P-type, One-sided Hexagonal Spiral Drift Detectors

Wei Chen
Physics Department

Emilio Gatti* **and Pavel Rehak**

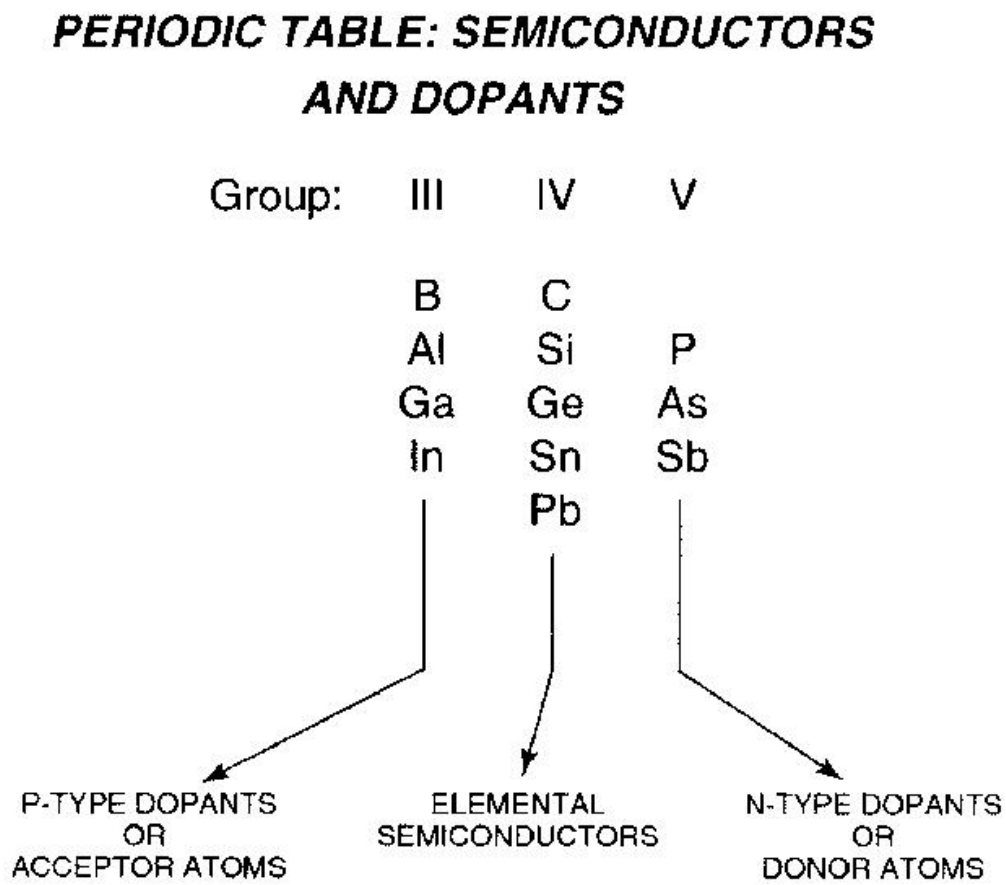
Instrumentation, Brookhaven National Laboratory,
*Politecnico di Milano

Contents

- Basic concept of silicon material and p-n diode
- Why one-sided hexagonal spiral drift?
- Why p-type material?
- Design, process and operation
- Test results and discussions
- Future plans
- Conclusions

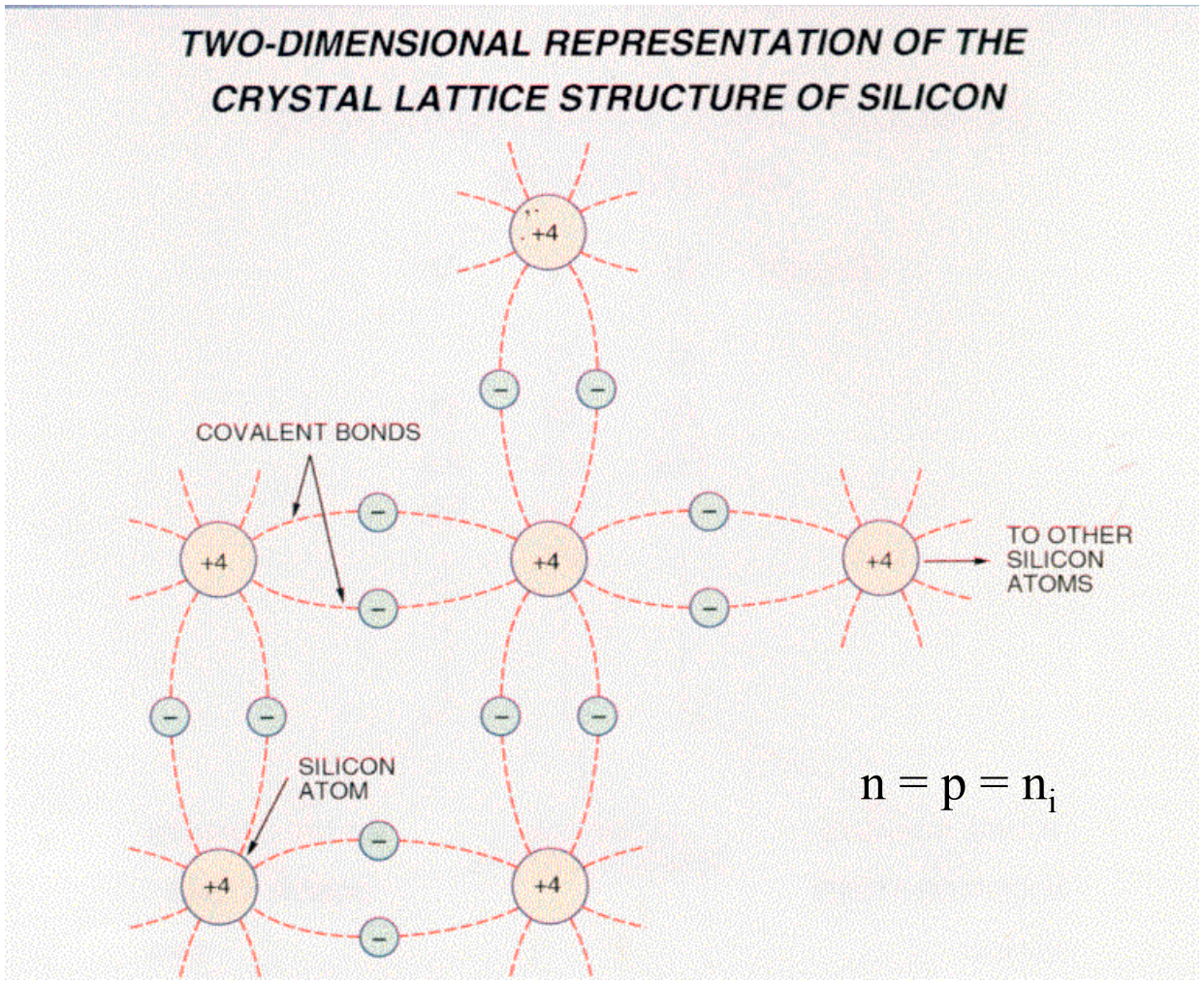
Basic Concept of Silicon

Silicon Material



Basic Concept of Silicon

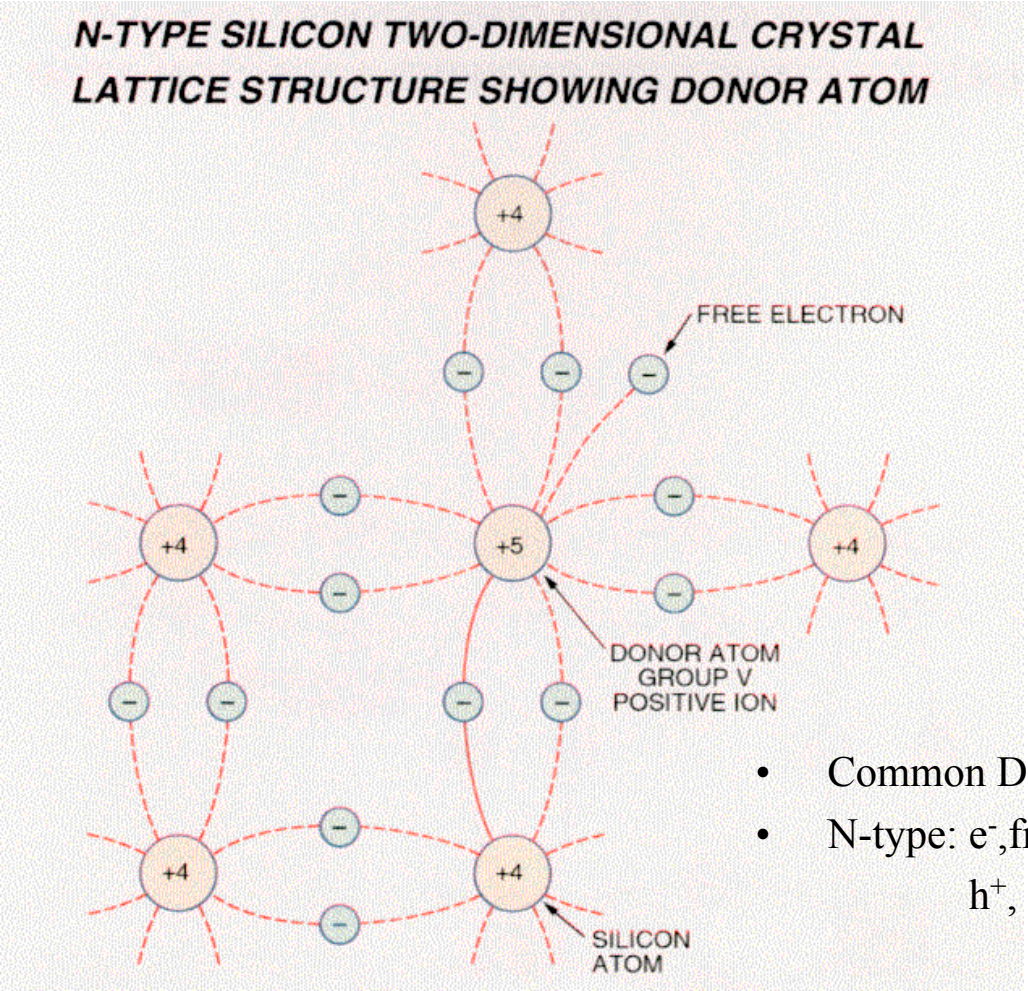
Silicon Lattice



$n = p = n_i$

Basic Concept of Silicon

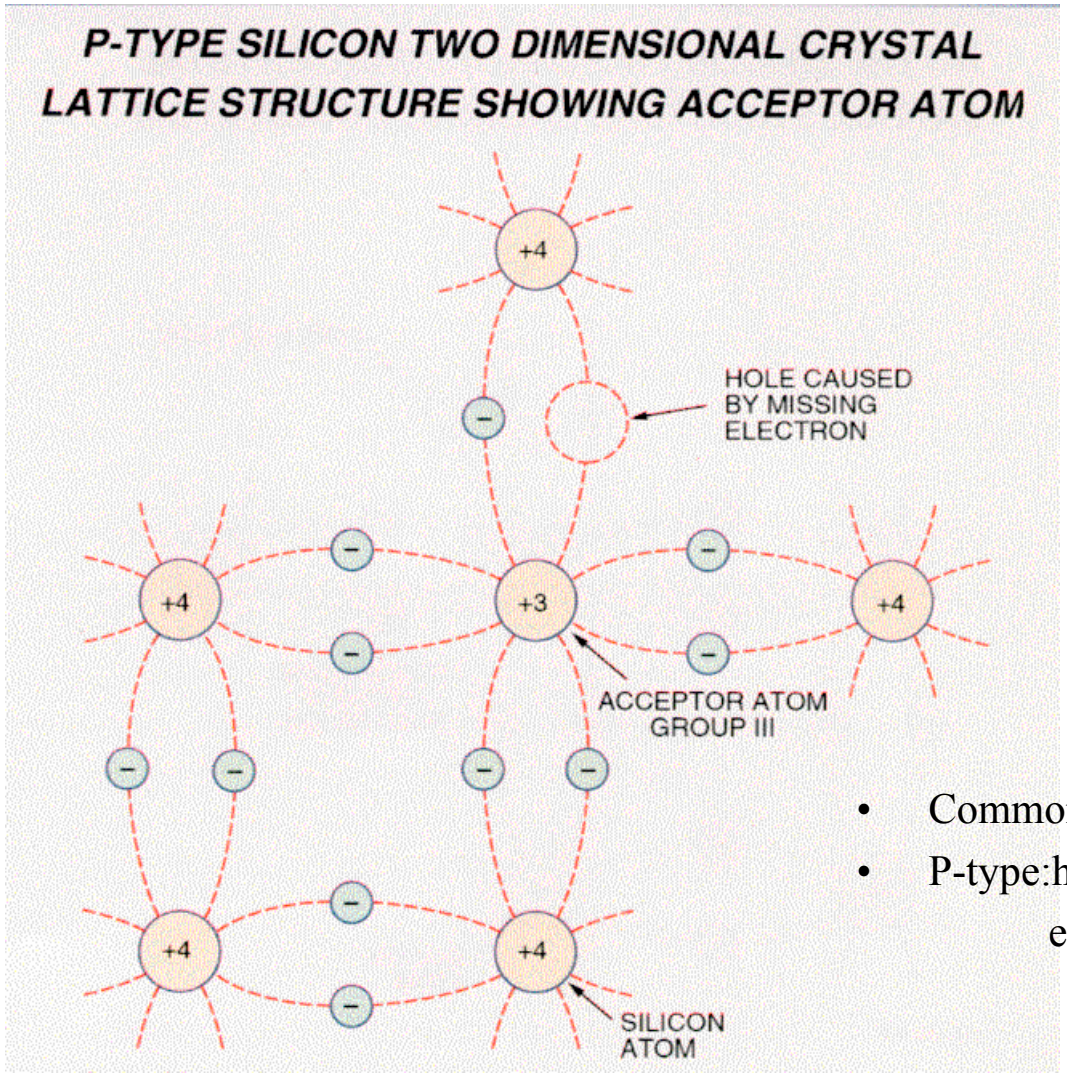
N-Type Silicon



- Common Doping impurity: B, P, As
- N-type: e^-,free carriers, majority
  h^+, minority

Basic Concept of Silicon

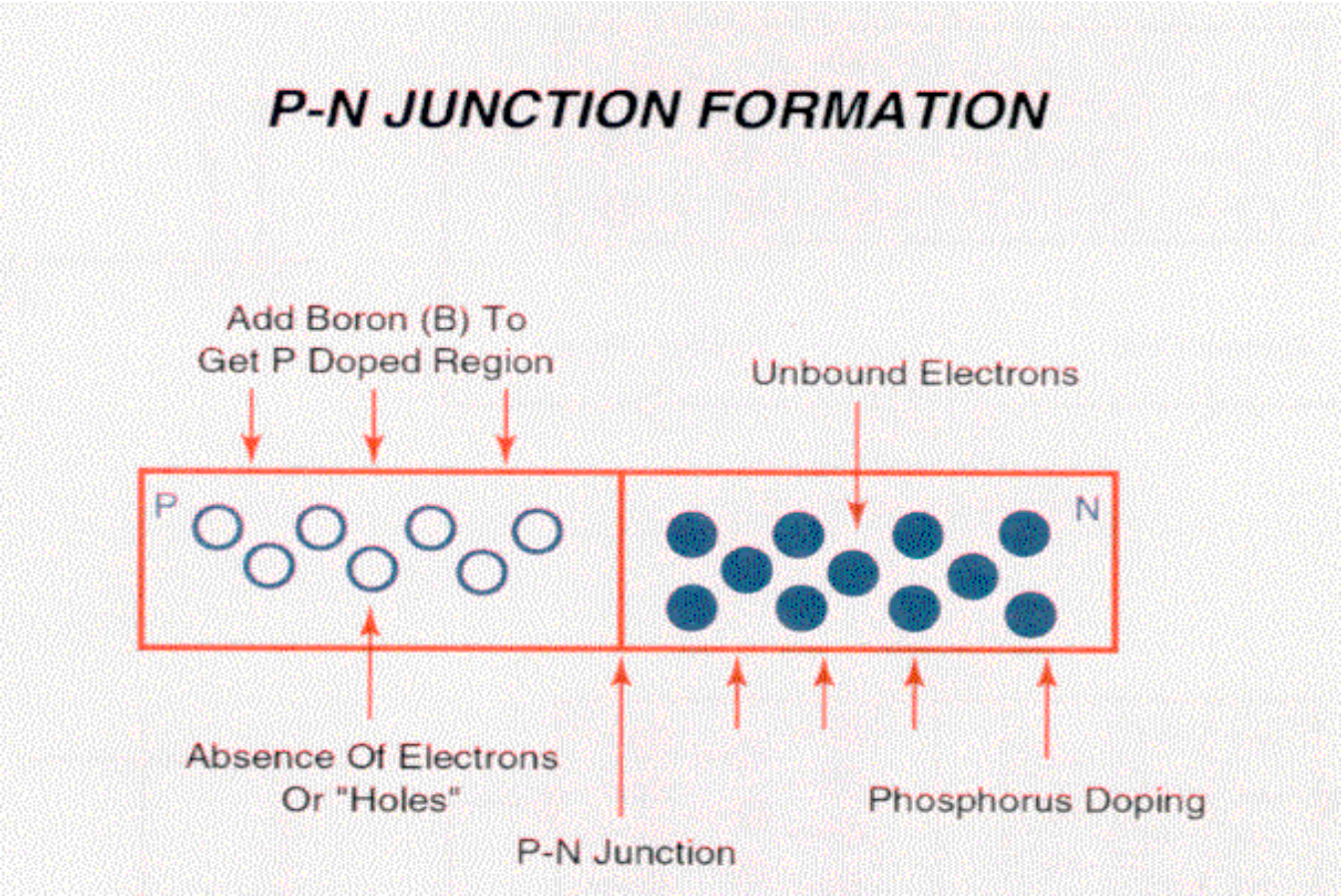
P-Type Silicon



- Common Doping impurity: B, P, As
- P-type:h^+,free carriers, majority
  e^-, minority

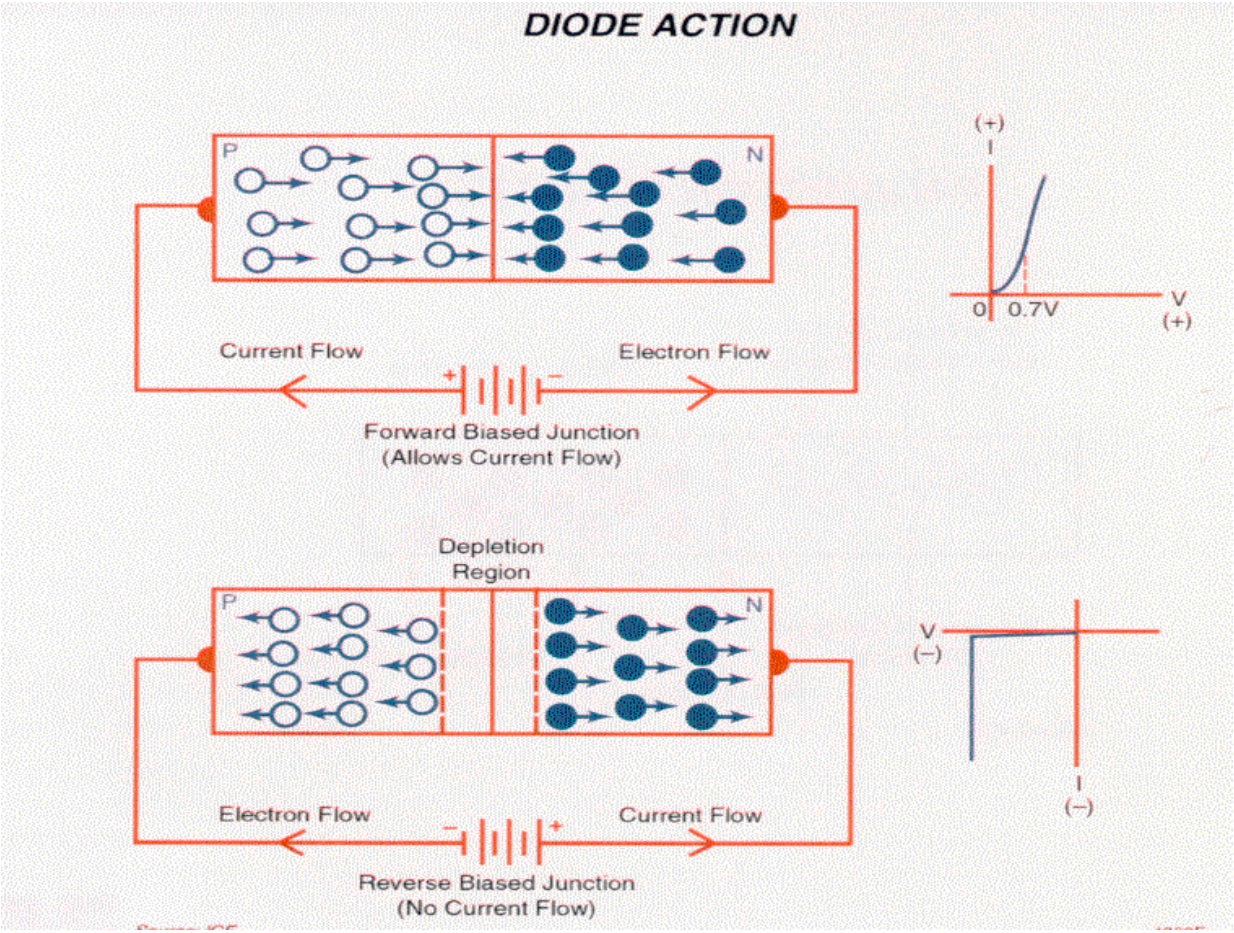
Basic Concept of p-n Diode

Junction



Basic Concept of p-n Diode

Rectify Diode



Basic Concept of p-n Diode

Diode Detector

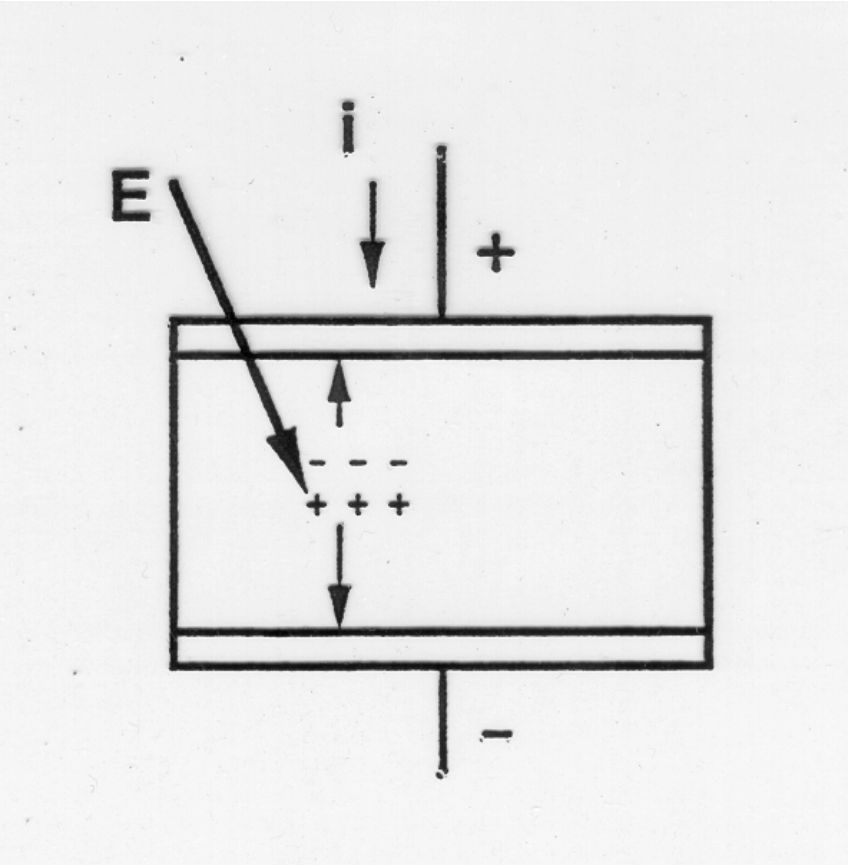
- P-type: 0.1μm
- N-type: 200-500μm
- $W=(2\varepsilon_s V/qNd)^{1/2}$

  $Nd=1/q\mu\rho$

  $\rho = W^2/(2\varepsilon_s \mu V)$

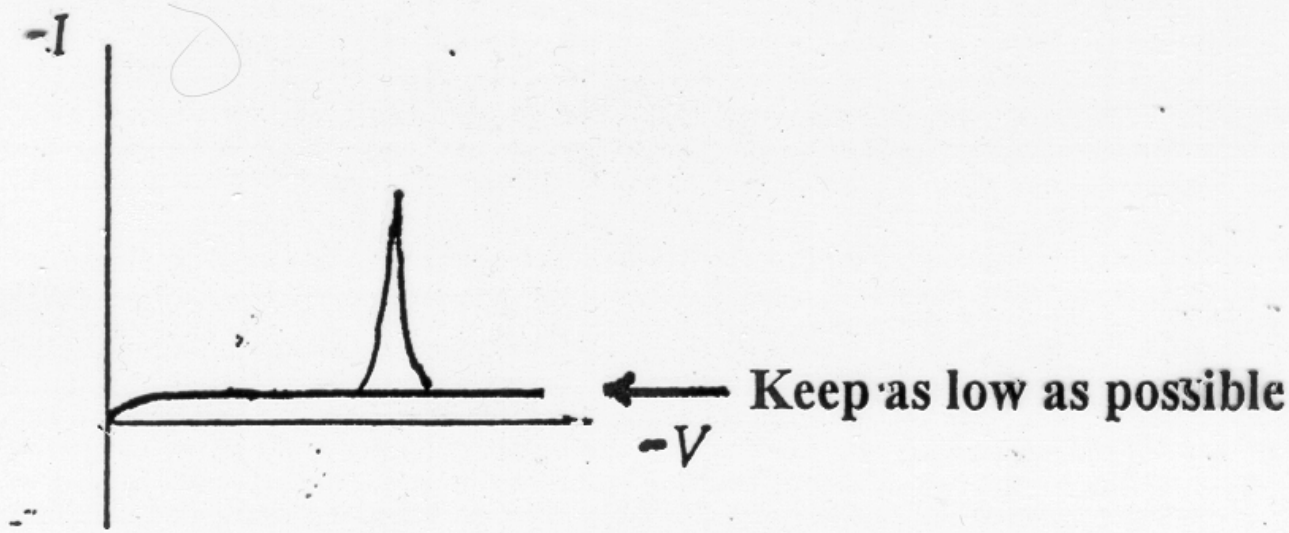
  V~100V, W~300μm,

  ρ ~3kΩcm



Basic Concept of p-n Diode

I-V Characteristic of Detector



Leakage Current

$$I = I_{surf} + I_{bulk} + I_{diff}$$

Why One-sided Hexagonal Spiral Drift

1) Low noise: low capacitance

low leakage current

2) 100% coverage

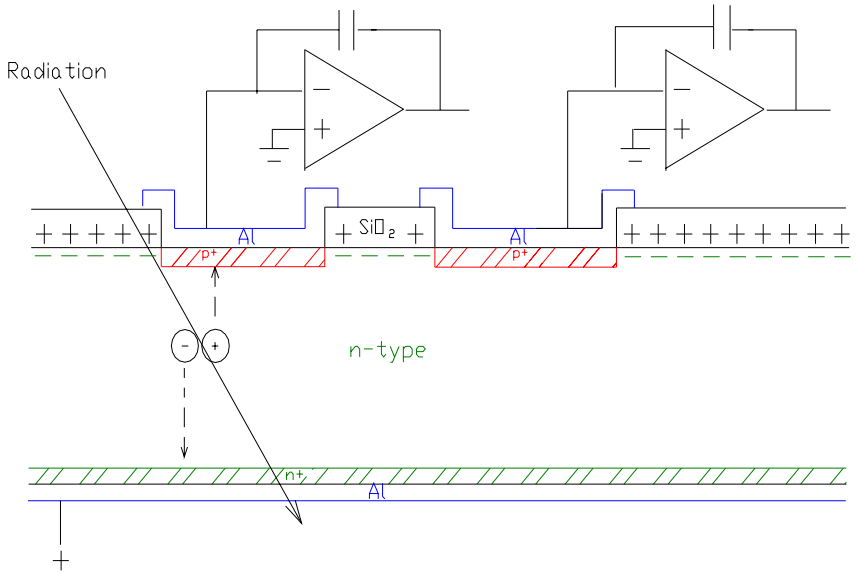
3) Single-sided design

4) As low number of bond as possible: **2/pixel**

Why P-type Material

Spectroscopic X-ray detector for EXAFS

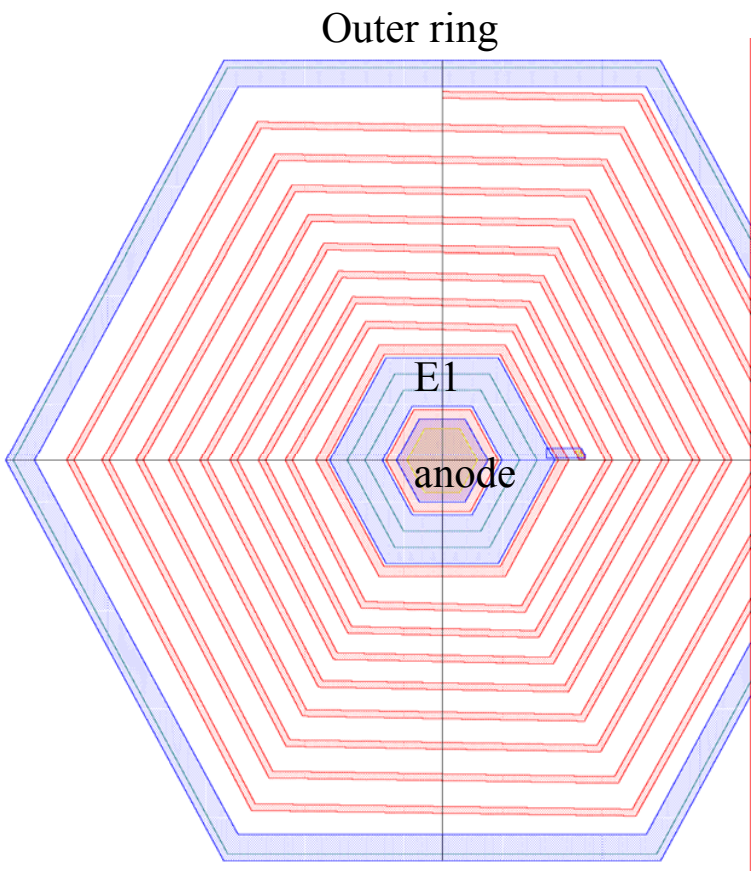
Conventional detector



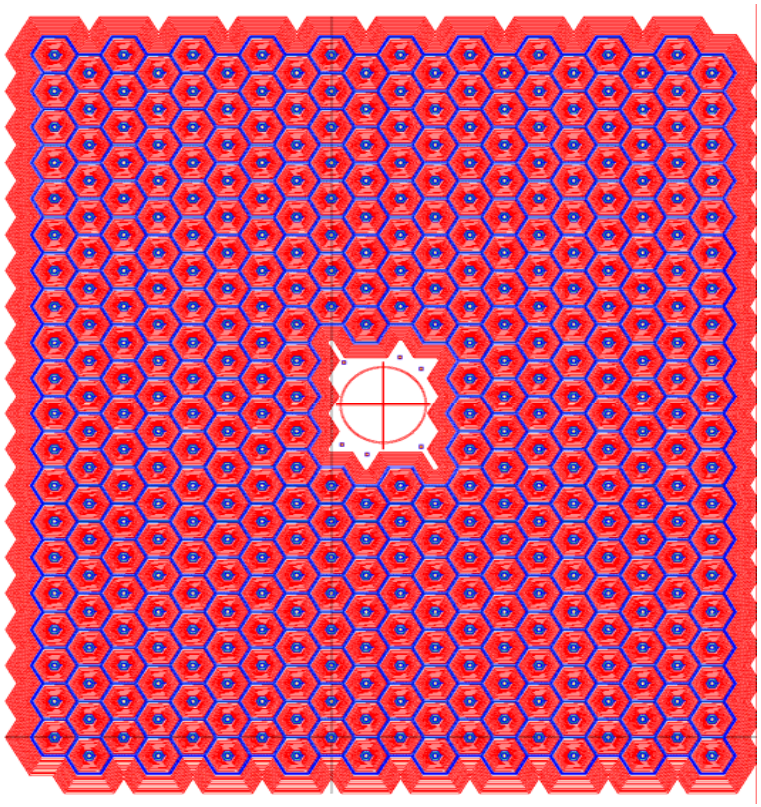
- Constraint of existing electronics
- Need positive polarity of signal
- Thin dead layer in entrance window
- Resistant to radiation damage by X-ray

Design, Process and Operation

design



1 mm^2 in area

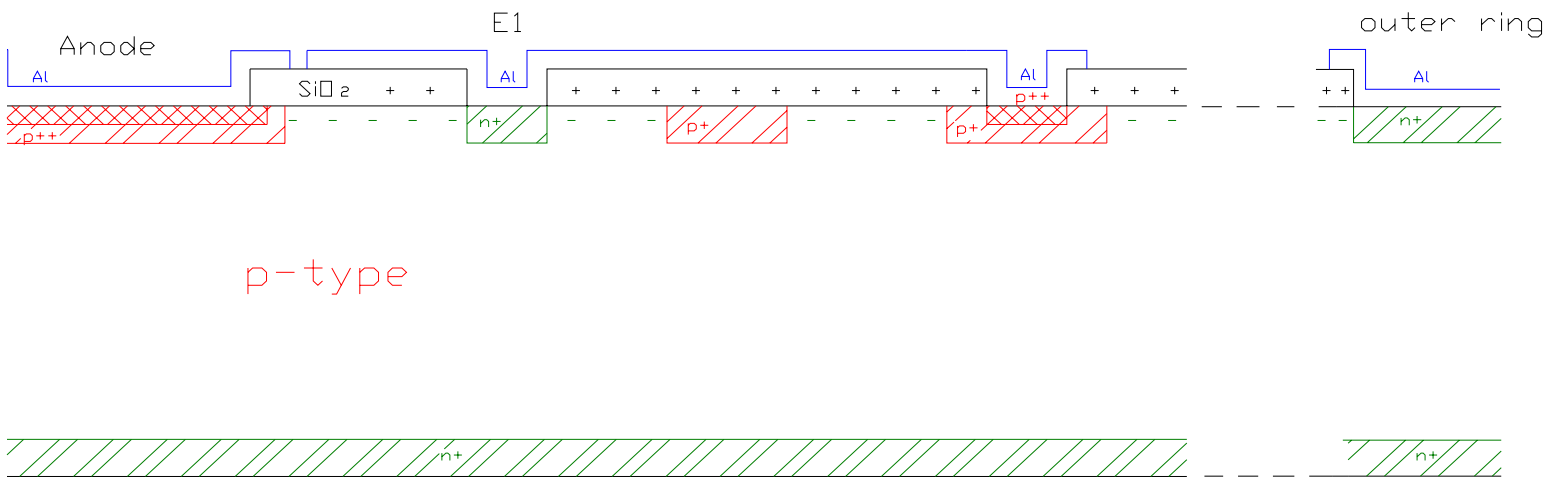


384 cell, 2x384+1 bonds

Design, Process and Operation

Process

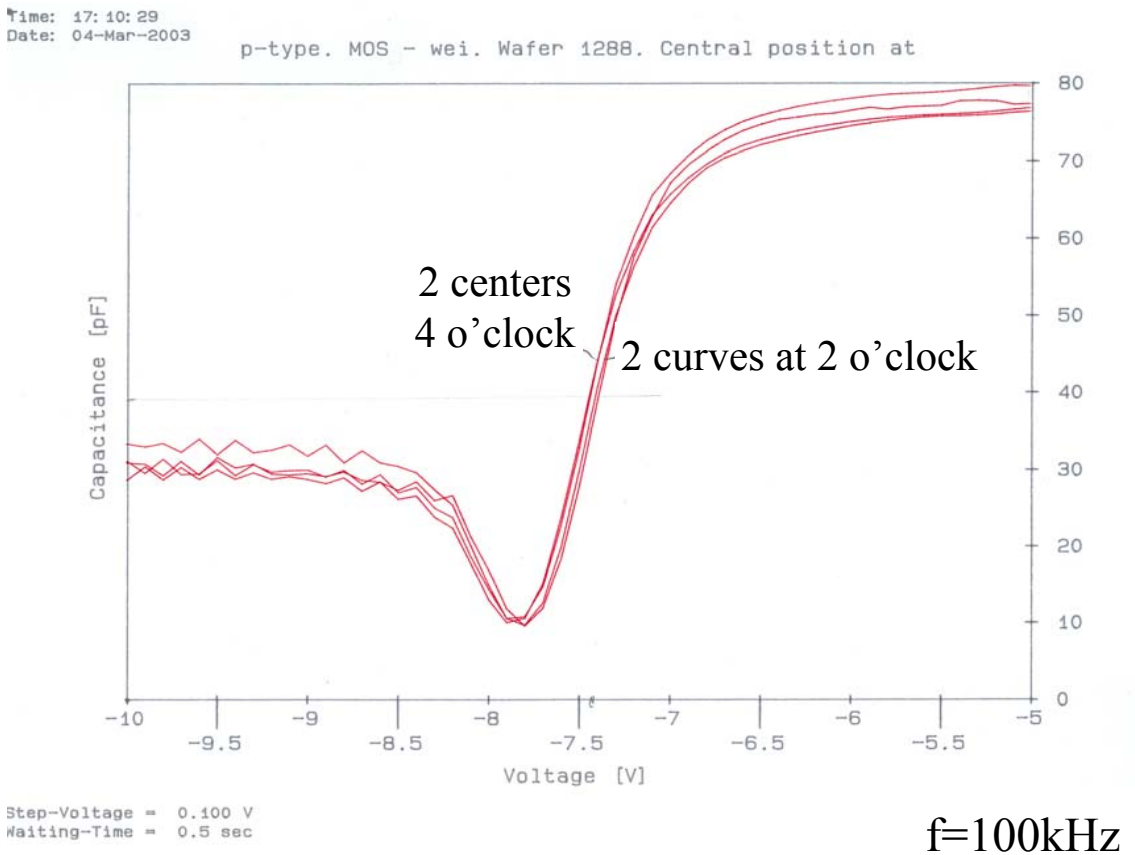
4 masks steps



- Front side: Boron: 200keV, $8x10^{11}/cm^2$
- Front side: Phos.: 20keV, $4x10^{14}/cm^2$; 50keV, $4x10^{14}/cm^2$
- Front side: Boron: 20keV, $2x10^{14}/cm^2$; Backside: Phos.: 20keV, $4x10^{14}/cm^2$; 50keV, $4x10^{14}/cm^2$
- Al

Design, Process and Operation

Process

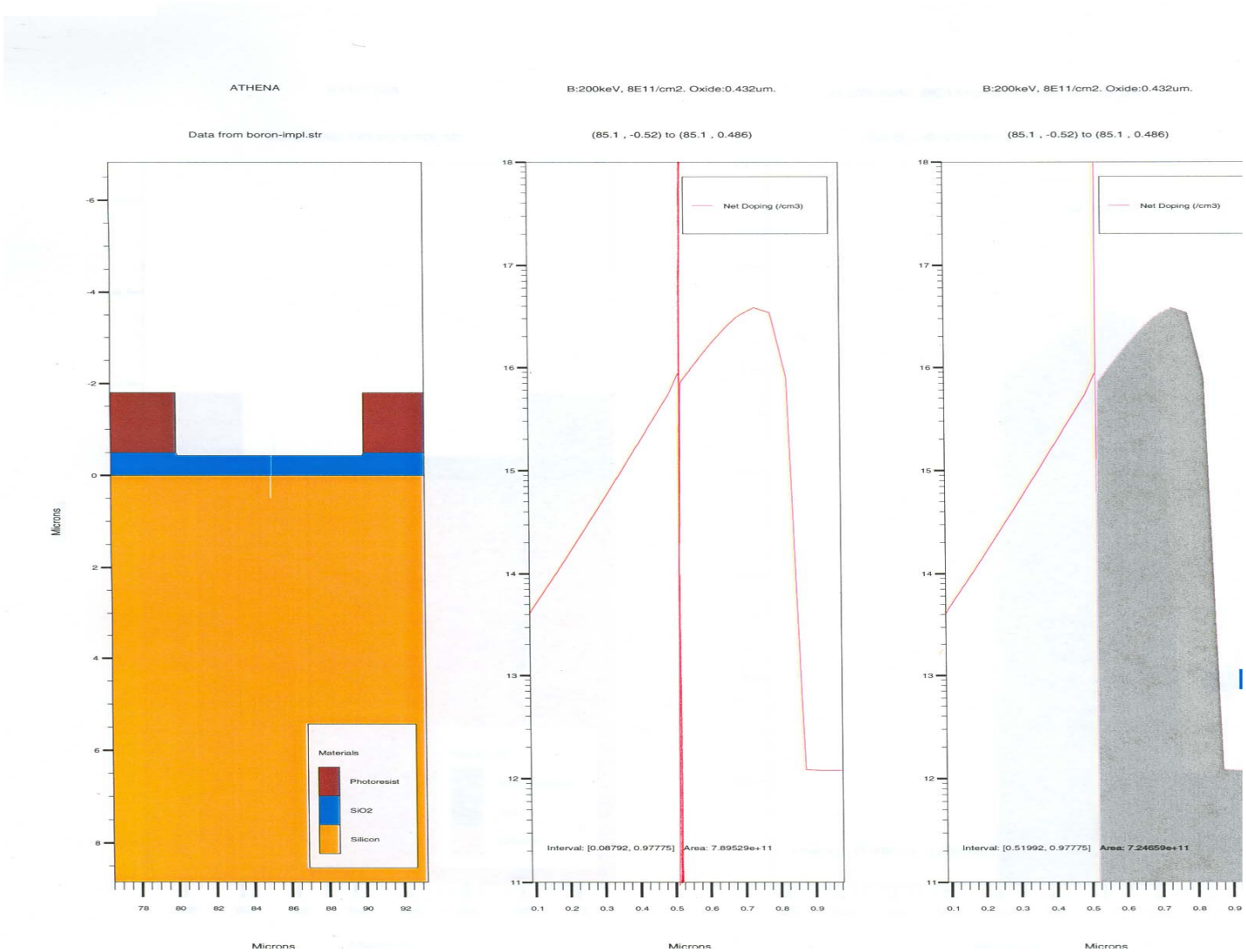


f=100kHz

- dV_{flat}=-7.2, C=80pF, s=1mm^2
- dQ=CdV
- λ=dQ/qs
  $\approx 3.6\text{x}10^{11}/\text{cm}^2$
- $d=\varepsilon\varepsilon_0 \cdot s/C$
  $\approx 0.432\mu m$

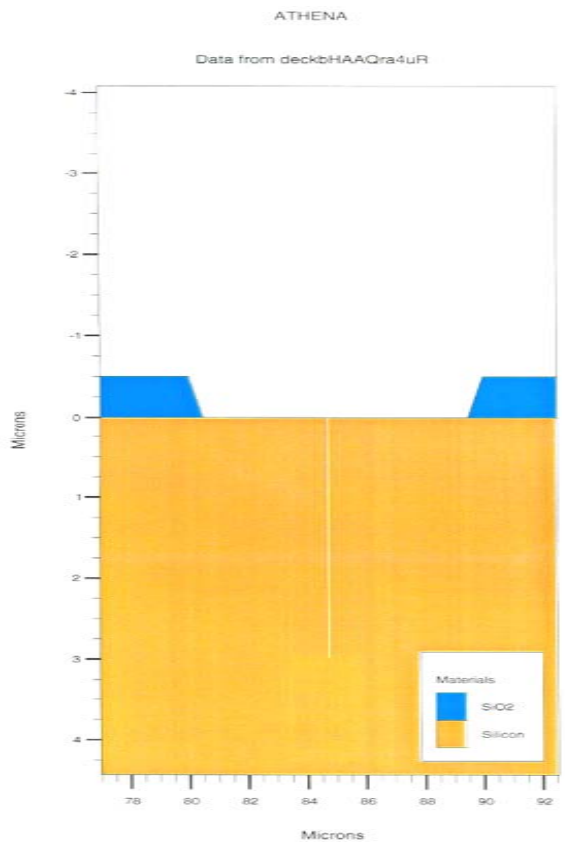
Design, Process and Operation

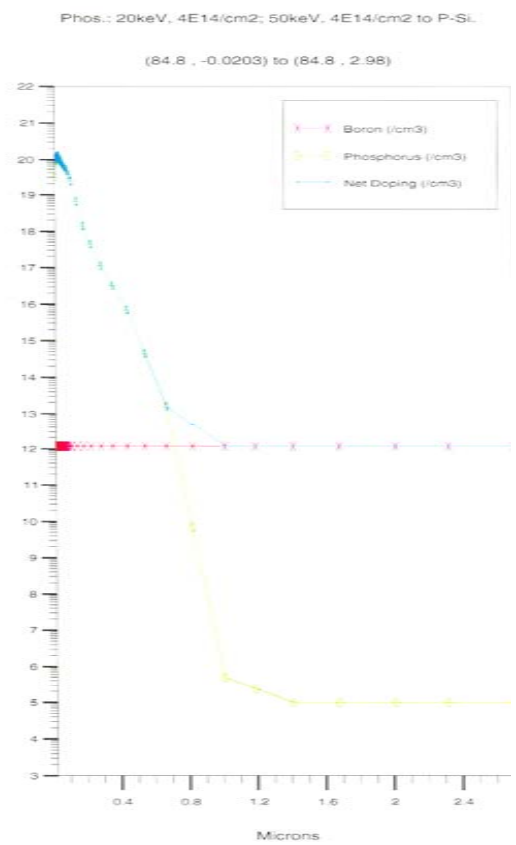
Process



Design, Process and Operation

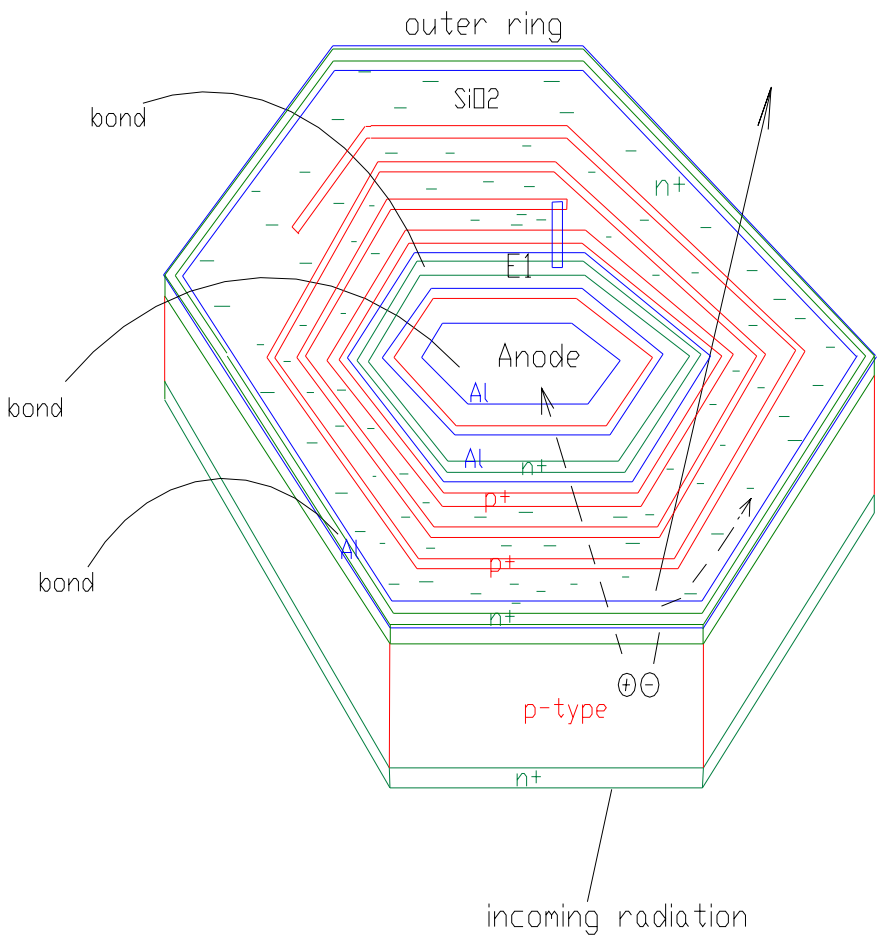
Process

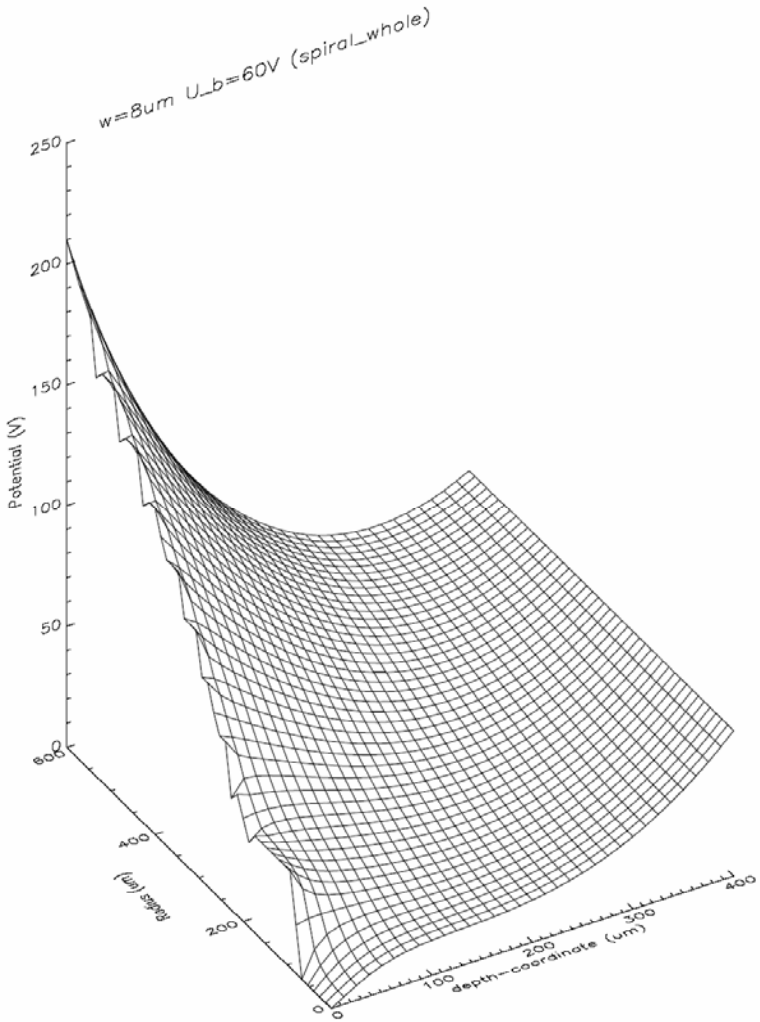




Design, Process and Operation

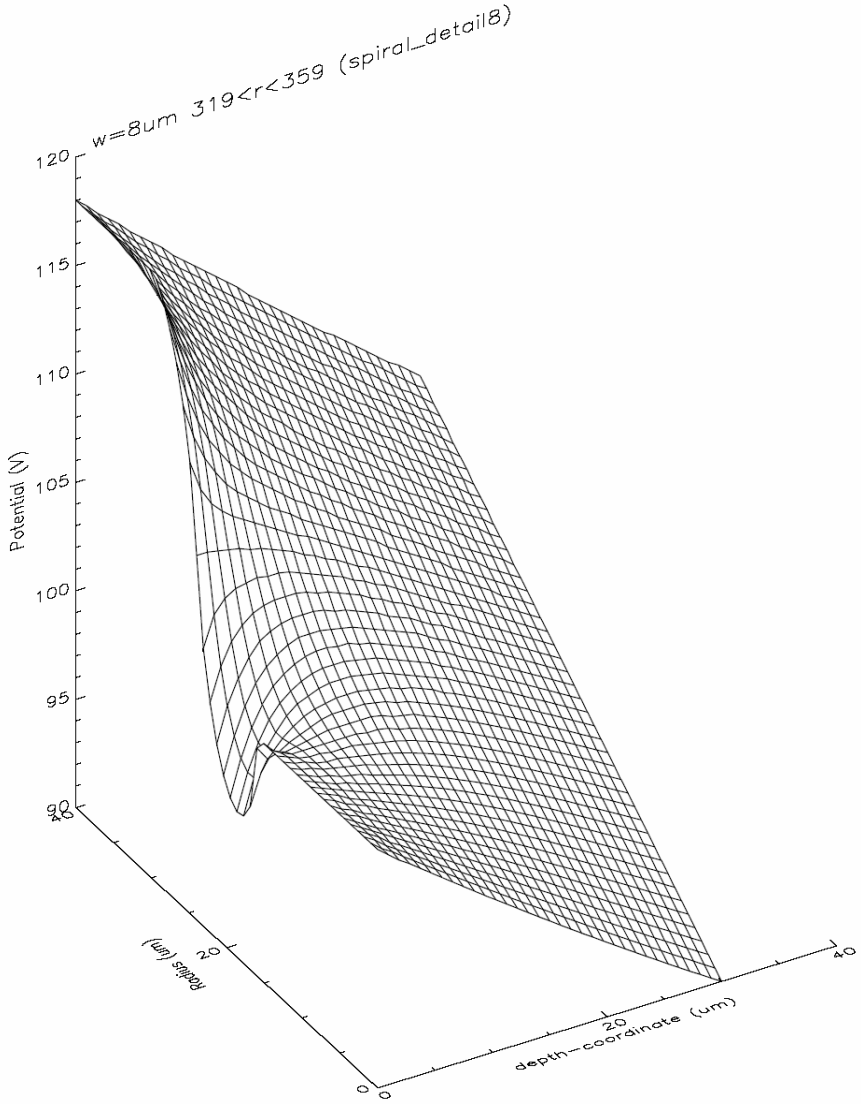
Operation

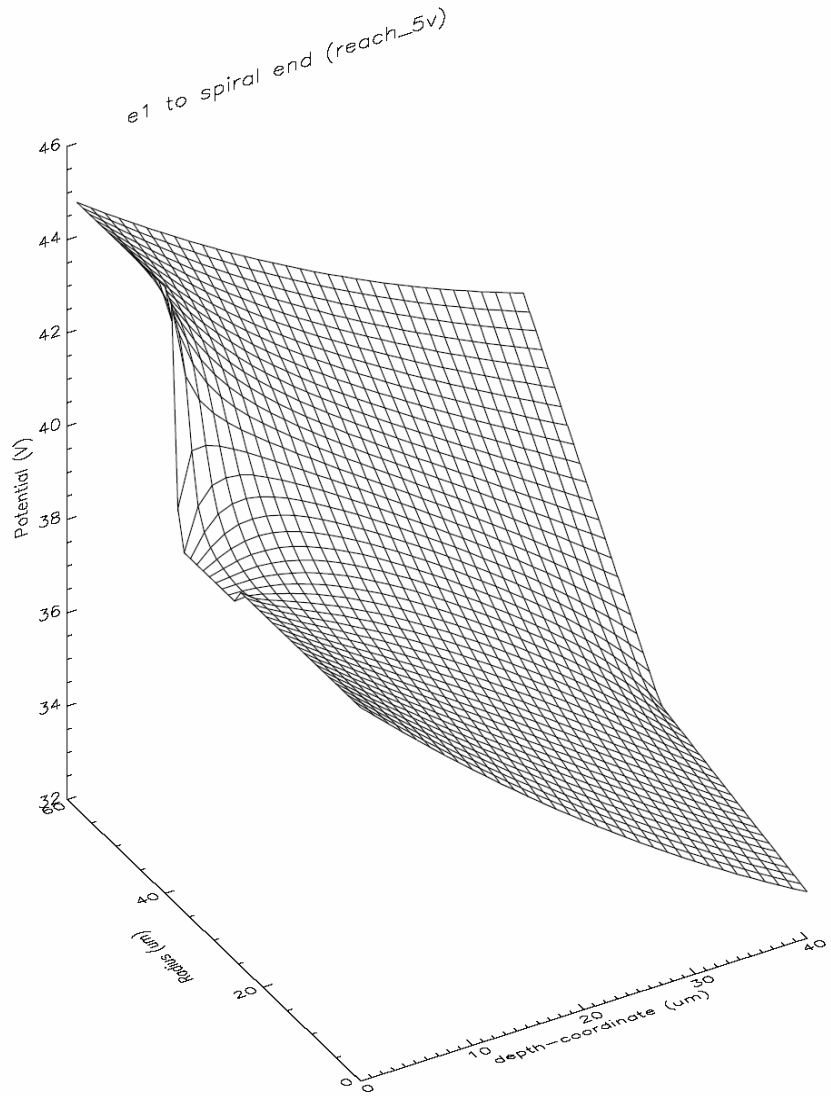




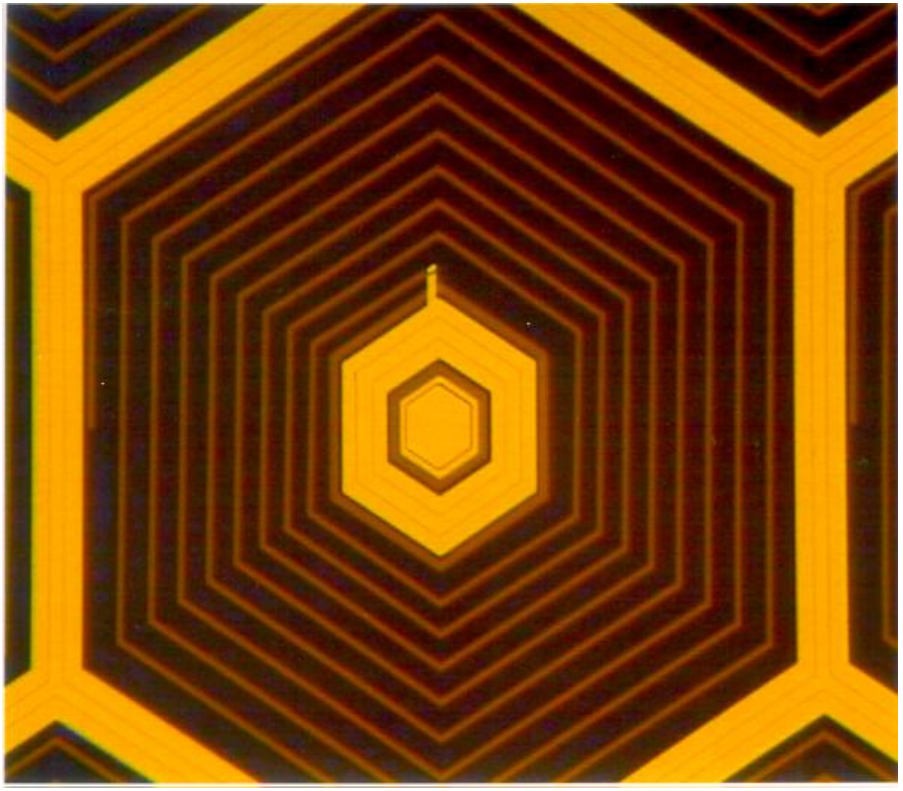
Design, Process and Operation

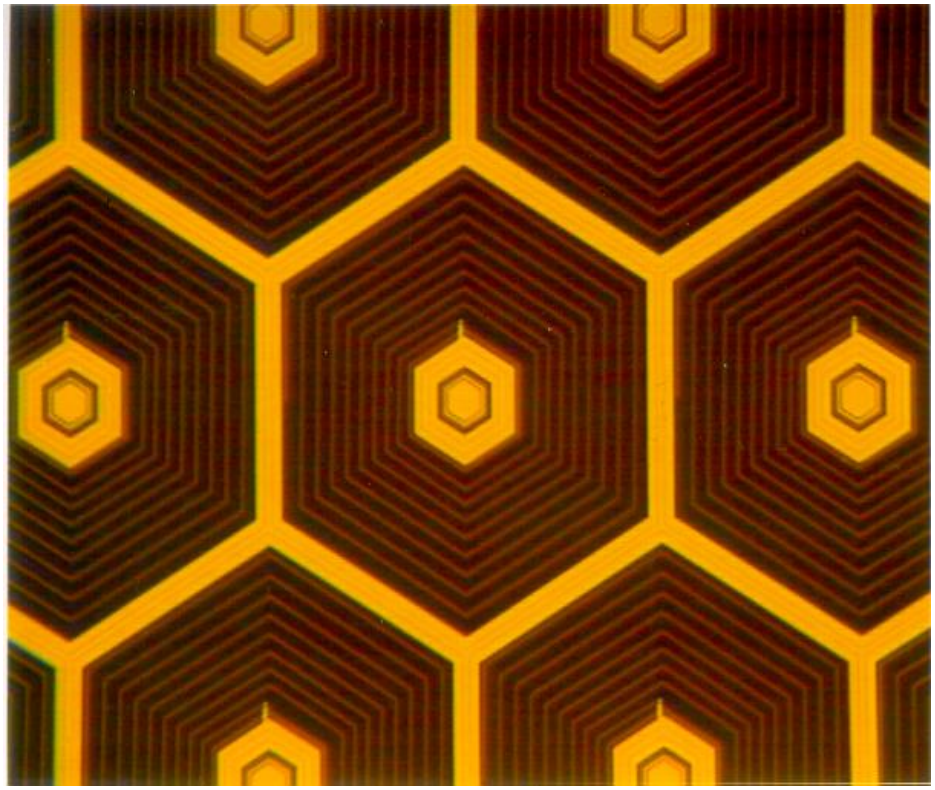
Operation





Two groups of detectors have been produced

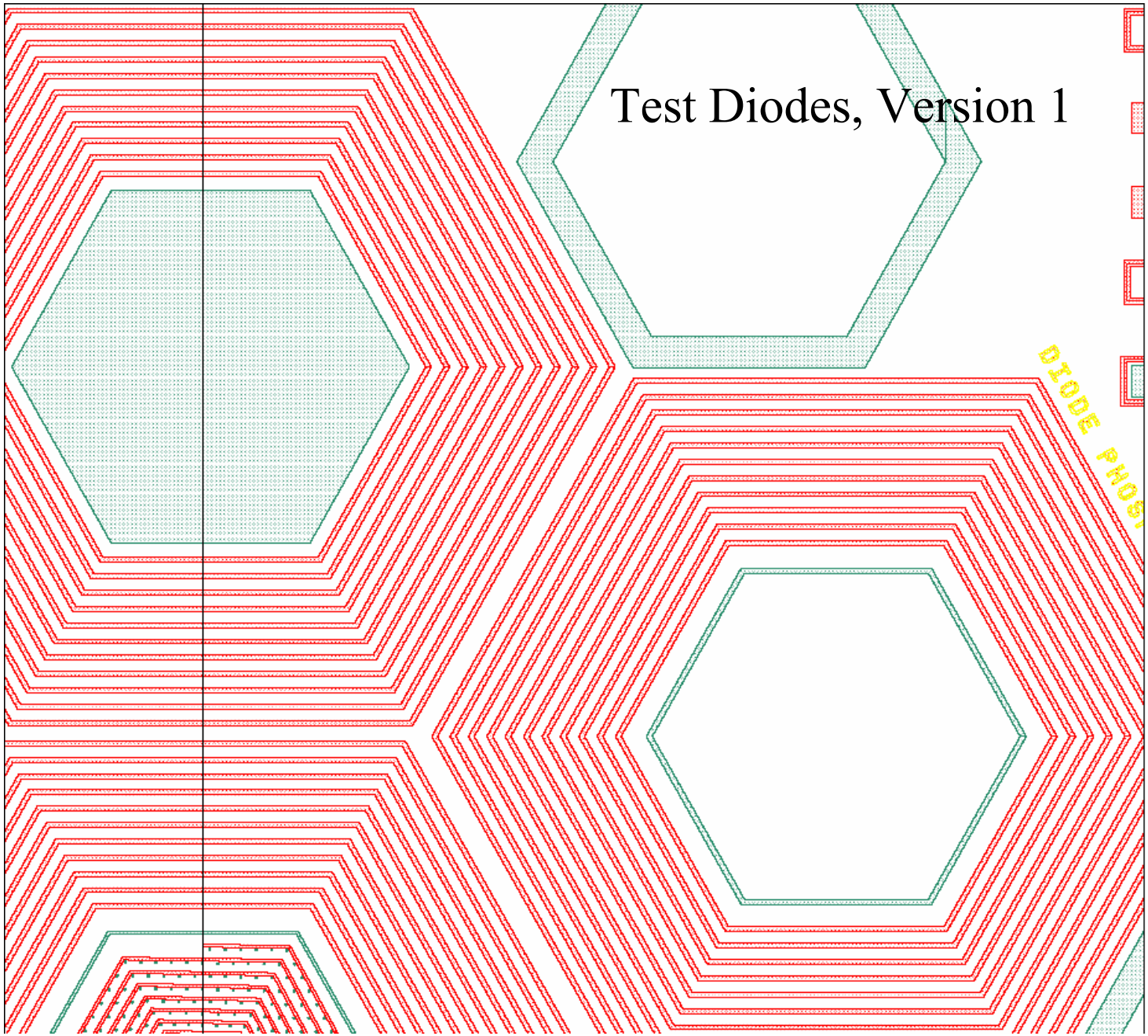




Group I: #1308 - #1311 (version 1)

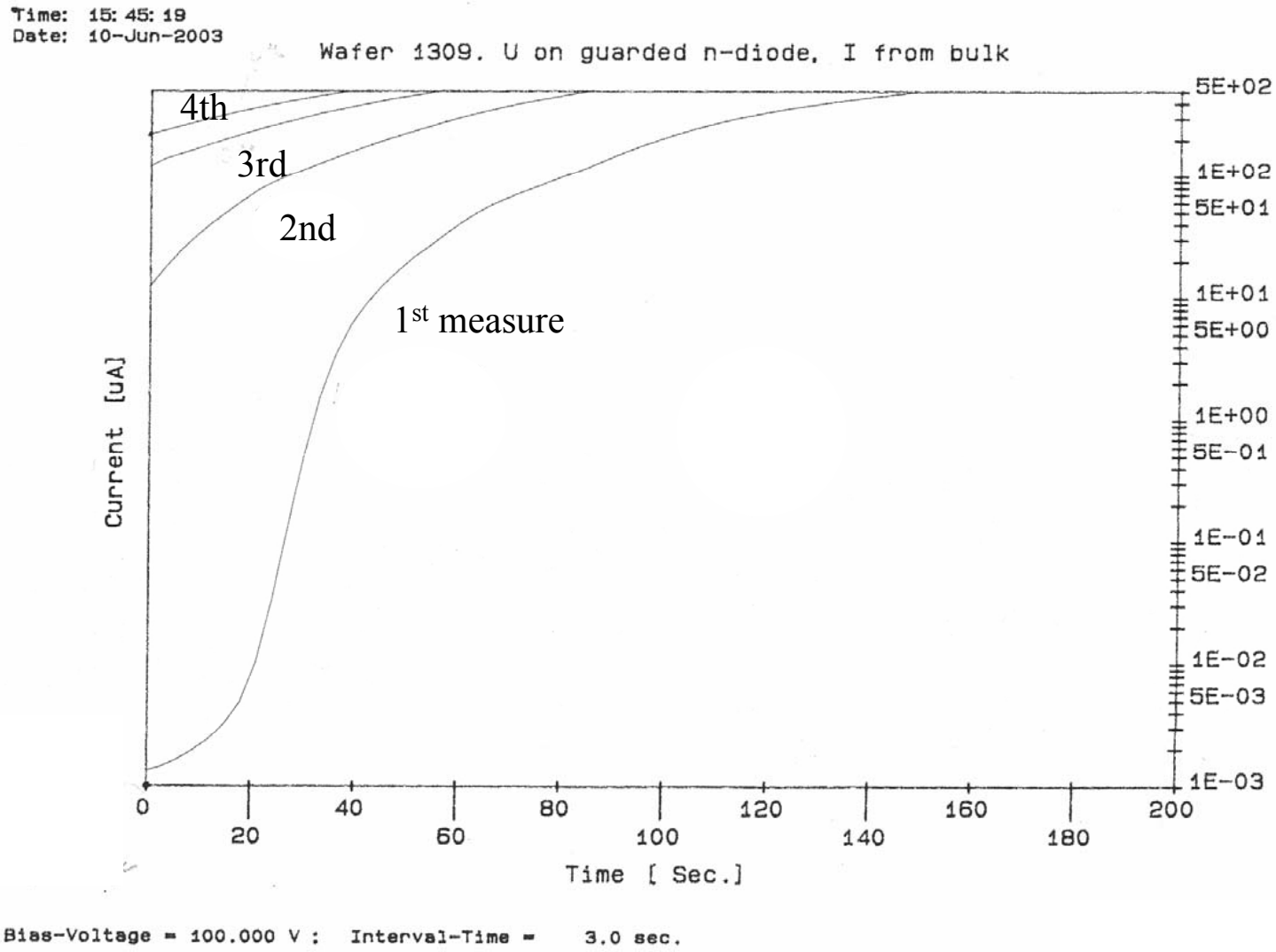
Group II: #1319 - #1322 (version 2)

Test Diodes, Version 1



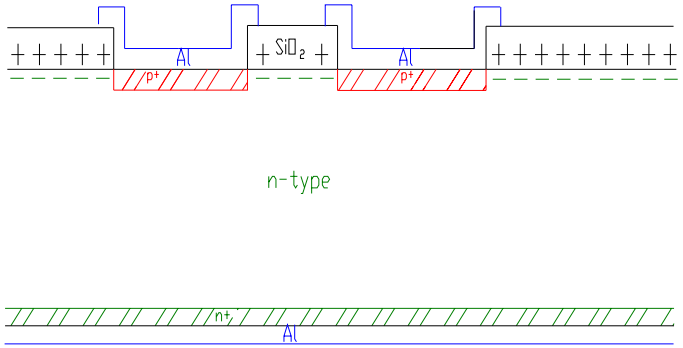
Test Results and Discussions

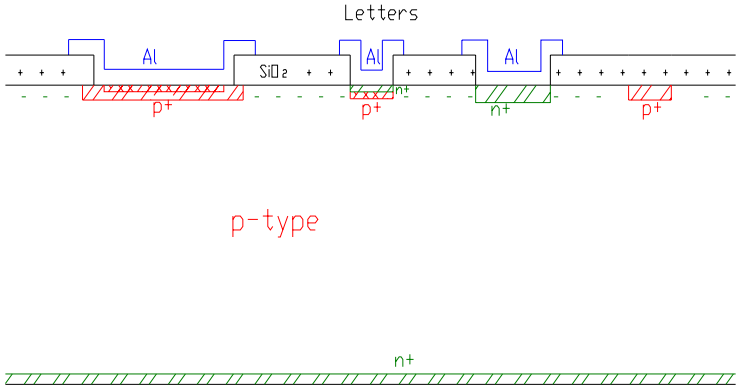
Diode Instability (group I)



Test Results and Discussions

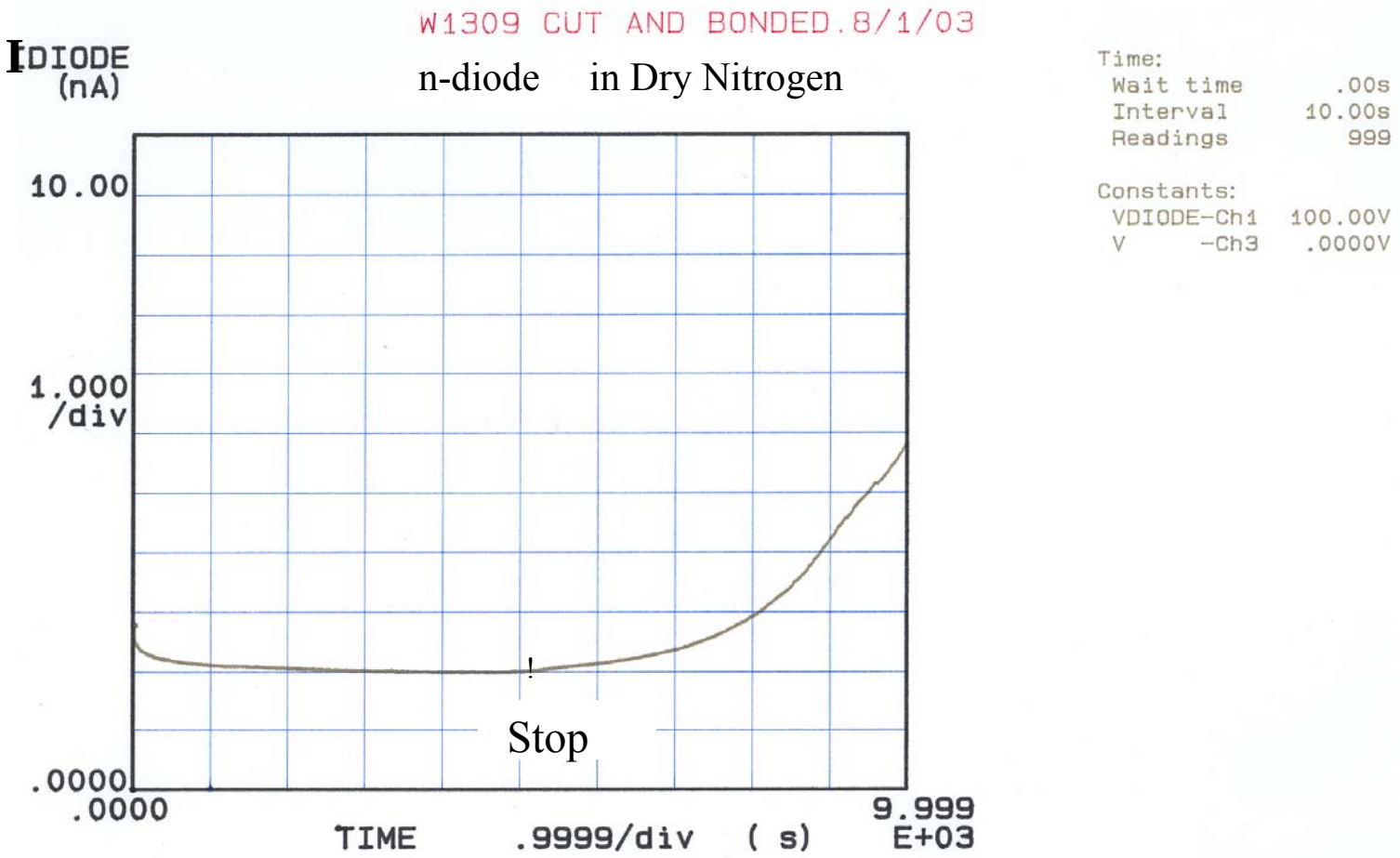
Comparison of n-type and p-type





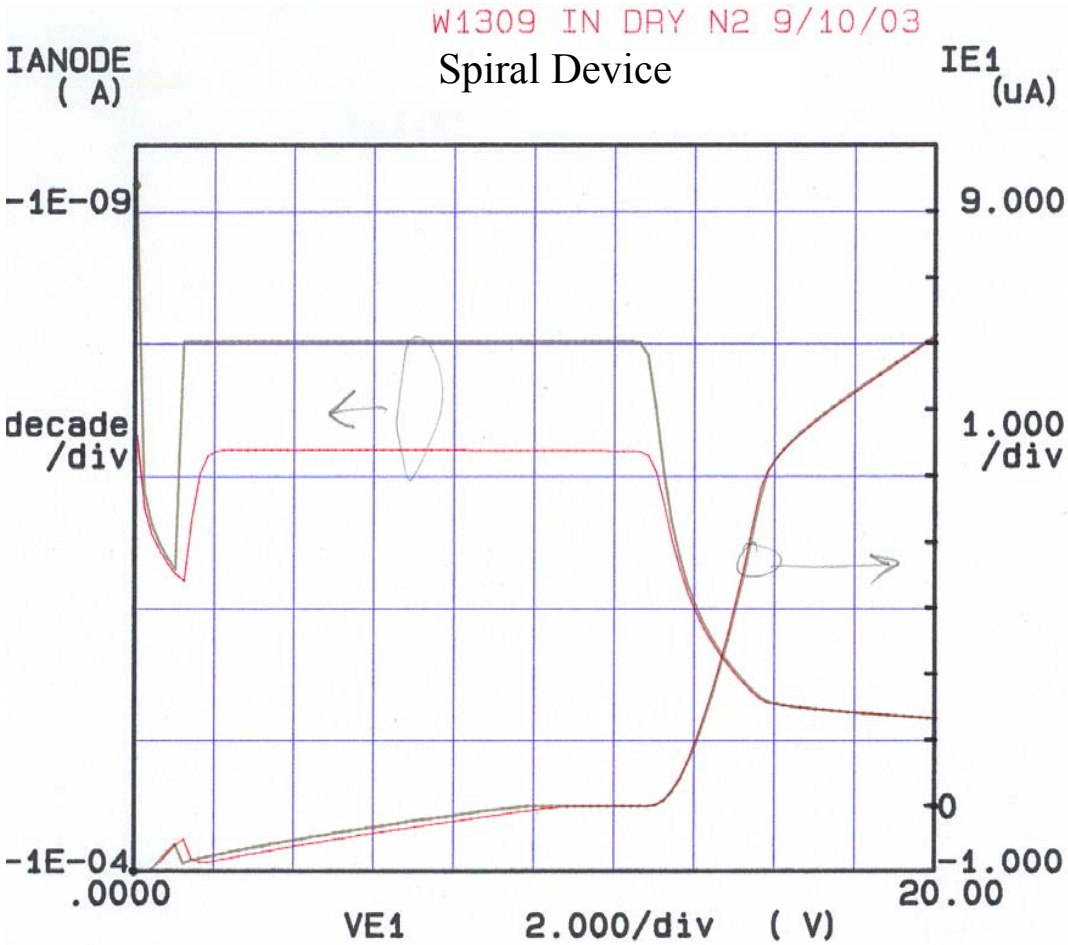
Test Results and Discussions

Dry N_2 Stabilize Diode (group I)



Test Results and Discussions

Spiral Drift Cell (group I)



Variable1:
VE1 -Ch2
Linear sweep
Start .0000V
Stop 20.000V
Step .2000V

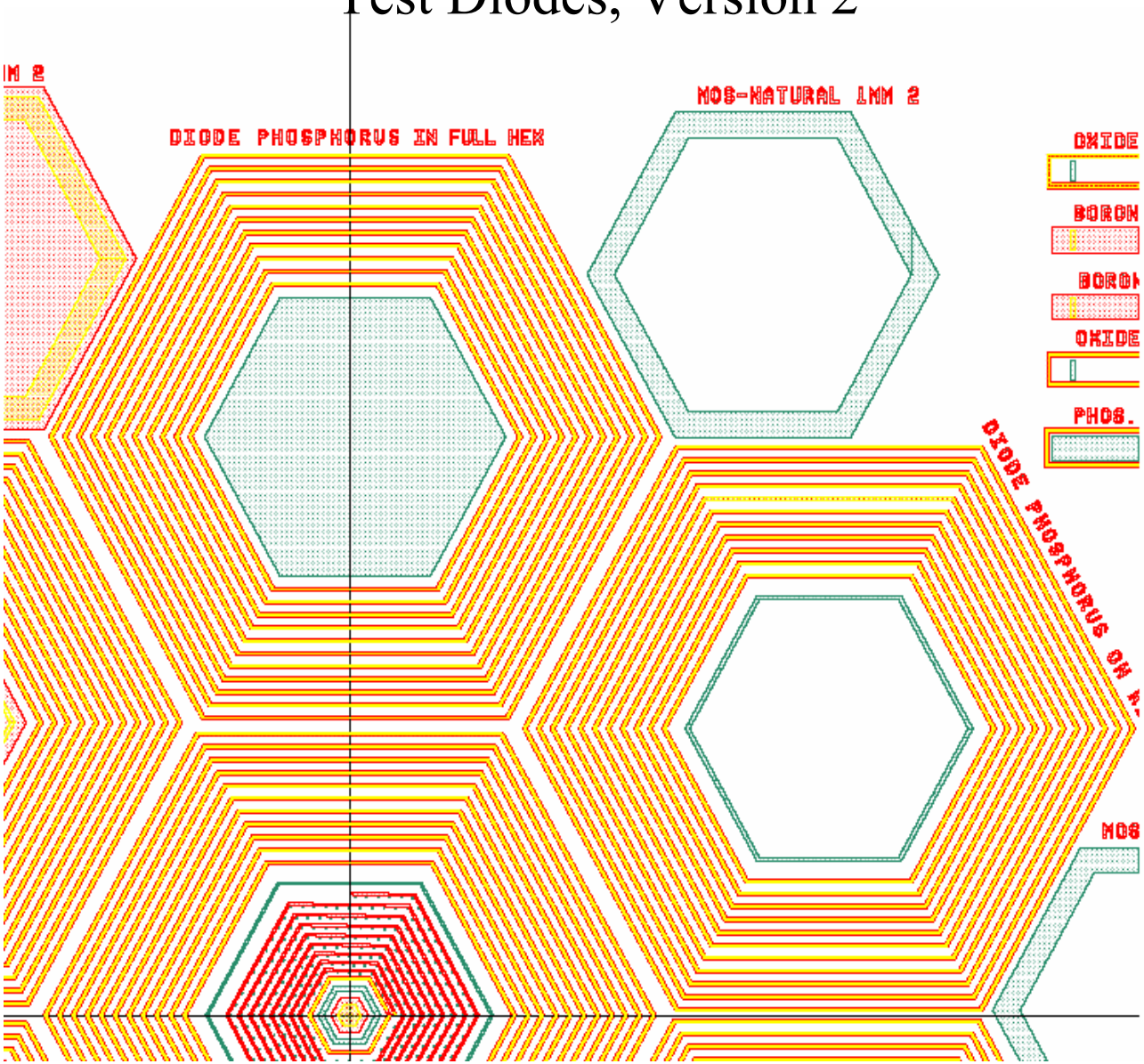
Constants:
IFRIN -Ch1 .000 A
VANODE-Ch3 .0000V
IFROUT-Ch4 .000 A
VLED -Vs1 .0000V

Vout=15V

Red: light on

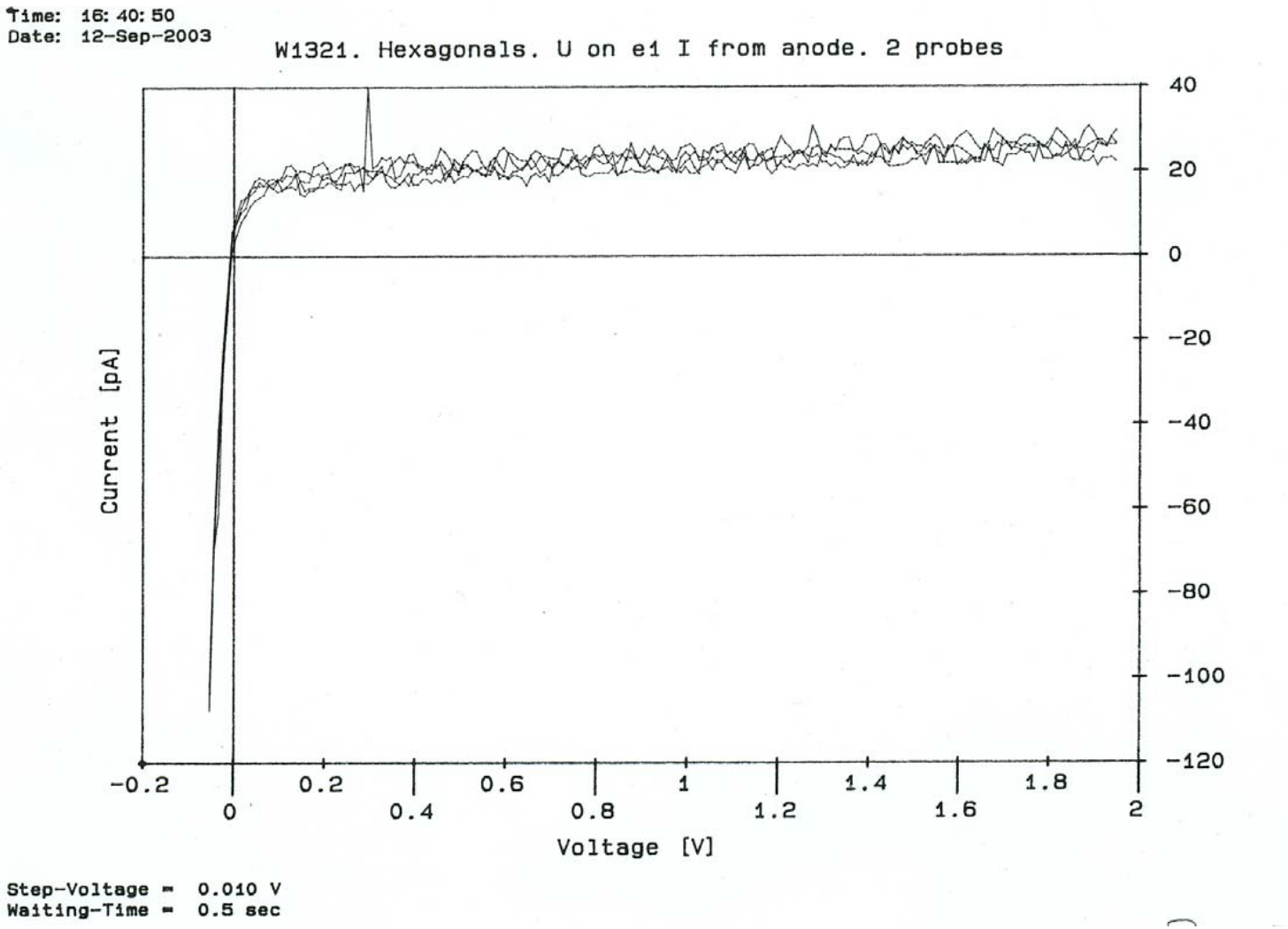
Green: light off

Test Diodes, Version 2



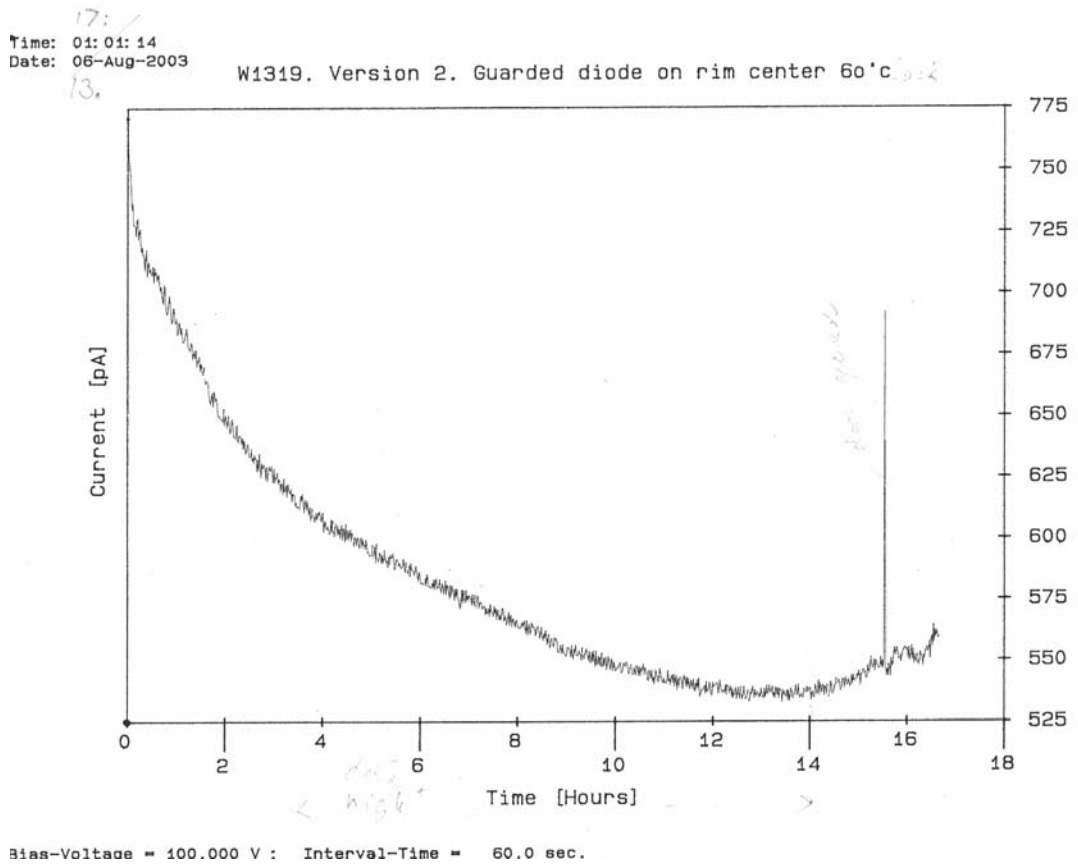
Test Results and Discussions

Diode in Regular Environment (group II)



Test Results and Discussions

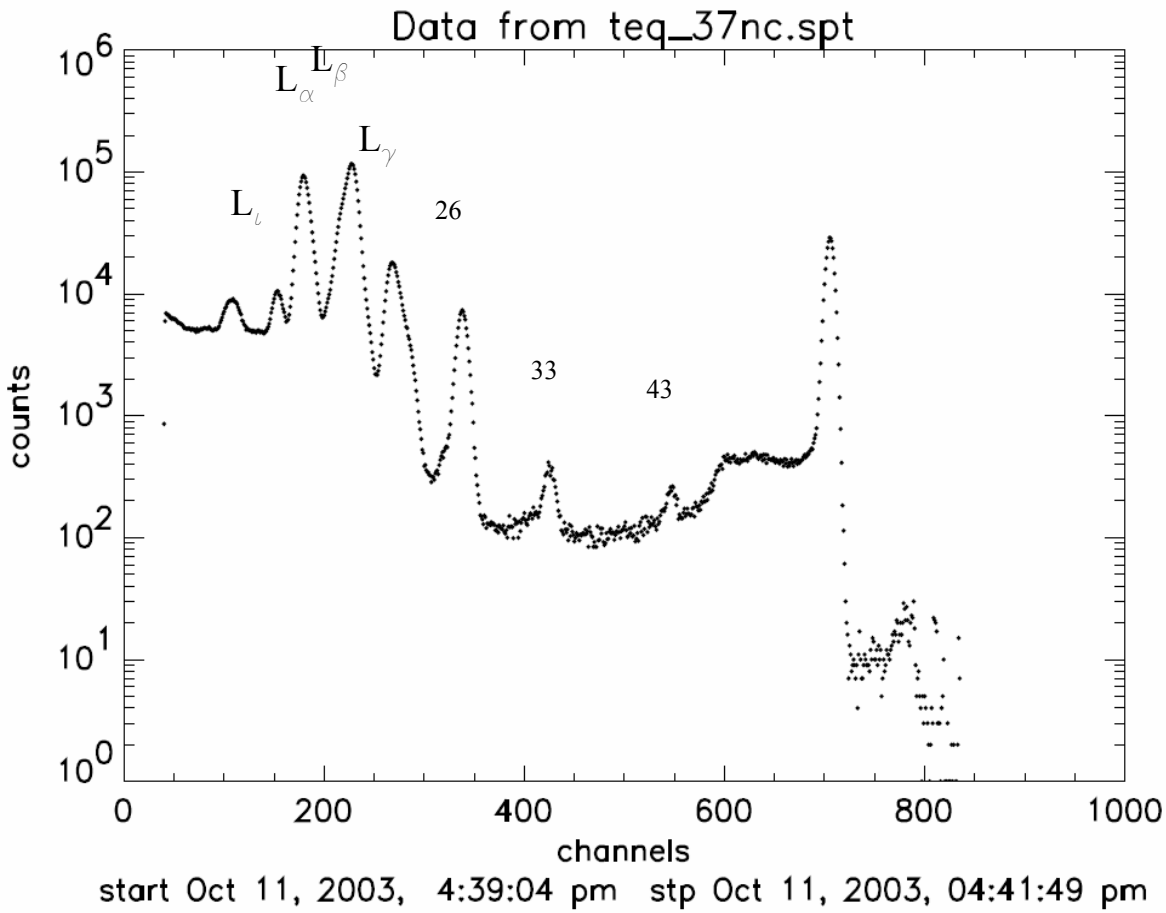
Diode in Regular Environment (group II)



Test Results and Discussions

Americium, Am^{241}, Spectrum (group I)

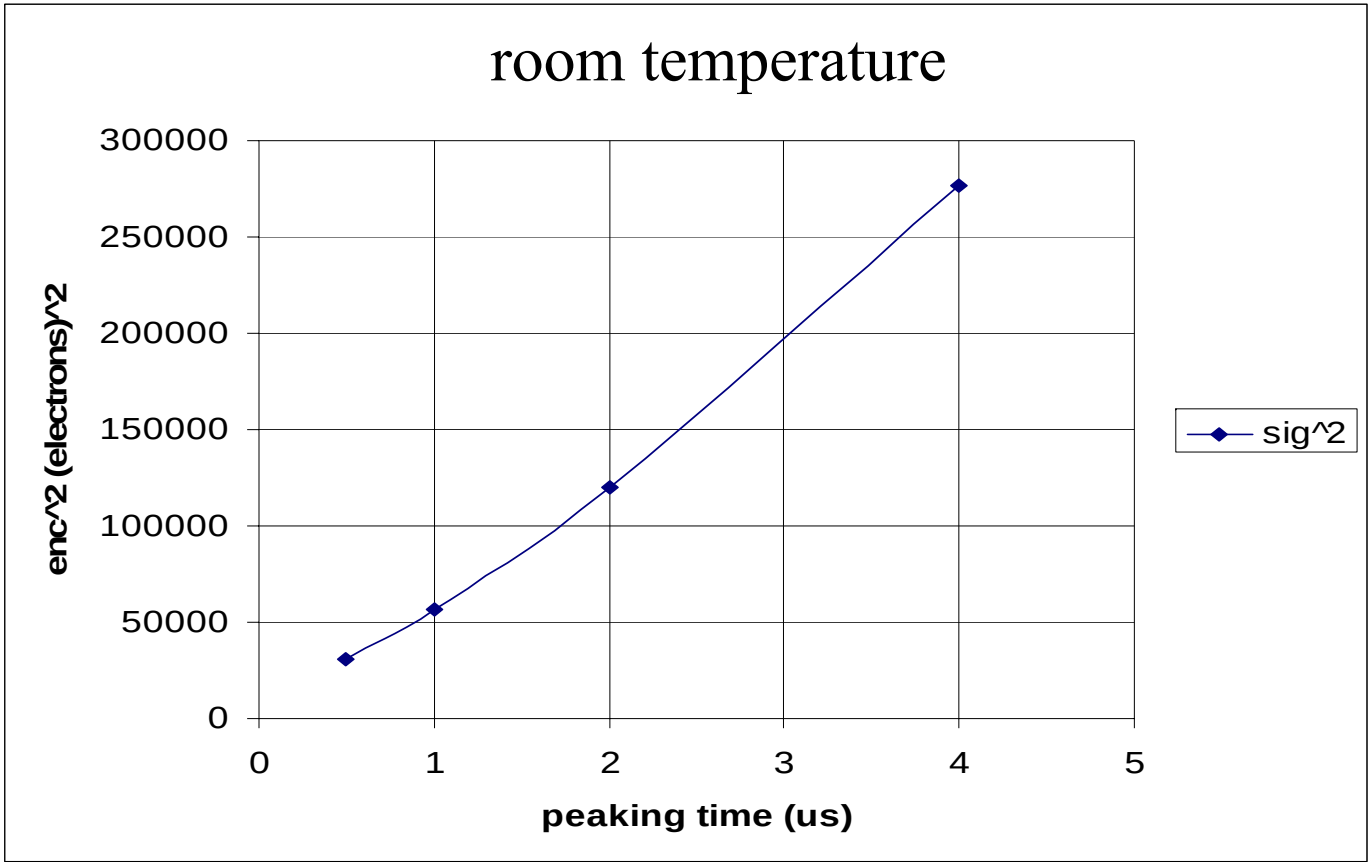
Room temperature



Outer ring: 150V. Back: 73V E1: 40V

Test Results and Discussions

Equivalent Noise Charge vs. Peaking time



Future Plan

- Stabilize the detector
- Reduce leakage current

Future Plan

Leakage current

- $I_{leakage}$: Generation of minority carriers
- <u>Depletion,</u> undepleted, and surface

$$I_g = I_{depl} + I_{diff} + I_{surf}$$

- Enhanced by presence of unwanted impurities

$$I_{depl} = 0.5q \cdot V \cdot n_i / \tau \ , \quad \tau = (\sigma \cdot v_{th} \cdot N_t)^{-1}$$

for detector of $1cm^2$ and $300\mu m$ thick,

If τ=1ms, I_{depl}=24nA

τ=10ms, I_{depl}=2.4nA

Future Plan

Leakage current

- Total elimination – impractical
  - Pervasiveness of those transition metals
  - Sensitivity of the leakage current to extremely small concentration
- Si: $5x10^{10}$ atoms/μm^3
- Wanted impurities: 1 atoms/ μm^3

  Racial=$0.2x10^{-10}$=0.02ppb
- So unwanted impurities: <<0.02ppb

Future Plan

Gettering

Concept: Suitable impurity sinks can be incorporated in electrically inactive regions.

Due to: at high T (900-1100˚C), most harmful impurities have high diffusivities.

- Intrinsic gettering
- Extrinsic gettering

Future Plan

Intrinsic gettering

- The bulk of the wafer forms the impurity sink leaving a thin, defect-free region near the surface where the active devices reside.
- Perfect for IC processing, not compatible with detectors where the depletion region extends to the backside contact of the wafer.

Future Plan

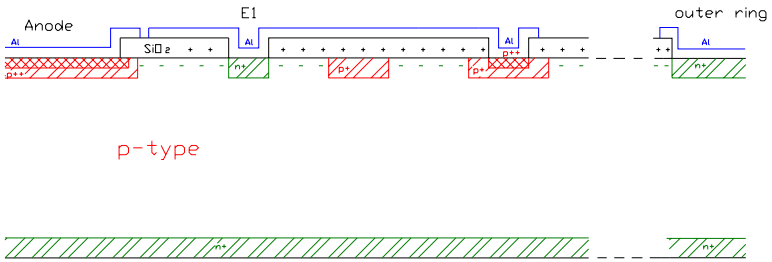
Extrinsic gettering

- Formation of a gettering layer on back side of the wafer, away from the active region of the device.
- Suitable for p-n diode detectors where the depleted layer extended to the backside.

Future Plan

Extrinsic Gettering

- Phosphorus doping, implantation
- Deposit polysilicon or silicon nitride film



Conclusions

- P-type one-sided hexagonal spiral drift detectors have been produced and they work.
- Currently dry nitrogen is used for stable operation of the detector. Technological solution including additional insulating layer is being investigated.
- Resolution is limited by the high leakage current. Using extrinsic gettering to reduce the leakage current is under way. We hope to see the improved resolution.