Silicon detector processing and technology: Part II

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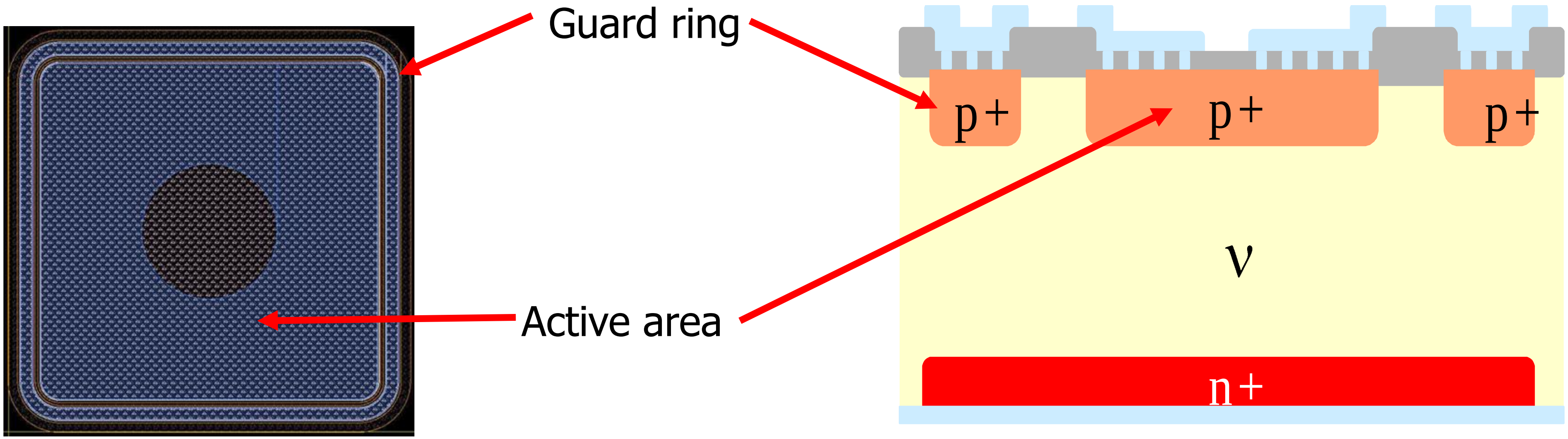
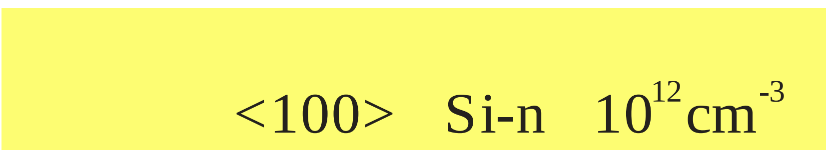
Simple pad detector P-on-N technology

- Most simple detecting structure
- No segmentation
- Simple processing
- Direct connection to readout electronics
- Guard ring is bisased at the same potential as central diode



Simple pad detector P-on-N technology

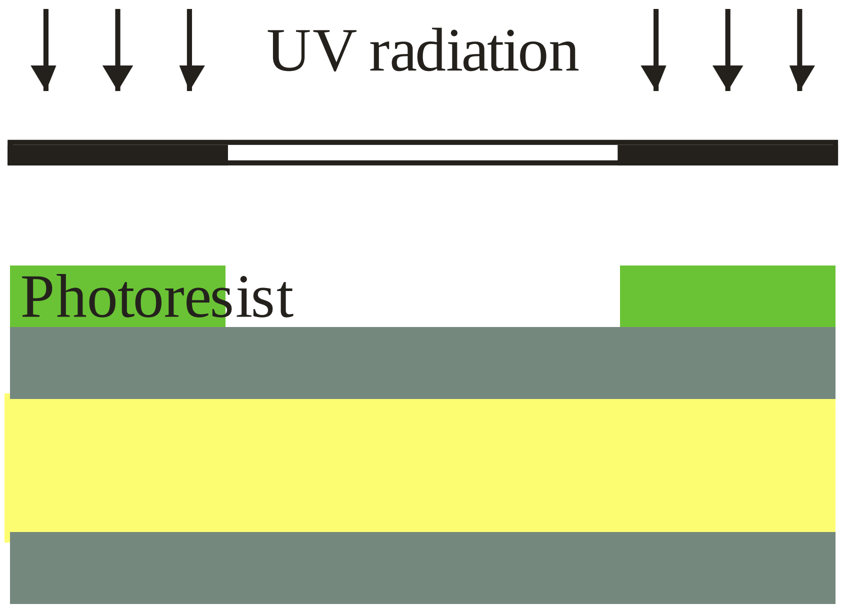
- **Initial wafer**
  - **FZ silicon <100>**
  - **N-type, 10^{12} cm^{-3}**



Simple pad detector P-on-N technology

- **Field oxide 1,000 nm**
- **Wet oxidation, 1100ºC)**

Simple pad detector P-on-N technology



- **1st Photolithography**
- **Junction area definition**

Simple pad detector P-on-N technology

- SiO_2 wet etching
  - Front and backside

Simple pad detector P-on-N technology

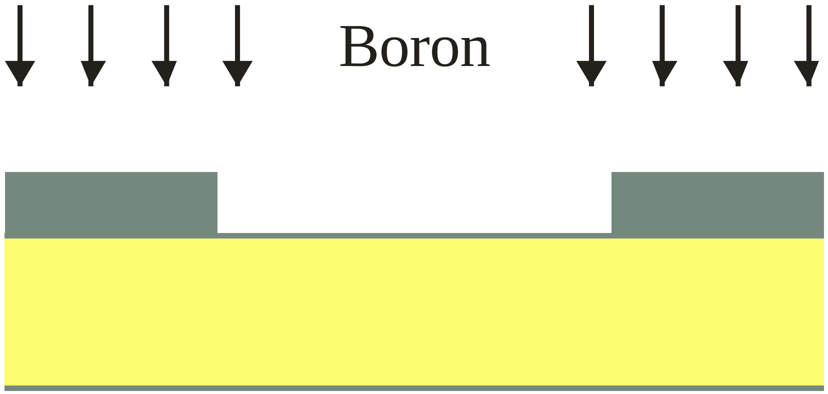
- Photoresist removal

Simple pad detector P-on-N technology

- Thin oxide growth
  - Dry thermal oxidation, 36.5 nm

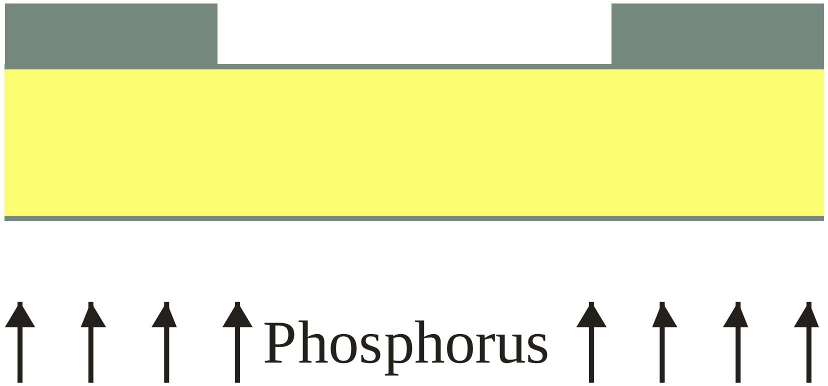
Simple pad detector P-on-N technology

- **N+ ion implant**
- **$4.2 \times 10^{15} cm^{-2}$, 100KeV**



Simple pad detector P-on-N technology

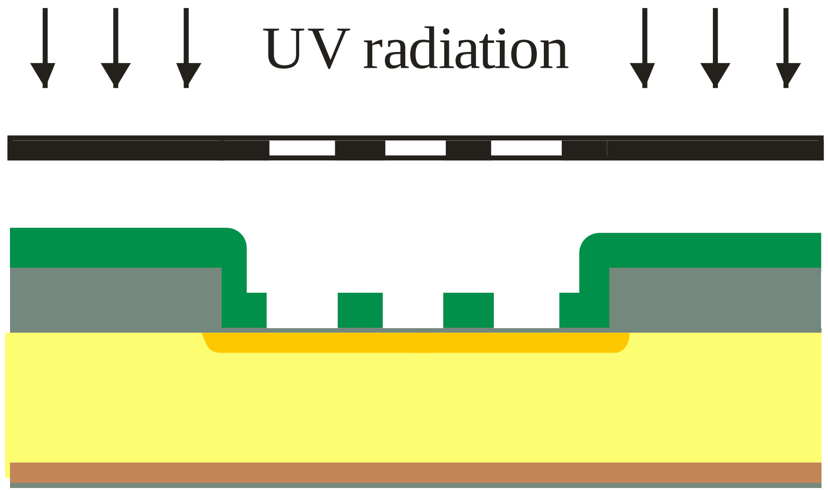
- P+ Ion implant
- $1\times10^{15}cm^{-2}$, 50KeV



Simple pad detector P-on-N technology

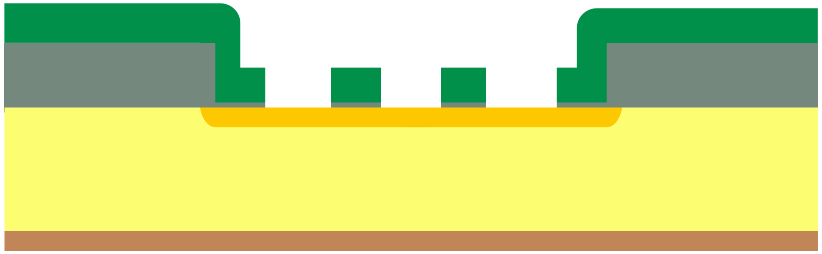
- Impurity drive-in
- 950ºC, 30 min

Simple pad detector P-on-N technology



- **2nd Photolithography**
- **Contact opening**

Simple pad detector P-on-N technology

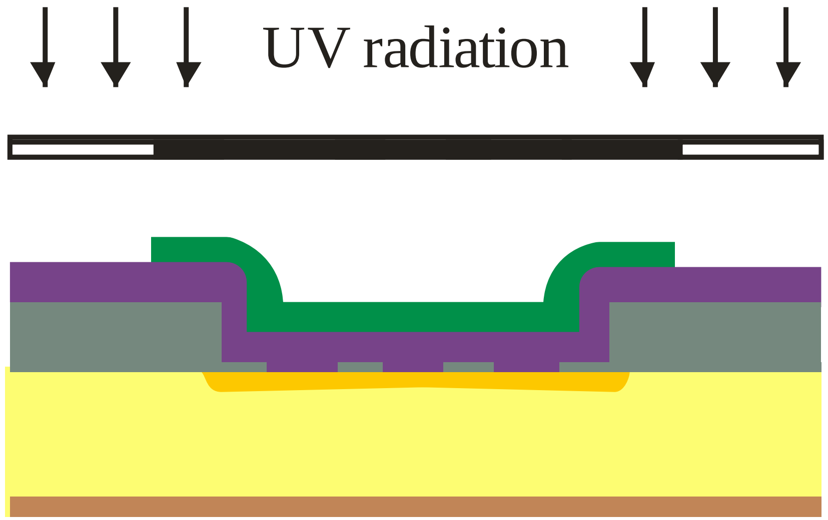


- **Oxide wet etch**
  - **Front and back sides**

Simple pad detector P-on-N technology

- **Front side metal deposition**
  - **1µm Al/Si/Cu (98.75%/0.75%/0.5%)**

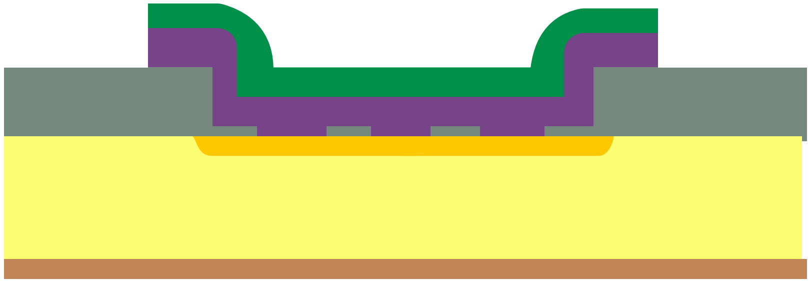
Simple pad detector P-on-N technology



- **3rd Photolithography**
- **Metal patterning**

Simple pad detector P-on-N technology

- Metal wet etching



Simple pad detector P-on-N technology

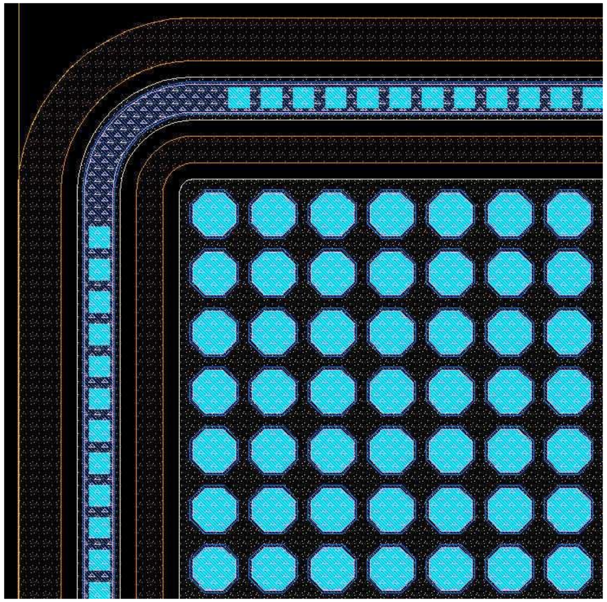
- Photoresist removal

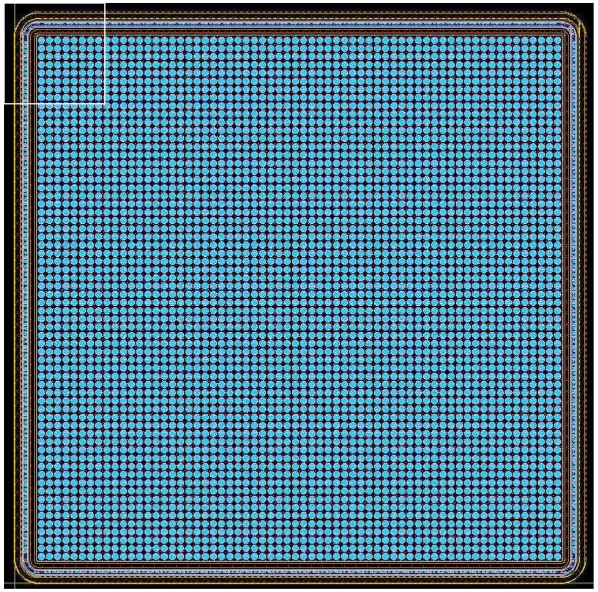
Simple pad detector P-on-N technology

- **Back side metal deposition**
  - **1µm Al/Si/Cu (98.75%/0.75%/0.5%)**
- **Metal sintering**
  - **350ºC, 20 min**
  - **H_2/N_2 mixture (forming gas)**

Other types of detectors

- **We have seen the fabrication sequence for a very simple pad detector**
- **There are other more complex detector geometries: Pixel and Strip detectors**
- **Pixel detectors are similar to pad detectors, but segmented in many individual diodes in a two-dimensional array**
- **Pixel size: 50 µm – 1 mm. Number of pixels: 16×16 up to 256×256 (65,000!)**

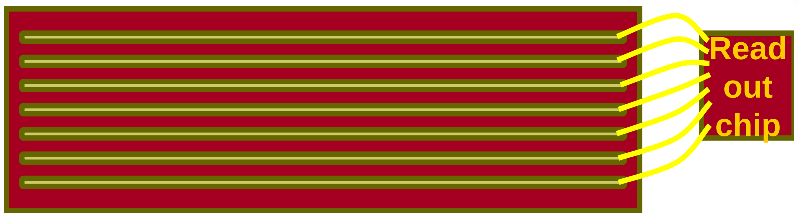




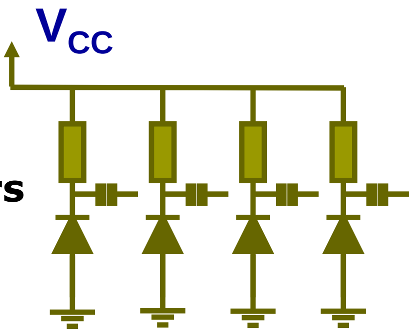
Strip detectors are by far more complex

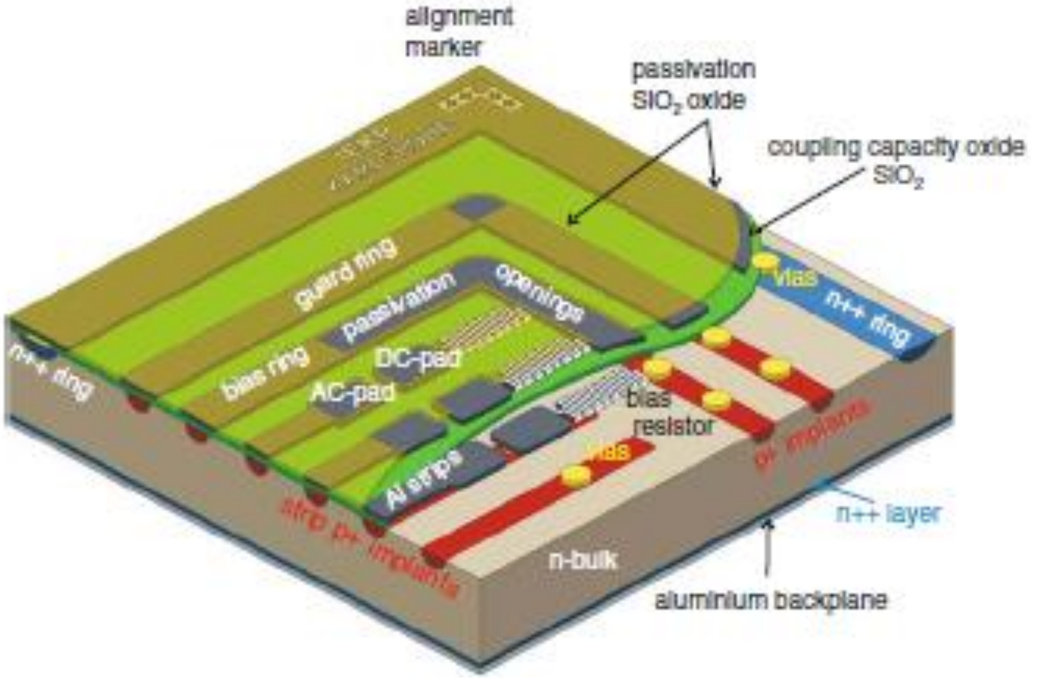
Strip detectors

- Diode shape: thin and long strips
  - Width: 20-100 µm
  - Length: 100 µm - 20 cm (or more)
- Many channels in a single chip
  - From 10 to 1,000
- Wire bonded to read-out electronics
  - Hybrid or multichip approaches
- Applications
  - Particle tracking
  - Position measurement



- Standard technology
  - Diode: strips
  - Bias: Polysilicon resistors
  - Coupling: AC
- Position sensitivity
  - Resolution 5 µm
- Technological options
  - Single side, Double side



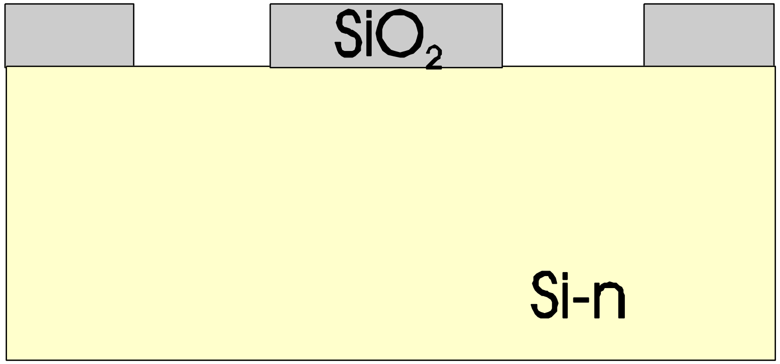


P-on-N strip detector fabrication technology

P-on-N strip detector fabrication process

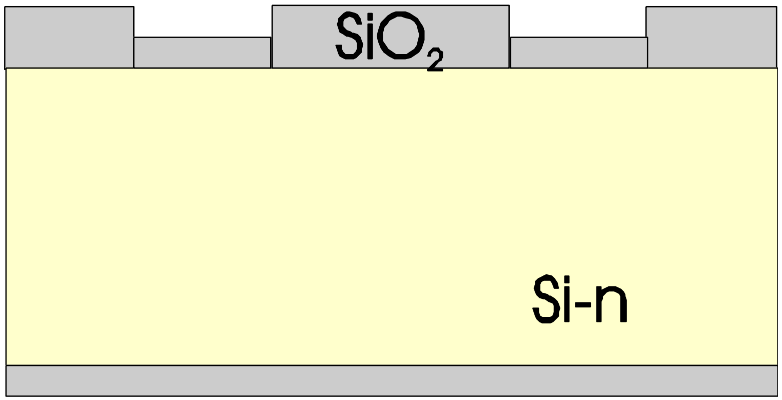
- Field oxide
  - 800 nm
  - 1100 ºC

P-on-N strip detector fabrication process



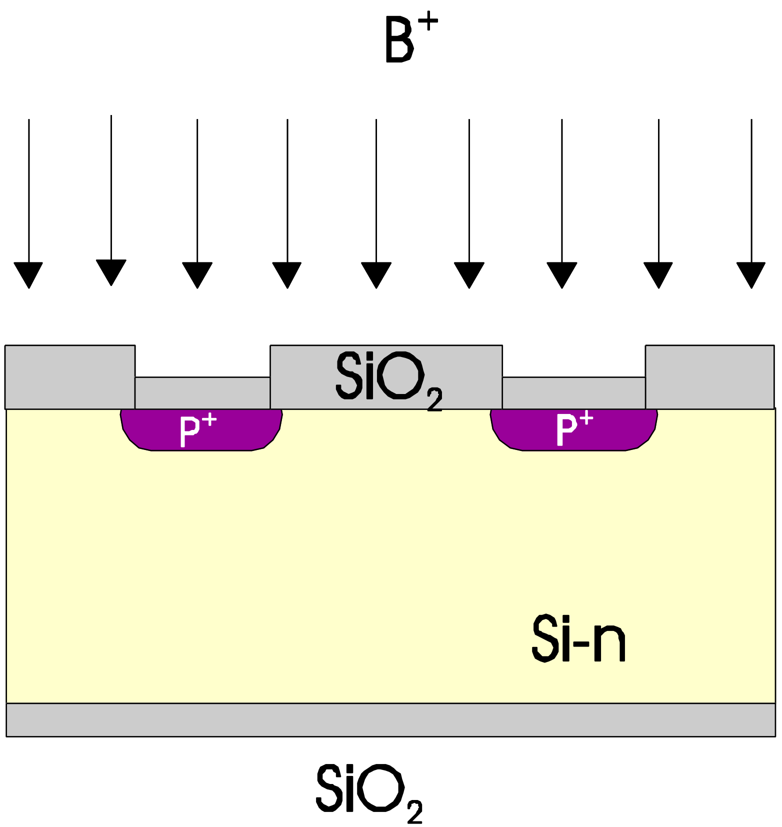
- 1st Photolithography
- Definition of P^+ junctions
  - Wet etching
  - Photoresist etching

P-on-N strip detector fabrication process



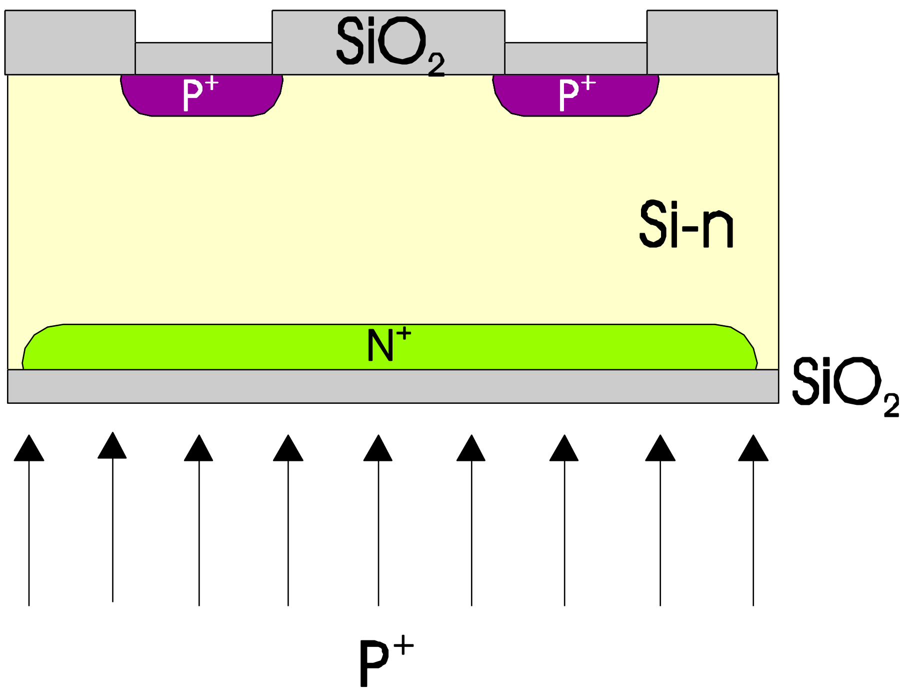
- Thin oxide
  - 36.5 nm
  - 950 ºC

P-on-N strip detector fabrication process



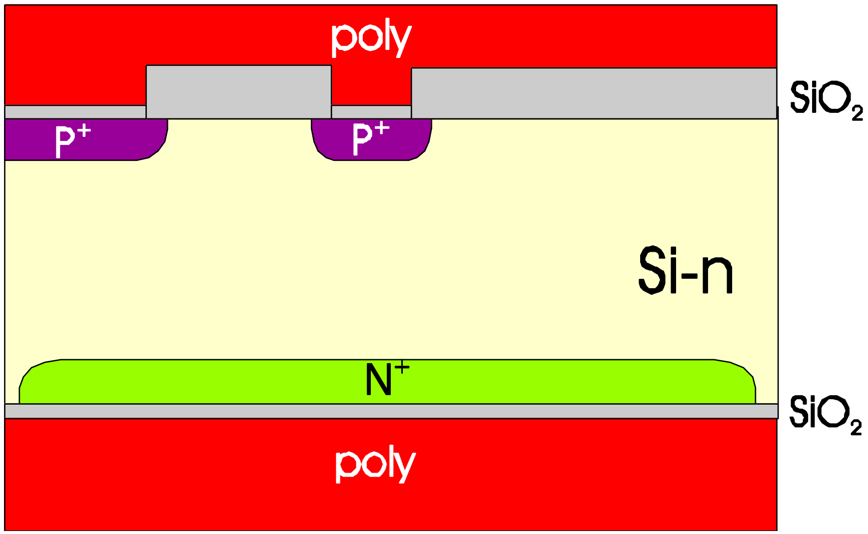
- Boron ion implant
  - 10^{15} cm^{-2}
  - 50 keV

P-on-N strip detector fabrication process



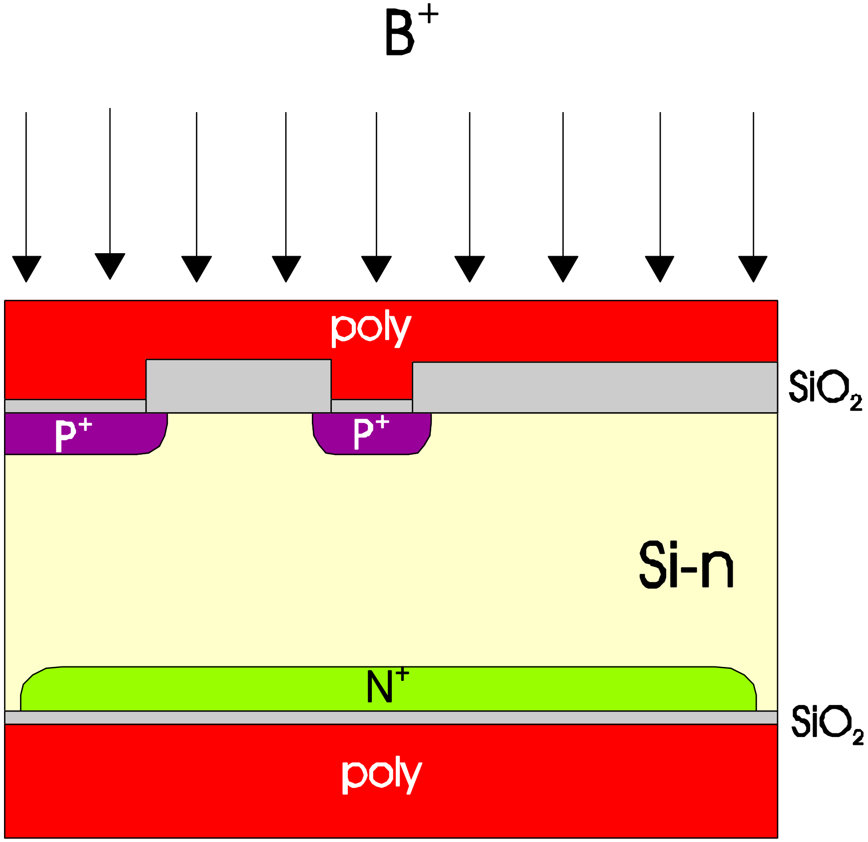
- Phosphorus backside ion implant
  - $4.2 \cdot 10^{15}$ cm^{-2}
  - 100 keV
- Without mask

P-on-N strip detector fabrication process



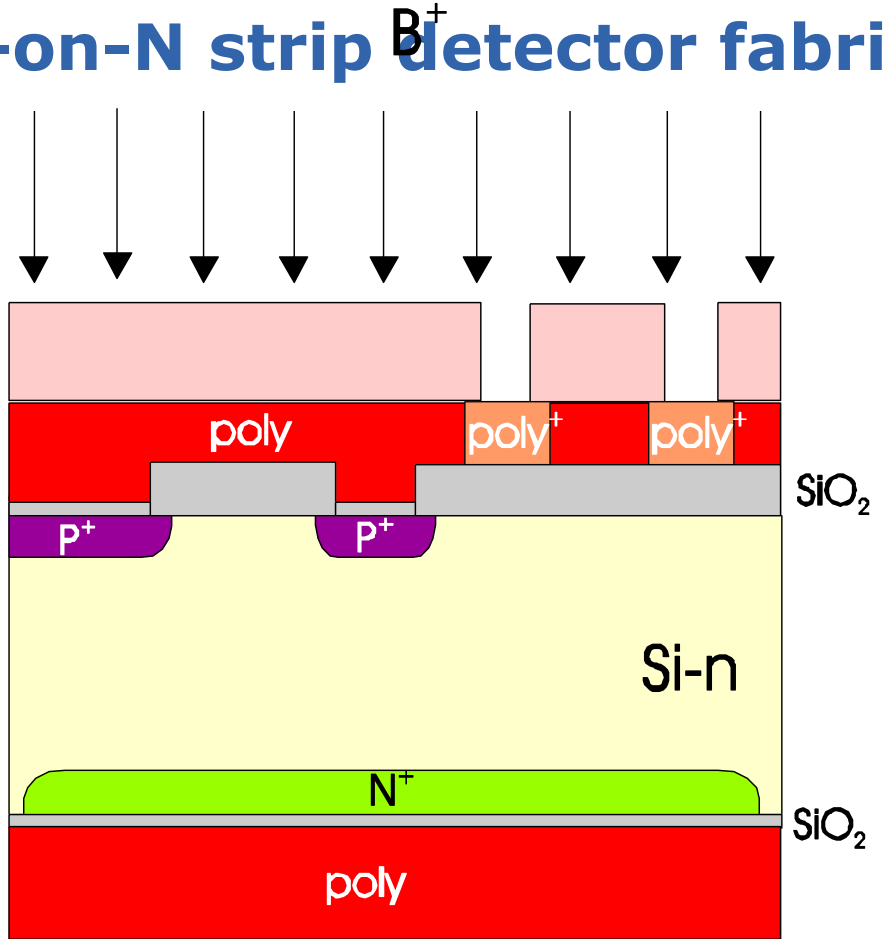
- Polysilicon LPCVD deposition
  - 600 nm
  - 630 ºC

P-on-N strip detector fabrication process



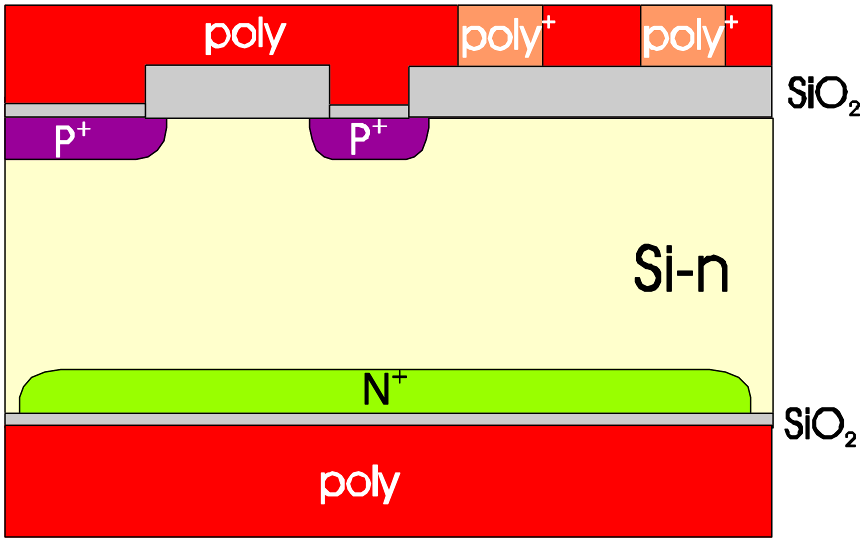
- Boron ion implant for poly doping
  - 1.5×10^{14} cm^{-2}
  - 100 keV

P-on-N strip detector fabrication process



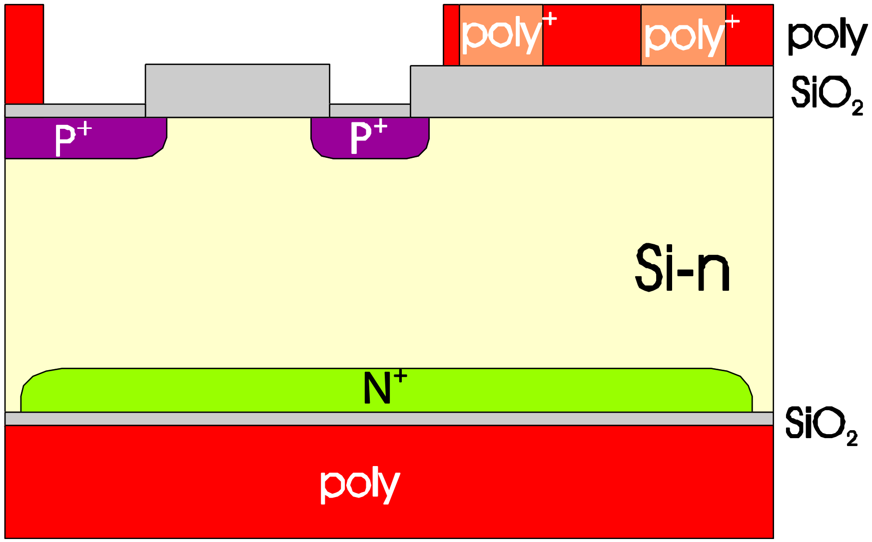
- **2nd Photolithography**
- **Low resistivity poly region definition**
- **Boron ion implant**
  - **10^{15} cm^{-2}**
  - **50 keV**

P-on-N strip detector fabrication process



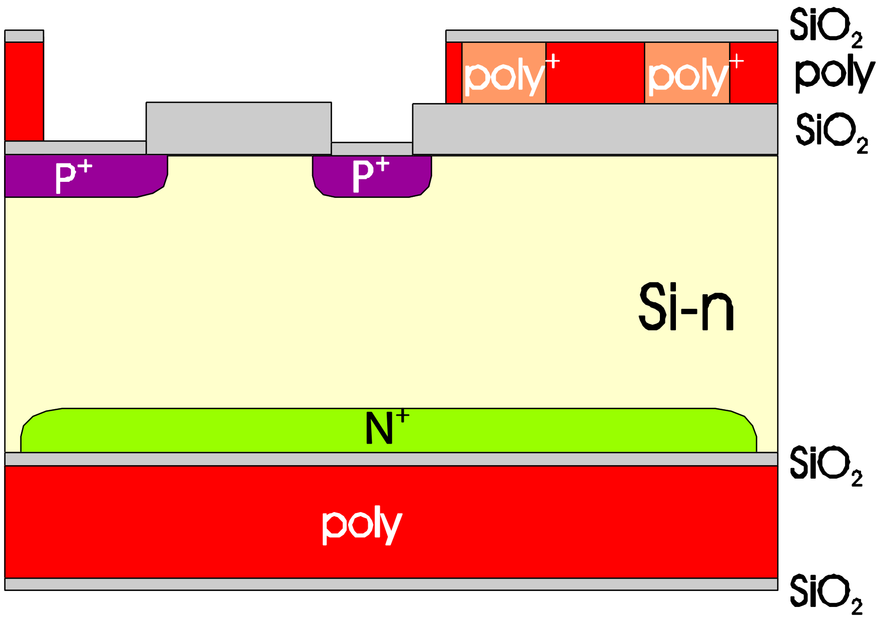
- Photoresist removal

P-on-N strip detector fabrication process



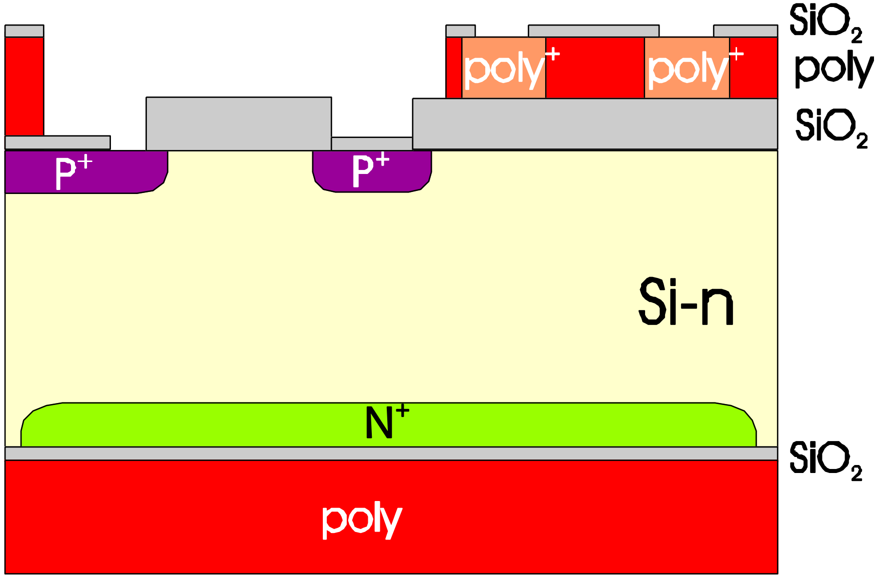
- **3rd Photolithography**
- **Polysilicon patterning**
  - **Photolithography**
  - **Dry etch**
  - **Photoresist etching**

P-on-N strip detector fabrication process



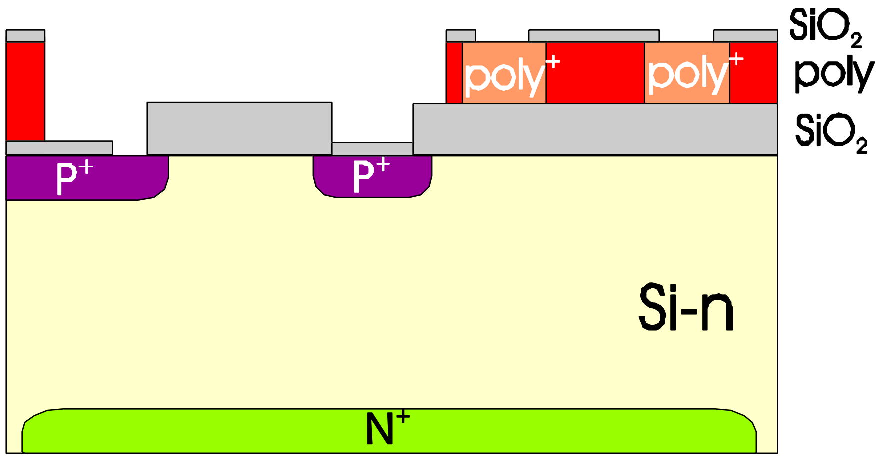
- Impurity activation
  - O_2, 950 ºC, 30 minutes

P-on-N strip detector fabrication process



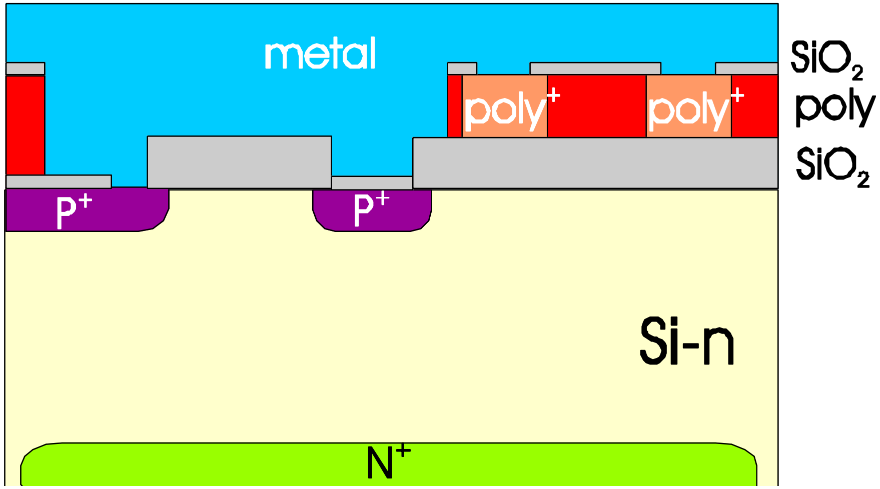
- 4th Photolithography
- Contact definition
  - Wet etching
  - Photoresist removal

P-on-N strip detector fabrication process



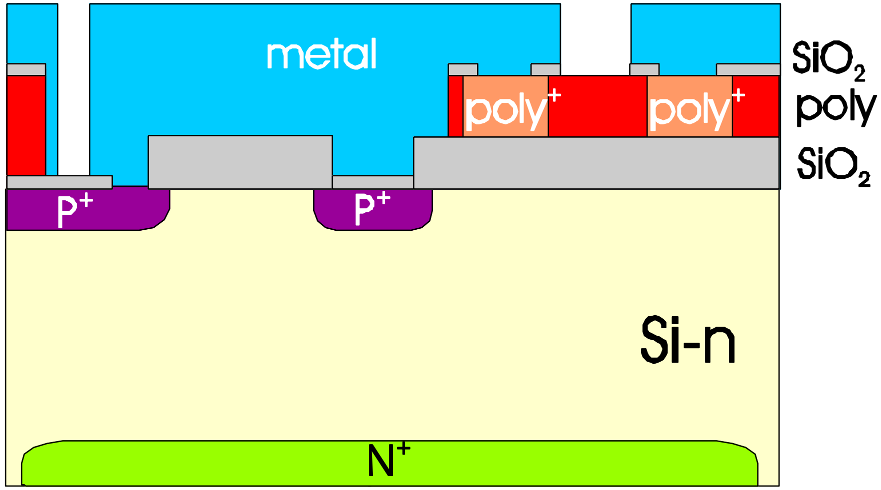
- **Backside etching**
  - **Front side protection with photoresist**
  - **Poly etching**
  - **SiO_2 etcihng**
  - **Protective photoresist removal**

P-on-N strip detector fabrication process



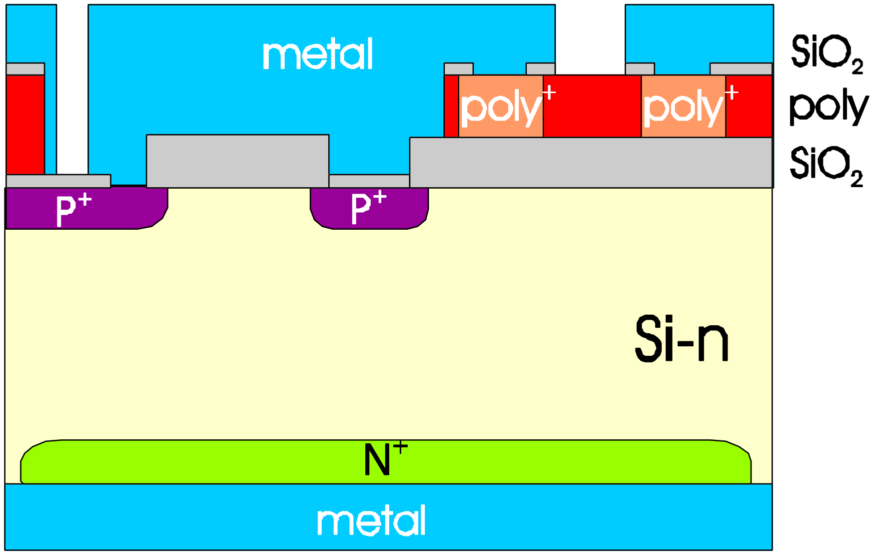
- **Front side metallization**
  - **Al/Si/Cu**
  - **1.5 µm**

P-on-N strip detector fabrication process



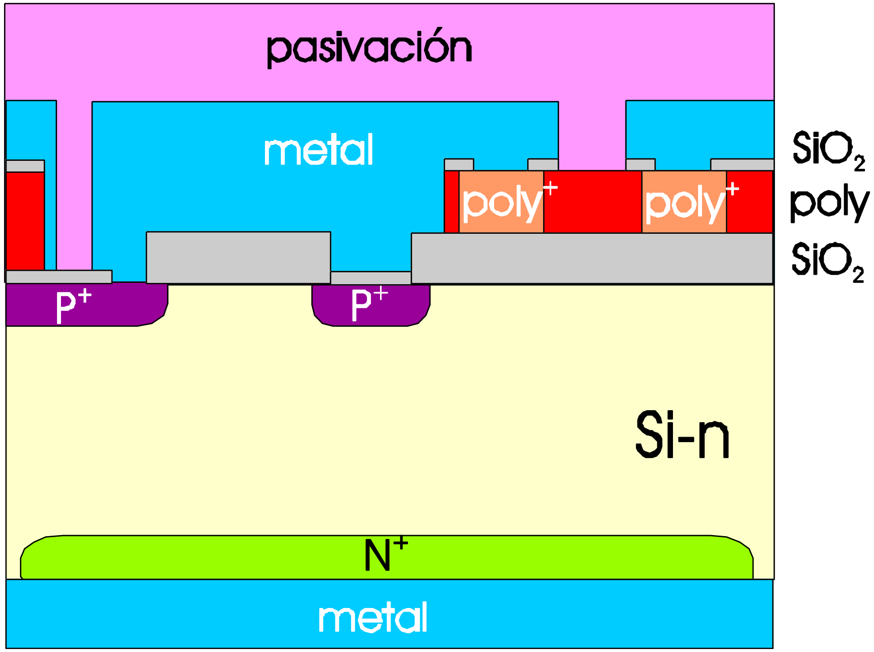
- **5th Photolithography**
- **Front side metal patterning**
  - **Wet etching**
  - **Photoresist removal**

P-on-N strip detector fabrication process



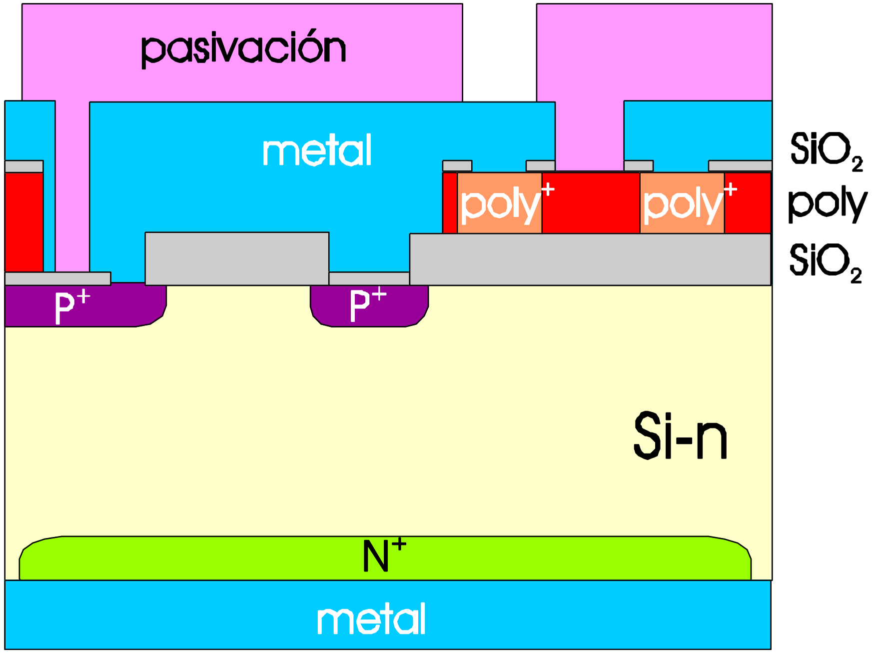
- Back side metallization
  - Al/Si/Cu
  - 1.0 μm
- Metal sintering
  - N_2/H_2, 350 ºC, 30 minutes

P-on-N strip detector fabrication process



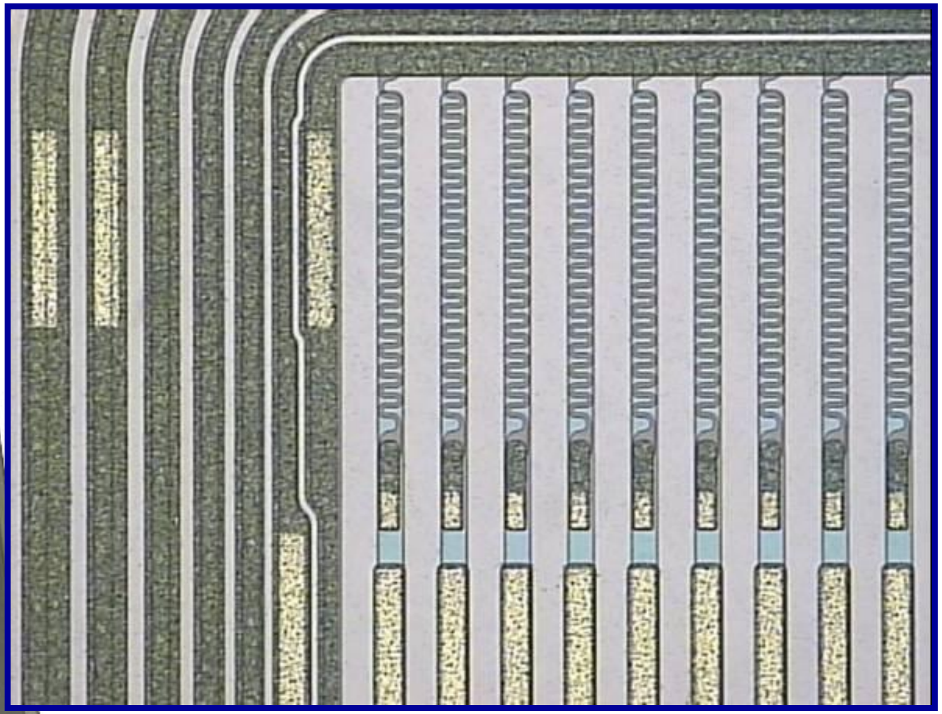
- **Passivation layer deposition**
  - **SiO_2 400 nm, PECVD**
  - **Si_3N_4 700 nm, PECVD**

P-on-N strip detector fabrication process

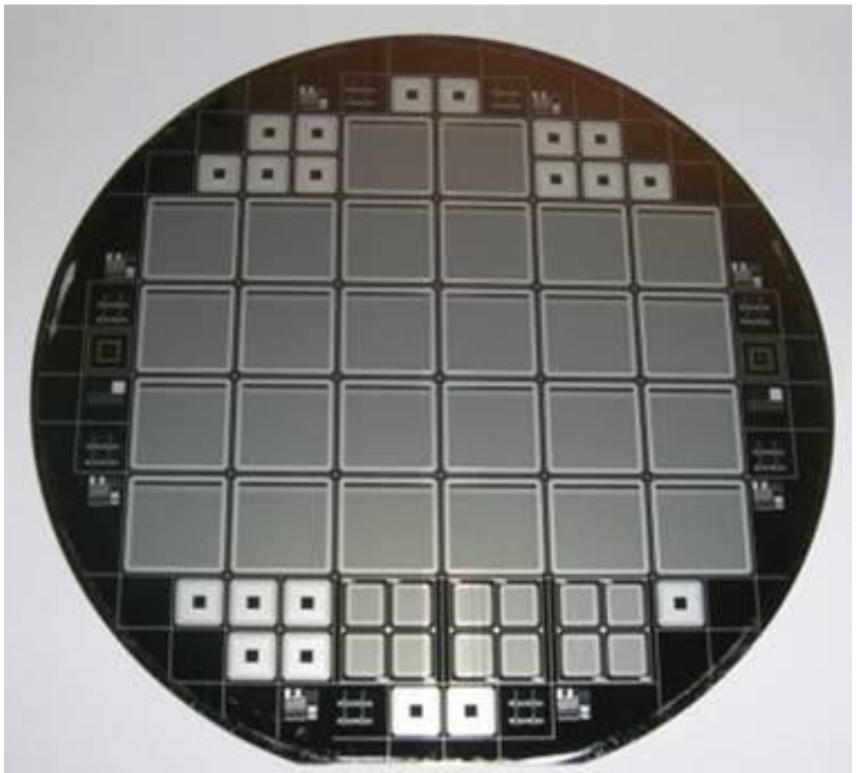


- **6th Photolithography**
- **Passivation layer patterning**
  - **Wet etching**
  - **Photoresist removal**

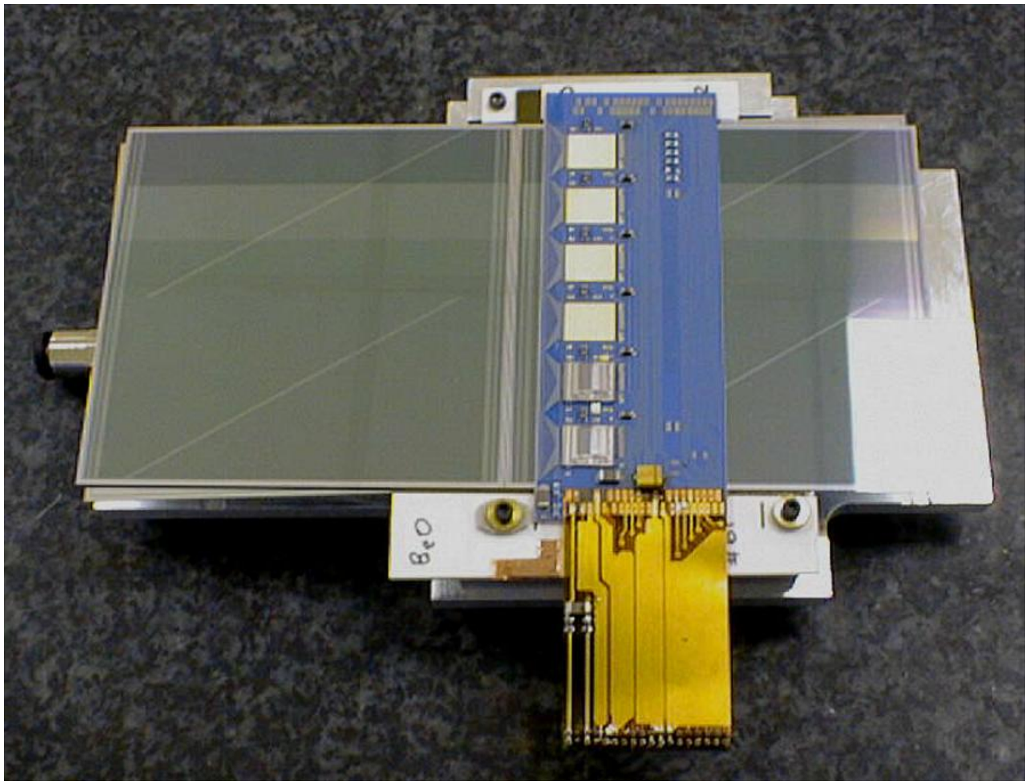
P-on-N strip detector fabrication process



Strip detectors



RD50 wafer of baby strip detectors



ATLAS barrel module

P-on-N technology

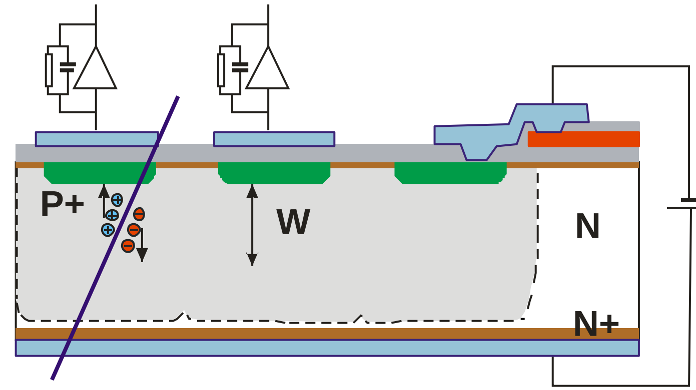
- P junctions on N substrate
- It is the simplest and more used technology
- 6 photolithographic levels
  - P+ implant
  - Polysilicon
  - Low resistivity poly
  - Contact opening
  - Metal
  - Passivation

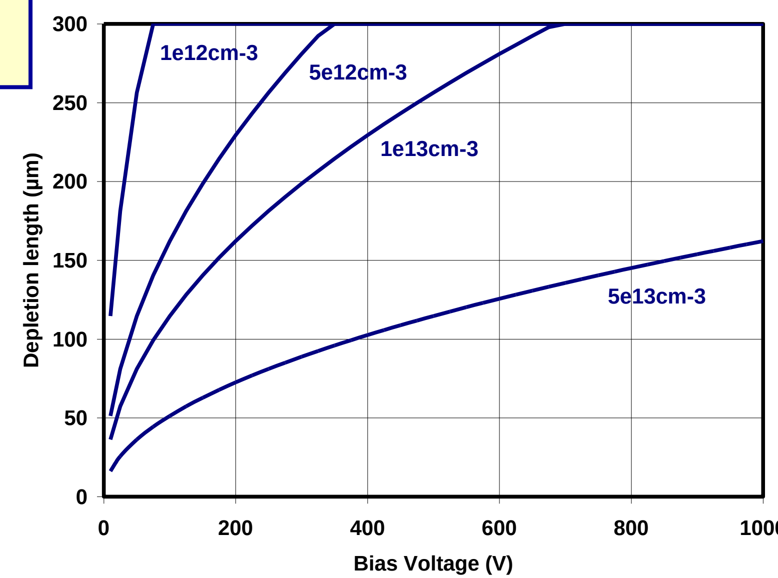
- Worse electrical performances
  - Hole collection in the amplifier

$$W = \sqrt{\frac{2\varepsilon_{Si}\varepsilon_0 V_{Bias}}{qN}} = \sqrt{\frac{2\varepsilon_{Si}\varepsilon_0}{q}}\sqrt{\frac{V_{Bias}}{N}}$$

Oxide
⇓
Positive charge
⇓
Substrate N
⇓
Accumulation layer
⇓
Harmless

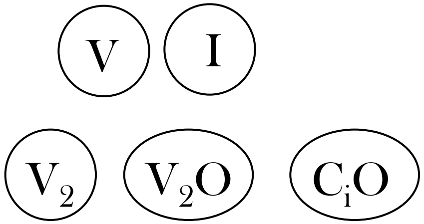
P-on-N

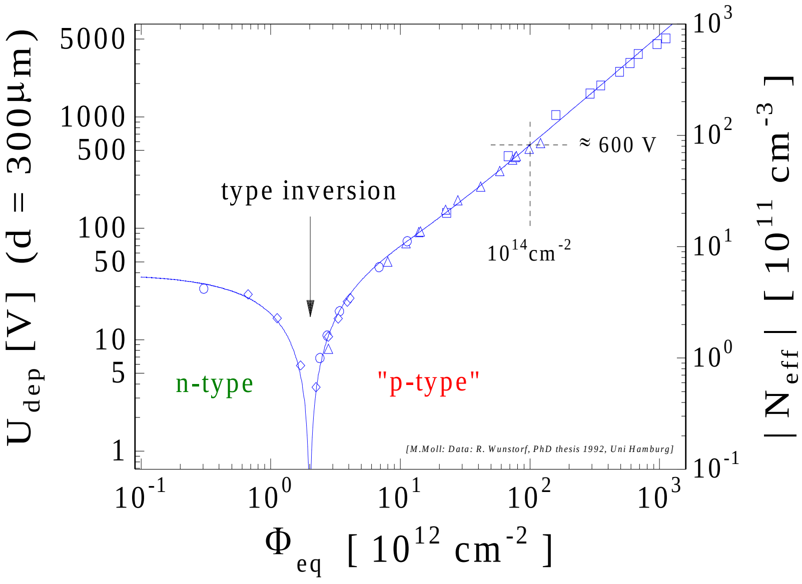




Radiation damage

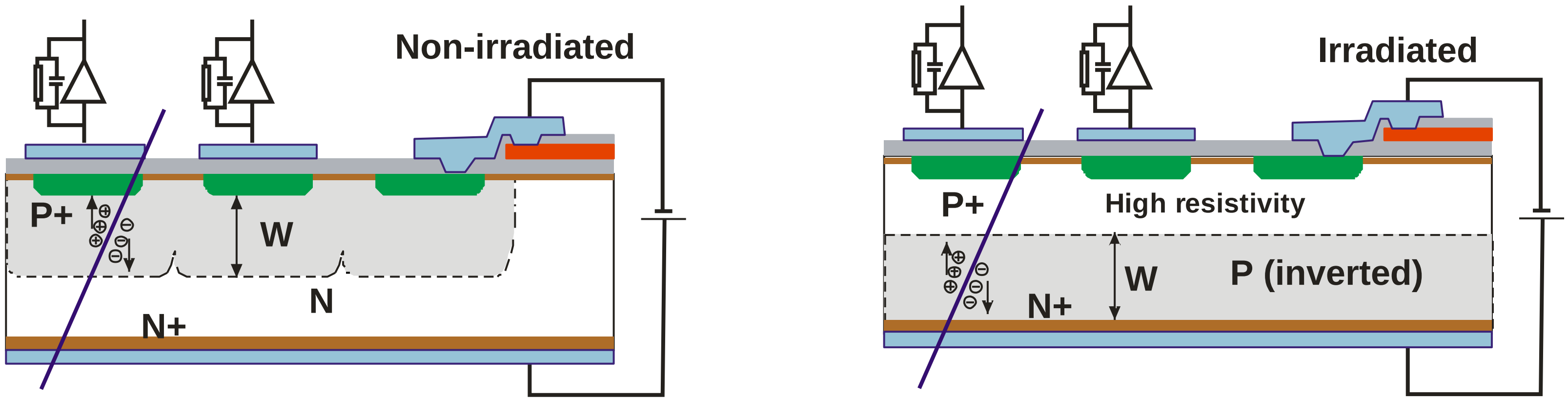
- **Radiation sensors are subjected to radiation (obviously)**
- **Radiation causes damage in silicon:**
  - **Particles produce atom displacements**
  - **Create vacant-interstitial pairs (Frenkel pairs)**
    - Also combinations of defects and clusters
- **Increase of deep level and trap concentration**
- **Variation of doping concentration**
  - **Vacancies behave as donors**
  - **N-type substrate is less n and eventually becomes P-type**
  - **P-type is more P**
- **Increase of full depletion voltage**
- **Finally full depletion is not reachable and detectors have to operate in partial depletion**
- **Along with higher leakage current**





P-on-N technology and radiation damage

- **Shows the smallest radiation hardness**
  - **N-substrate type inversion (to P type)**
  - **Bulk inversion to p-type at around $2x10^{13}$ 1 MeV neutron equivalent**



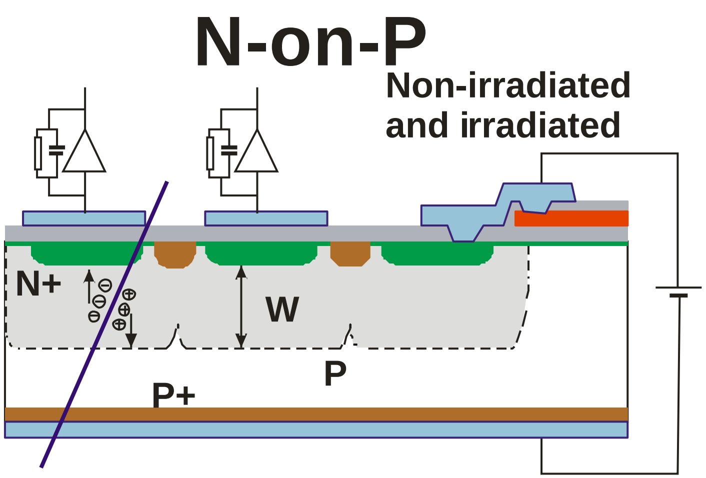
- **After substrate type inversion junction moves from top to bottom**
- **Operation in partial depletion problematic**
  - **High resistivity zone close to electrodes**

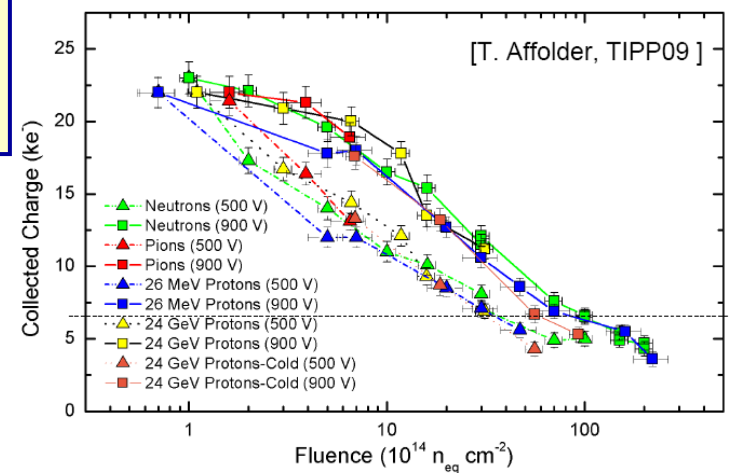
N-on-P technology

- N junctions on P substrate
- No substrate inversion due to radiation
- Possible operation in partial depletion
- More radiation hard
- Electron collection

- Simple layout does not work due to inversion layer
- More complex technology
  - 7 layers
- Oxygenated P-type wafers difficult to process
- Still sufficient signal (7000e-) in p-type FZ strip sensors after 10^{16} neq/cm² for 900V

Oxide
⇩
Positive charge
⇩
Substrate P
⇩
Inversion layer
⇩
Short circuit between strips

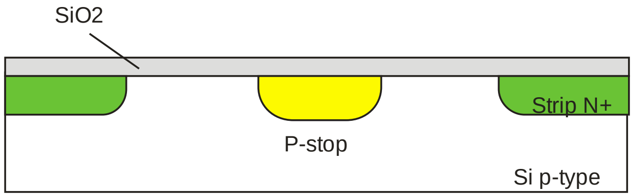


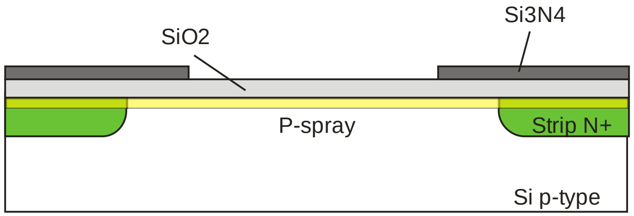


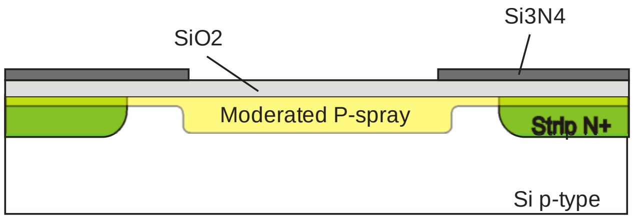
Insulation schemes in N-on-P

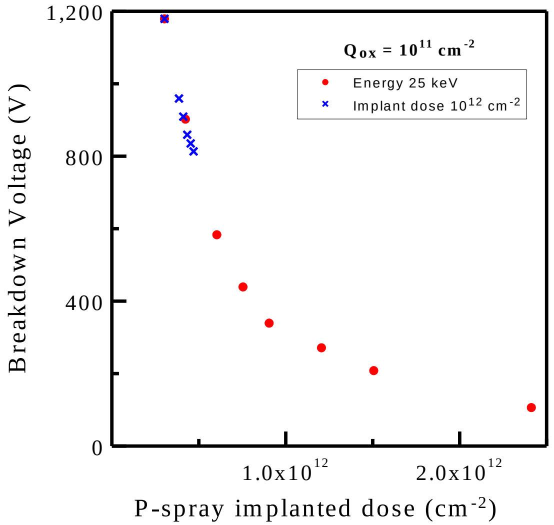
- All insulation schemes have pros and cons
- P-stop is the most reliable
  - Lower breakdown voltage
  - Noisy operation (microdischarges)
- P-spray
  - Reverse relationship between insulation and VBD
- Moderated p-spray
  - Intermediate solution

- Although it seems that N-on-P is the selected technology for upgraded experiments, insulation schemes is still a question under discussion



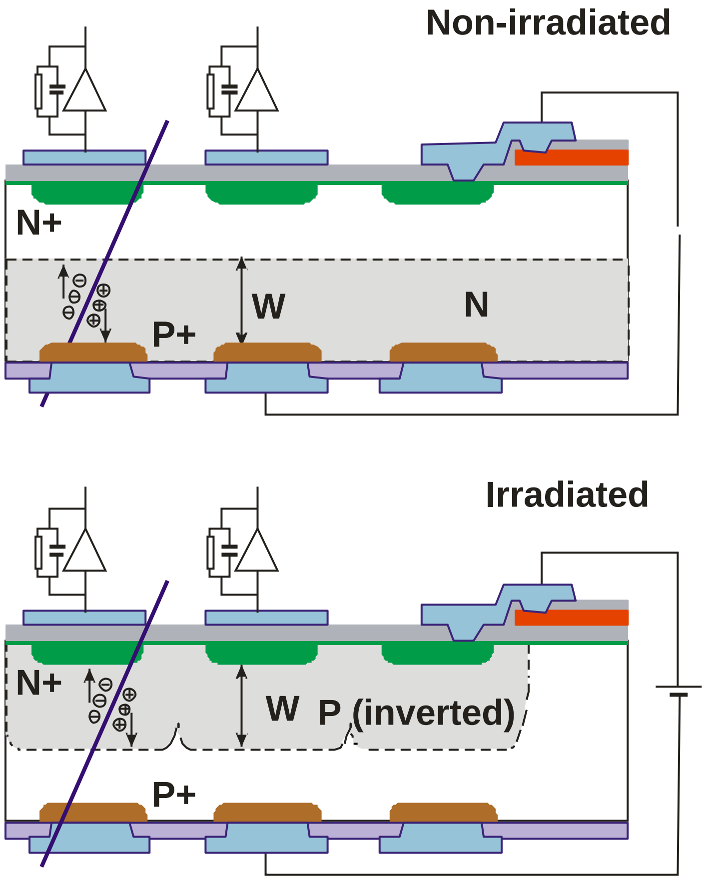






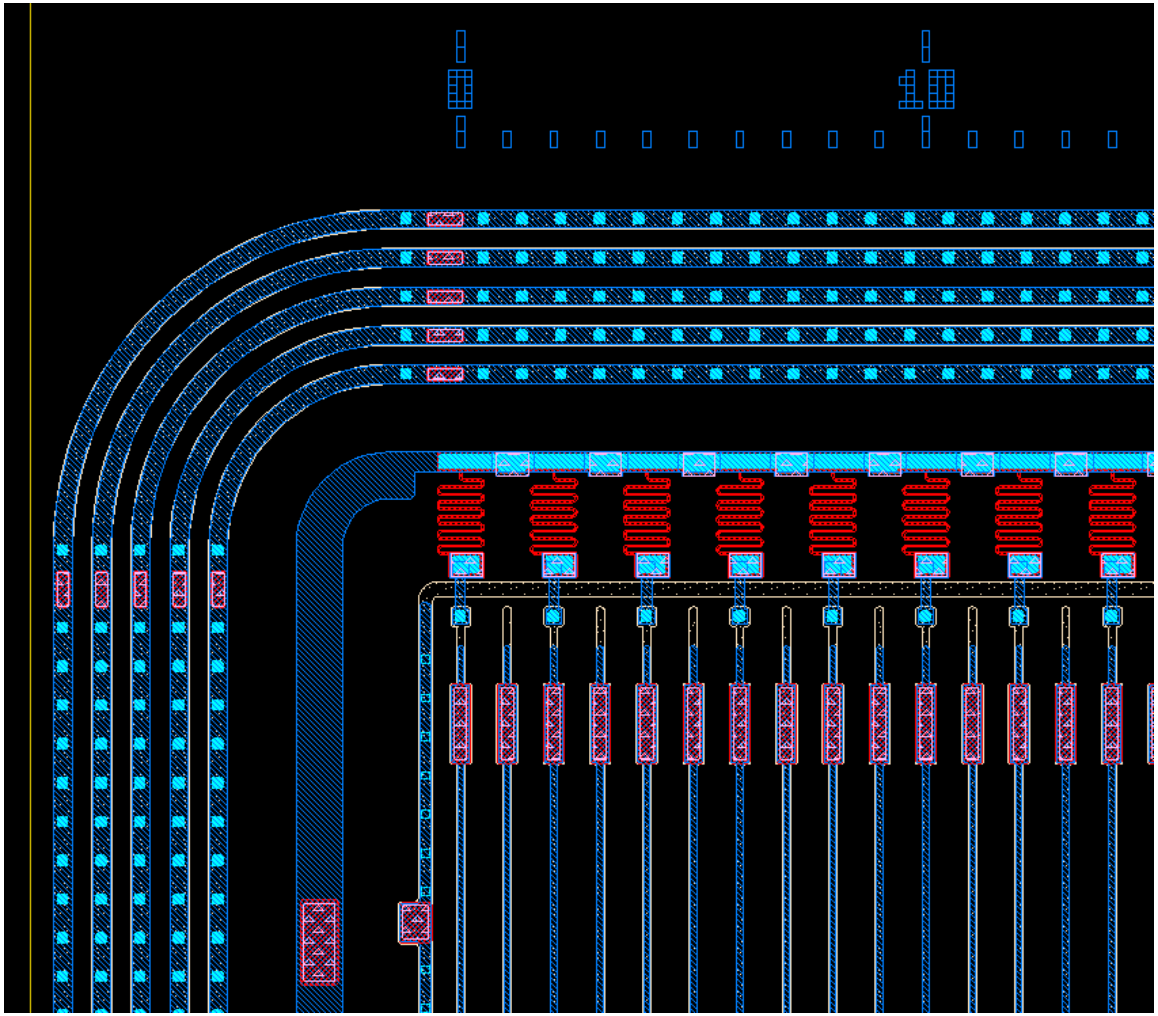
N-on-N technology

- Before irradiation junction is on the back side
- Type inversion under radiation
  - Junction moves to the top surface
- The highest radiation hardness
- Accumulation layer on top side
  - No need for p-stops before irradiation
  - Needed after
- But, short circuit on the bakside
  - Located along the edges
- Need two side processing
  - Very difficult and expensive
  - 10 photolithographic layers
  - Also, difficult to test and bond



P-on-N strip detector layout

P-on-N layout
Simple strips

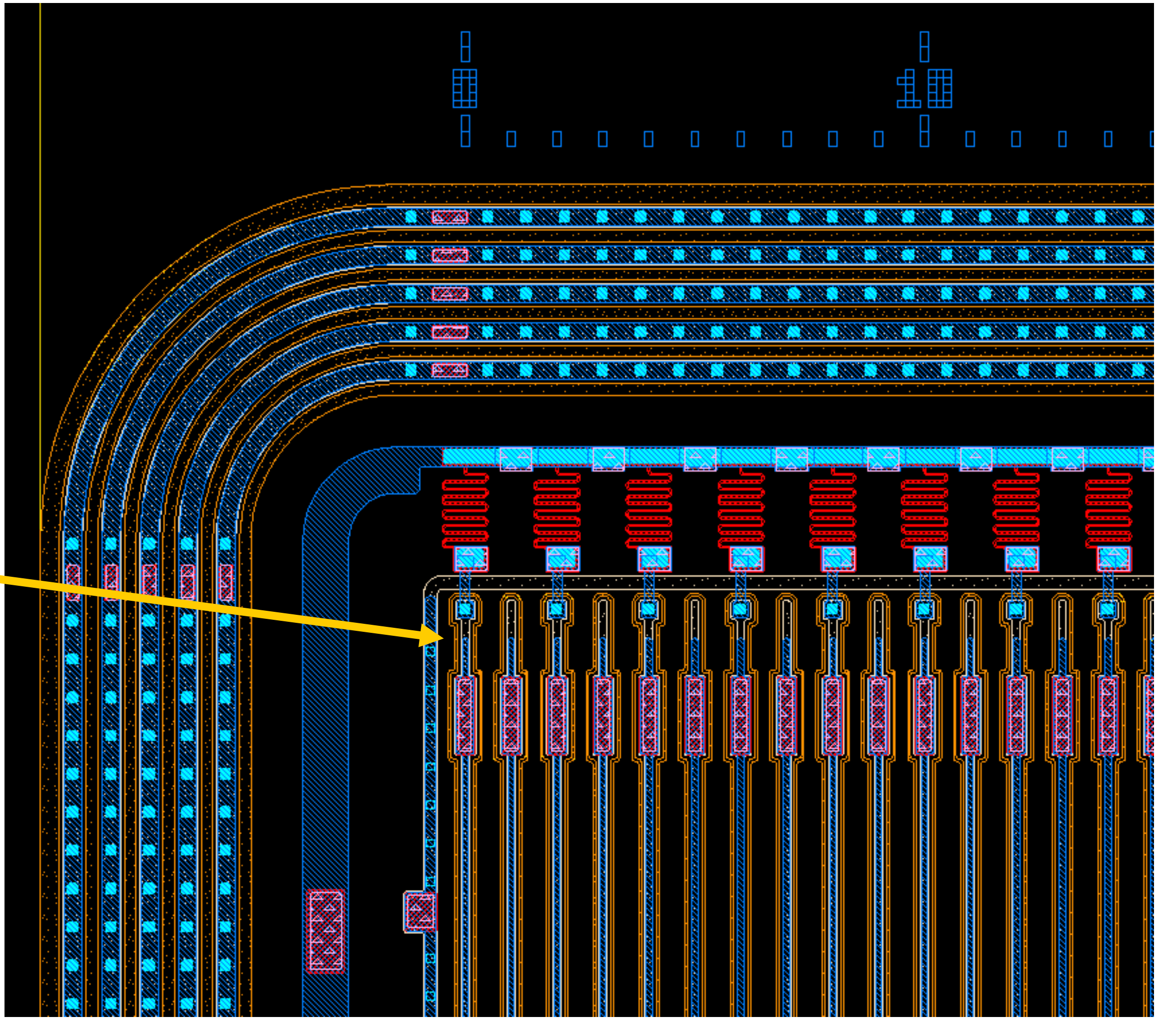


N-on-P strip detector layout

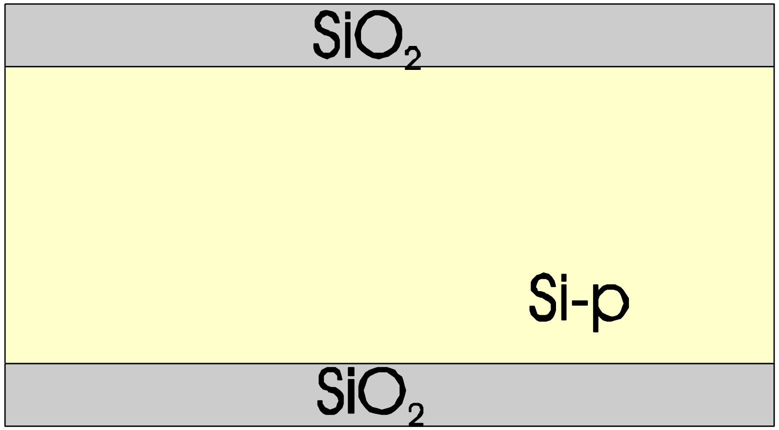
N-on-P layout

Similar to P-on-N

But with P-stop structures between strips

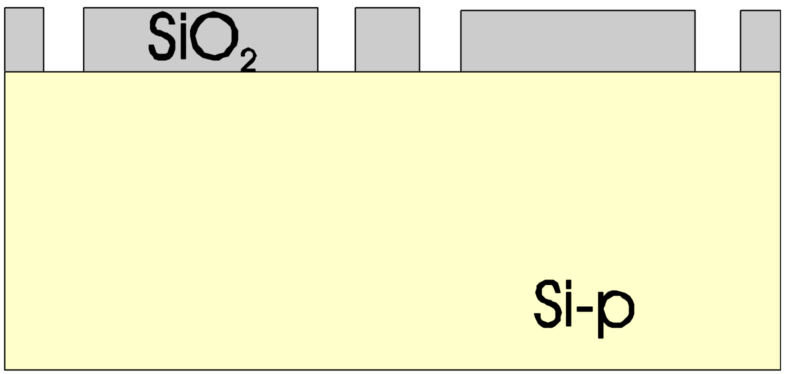


N-on-P strip detector fabrication process



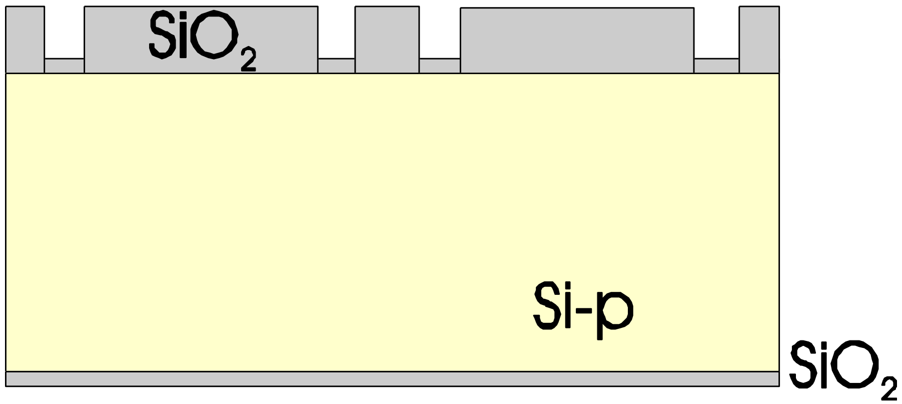
- **Thick oxide growing**
  - **H_20**
  - **800 nm**
  - **1100 ºC**

N-on-P strip detector fabrication process



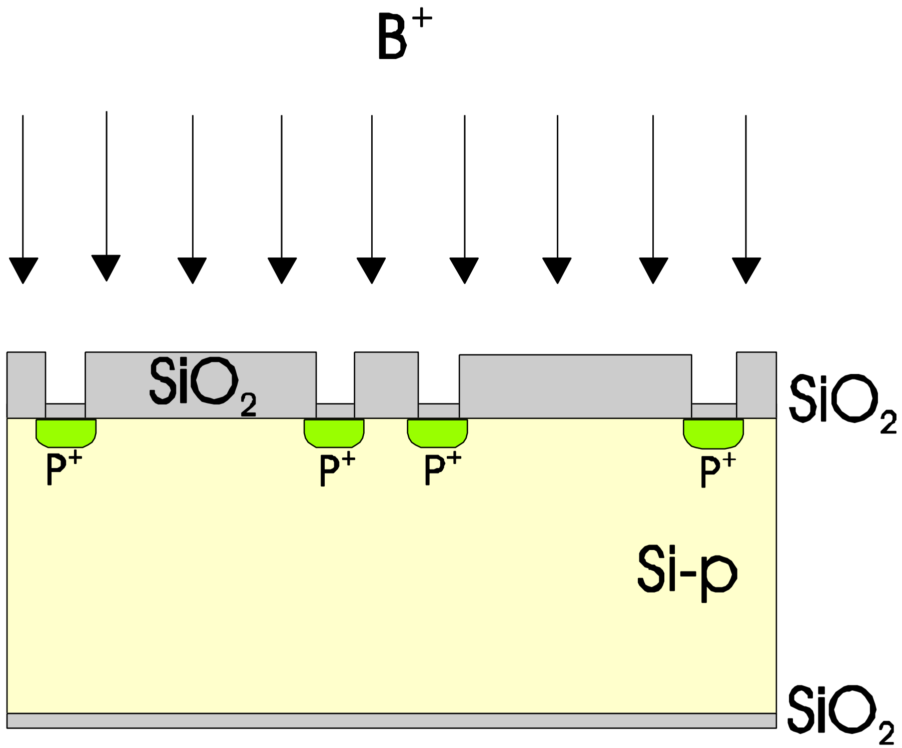
- 1st Photolithgraphy
- P-stops
- Wet etching
- Photoresist removal

N-on-P strip detector fabrication process



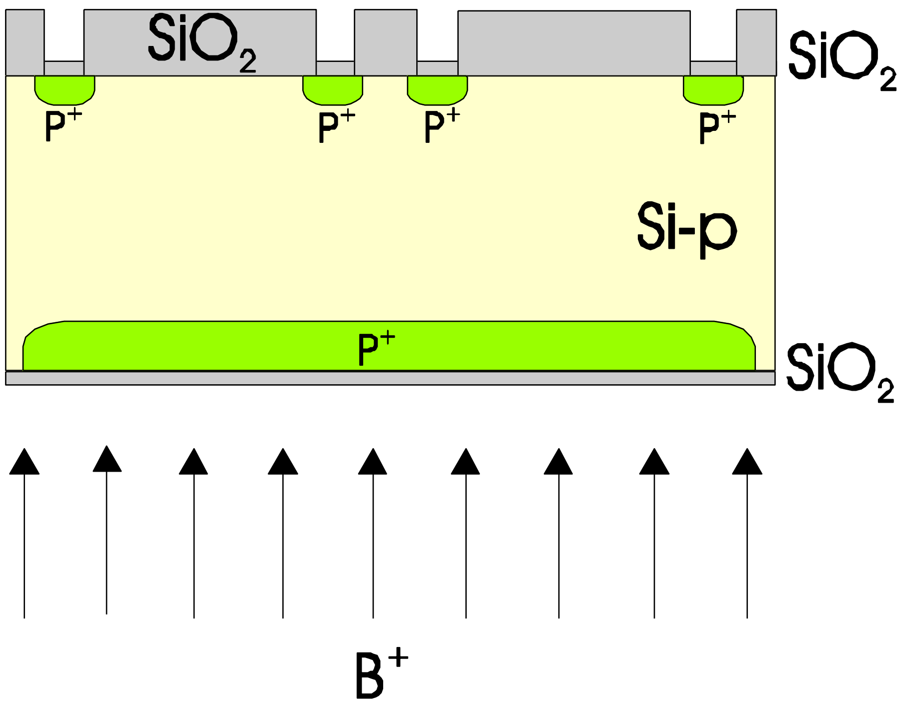
- Thin oxide
  - O_2
  - 36.5 nm
  - 950 ºC

N-on-P strip detector fabrication process



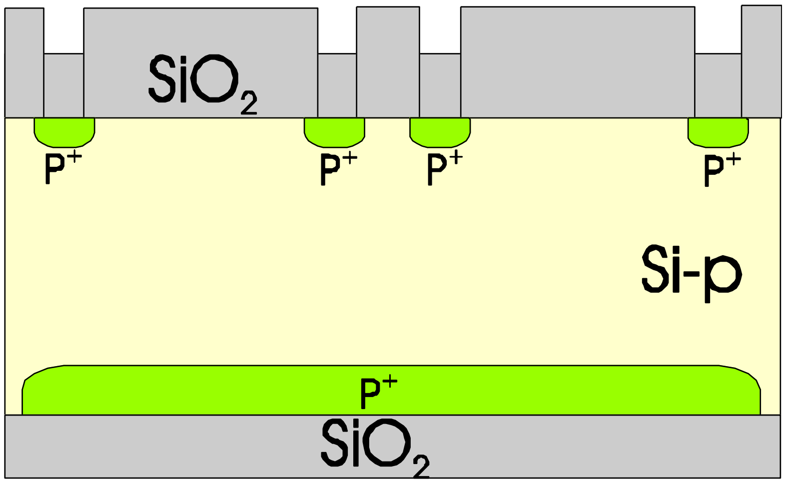
- **Front side Boron ion implant**
  - **P-stops**
  - **10^{12} - 10^{14} cm^{-2}**
  - **50 keV**

N-on-P strip detector fabrication process



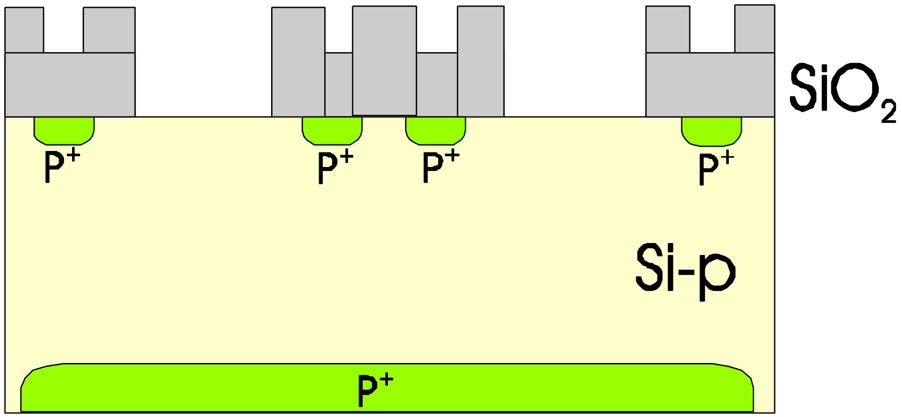
- **Back side Boron implant**
  - **Backside contact**
  - **10^{15} cm^{-2}**
  - **50 keV**

N-on-P strip detector fabrication process



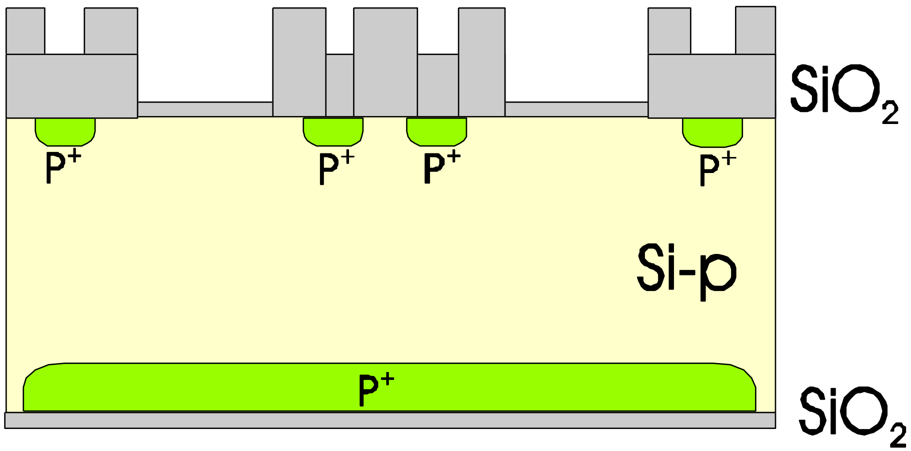
- Thick oxide re-growing
  - 800 nm
  - 1100 ºC

N-on-P strip detector fabrication process



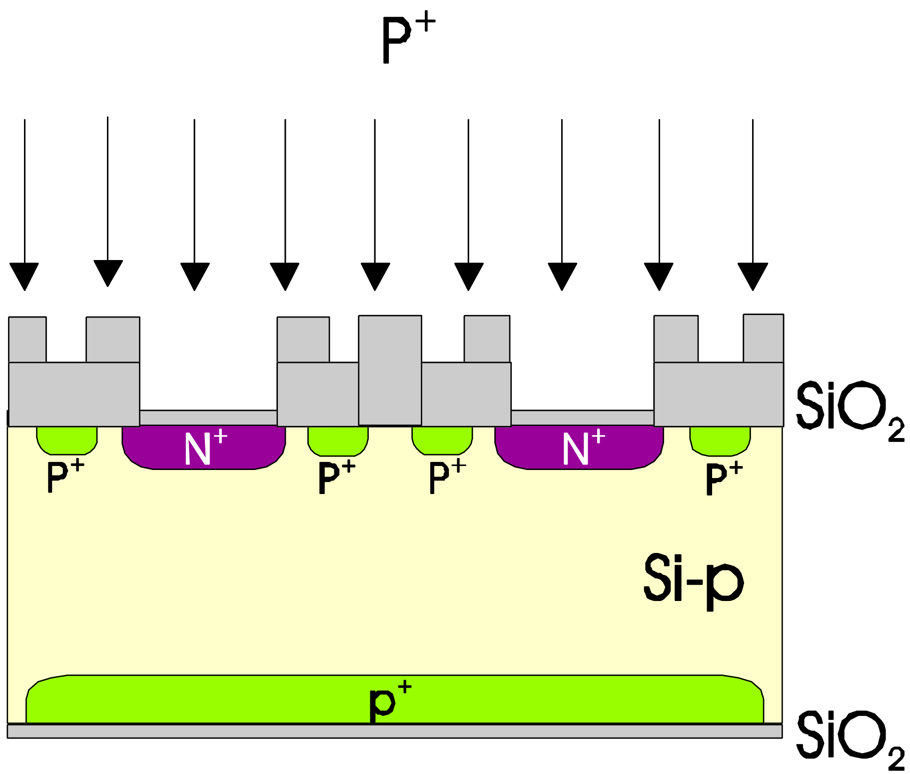
- 2nd Photolithpgraphy
- N+ junctions
- Wet etching
- Photoresist removal

N-on-P strip detector fabrication process



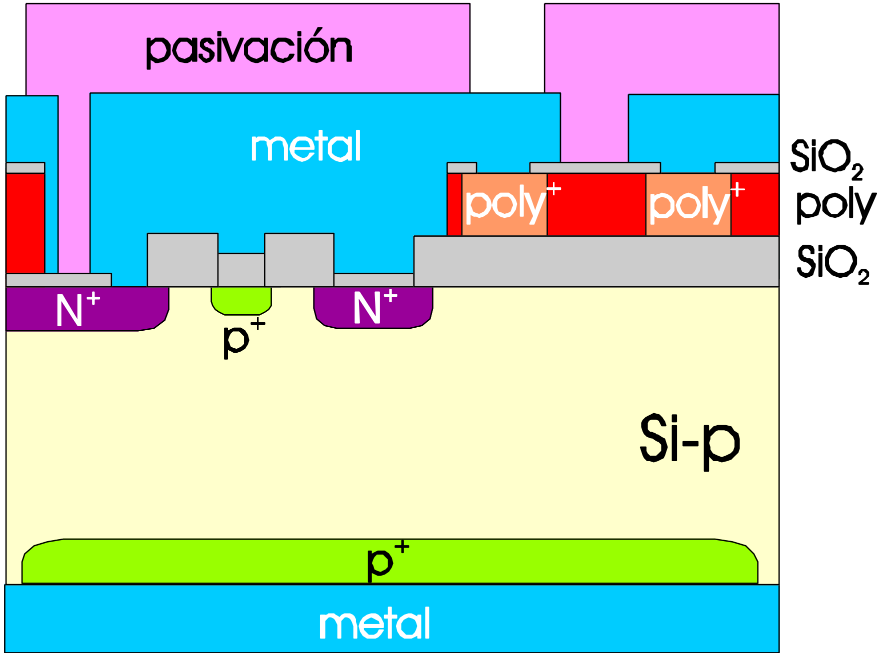
- Thin oxide growing
  - O_2
  - 36.5 nm
  - 950 ºC

N-on-P strip detector fabrication process



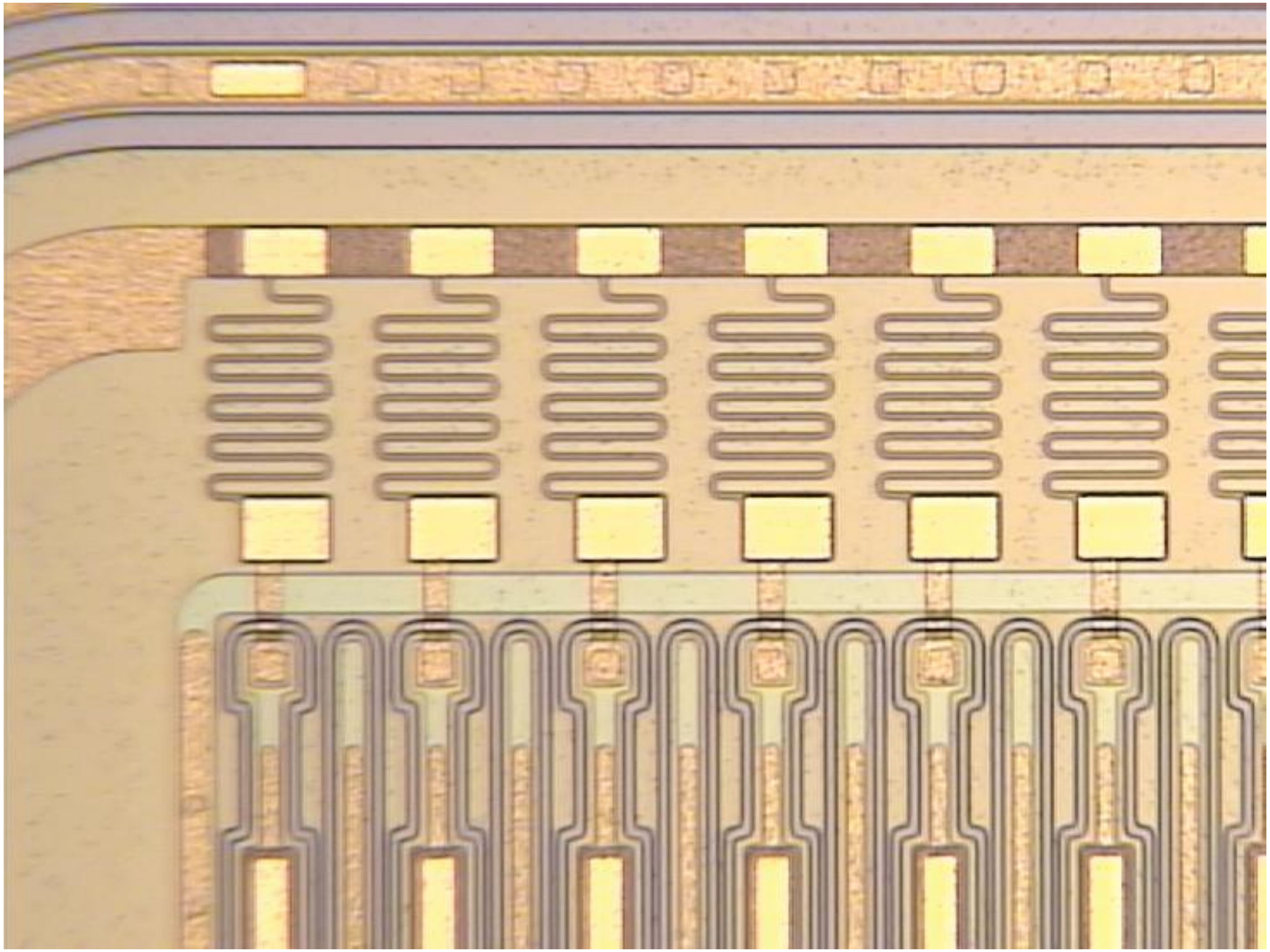
- **Phosphorus implant**
  - **Strips junctions**
  - **$4.2 \cdot 10^{15}$ cm^{-2}**
  - **100 keV**

N-on-P strip detector fabrication process



- From this point the rest of the processing is similar to P-on-N devices
- Photolithographies
  - 3rd) Polysilicon
  - 4th) Low resistivity poly
  - 5th) Contact opening
  - 6th) Metal
  - 7th) Passivation

N-on-P strip detector fabrication process



N-on-N strip detector fabrication process

- **There is one standard technology missing to study**
- **N-on-N technology is very complex**
- **In P-on-N and N-on-P all the photolithographic processes are performed on the front side**
  - **(P-stops)**
  - **P+ or N+ implants**
  - **Polysilicon**
  - **Low resistivity poly**
  - **Contact opening**
  - **Metal**
  - **Passivation**
- **In N-on-N it is necessary to structure the backside, and there are 3 photolithograpic steps to be performed on the backside**
  - **P+ implants with SiO_2 mask**
  - **Contact opening**
  - **Metal**
- **It is necessary to use a double side aligner**
- **The cost is high, and it is not commonly used in LHC experiments**

Epilogue

- There are other advanced micro fabrication techniques:
  - RTP: Rapid Thermal Processing
  - CMP: Chemical Mechanical Polishing
  - Wafer bonding
  - DRIE: Deep silicon etching
  - Metal via formation
  - Bump bonding
  - DWA: Direct wafer attachment
  - …
- And many other advanced detectors:
  - Double side detectors
  - 3D detectors
  - Slim edge
  - Thin detectors
  - Trenched detectors
  - Depfets
  - MAPS
  - …

We had not time to study them today
Maybe we can continue in another occasion