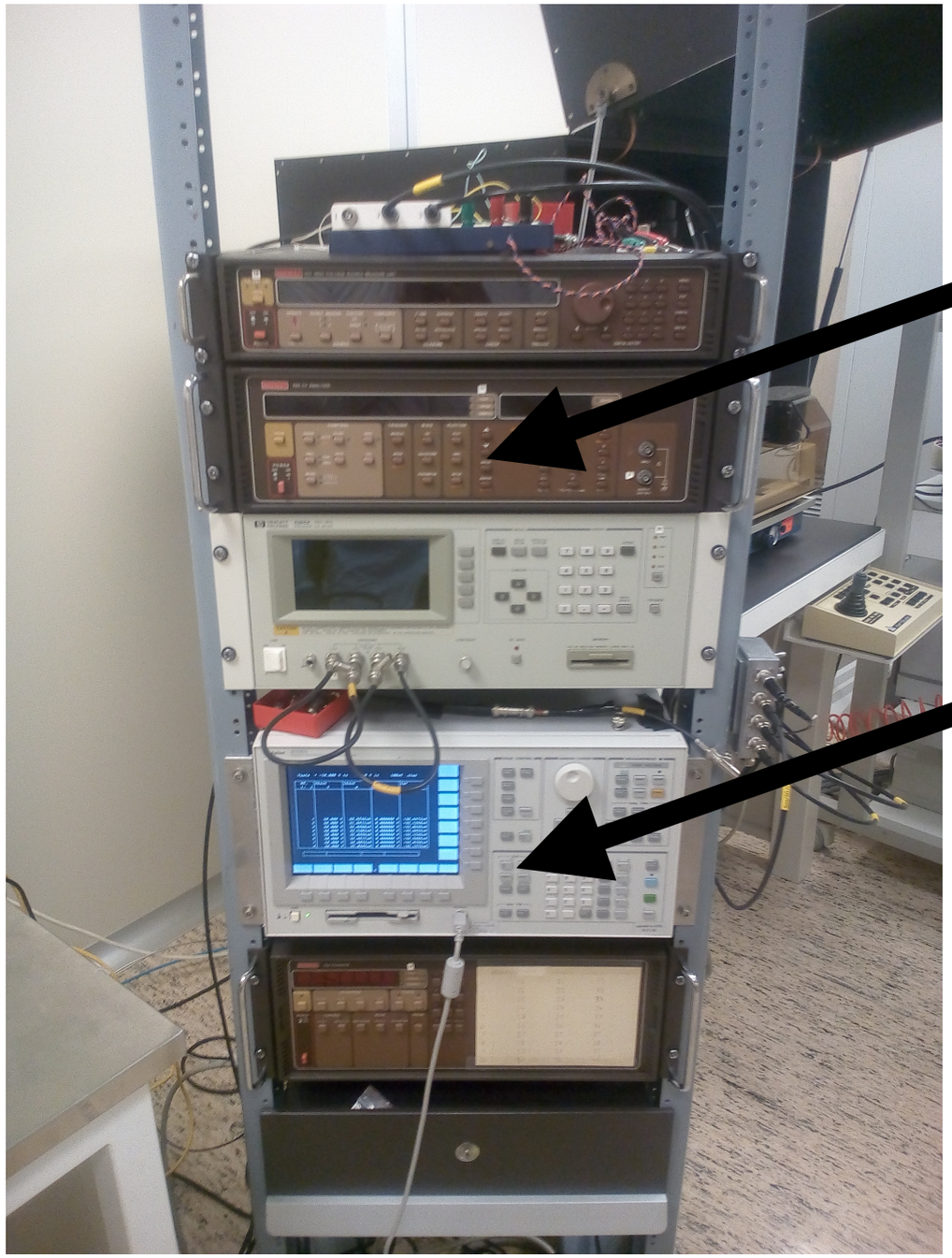
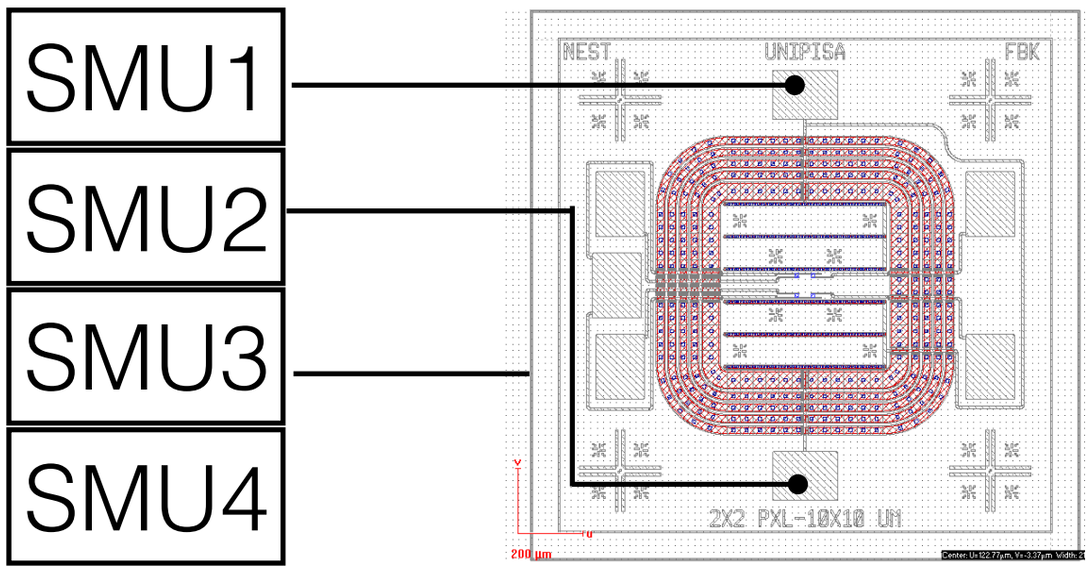
Instruments



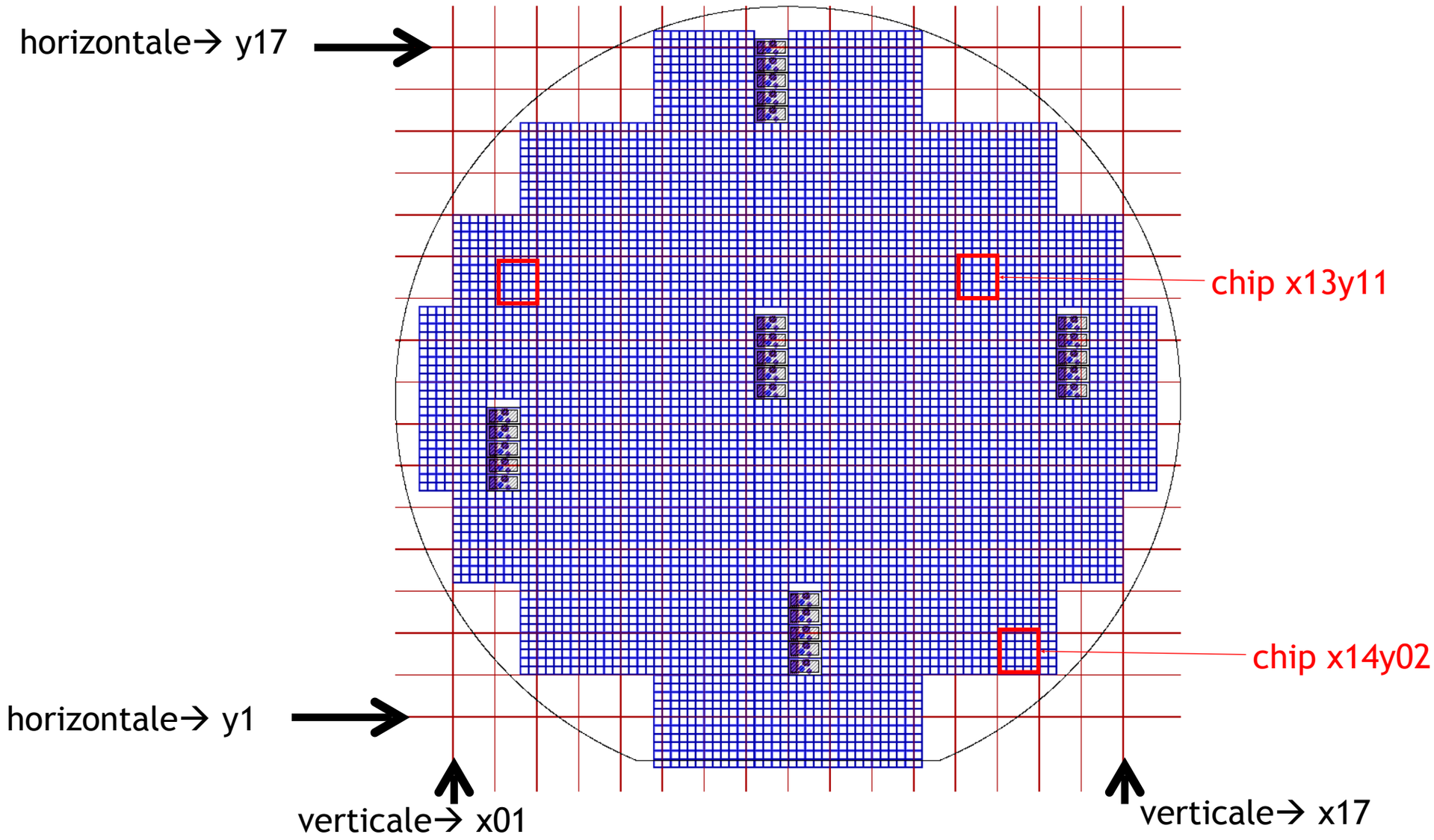
- KEITHLEY 590
  - CV Analyzer
- Agilent 4156C
  - Semiconductor Parameter Analyzer

Sensor Structures



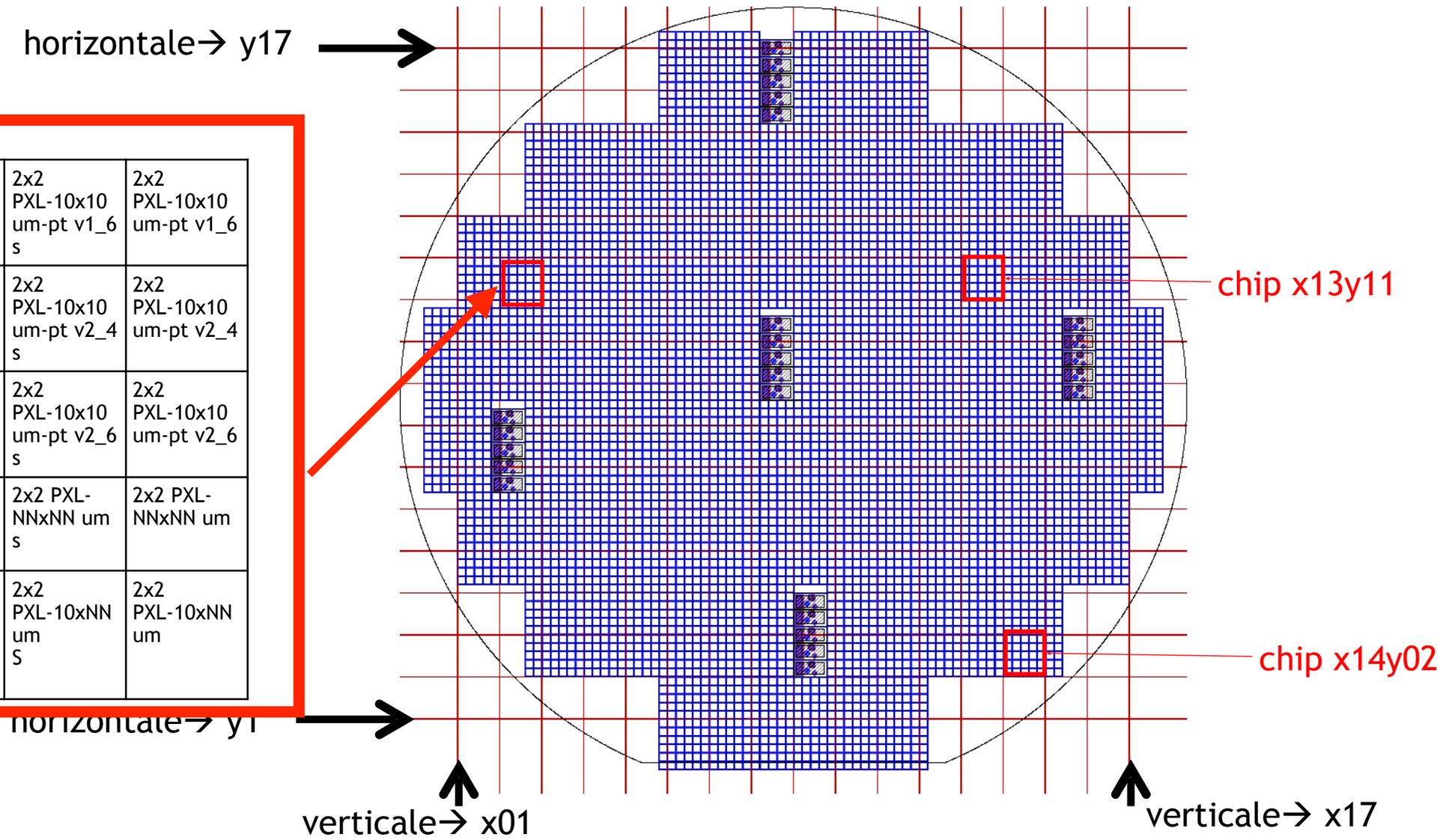
- I-V Curves
  - Reverse Bias 0 V - 50 V
  - 1 V steps
- A = 0.25 mm^2

Sensor Structures

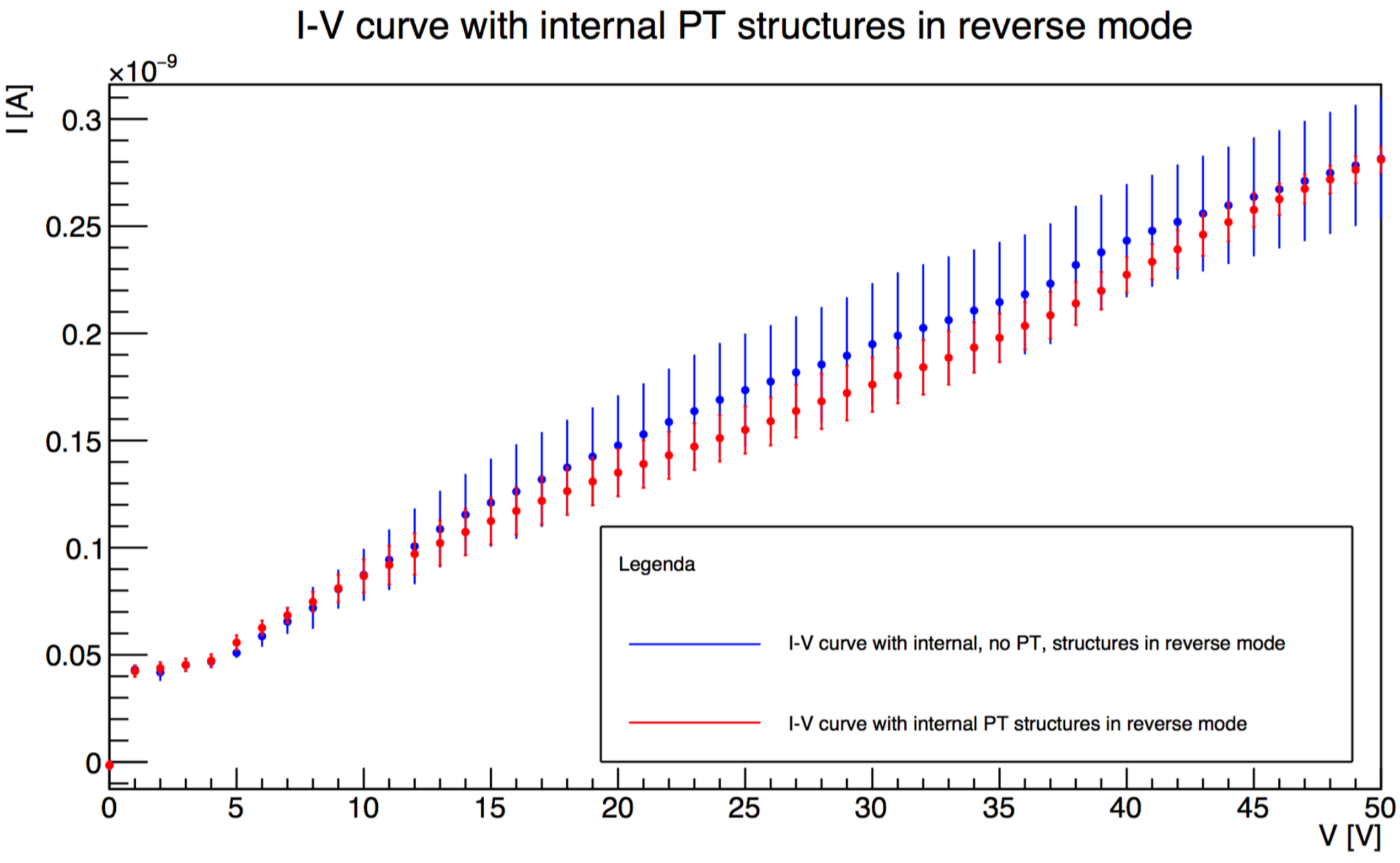


Sensor Structures

2x2 PXL-10x10 um-pt v1_6	2x2 PXL-10x10 um-pt v1_6	2x2 PXL-10x10 um-pt v1_6 s	2x2 PXL-10x10 um-pt v1_6 s	2x2 PXL-10x10 um-pt v1_6
2x2 PXL-10x10 um-pt v2_4	2x2 PXL-10x10 um-pt v2_4	2x2 PXL-10x10 um-pt v2_4 s	2x2 PXL-10x10 um-pt v2_4 s	2x2 PXL-10x10 um-pt v2_4
2x2 PXL-10x10 um-pt v2_6	2x2 PXL-10x10 um-pt v2_6	2x2 PXL-10x10 um-pt v2_6 s	2x2 PXL-10x10 um-pt v2_6 s	2x2 PXL-10x10 um-pt v2_6
2x2 PXL-NNxNN um	2x2 PXL-NNxNN um	2x2 PXL-NNxNN um s	2x2 PXL-NNxNN um s	2x2 PXL-NNxNN um
2x2 PXL-10xNN um	2x2 PXL-10xNN um	2x2 PXL-10xNN um S	2x2 PXL-10xNN um S	2x2 PXL-10xNN um

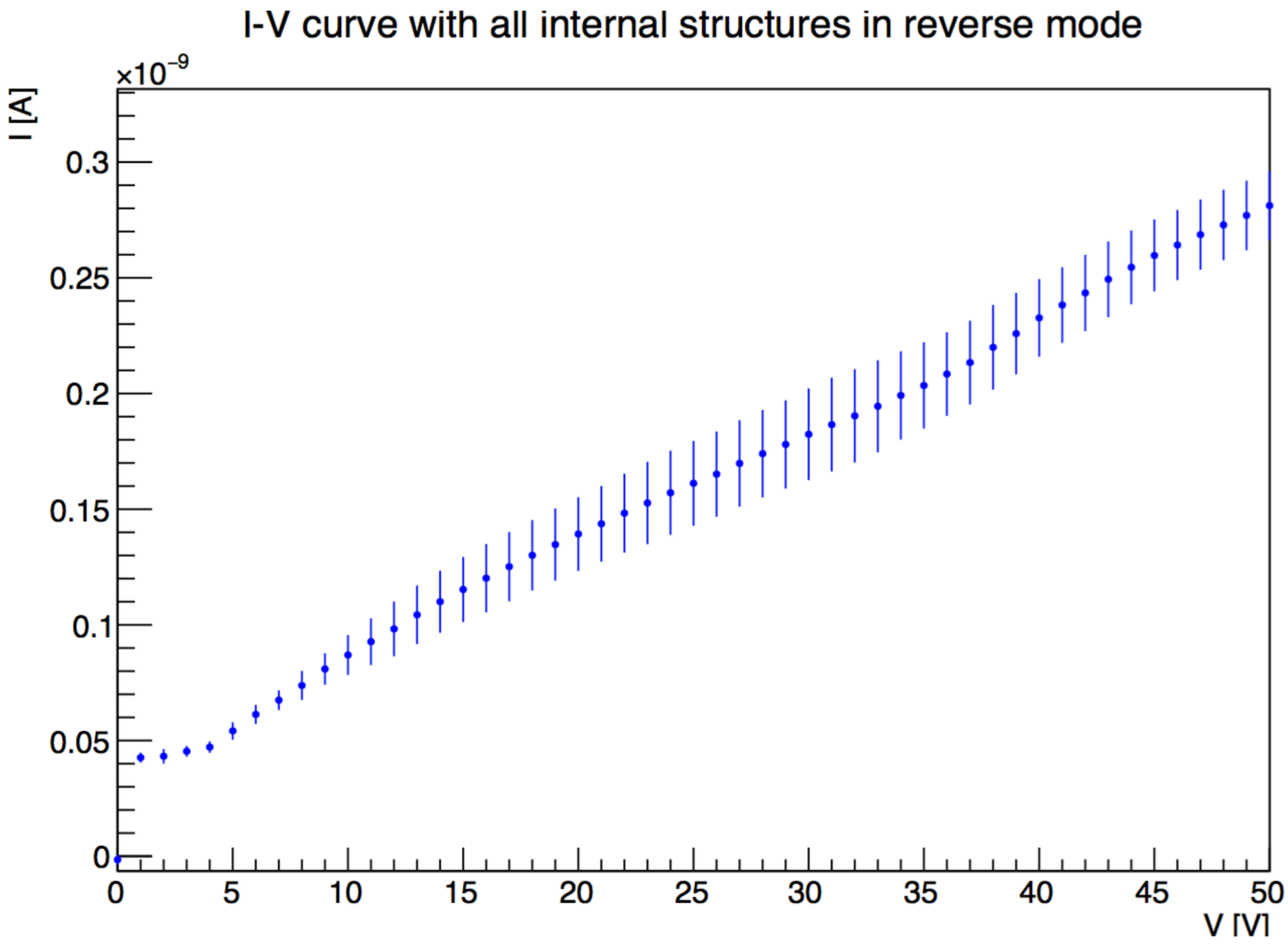


Sensor Structures



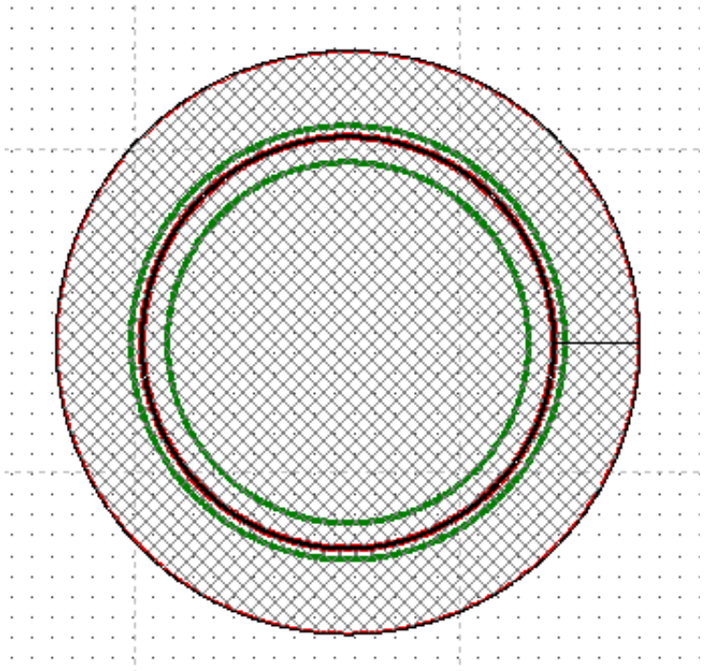
300 nm

Sensor Structures



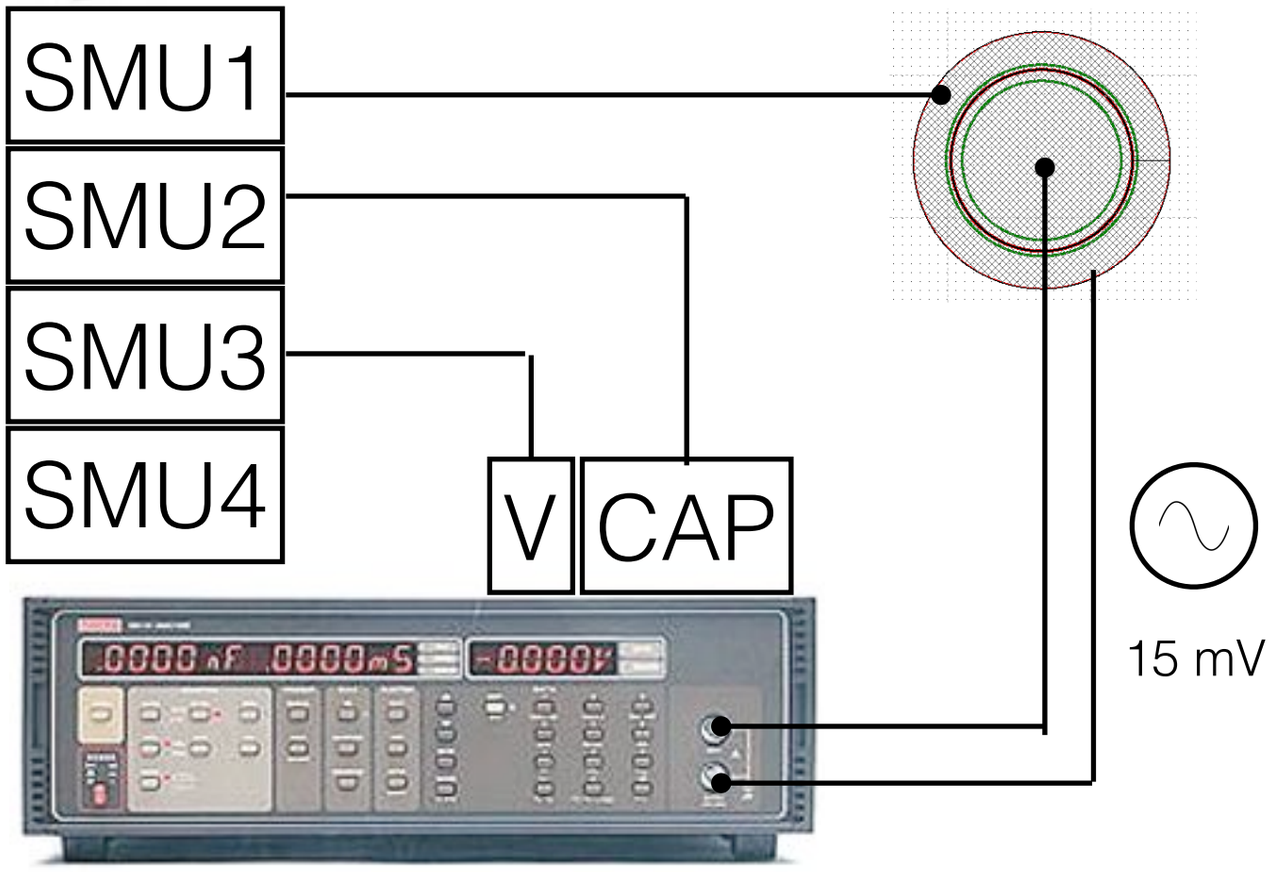
300 nm

Test Structures



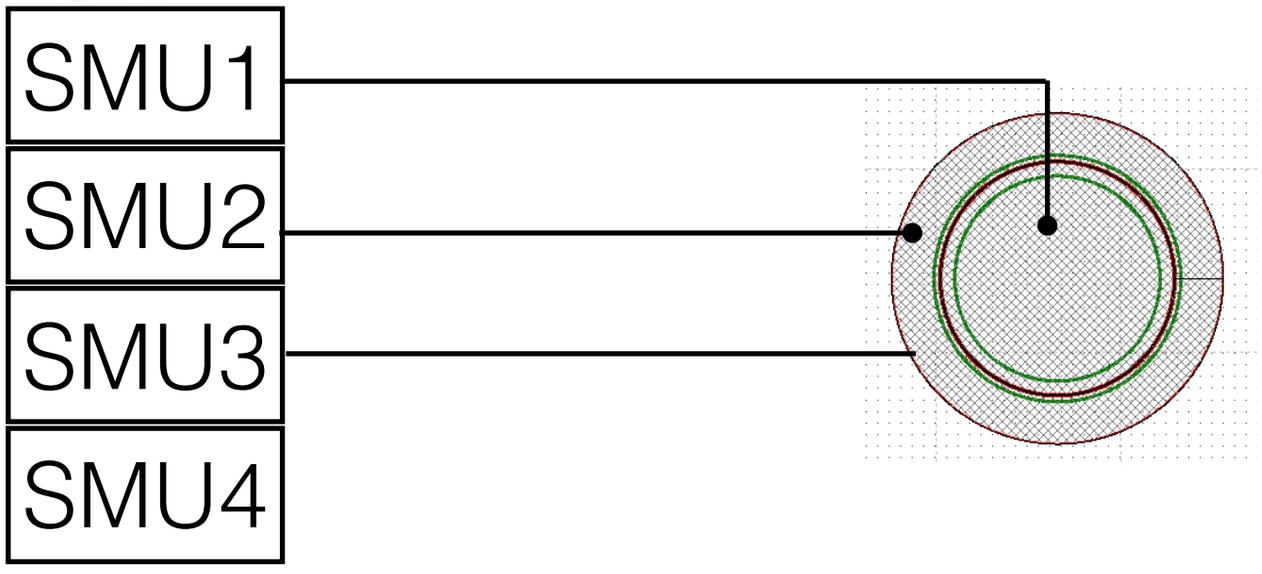
- Diode
  - **d =1 mm, A = 0.785 mm²**
  - C-V curves (100 kHz, 15 mV)
  - I-V 0 V - 50 V

Test Structures



- Diode
  - d =1 mm, A = 0.785 mm^2
  - **C-V curves (100 kHz, 15 mV)**
  - I-V 0 V - 50 V

Test Structures



- Diode
  - d =1 mm, A = 0.785 mm^2
  - C-V curves (100 kHz, 15 mV)
  - **I-V (0 V - 50 V)**

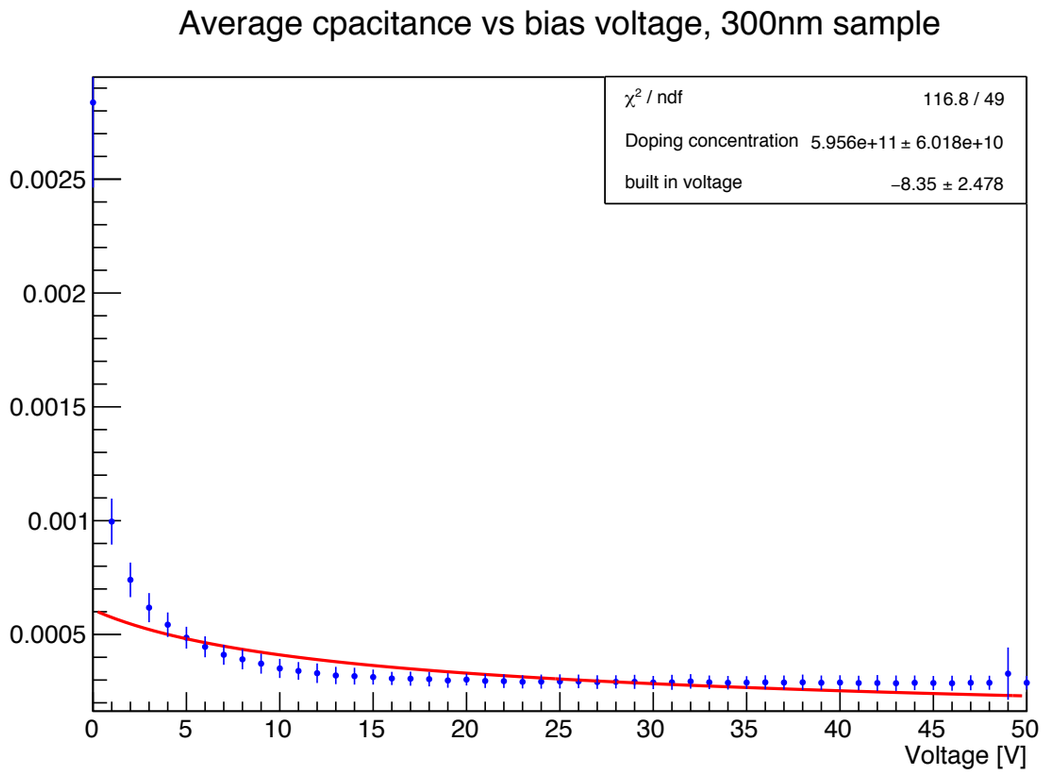
$$(1) \quad w = \sqrt{\frac{2\epsilon_s \cdot (\phi_i - V)}{q \cdot N_d}} \quad \mathrm{N_d} << \mathrm{N_a}$$

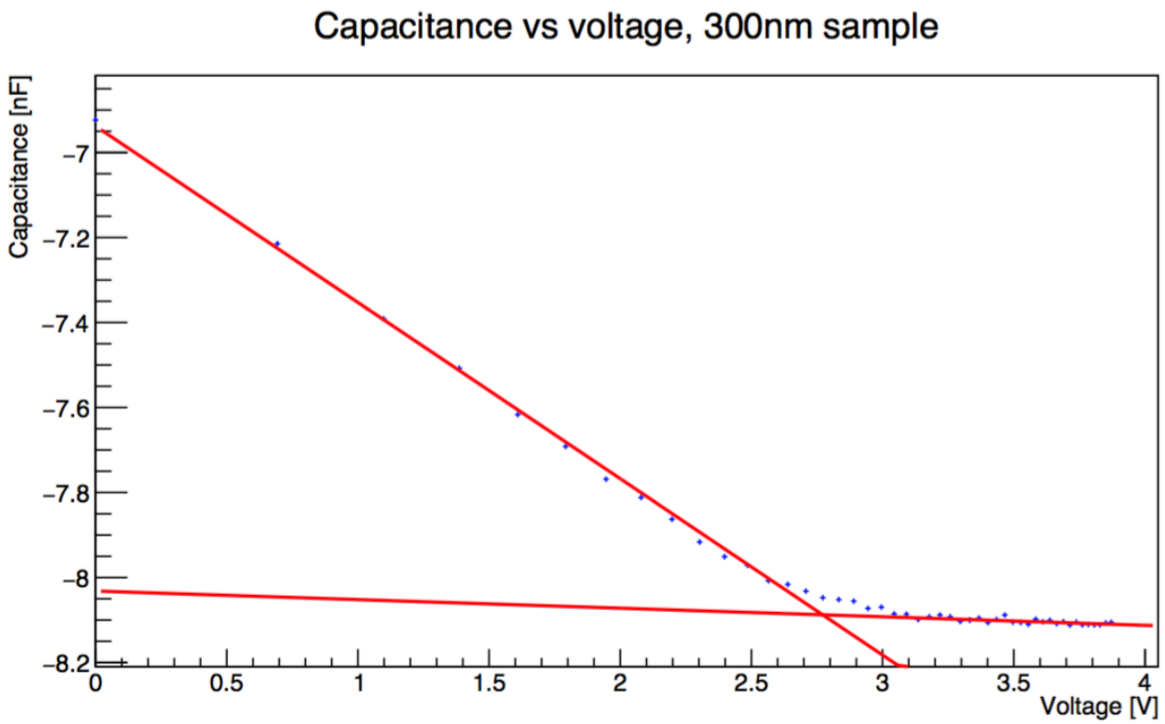
$$(2) \quad C = \frac{\epsilon_s \cdot A}{w}$$

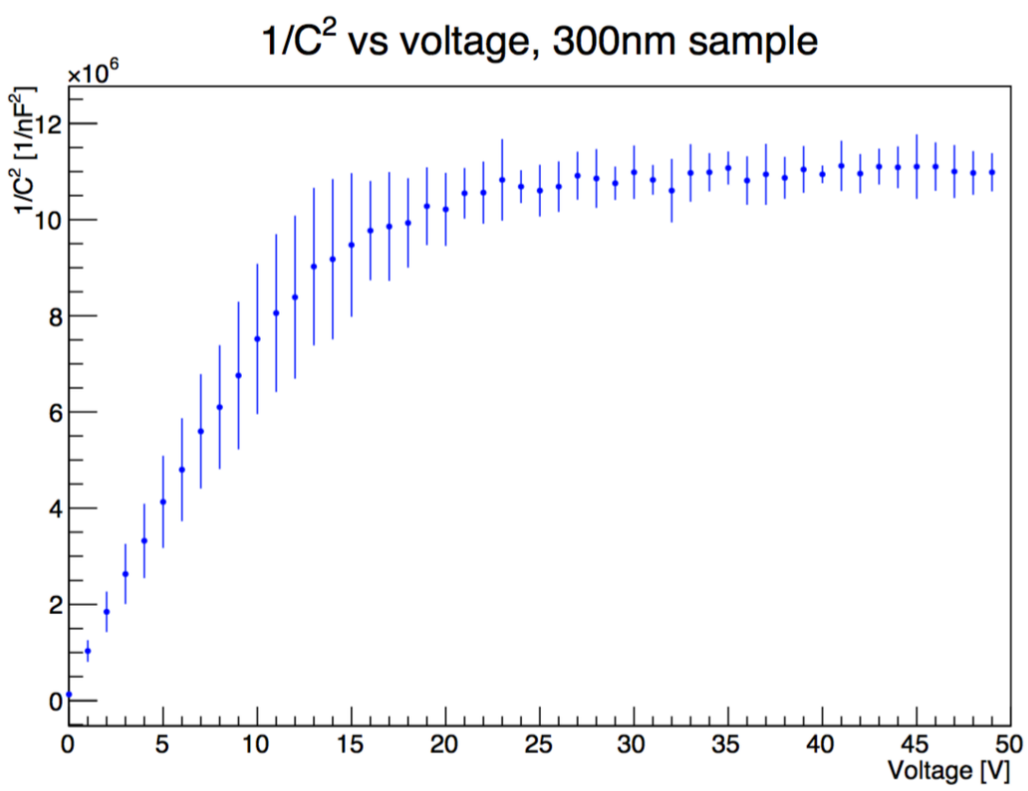
$$(3) \quad \frac{1}{C^2} = \frac{2}{q \cdot \epsilon_s \cdot A^2 \cdot N_d}(\phi_i - V)$$

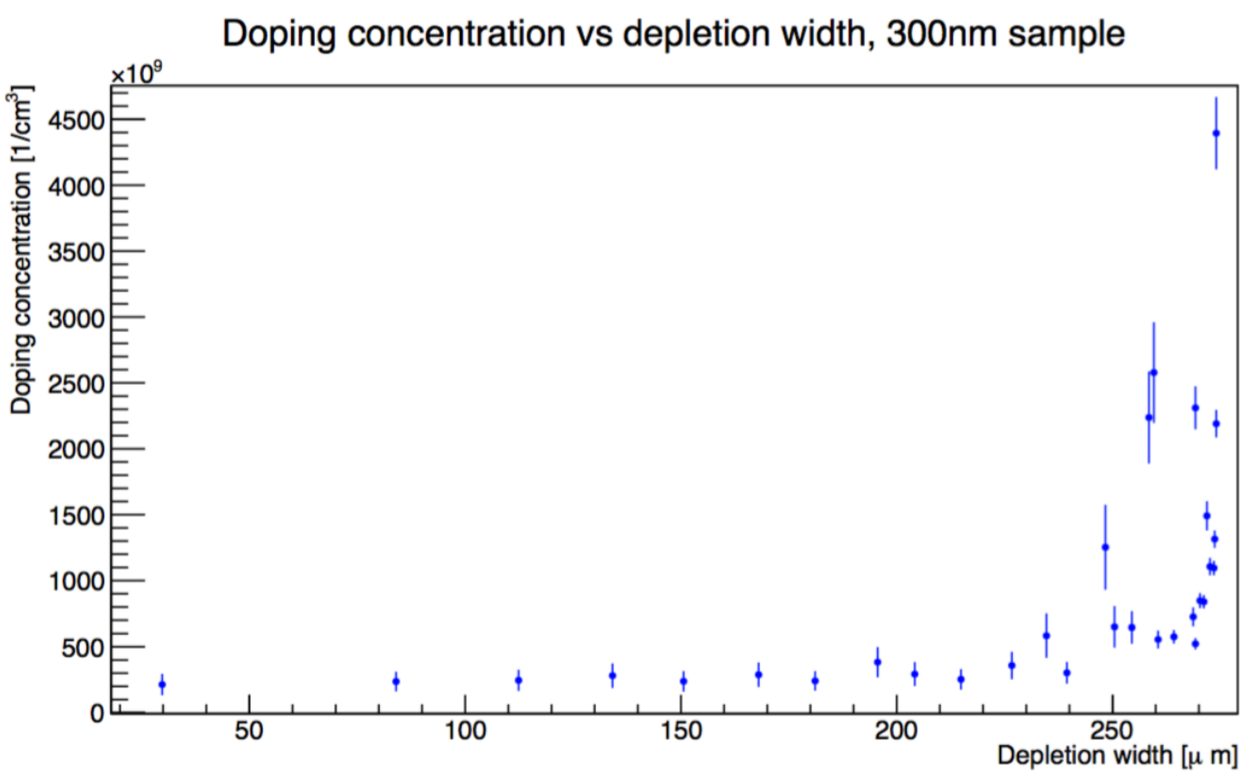
$$(3.1)\, C = \sqrt{\frac{q \cdot \epsilon_s \cdot A^2 \cdot N_d}{2(\phi_i - V)}}$$

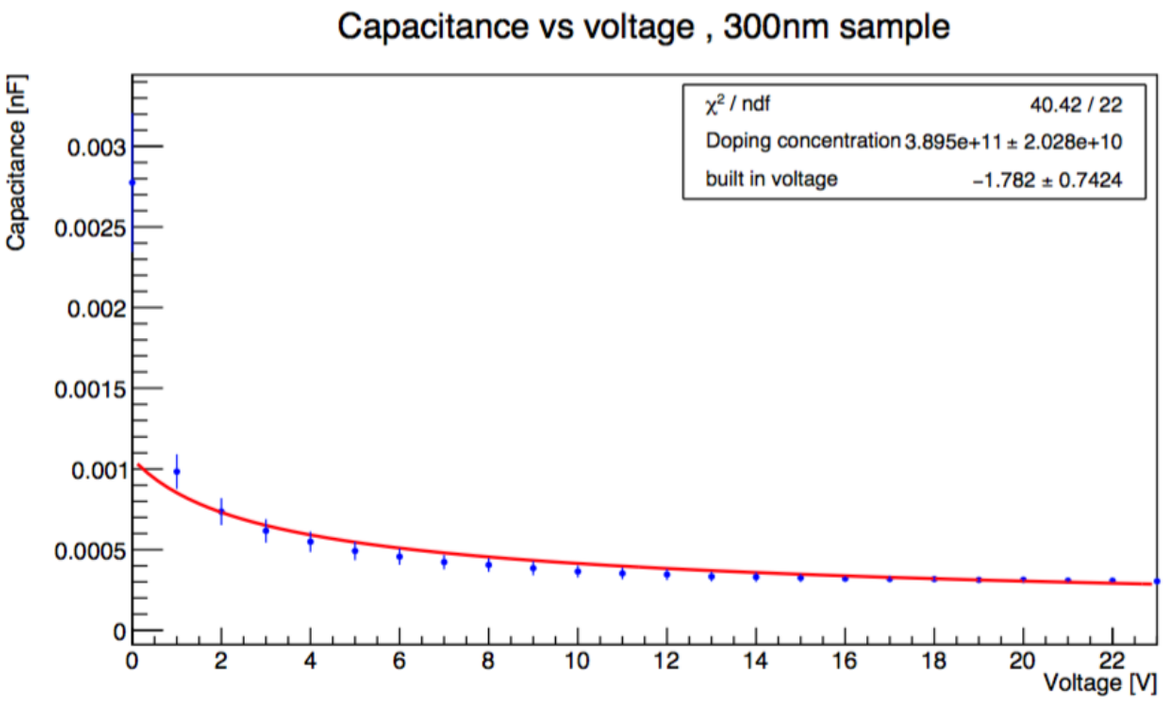
$$(4) \quad N_d = \frac{2}{q\epsilon_s A^2} \cdot \frac{1}{\Delta} \quad : \Delta = \frac{\partial(\frac{1}{C^2})}{\partial V}$$

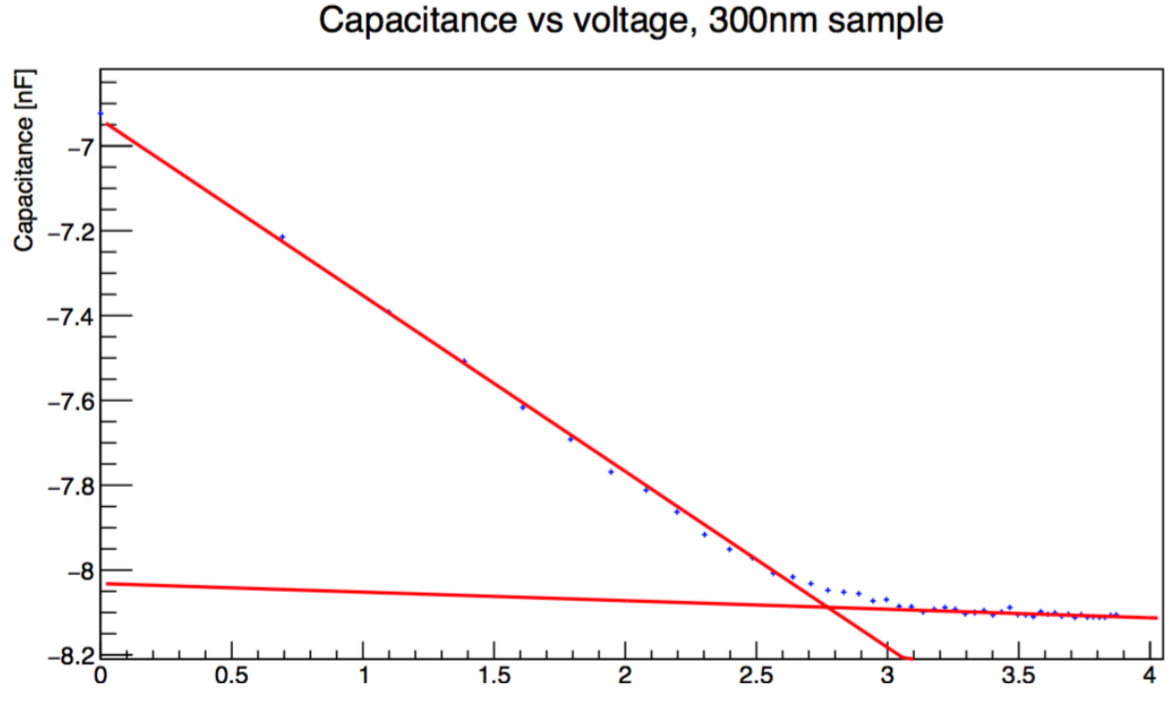

Average cpacitance vs bias voltage, 300nm sample
χ^2 / ndf 116.8 / 49
Doping concentration 5.956e+11 ± 6.018e+10
built in voltage −8.35 ± 2.478
0.0025
0.002
0.0015
0.001
0.0005
0 5 10 15 20 25 30 35 40 45 50
Voltage [V]

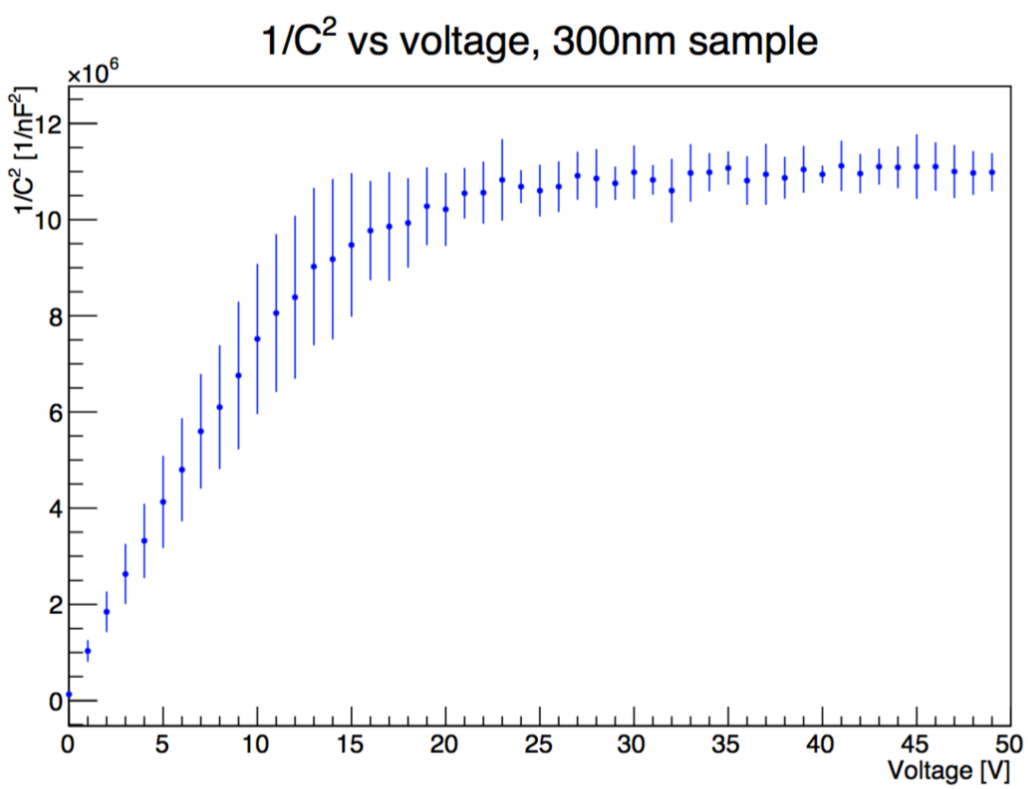

Capacitance vs voltage, 300nm sample
Capacitance [nF]
−7
−7.2
−7.4
−7.6
−7.8
−8
−8.2
0 0.5 1 1.5 2 2.5 3 3.5 4
Voltage [V]

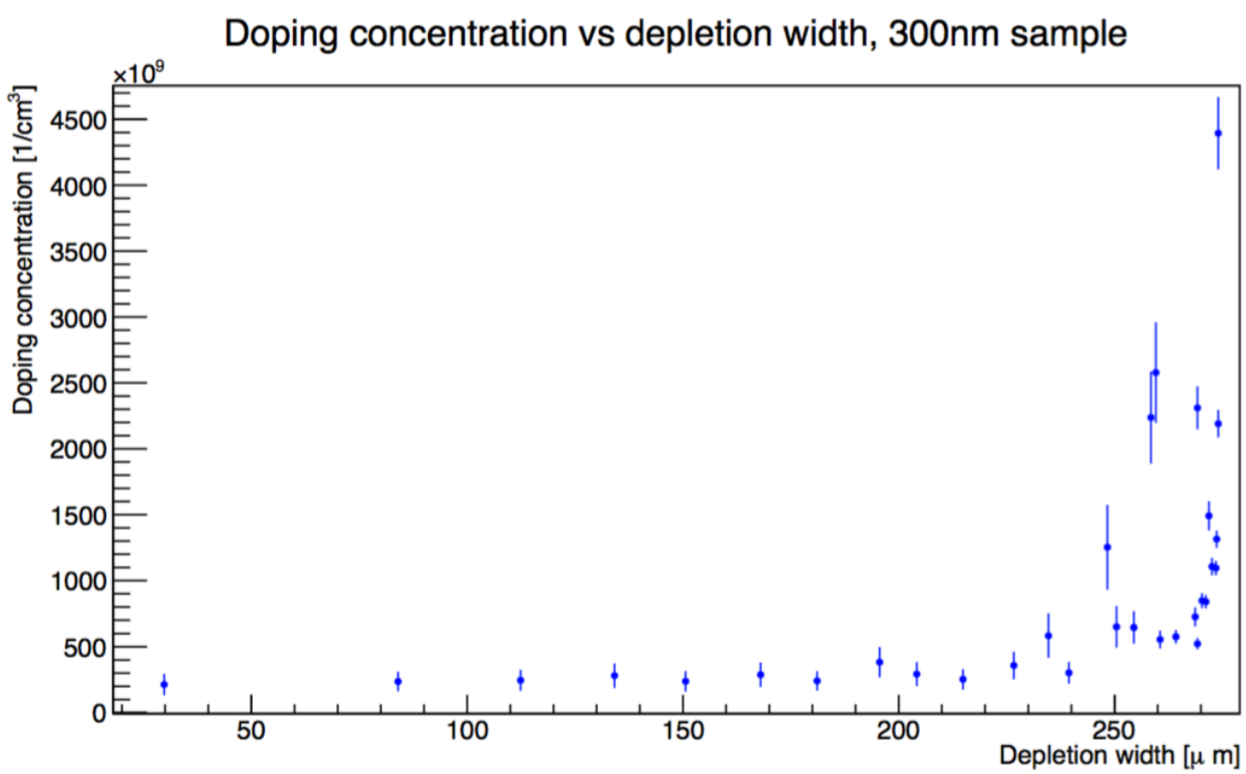

$1/C^2$ vs voltage, 300nm sample
$\times 10^6$
$1/C^2$ [1/nF^2]
12
10
8
6
4
2
0
0 5 10 15 20 25 30 35 40 45 50
Voltage [V]

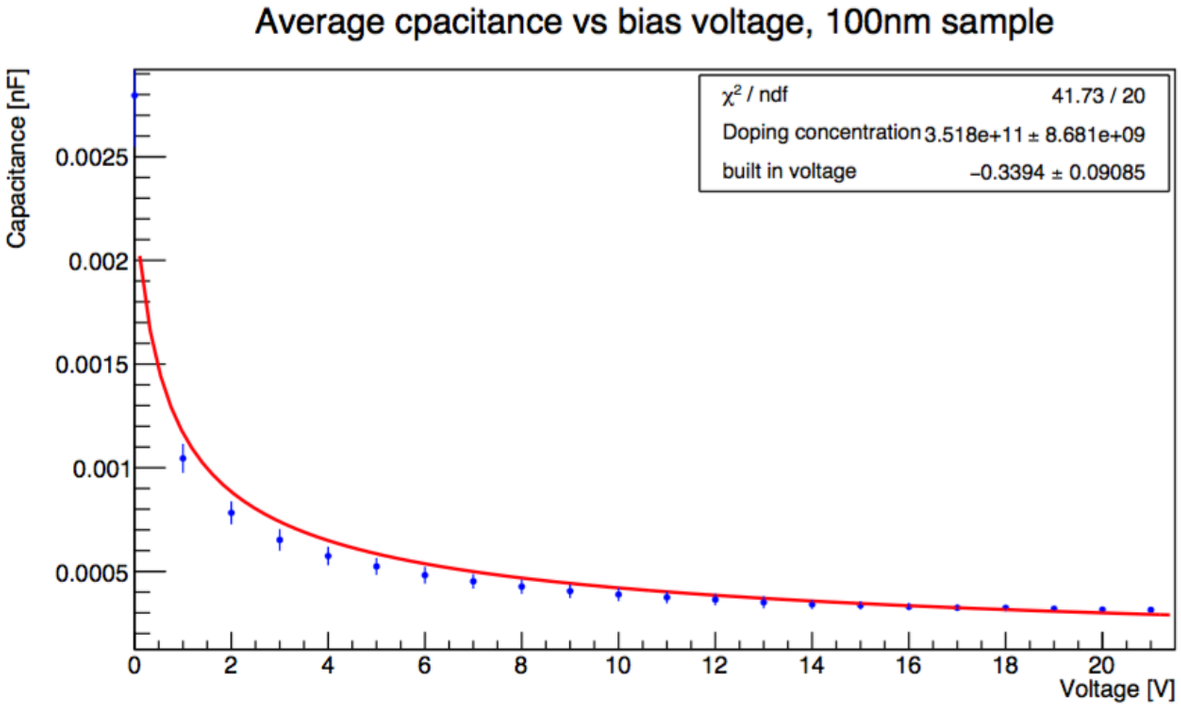

Doping concentration vs depletion width, 300nm sample
$\times 10^9$
Doping concentration [1/cm^3]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
50 100 150 200 250
Depletion width [μ m]

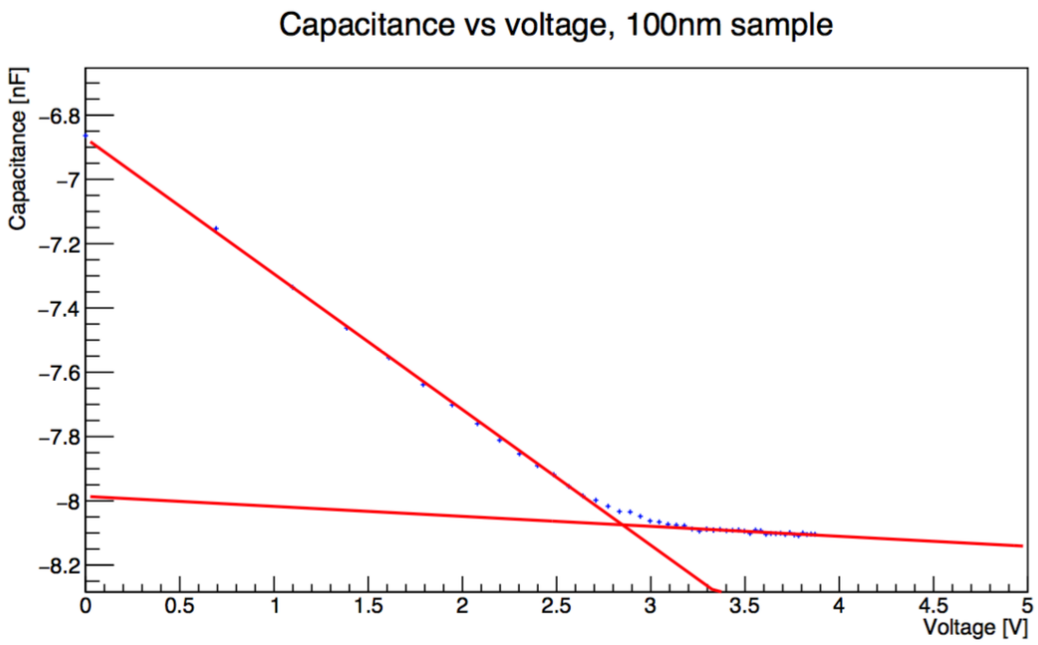

Capacitance vs voltage , 300nm sample
χ² / ndf 40.42 / 22
Doping concentration 3.895e+11 ± 2.028e+10
built in voltage −1.782 ± 0.7424
Capacitance [nF]
Voltage [V]

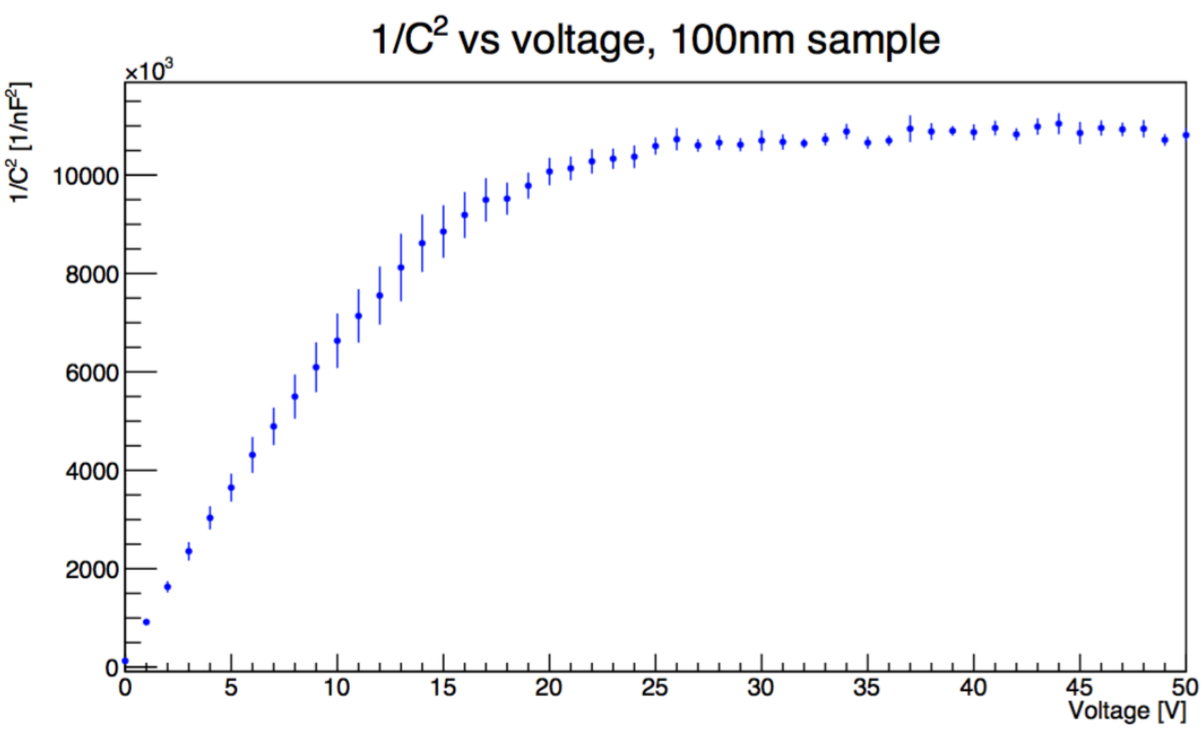

Capacitance vs voltage, 300nm sample
Capacitance [nF]

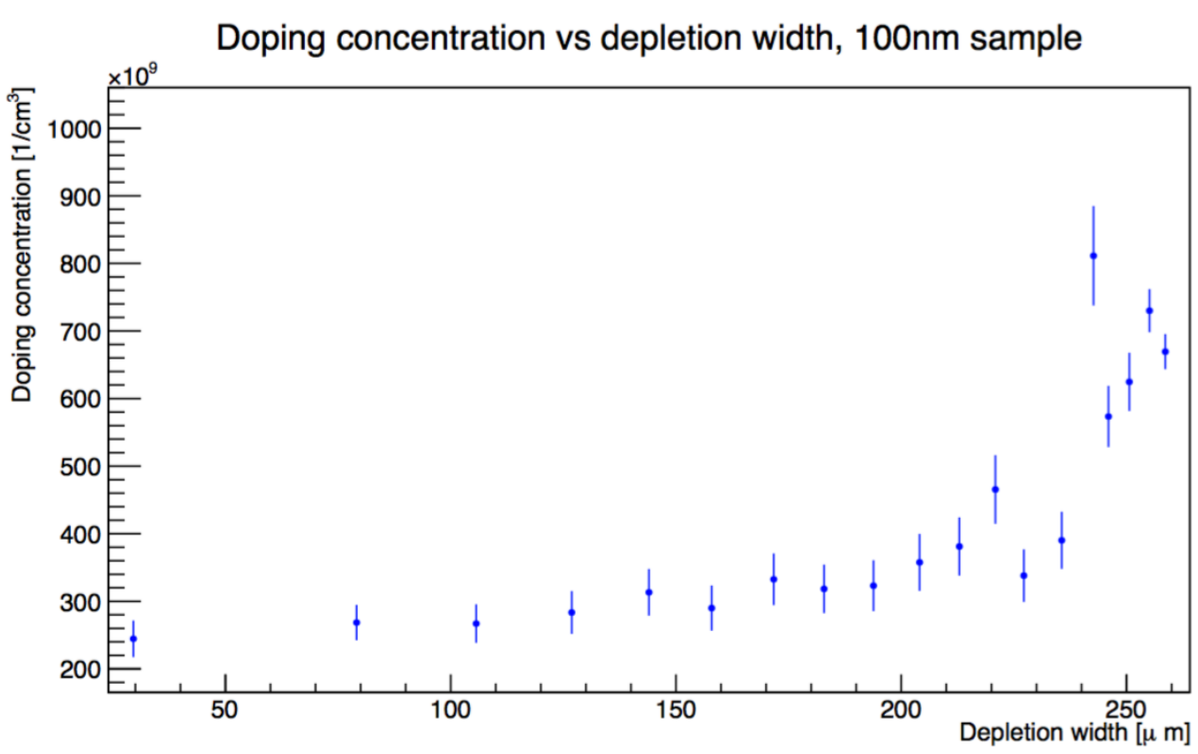

1/C² vs voltage, 300nm sample
×10⁶
1/C² [1/nF²]
Voltage [V]


Doping concentration vs depletion width, 300nm sample
×10⁹
Doping concentration [1/cm³]
Depletion width [μ m]


Average cpacitance vs bias voltage, 100nm sample
χ² / ndf 41.73 / 20
Doping concentration 3.518e+11 ± 8.681e+09
built in voltage −0.3394 ± 0.09085
Capacitance [nF]
Voltage [V]


Capacitance vs voltage, 100nm sample
Capacitance [nF]
Voltage [V]

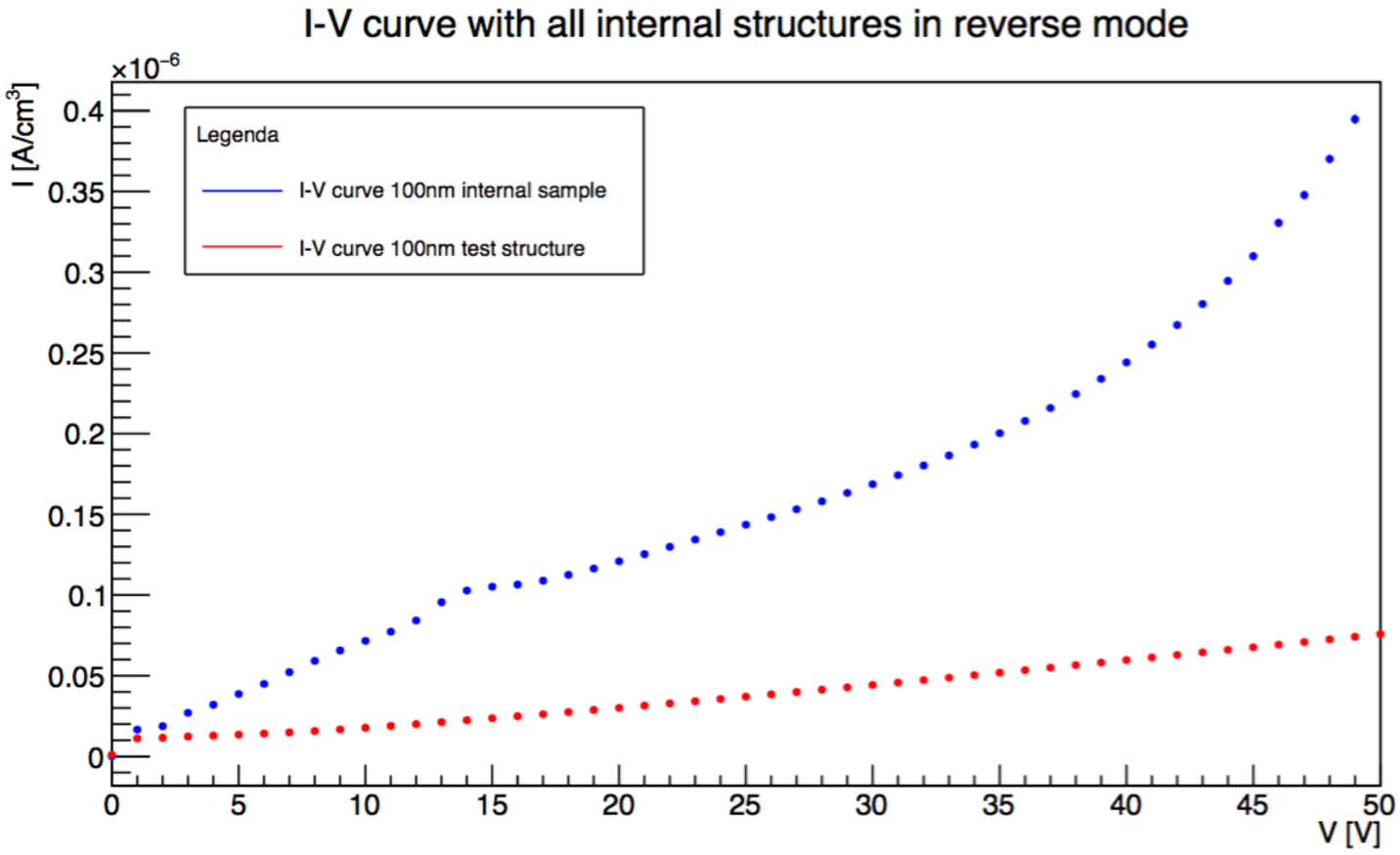

1/C² vs voltage, 100nm sample
1/C² [1/nF²]
Voltage [V]

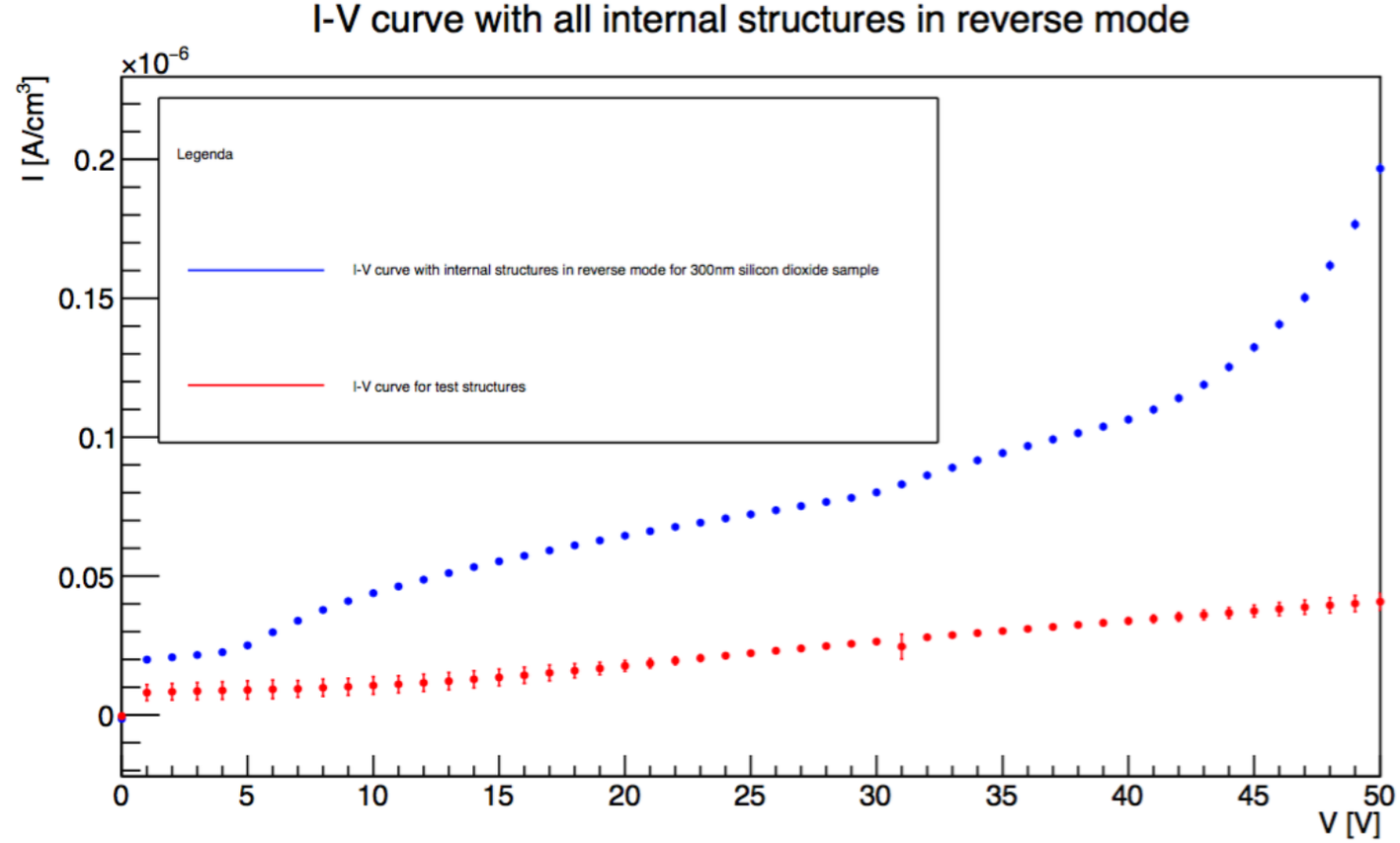

Doping concentration vs depletion width, 100nm sample
Doping concentration [1/cm³]
Depletion width [μ m]

SiO_2 width [nm]	300	100
Depletion width w [μm]	276 +- 7	271 +- 5
Depletion Voltage [V]	16.4+-1.7	17.5+-0.9
Doping Concentration from C-V $[1/cm^3]$	$(3.9+-0.2)*10^{11}$	$(3.51+-0.09)*10^{11}$
Doping Concentration from $\delta(1/C)/\delta$ $[1/cm^3]$	$\frac{(2.+-0.1)*10^{11}}{(5.+-0.6)*10^{11}}$	$\frac{(2.4+-0.2)*10^{11}}{(4.2+-0.6)*10^{11}}$

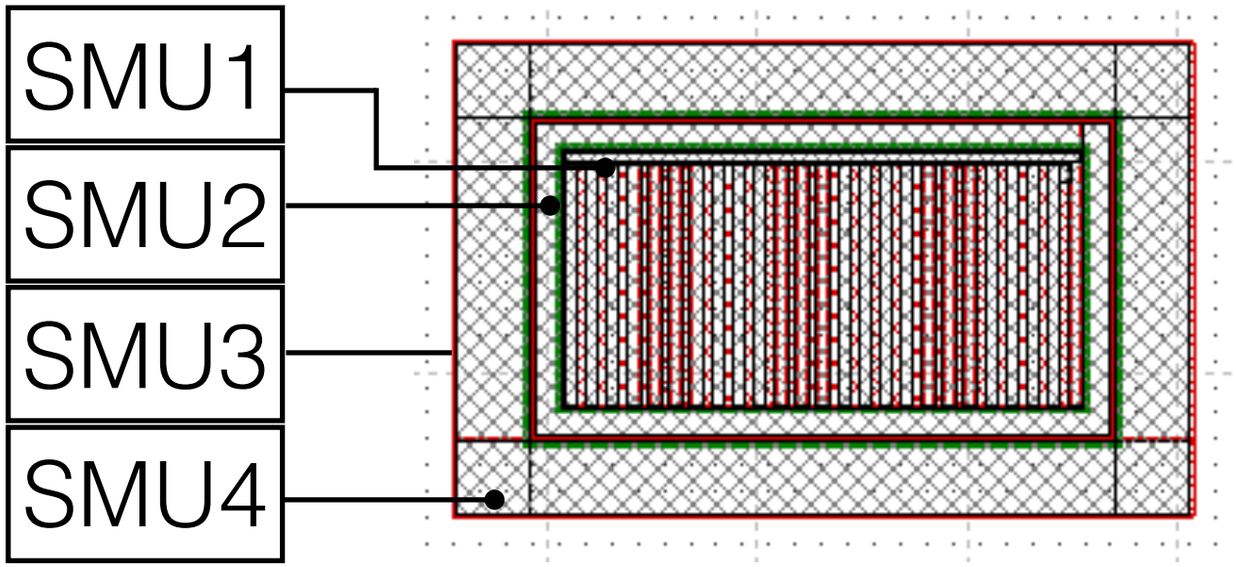
SiO_2 width [nm]	300	100
Depletion width w [μm]	276 +- 7	271 +- 5
Depletion Voltage [V]	16.4+-1.7	17.5+-0.9
Doping Concentration	$(3.9+-0.2)*10^{11}$	$(3.51+-0.09)*10^{11}$
Doping Concentration from δ(1/C)/δ [$1/cm^3$]	$(2.+-0.1)*10^{11}$ ——— $(5.+-0.6)*10^{11}$	$(2.4+-0.2)*10^{11}$ ——— $(4.2+-0.6)*10^{11}$

Doping concentration $7*10^{11}$ -> resistivity ρ = 6 kΩcm

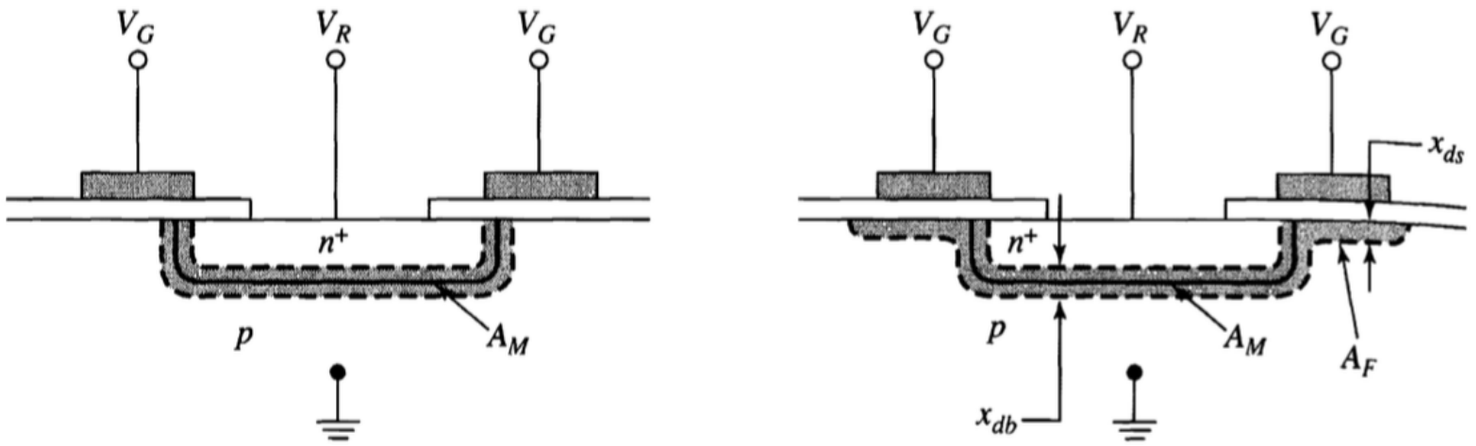

I-V curve with all internal structures in reverse mode
×10⁻⁶
I [A/cm³]
Legenda
I-V curve 100nm internal sample
I-V curve 100nm test structure
V [V]


I-V curve with all internal structures in reverse mode
×10⁻⁶
I [A/cm³]
Legenda
I-V curve with internal structures in reverse mode for 300nm silicon dioxide sample
I-V curve for test structures
V [V]

Test Structures



- Gate controlled Diode
  - I = 2 mm, w = 1 mm, A = 2 mm^2
  - I-V curves
    - V_{gate} (-10 V - 6 V)
    - Constan bias voltage (V_{back})



(*a*) (*b*)

FIGURE 8.20 Gated-diode structure showing depletion regions: (*a*) when the gate voltage is V_{FB} for the *p*-region, and (*b*) when the gate causes a depletion region of width x_{ds} at the silicon surface.

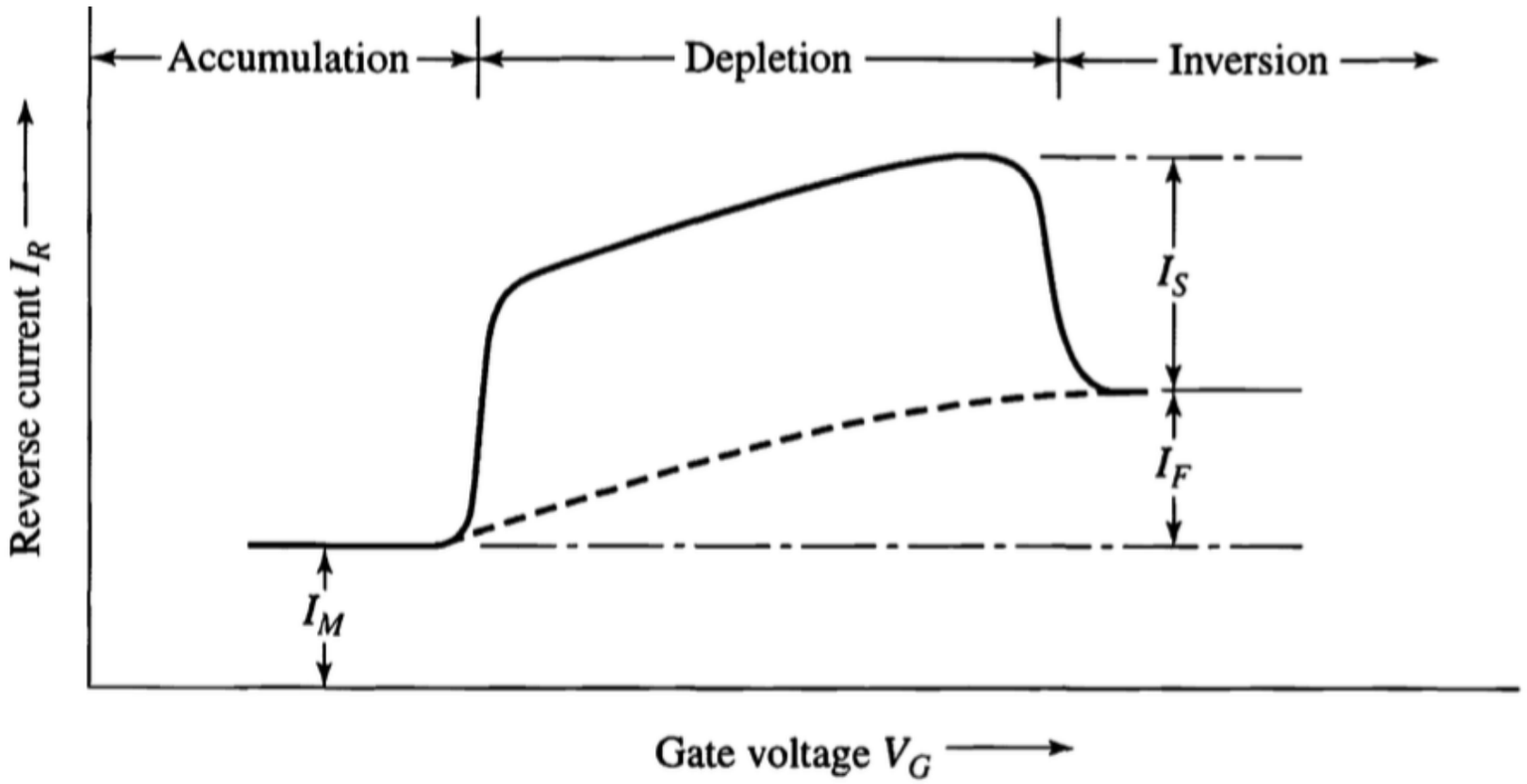


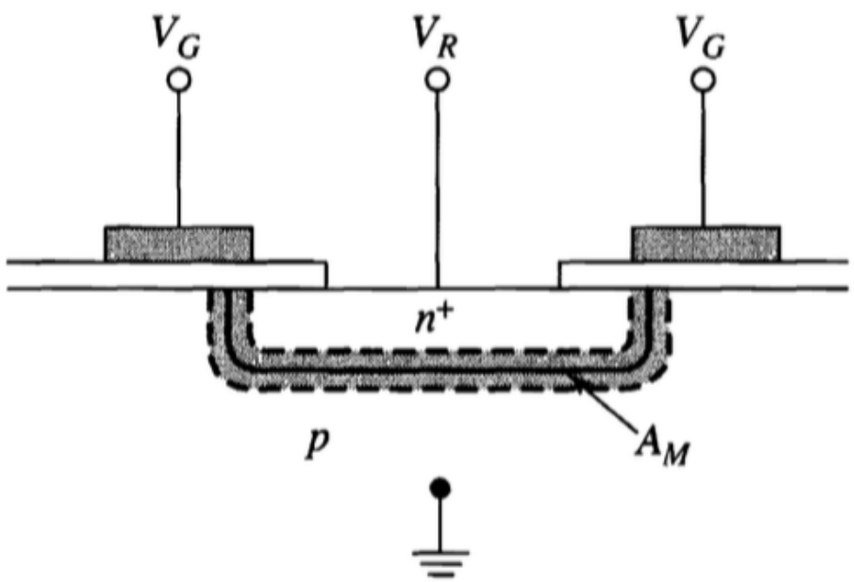
FIGURE 8.21 Reverse current in the gated diode as a function of V_G showing the marked increase in leakage when the surface is depleted.

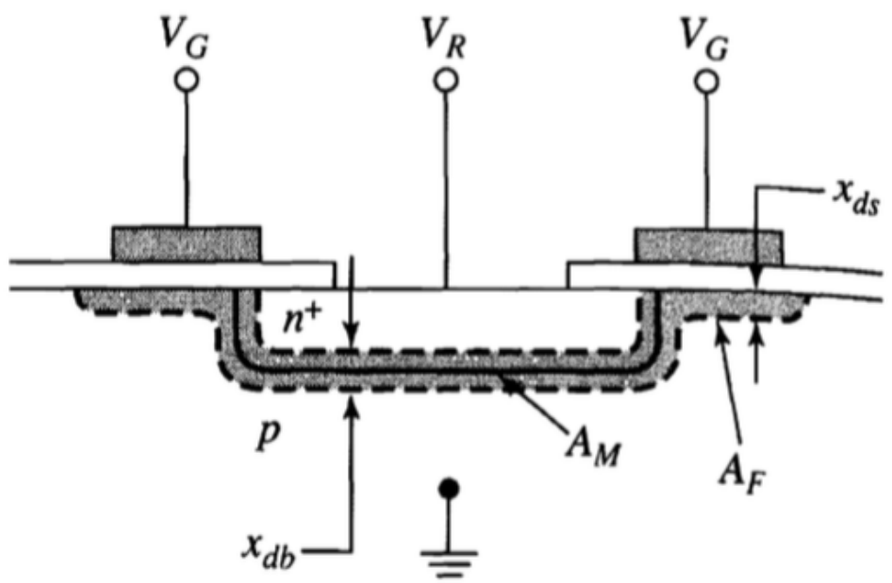
$$I_R = I_M + I_F + I_S$$

$$I_M = \frac{qn_i}{2\tau_0} x_i A_M \quad x_i \sim \sqrt{V_{back} - \phi_i}$$

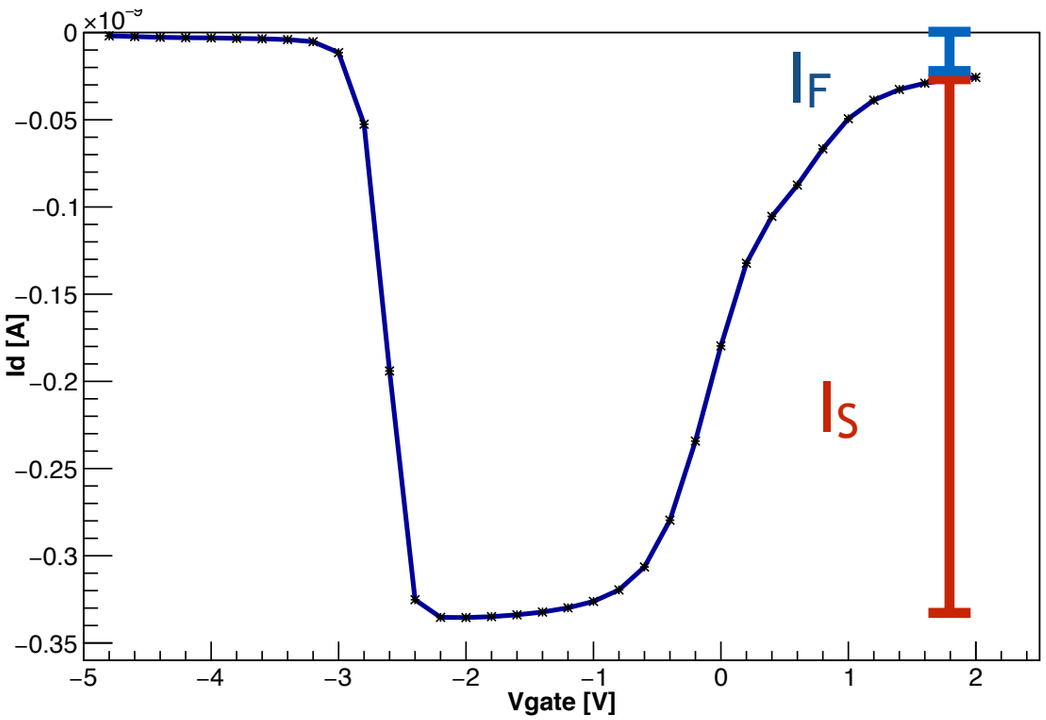
$$I_F = \frac{qn_i}{2\tau_0} x_{ds} A_F$$

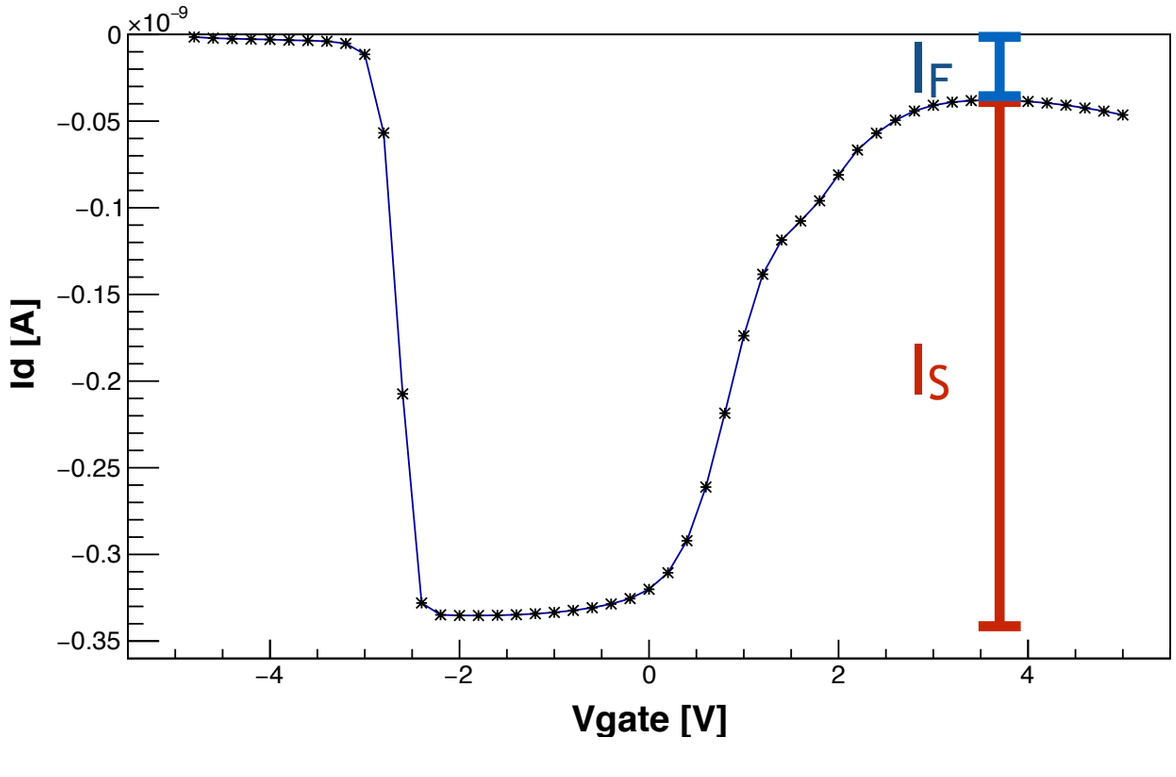
$$I_S = \frac{qn_i s_0 A_F}{2} \qquad p_s/n_s << n_i$$

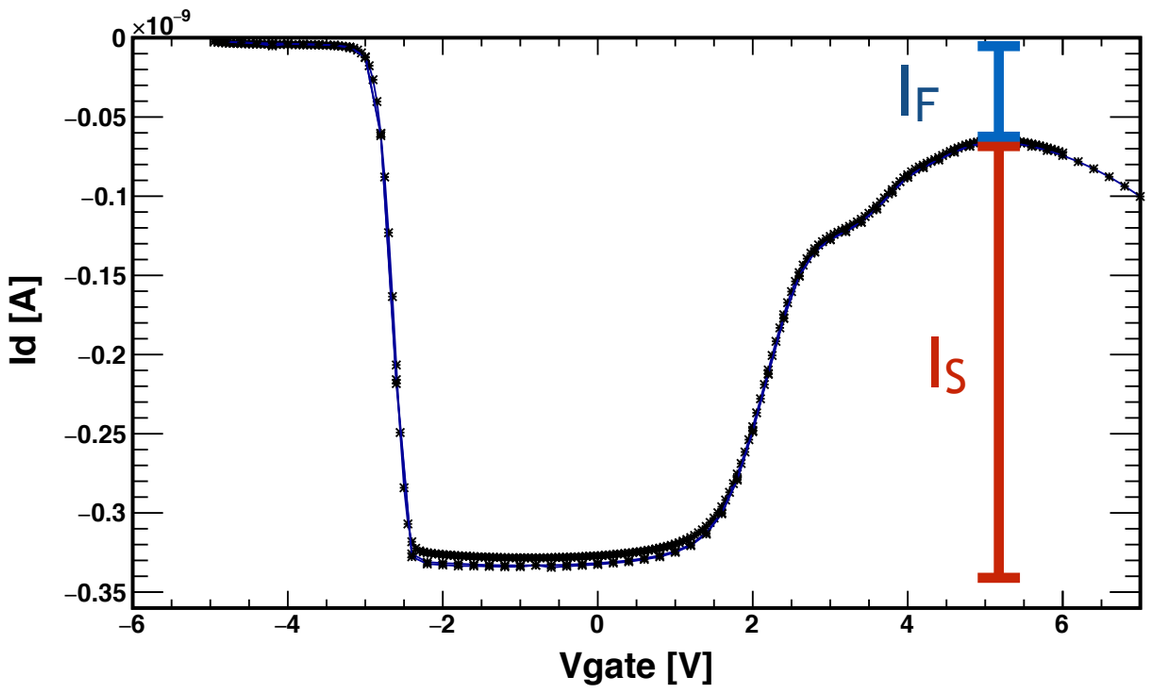




100 nm SiO_2

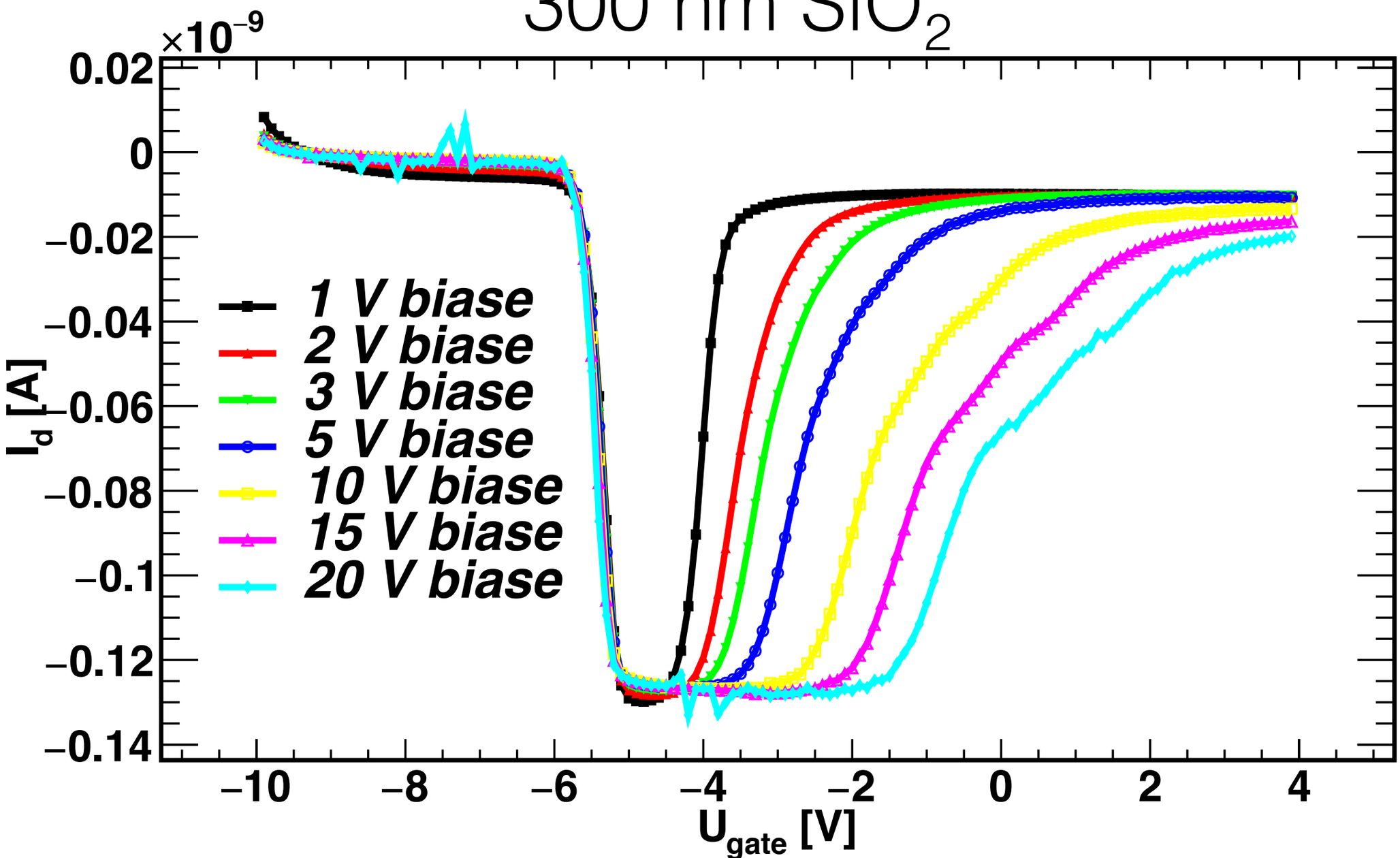




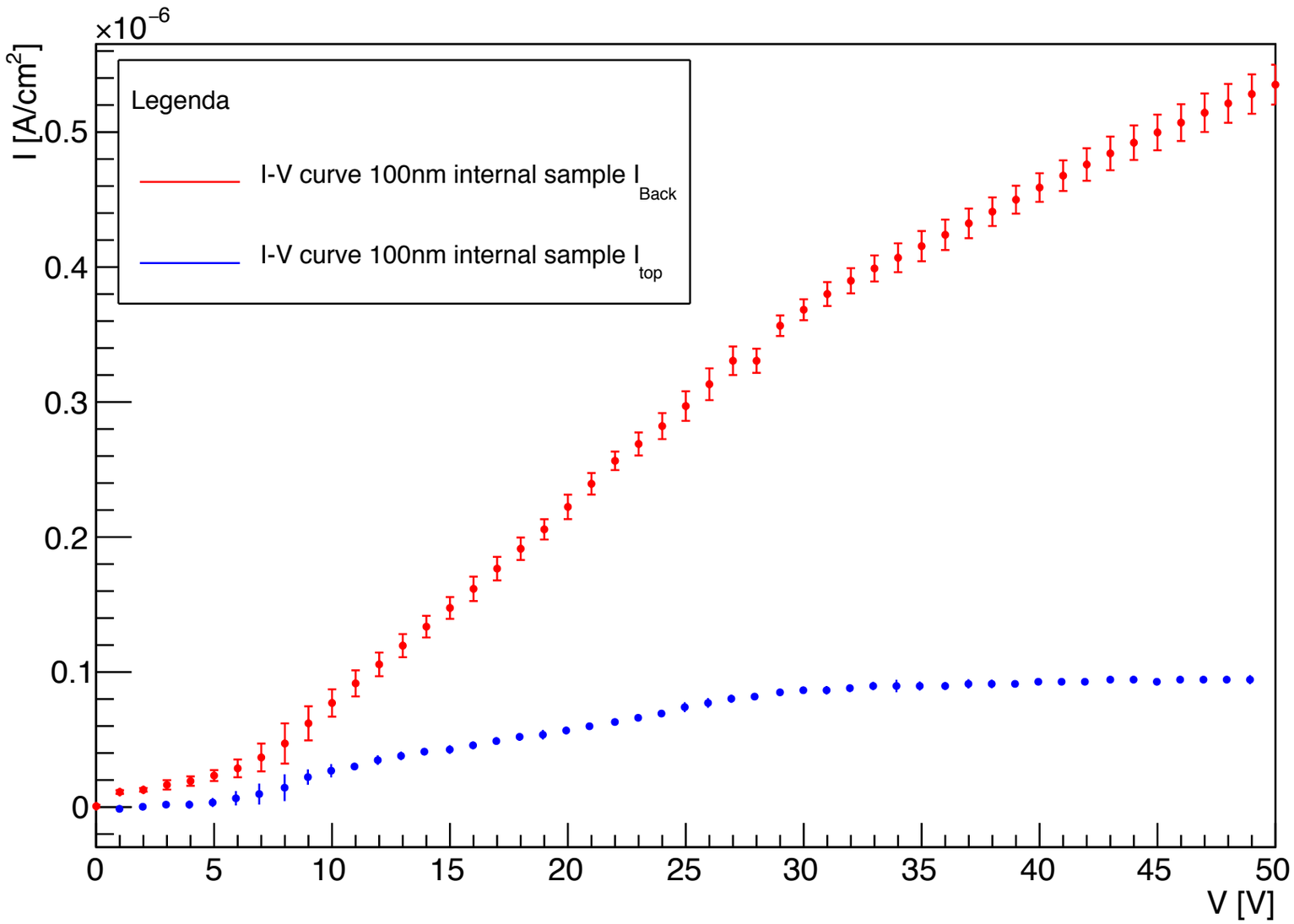


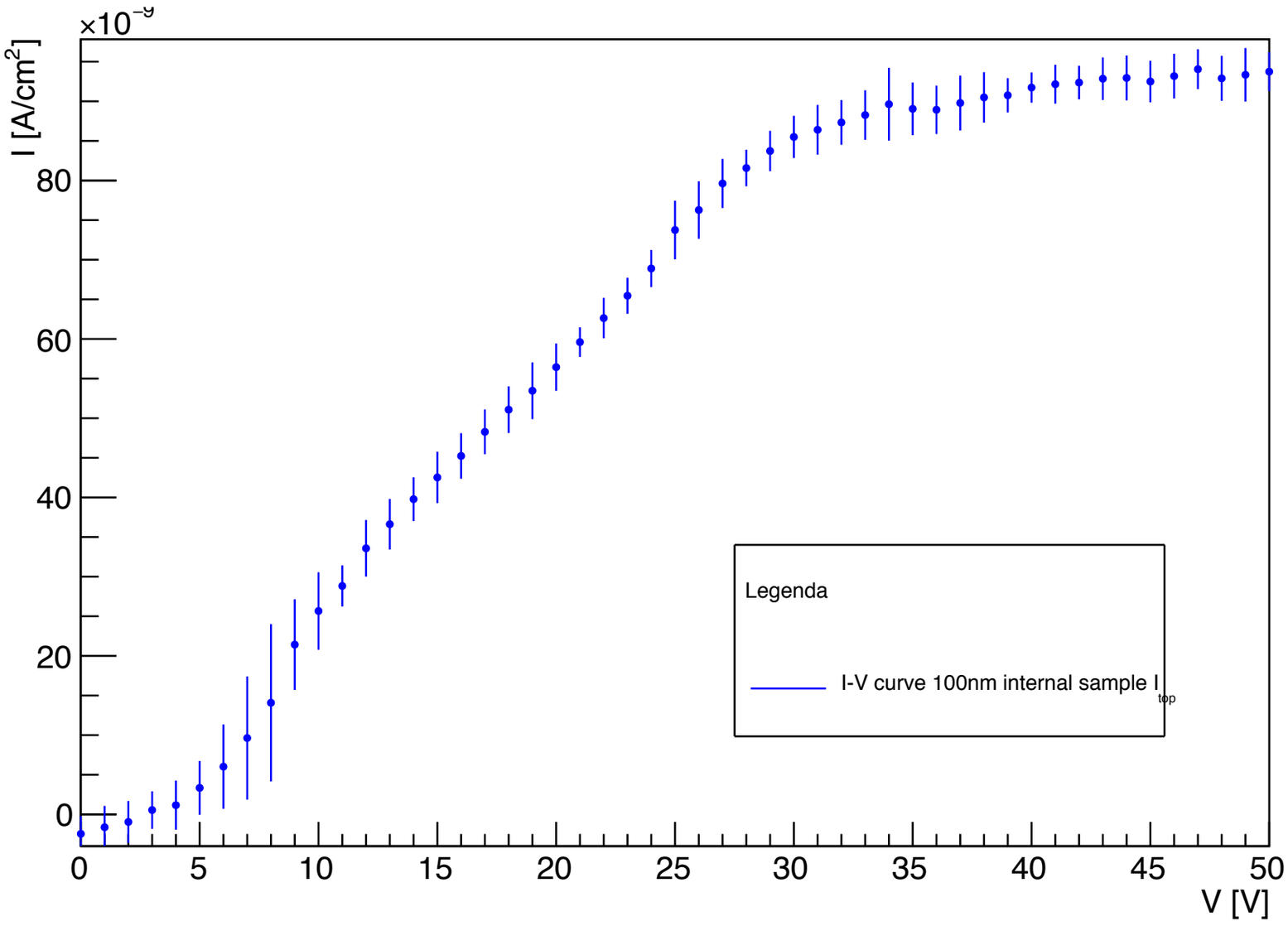
V_{biase}	5 V	10 V	**20 V**
I_S	0.304 nA	0.290 nA	**0.259 nA**
I_S/A	15.2 nA/ cm^2	14.5 nA/ cm^2	**12.95 nA/cm^2**

300 nm SiO_2



V_{biase}	1 V	2 V	3 V	5 V	10 V	15 V	**20 V**
I_S	0.117 nA	0.117 nA	0.116 nA	0.116 nA	0.113 nA	0.110 nA	**0.107 nA**
I_S/A	5.85 nA/ cm^2	5.85 nA/ cm^2	5.8 nA/ cm^2	5.8 nA/ cm^2	5.65 nA/ cm^2	5.5 nA/ cm^2	**5.35 nA/ cm^2**


×10⁻⁶
I [A/cm²]
0.5
0.4
0.3
0.2
0.1
0
Legenda
I-V curve 100nm internal sample I Back
I-V curve 100nm internal sample I top
0
5
10
15
20
25
30
35
40
45
50
V [V]


×10⁻⁹
I [A/cm²]
80
60
40
20
0
0
5
10
15
20
25
30
35
40
45
50
V [V]
Legenda
I-V curve 100nm internal sample I top