Fabrication and Characterization of PN Junction Diodes and Photodiodes

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Outline

- Introduction
- Objectives
- Concept Building
- Experimentation
- Discussion
- Acknowledgement

Introduction

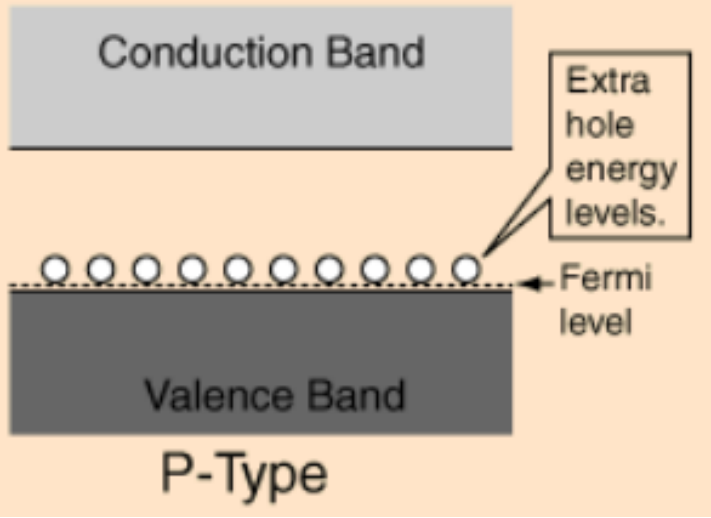
- Microelectronic Fabrication is an integral part of Semiconductor Industry
- Fabrication Skills are highly demanded by Recruiters and Industry Experts
- These skills are essential to be a Process Engineer, Yield Engineer, Fab Engineer
- Process engineers brings Product into the Physical World from design phase
- Processing was crucial in building finFETs, 3D NAND and continuing Moore’s Law

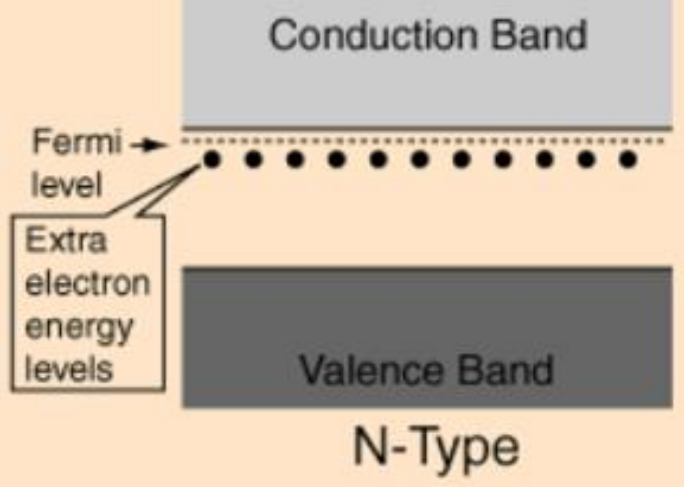
Objectives

- To understand working mechanism of P-N diodes and Photodiodes
- To learn diode fabrication techniques
- To perform fabrication of P-N diodes and Photodiodes and characterize them
- To analyze the characterization data and assess the performance

Concept Building

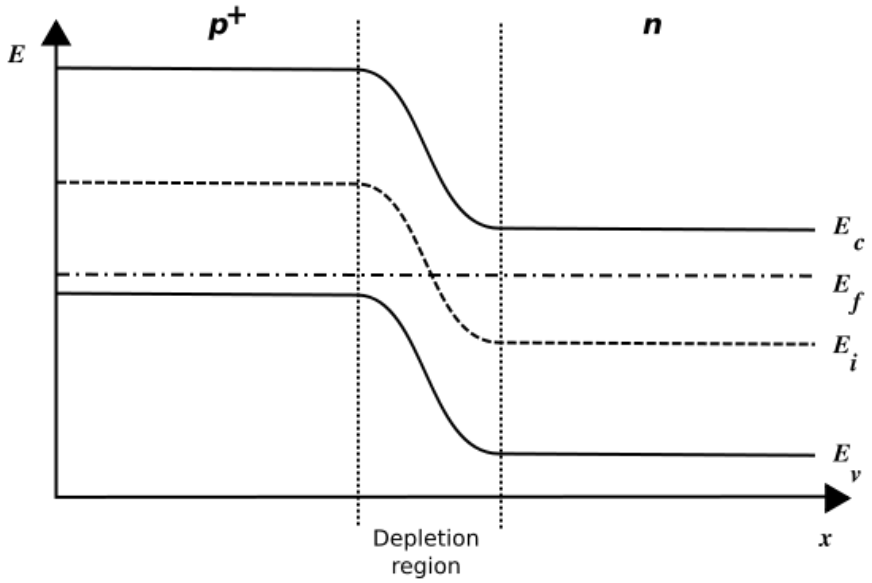
- Fermi Level in Semiconductors:
  - Near Conduction Band in N-Type Semiconductor
  - Near Valence Band in P-Type Semiconductor





Concept Building

- When P- N Type Materials are joined their Fermi Levels Align with each other
- Conduction and Valence Band bend in the process



Concept Building

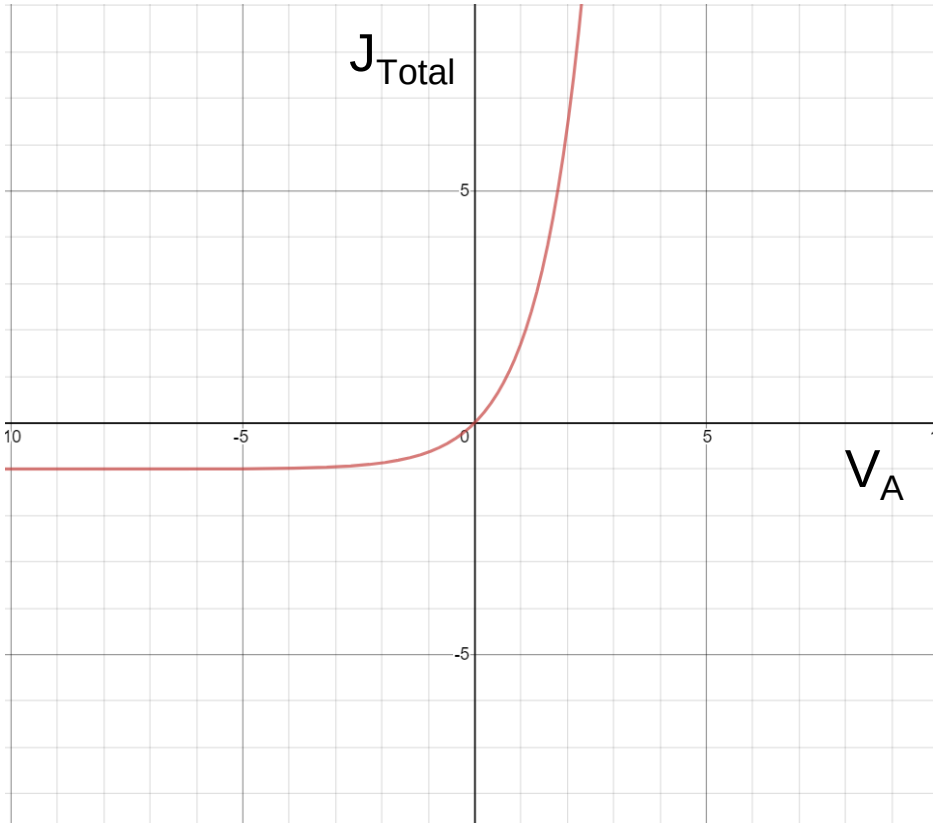
- Current through the Junction
  - Diffusion of Majority Carrier Across Junction $J_{Diffusion}$
  - Drift of Minority Carrier Across Junction J_{Drift}
- Directionally Opposite to each other
- Under zero External Bias, they cancel each other
- Under External Bias,

$$J_{Total} = J_{Diffusion} + J_{Drift}$$

$$J_{Total} = J_o * e^{\frac{(V_A - V_{BI})}{K_B * T}} - J_o$$

Concept Building

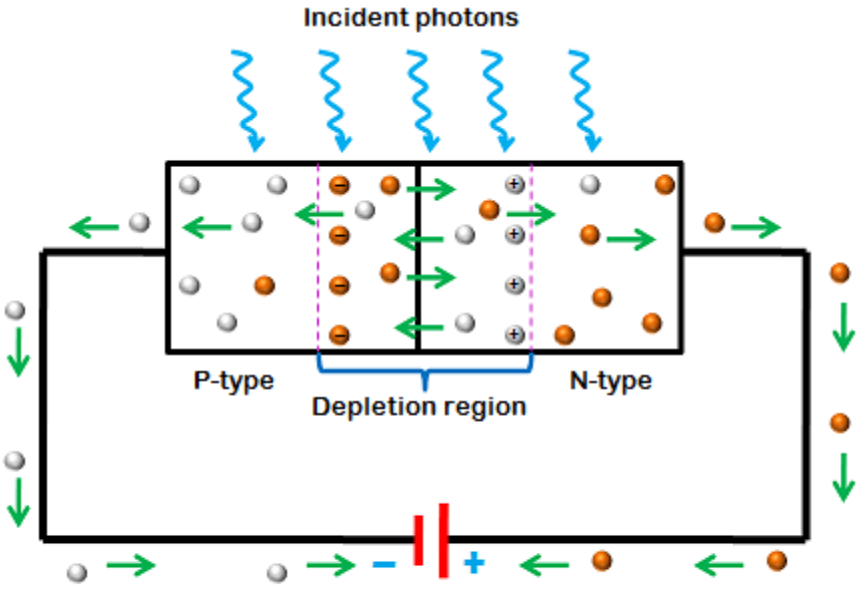
- In F Bias, Diffusion current dominates
- In R Bias, Drift current dominates



Typical I-V curve

Concept Building

- Photodetection: Shining Light on any semiconductor with energy more than its Band Gap and detecting current

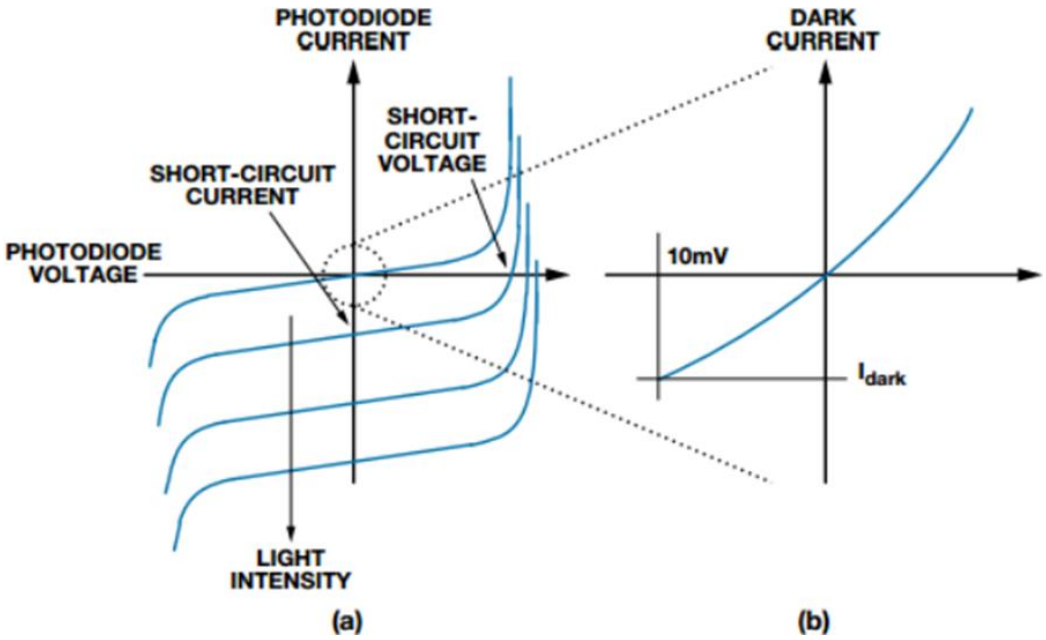


PN Junction photodiode

www.physics-and-radio-electronics.com

Concept Building

- Key Parameter: Ratio of R Bias Current in presence of light to R Bias Current in absence of light.(I_{ph}/I_{dark})



Fabrication

The fabrication consists of the following steps

- Oxidation
- Photolithography
- Etching
- Spin On Glass Doping and Diffusion
- Metalization
- Liftoff
- Rapid Thermal Annealing

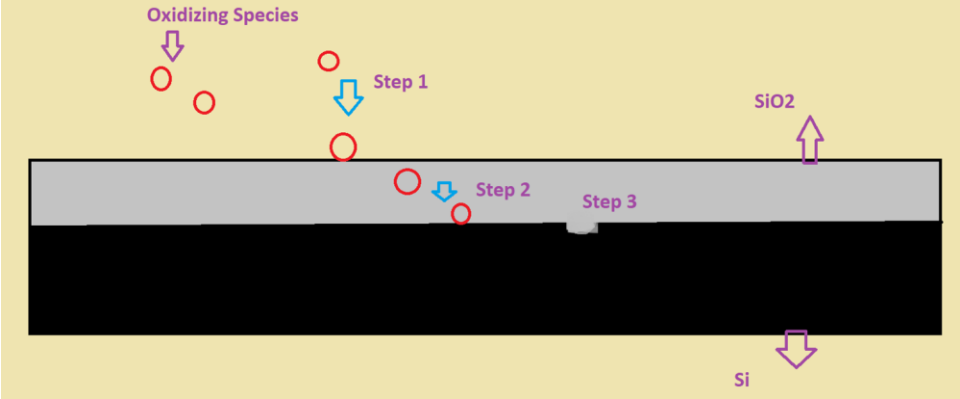
Oxidation

- Oxide Layers are present on the substrate to electrically isolate different devices and due to their excellent dielectric properties
- We can either grow or deposit oxide layer onto the substrate. Oxides that are grown on the substrate ensure pure oxide-substrate interface.
- Oxides can be grown by

Wet Oxidation	**Dry Oxidation**
$Si + 2H_2O \longrightarrow SiO_2 + 2H_2$	$Si+O_2 \longrightarrow SiO_2$
Faster growth rate	Slow Growth Rate
Low Quality Oxide Layer	High Quality Oxide Layer

The Kinetics of Oxidation follow the Deal Grove Model

1. The oxidising species should be transported from the bulk of the gas to the oxide-gas interface
2. The species must diffuse through the oxide to the oxide - Si interface
3. Reaction occurs at the interface



At the start of the oxidation process the rate is limited by the third step. Once oxidation has proceeded for a short period of time the rate limiting step is now step 1 due to the formation of an oxide layer

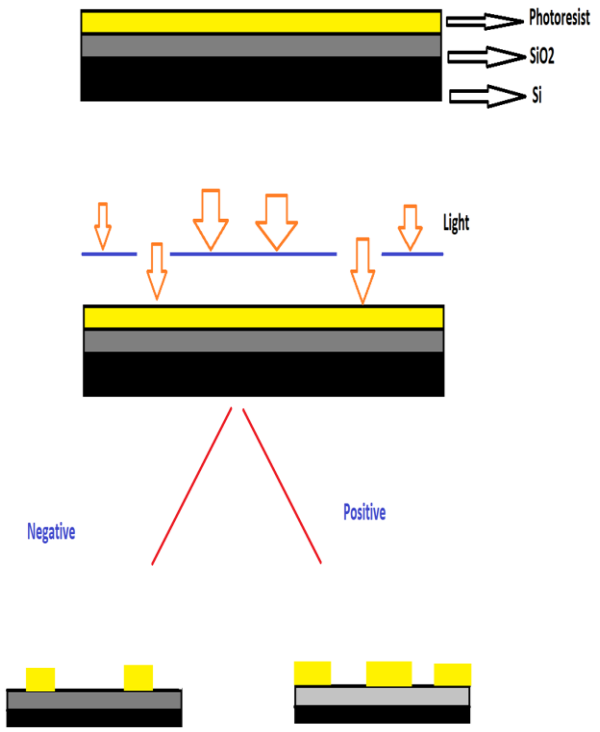
Photolithography

- Photolithography is a process used in microfabrication to pattern parts of a thin film or the bulk of a substrate.

The photolithography process involves the following steps

- Surface Preparation
- Spin Coating
- Pre Bake (Soft Bake)
- Alignment
- Exposure
- Development
- Post- Bake (Hard Bake)

Karl Suss MJB 3 Mask Aligner



Photoresists consists of 3 main components, resin, sensitizer and solvent.

Photoresist can be classified into two types based on its reaction to incident light

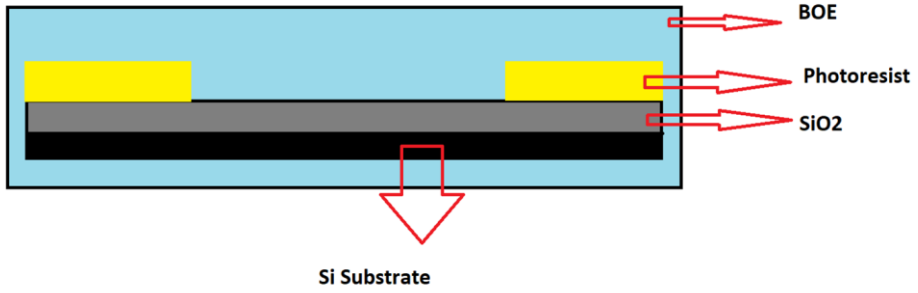
Positive Photoresist	Negative Photoresist
Resin Dissolves when exposed to light due to chain scission	Cross linking occurs and the photoresist strengthens when exposed to light
We get a positive image of the mask	Negative image of the mask
What shows goes	What does not show goes
Overcut Profile	Undercut Profile

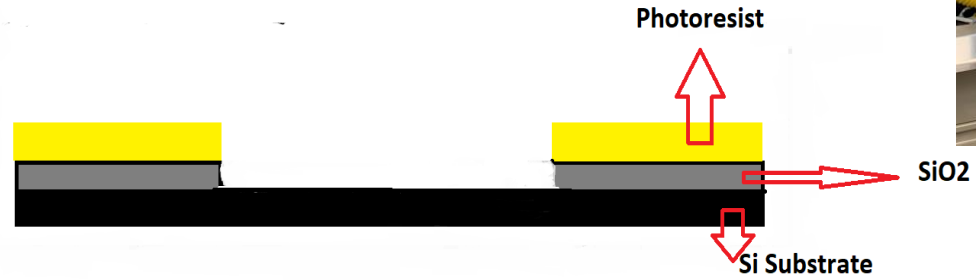
Etching

- Etching is a subtractive technique that uses principle of corrosion to dissolve and remove the desired material in the desired area. We use it to etch the oxide to as determined by the photoresist patterned onto the wafer
- There are two main types of etching

Wet Etching	Dry Etching
Fast Etch rate	Slow Etch Rate
Isotropic Etch	Anisotropic Etch
Highly Selective	Low Selectivity

- BOE (Buffered Oxide Etchant) is a chemical used for wet etch which is a mixture of Buffer NH_4F and HF.
- HF is a highly corrosive acid and hence safety is of the utmost importance. Ensure all PPE is worn(Neoprene suit and Gloves) and keep calcium gluconate cream for emergencies.





SoG Doping and Diffusion

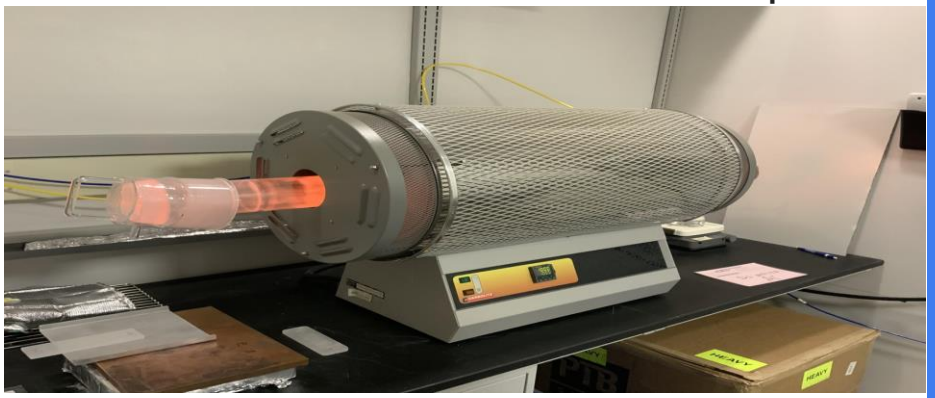
Doping is the intentional introduction of impurities into an intrinsic semiconductor for the purpose of modulating its electrical, optical and structural properties.(wikipedia-doping_semiconductor)

The dopants need to be redistributed through diffusion.

Diffusion - Any material tends to redistribute itself to reduce concentration gradient.

N-type dopant - Phosphorus

In this process, a Group 5 element behave as an electron donor, and Group 3 element as an acceptor.

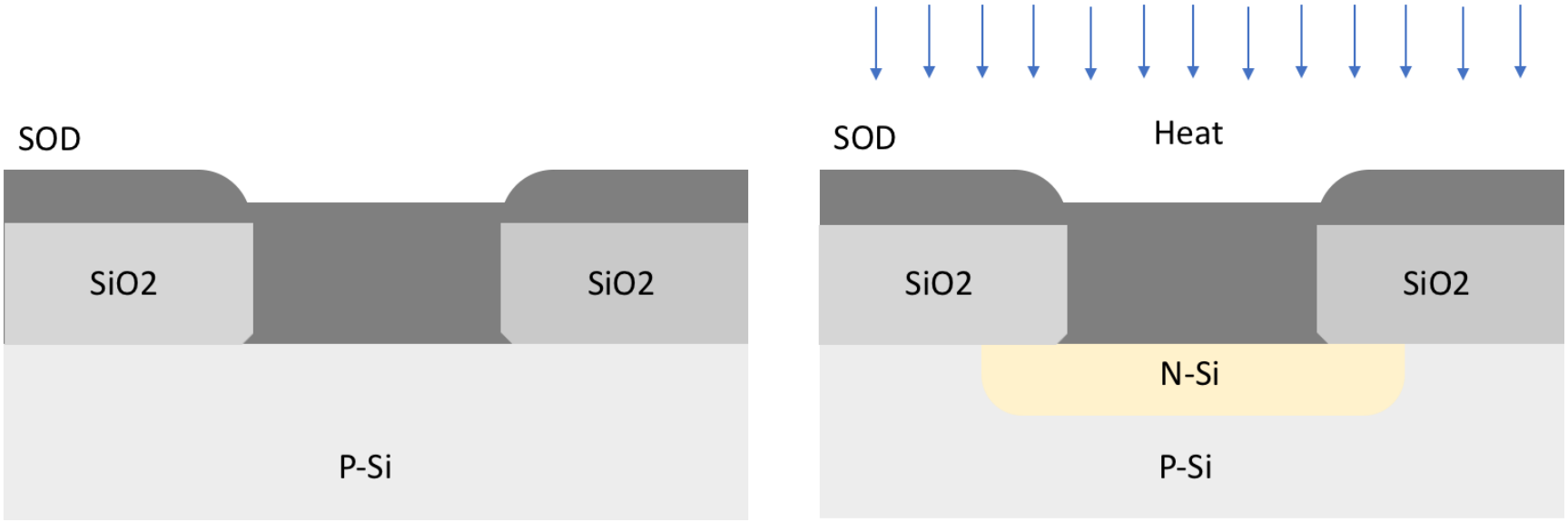


SoG Doping and Diffusion

Spin-on-glass (SOG) is a mixture of silicon dioxide and dopants either group 3/group 5 elements, suspended on a solvent solution.

SOG is applied to a doped silicon wafer by spin coating just like photoresist. Doped SOG is called Spin-on Dopant (SOD).

After this, the dopants from SOG diffuse into the wafer by subjecting it to a high temperature of about 1000℃



SoG Doping and Diffusion

Pros

- Even and constant doping with high yield
- No implantation defects
- No use of toxic gases
- Not a costly process
- Application for variable structure

Cons

- Unsteady on high aspect ratio trench
- Probable of particulate defects
- Toxic property of some SOD
- Cause of losing field oxide
- Residue degrading systems

Metallization

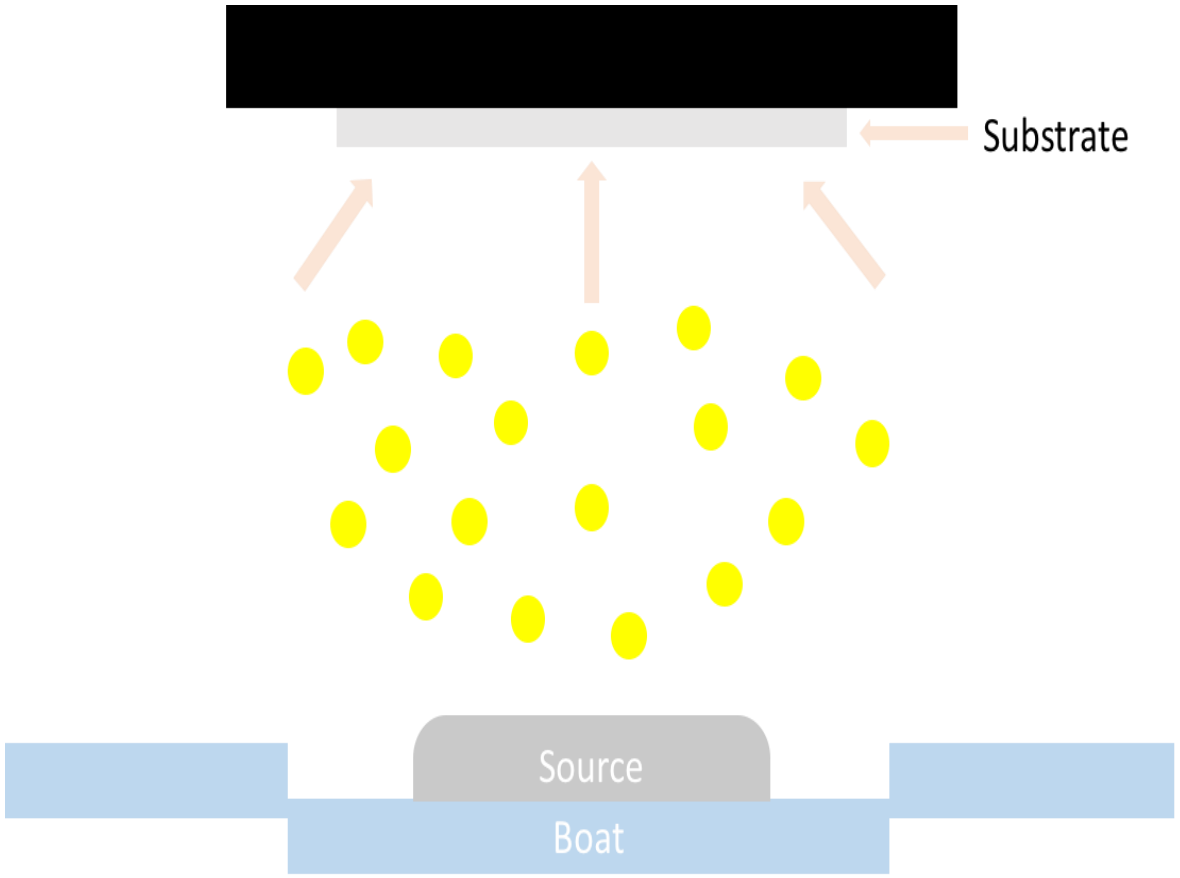
Metallization is a process that produce contact(making signal in and out) and interconnection(making connect line from device to other devices).

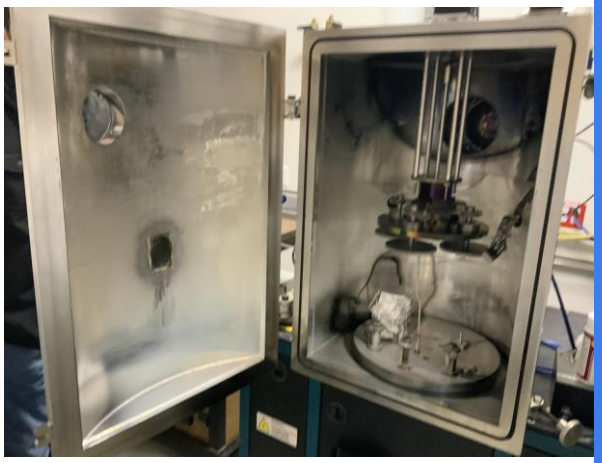
- The desired properties of the metallization
- Low resistivity.
- Easy to form.
- Easy to etch for pattern generation.
- Should be stable in oxidizing ambient , oxidizable.
- Mechanical stability; good adherence, low stress.
- Stability throughout processing including high temperature sinter, dry or wet oxidation, gettering, phosphorous glass (or any other material) passivation, metallization.

Aluminium is commonly used to create metal contacts

Metallization

Thermal Evaporation





PVDx1800

Metallization

Lift-off process

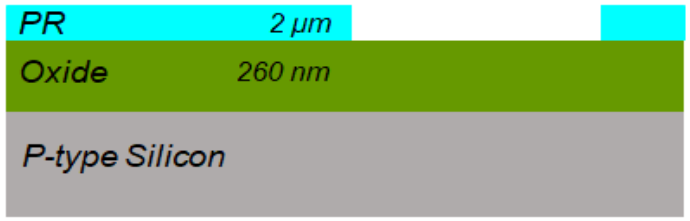
Photolithography

Deposition

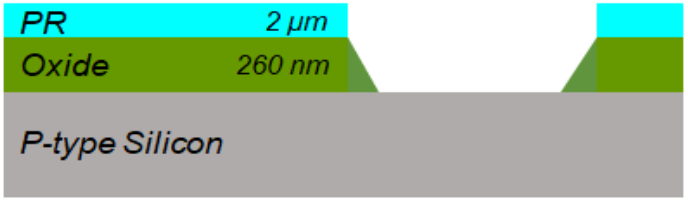
PR remove

Diode Fabrication

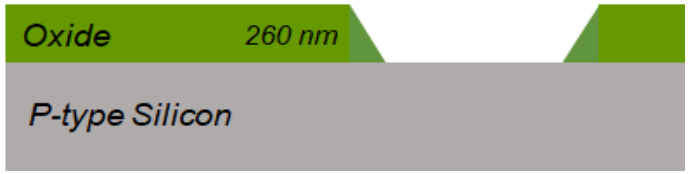
Photolithography for n-doping



BOE Etching



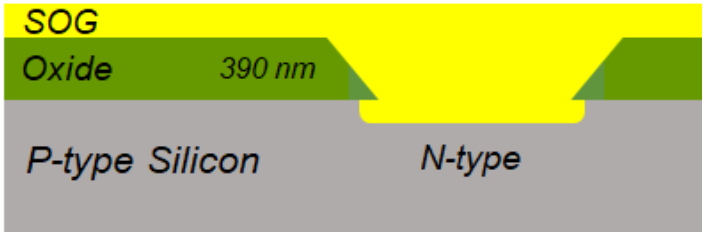
PR Stripping



Spin Coat	PR name: AZ1512, Speed: 1800 rpm, Time: 30 sec
Pre-bake	Temperature: 112°C, Time: 120 sec
Exposure	Intensity: 7.5 mW/cm³, Dosage: 110 mJ/cm³, Time: 23 sec
Develop	Developer: AZ300, Time: 75 sec
Etching	Etch rate: 100 nm/min, Time: 180 sec
PR Strip	Time in Acetone/IPA/DI water: 120 sec/15 sec/5 min
Descum	O2/N2 flow rate: 0.08/0.4 sccm, Time: 1 min, RF power: 90 W

Diode Fabrication

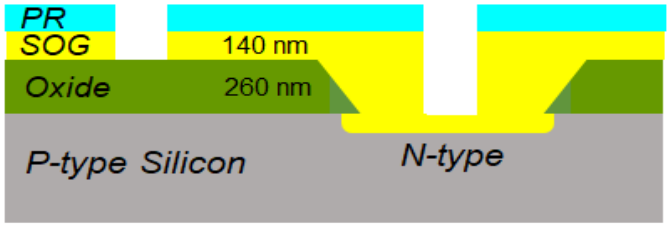
SOG Coating + Thermal diffusion



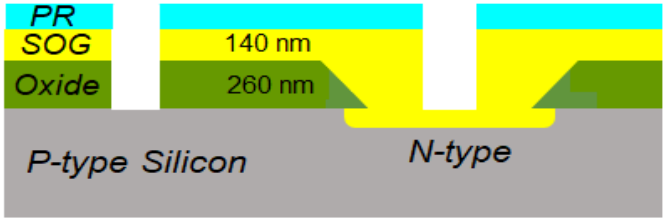
SOG Spinning	Speed: 3000 rpm, Time: 30 sec
Bake	Temperature: 175˚C, Time: 8 mins
Thermal Diffusion	Temperature: 1000˚C, N2 flow rate: 1 L/min, Time: 1 hr 30 mins

Diode Fabrication

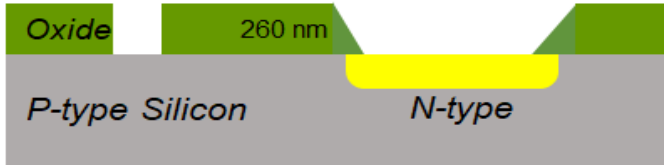
Photolithography #2 for P and N vias



BOE Etching

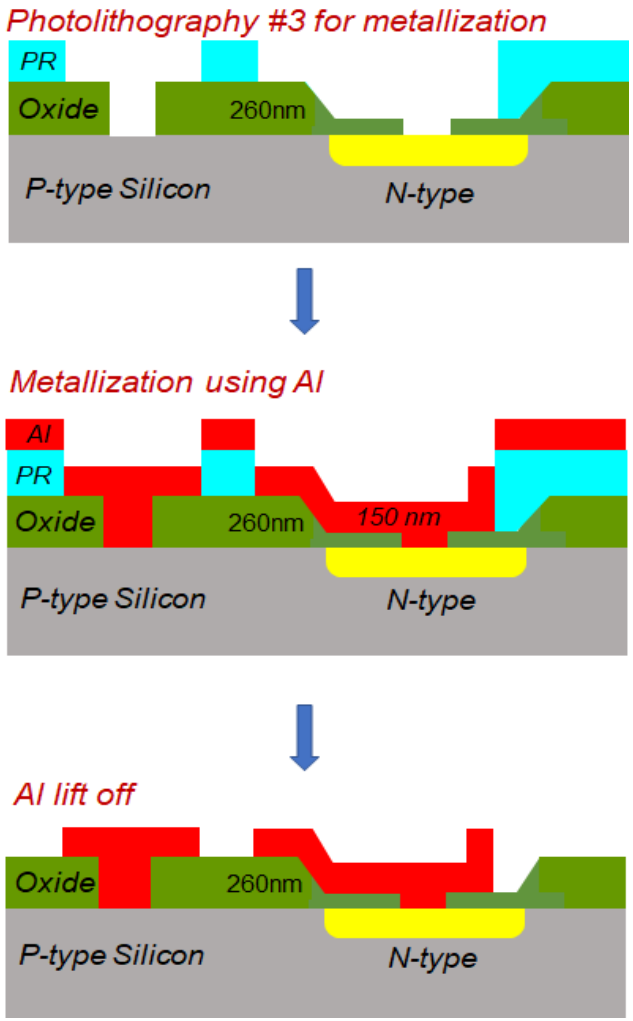


Strip off PR + Drive-in



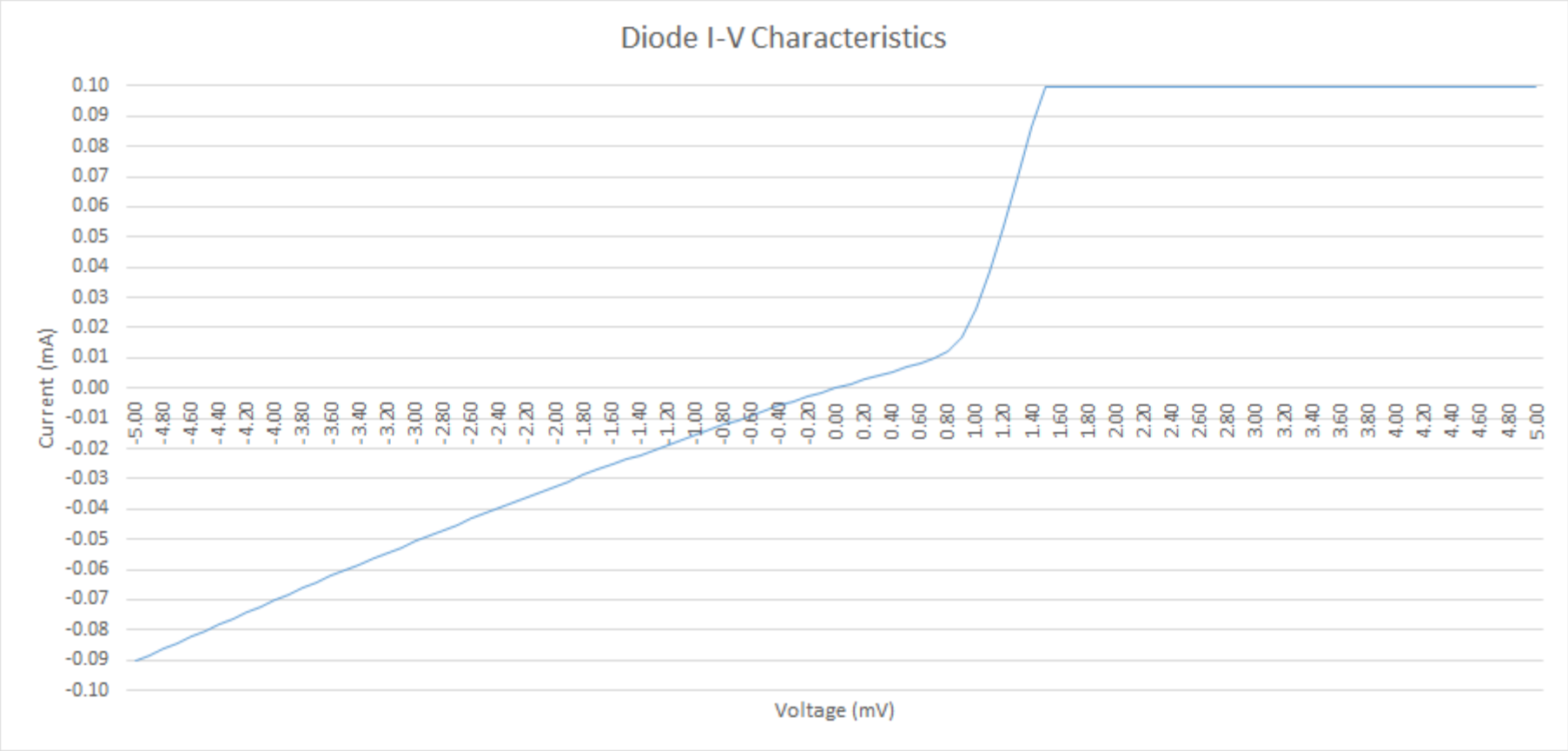
PR Coating	PR name: AZ1512, Type: Positive, Speed: 1800 rpm, Time: 30 sec
PR Pre-bake	Temperature: 112°C, Time: 2 mins
Exposure	Mask type: clear field, Intensity: 8 mW/cm³, Dosage: 110 mJ/cm³, Time: 15 sec
Developing	Developer: AZ300MIF, Time: 75 sec
Descum	O2/N2 flow rate: 0.08/0.4 sccm, Time: 1 min, RF power: 90 W
Post-development bake	Temperature: 112°C, Time: 2 mins
Etching	Etch rate: 100 nm/min, Time: 4 mins
PR strip	Time in Acetone/ IPA/ DI water: 2 mins/ 10 sec/ 5 mins
Descum	O2/N2 flow rate: 0.08/0.4 sccm, Time: 1 min, RF power: 90 W
Drive-in	Temperature: 1000°C, Time: 1 hr, N2 flow rate: 1 L/min

Diode Fabrication



PR Coating	PR name: AZNLOF2035, type: negative, Spin speed: 3500 rpm, Time: 30 sec
Pre-bake	Temperature: 112°C, Time: 180 sec
Exposure	Mask type: clear field, Intensity: 6.4 mW/cm³, Dosage: 110 mJ/cm³, Time: 19 sec
Develop	Developer: AZ300MIF, Time: 150 sec
Descum	O2/N2 flow rate: 0.08/0.4 sccm, Time: 1 min, RF power: 90 W
Etching	Time: 30 sec
Thermal Evaporation	Metal: Al, Temperature: 112°C, Time: 10 mins, No.of pellets: 6, Power: 180W, Pressure: 1.7 E-5 torr
Lift off	Temperature of water bath: 70°C, Time: 15 mins

Results P-N Diode



P-N Diode Continued

- Reverse Bias: ohmic behavior with linear relation between voltage and current
- Forward Bias: Ideal forward diode behavior
- This ohmic behaviour in the reverse bias can be attributed to the presence of a parasitic resistive channel in parallel to the P-N diode channel.

P-N Diode Continued

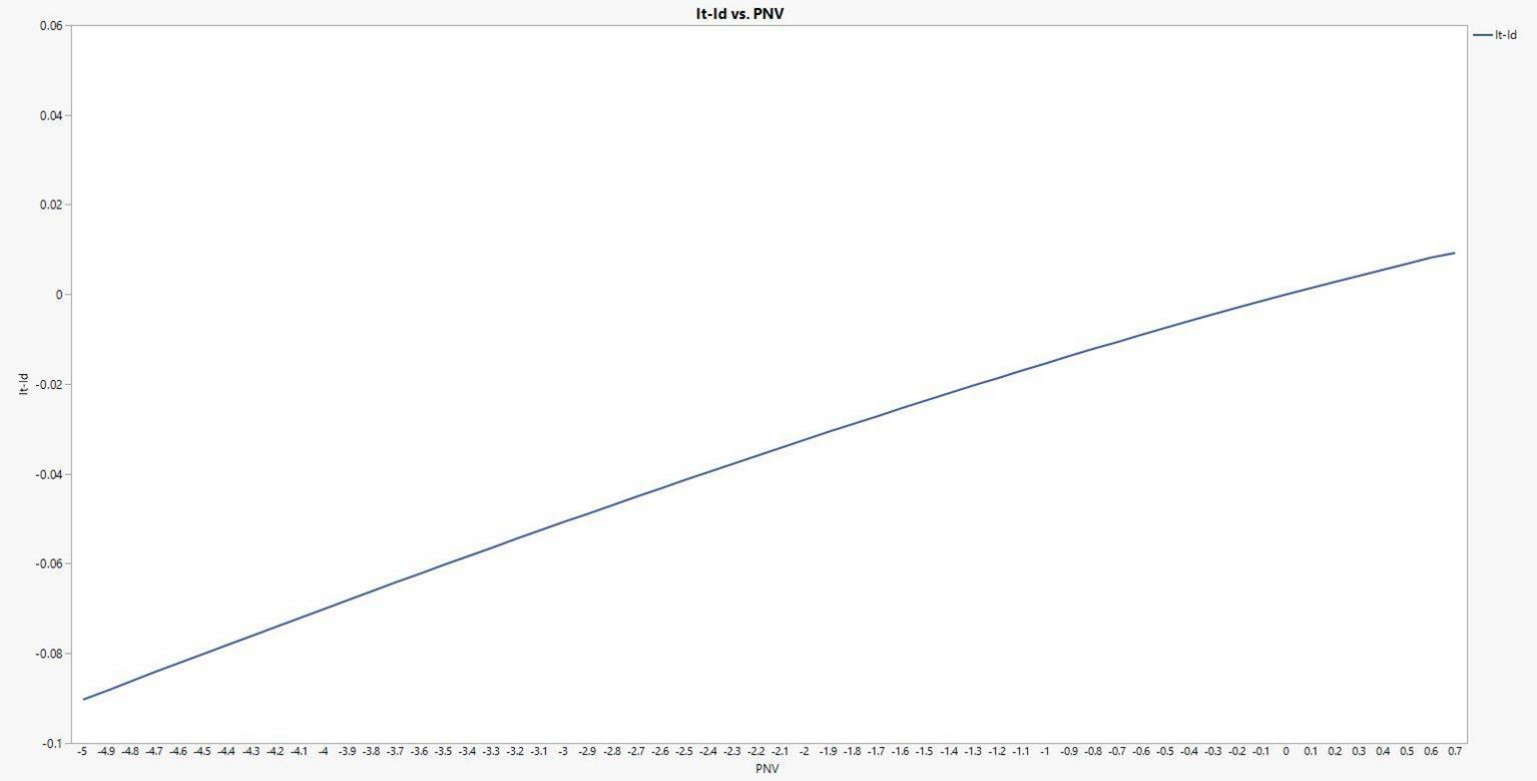
- The current flowing through the resistive channel/branch will be the total current in the defective diode circuit minus current through the diode channel/branch.

$$I_{Total} = I_{Diode} + I_{Resistor}$$

$$I_{Resistor} = I_{Total} - I_{Diode}$$

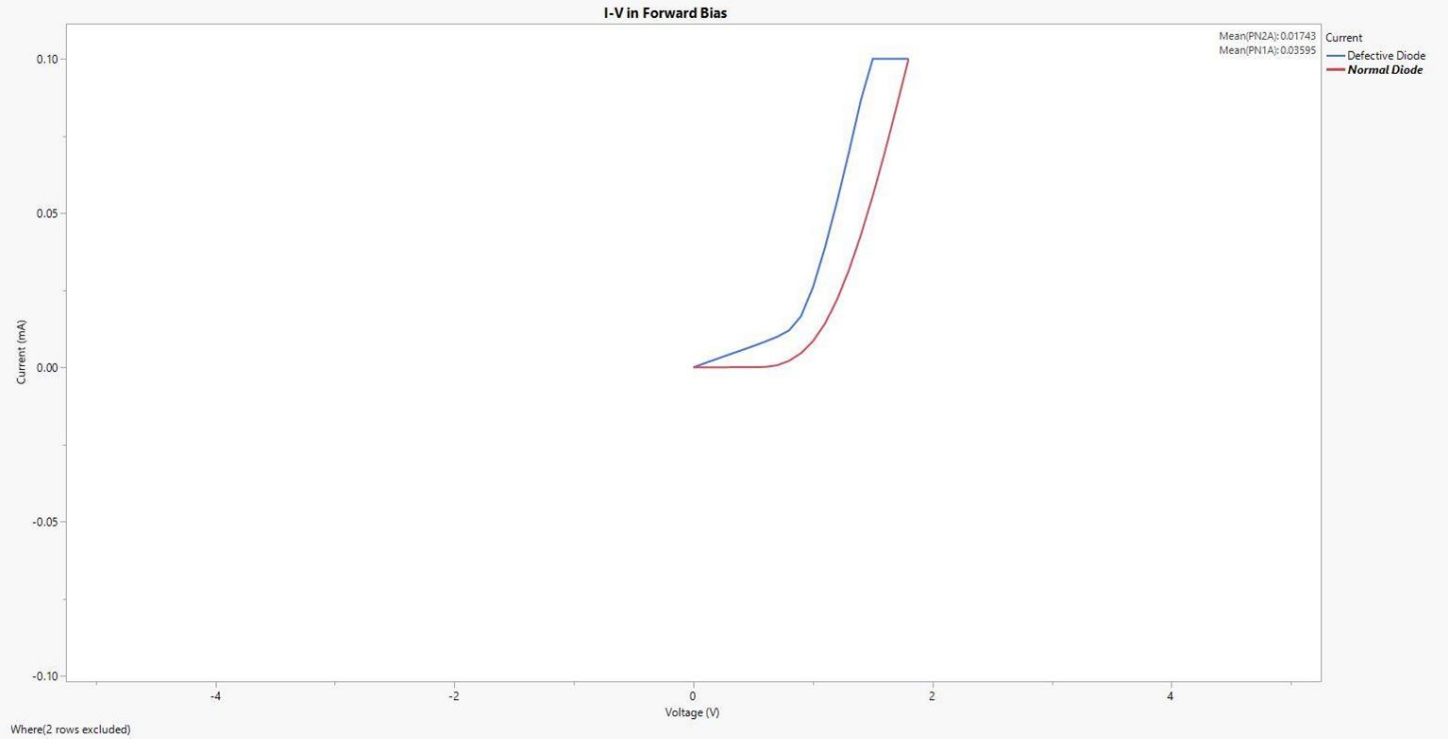
P-N Diode Continued

- Plot this difference against voltage in the V_{BR} to V_{TH} Region.



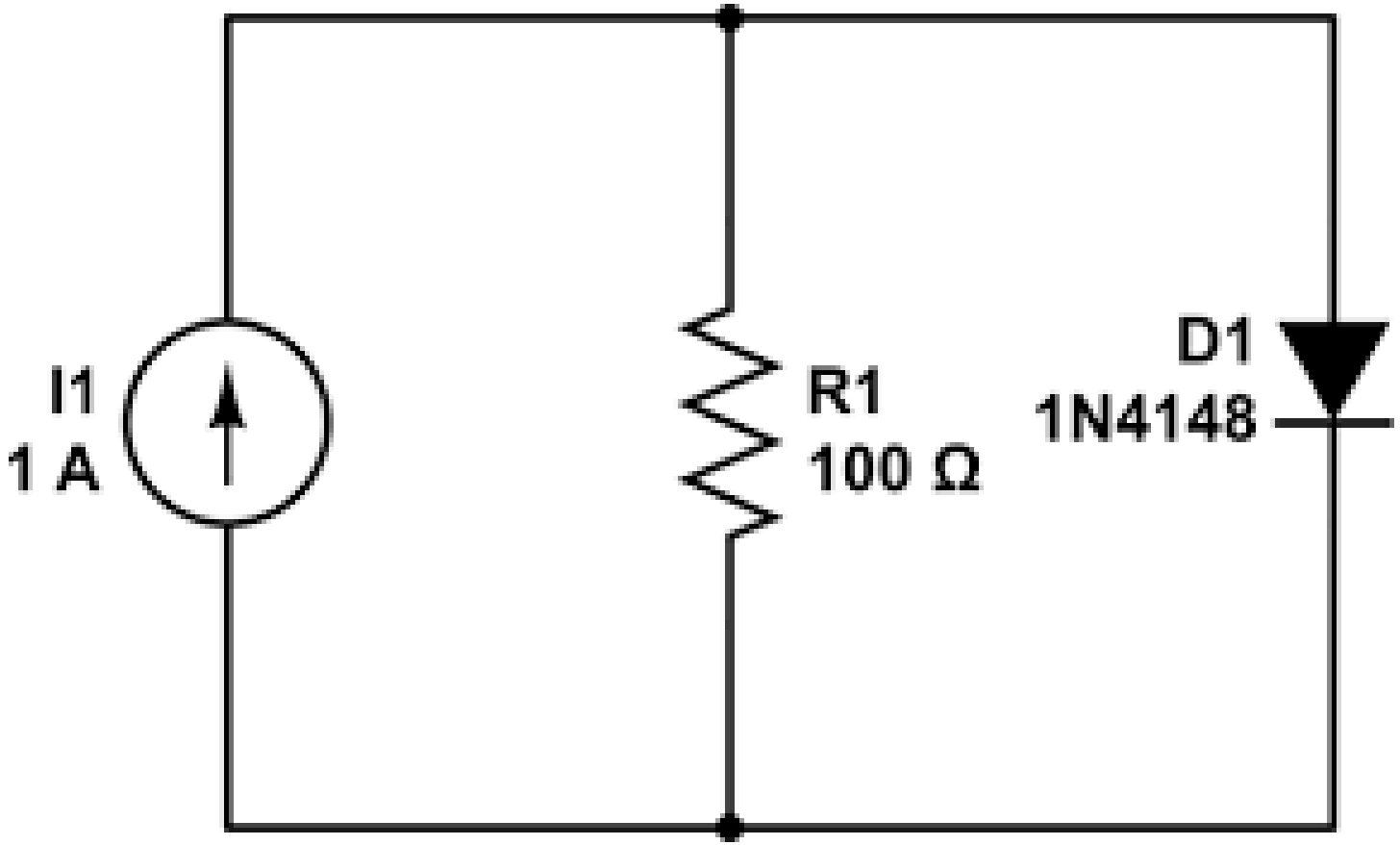
P-N Diode Continued

- The red curve is the FB curve of normally working diode and blue is that of defective diode.



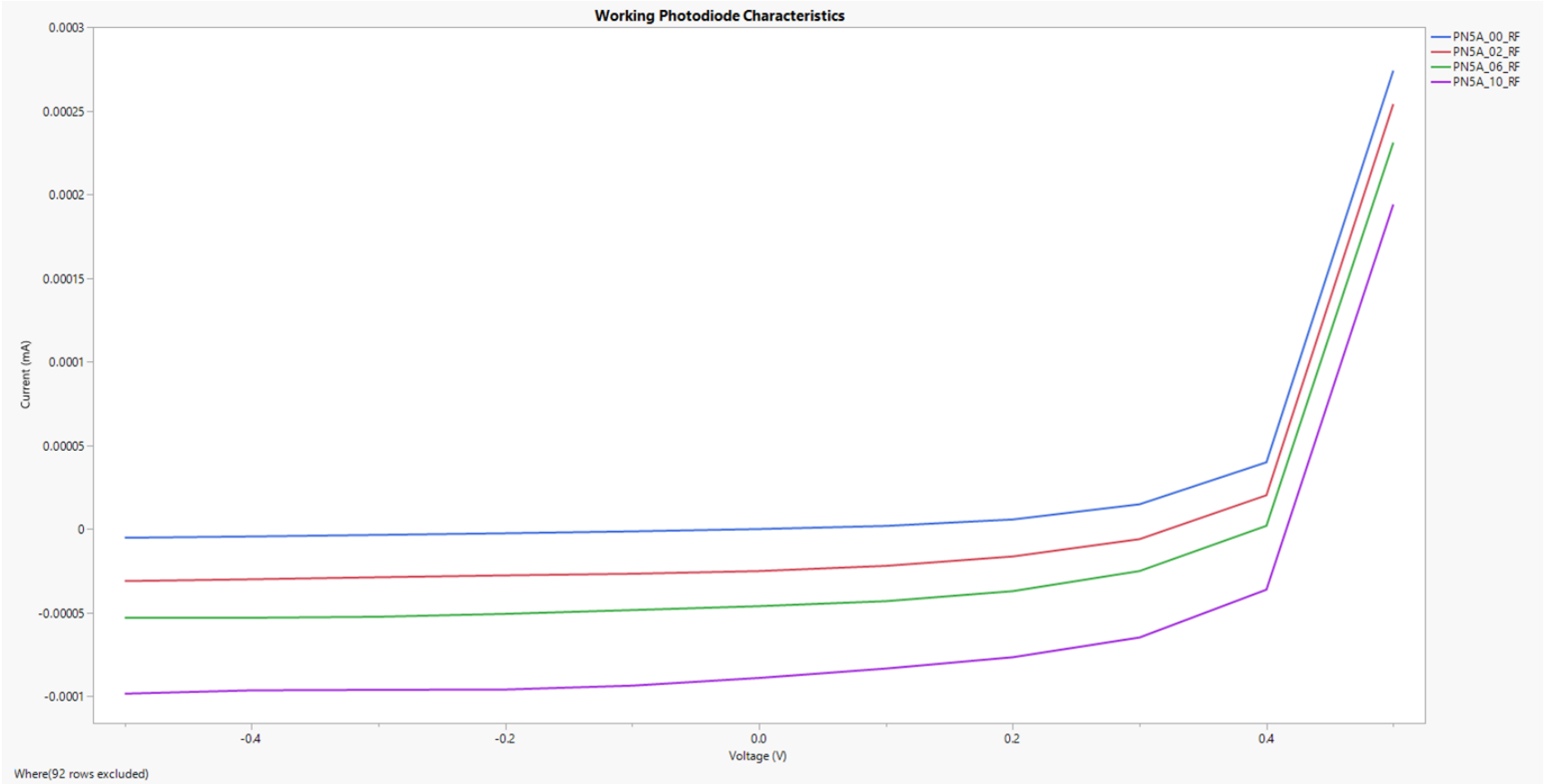
P-N Diode Continued

Our interpreted circuit diagram



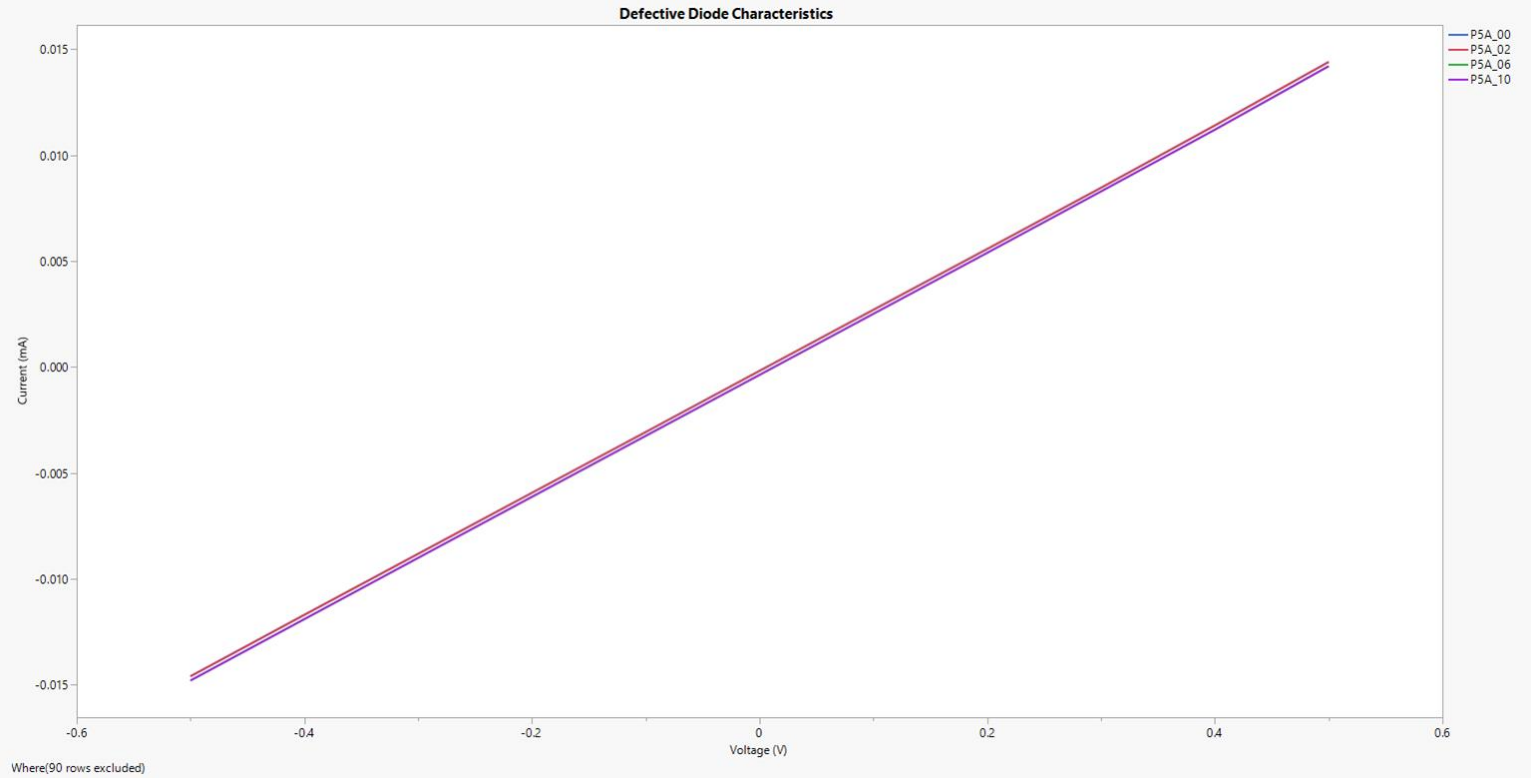
Photodiode Results

- Expected output



Photodiode Results

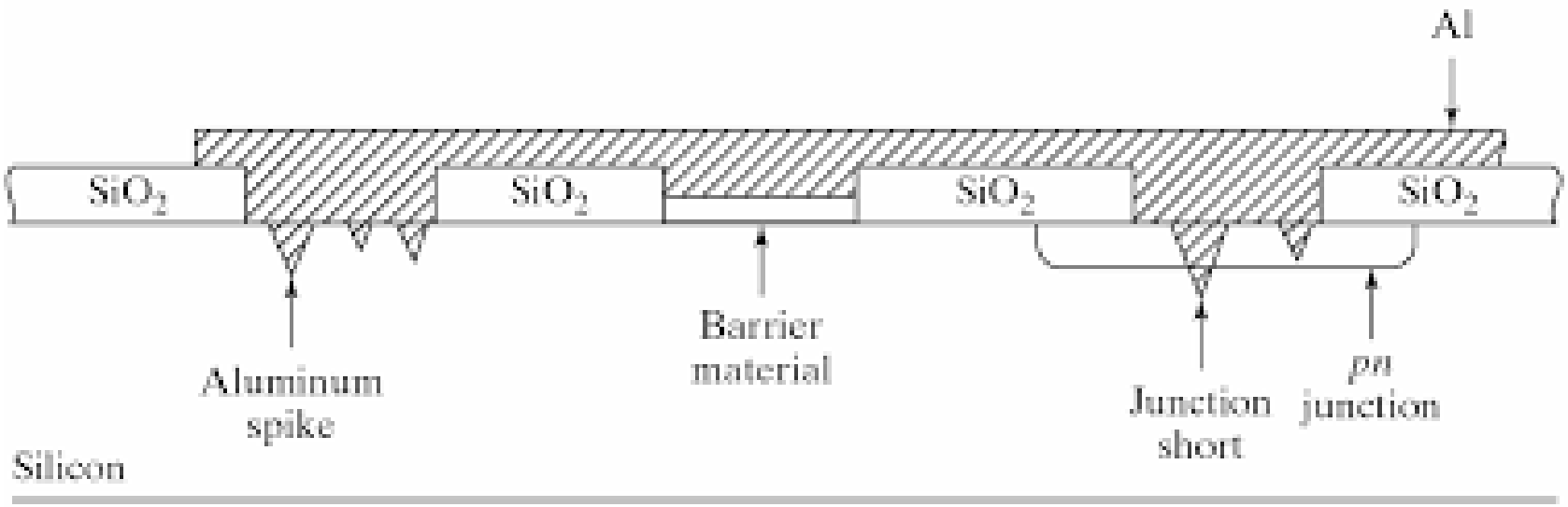
- Our photodiodes output



Photodiodes Continued

- Possible causes of Parasitic resistive channel:

  Metal Spike causing short across N region



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- A big thank you to the Nanoscale Research Facility for a state of the art teaching lab.
- We thank the ECE Dept for providing this course