Using an Alumina (Al_2O_3) Layer to Achieve Strip Isolation in P-Type Silicon Devices

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with

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- Marc Christophersen and Bernard Phlips (NRL) have shaped this project and have been processing the ATLAS07 p-type sensors

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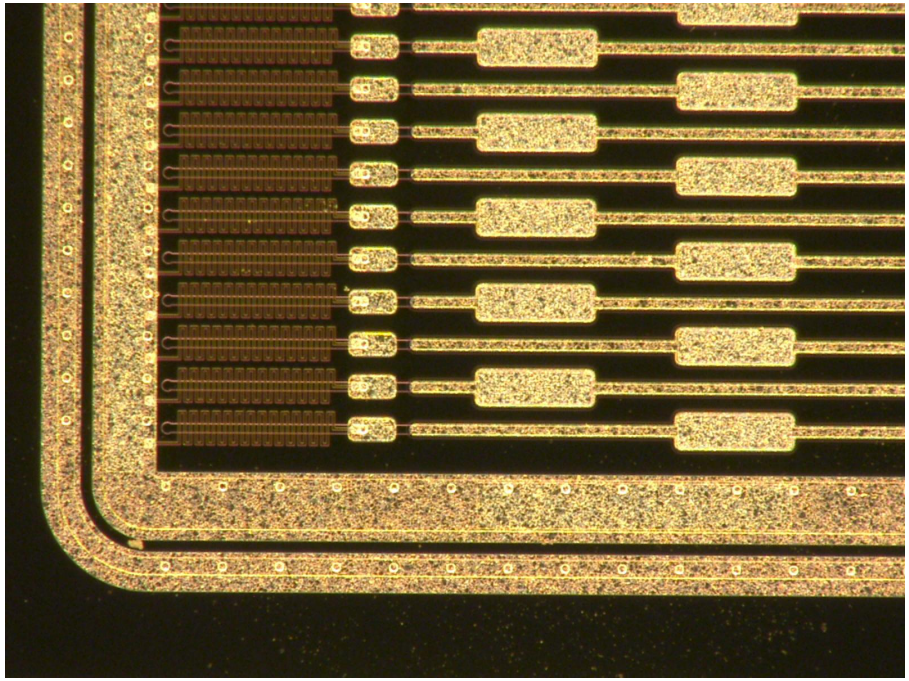
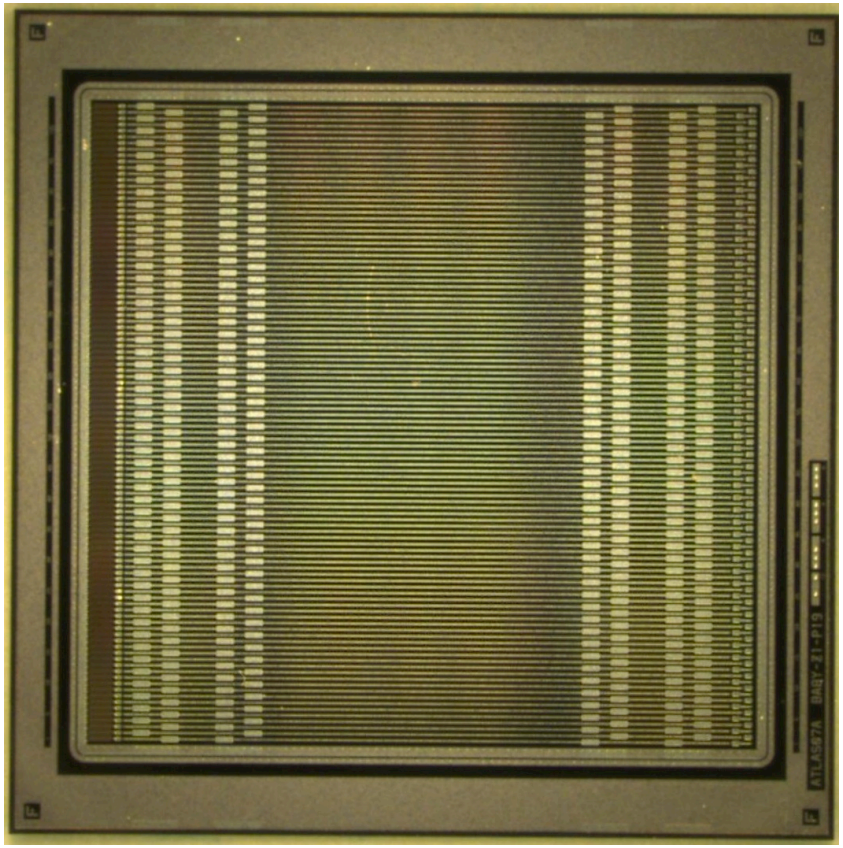
Silicon Strip Detectors

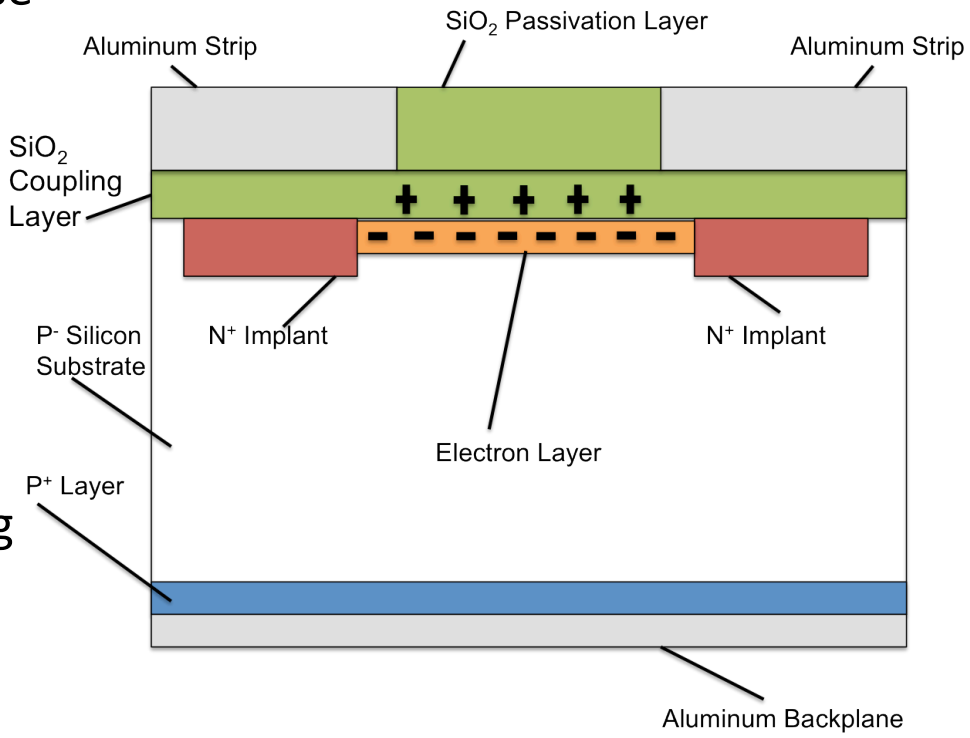
- Silicon strip detectors are used in particle tracking systems
- Proper inter-strip isolation is necessary for accurate position resolution





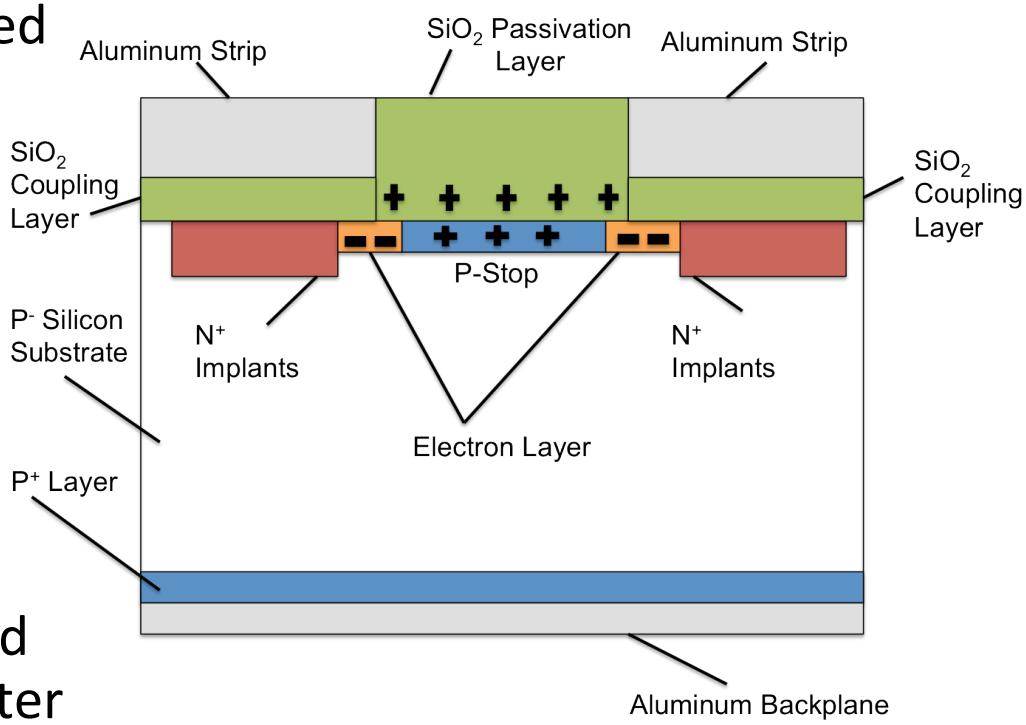
Strip Isolation Problem in P-Type Silicon Sensors: Electron Accumulation Between Electrodes

- P-type Silicon Sensors are the base line for the ATLAS Upgrade Inner Detector
- Positive charges in the oxide are trapped at the substrate-oxide interface
- Positive charges attract electrons which accumulate between implants, shorting them, resulting in poor position resolution
- Poor inter-strip resistance at low bias voltage on devices without special treatment.



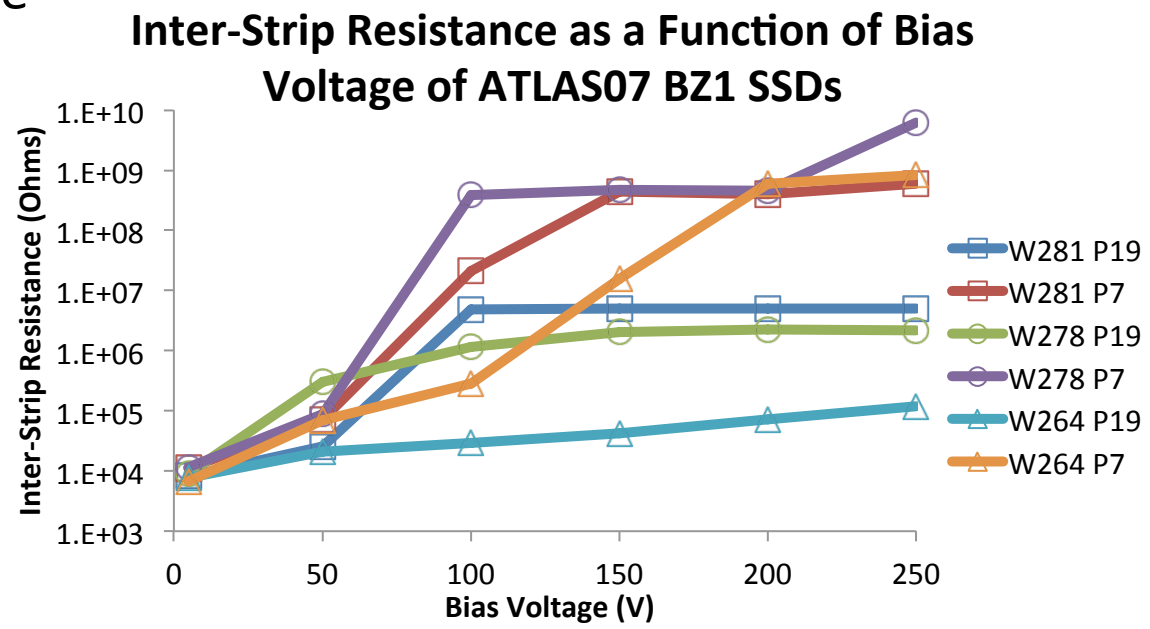
Typical Electrode Isolation: P-Stop/P-Spray

- P-stop/spray is positively doped which interrupts the electron layer
- P-stop can lead to early breakdown
- Masking step necessary for p-stops which adds to cost and complexity of manufacturing devices
- Depositing a positively charged insulator between the strip after manufacturing would isolate the strips and allow to tune the isolation



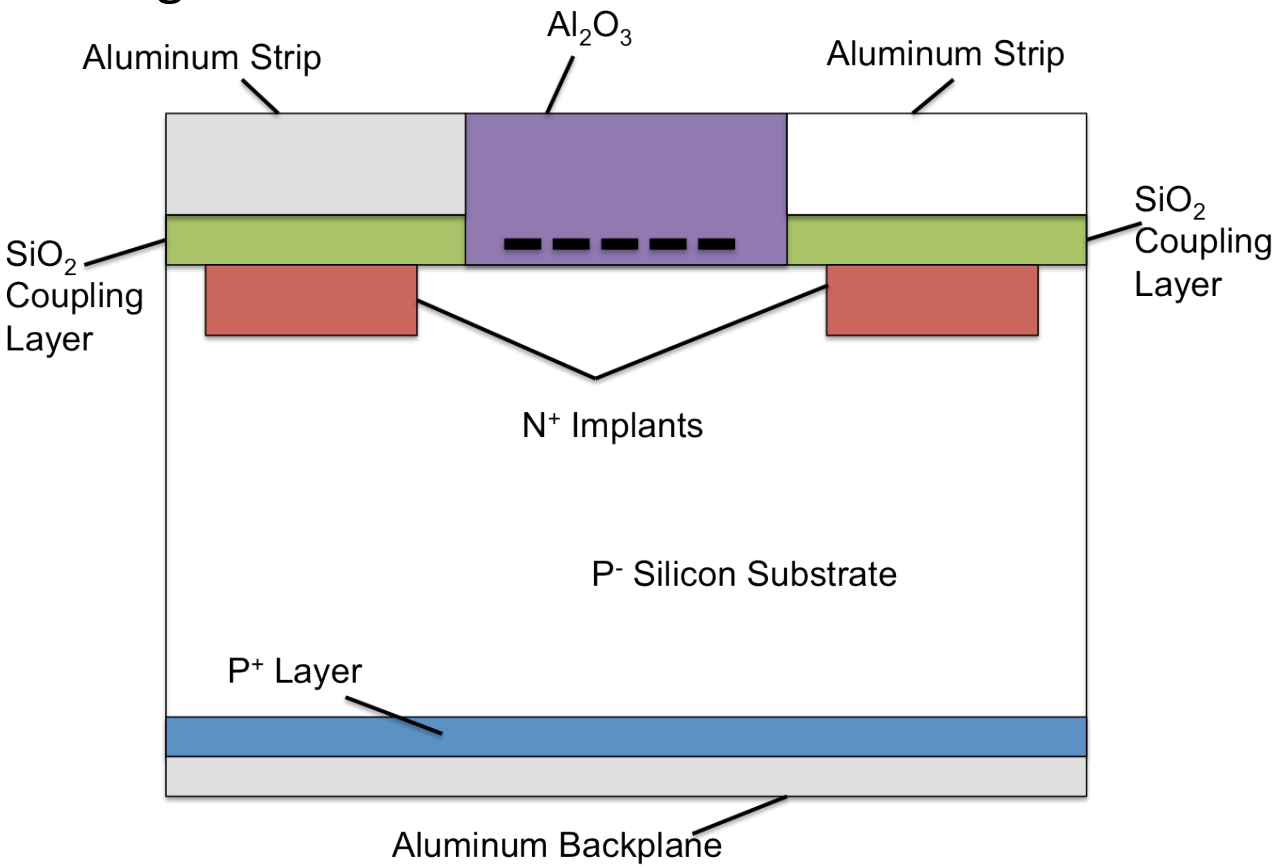
ATLAS07 BZ1 SSD

- As part of the ATLAS Upgrade program, n-on-p type silicon strip sensors were manufactured by Hamamatsu Photonics (HPK) in the ATLAS07 mask set. To investigate isolation issues, BZ1 sensors were manufactured with no isolation structures
- As mentioned before, they exhibit low inter-strip resistance at low bias voltage



Alumina as Surface Passivation

- Alumina (Al_2O_3), applied via atomic layer deposition, has negative space charge and might prevent electrons from accumulating between electrodes

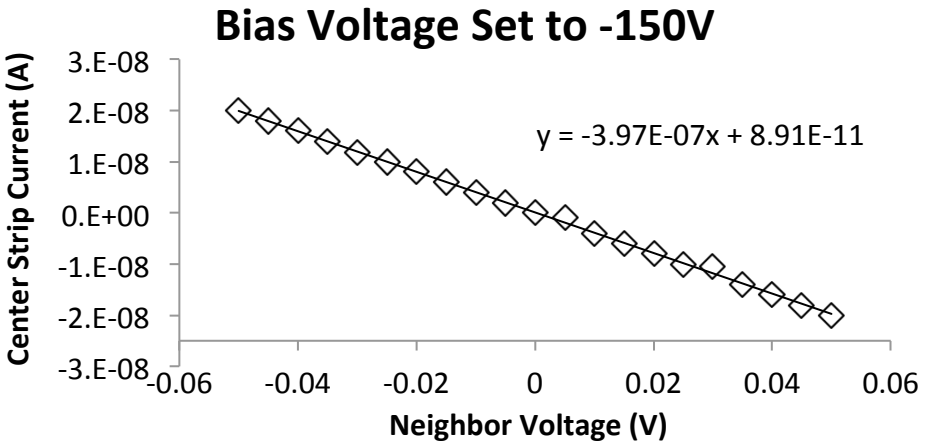


Alumina ALD

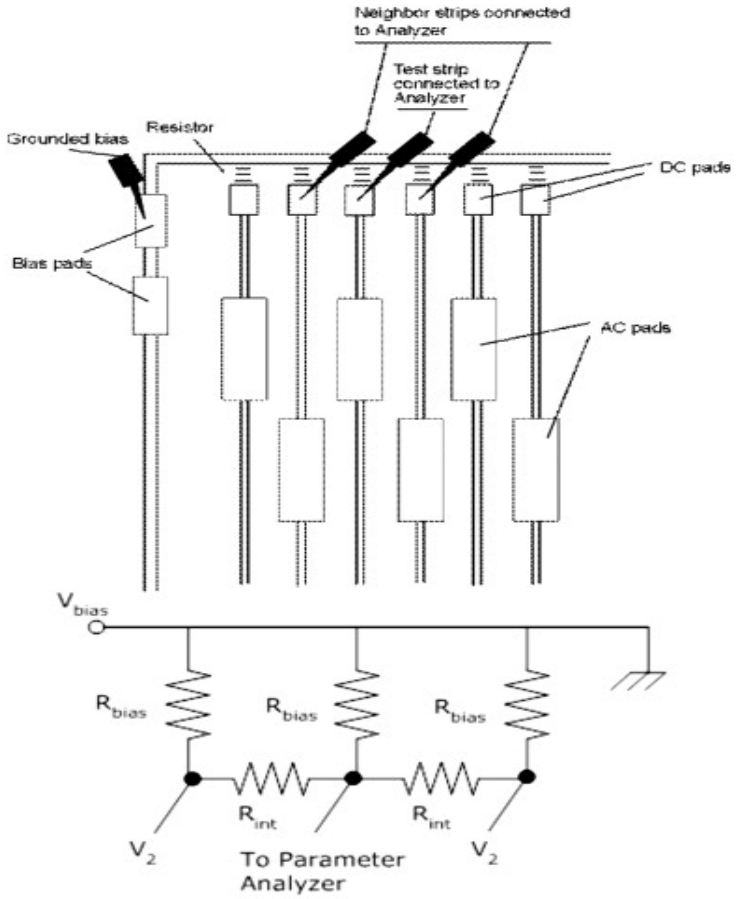
- Alumina applied via atomic layer deposition (ALD) has electrons trapped at the substrate-oxide interface instead of positive charges
- Negative interface charge between alumina and silicon surface repel electrons increasing isolation between strips
- No masking step required
- Original SiO_2 on ATLAS07 BZ1 SSDs had to be removed (wet etch) before alumina could be applied
- We measured the inter-strip resistance post ALD
- The effect of this treatment on leakage current and bias resistance was evaluated

Inter-Strip Resistance Measurement / Calculation

$$R_{Inter-strip} = -2\left[\frac{dI_{Center}}{dV_{Center}}\right]^{-1}$$

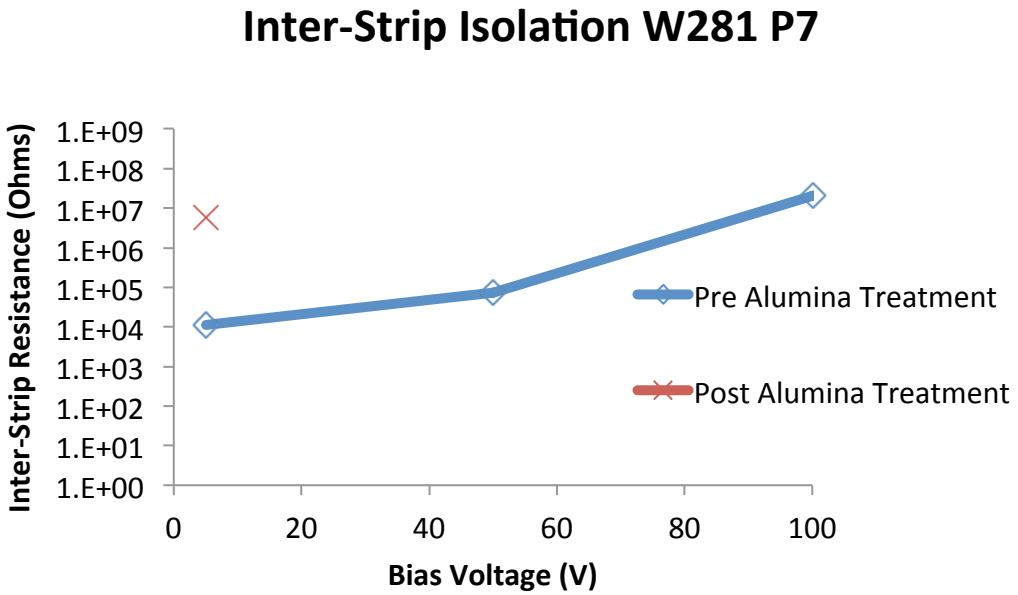


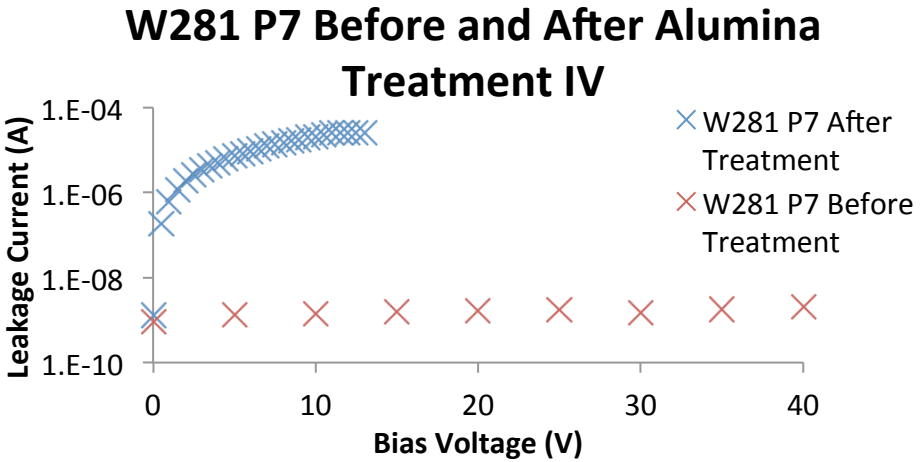
$R_{Inter\text{-}strip}$ = 2/(3.97*10^{-7} 1/Ω) = 5.0MΩ



Alumina Effect on Inter-Strip Resistance

- W281 P7 showed increased inter-strip resistance by 3 orders of magnitude at low bias voltage after alumina treatment

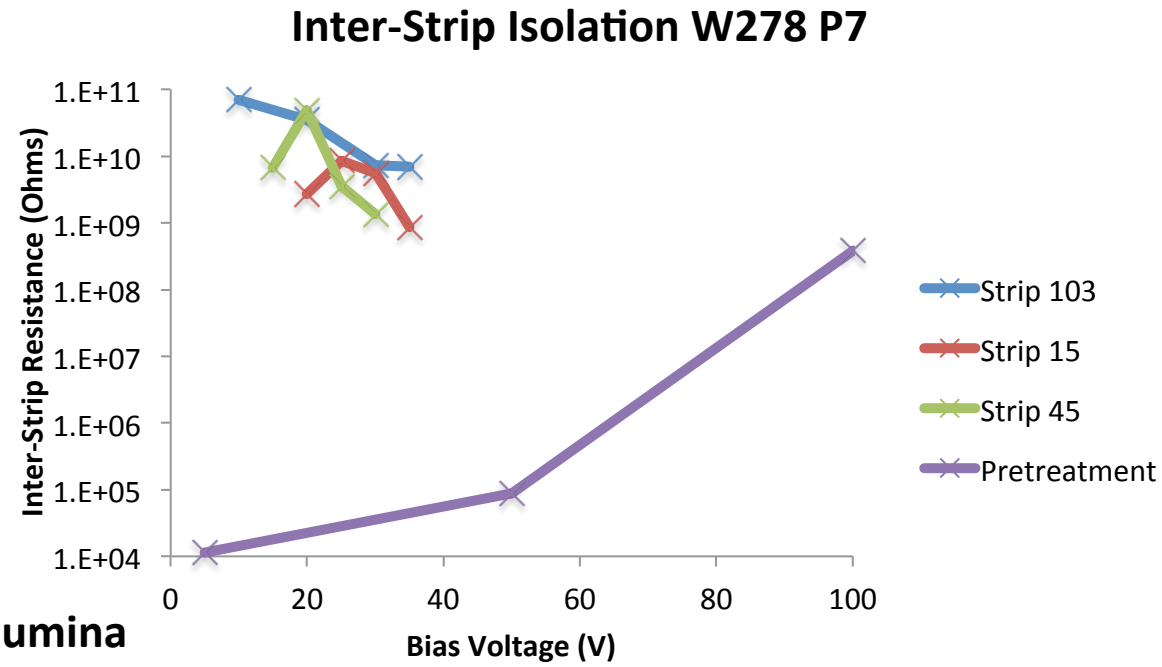


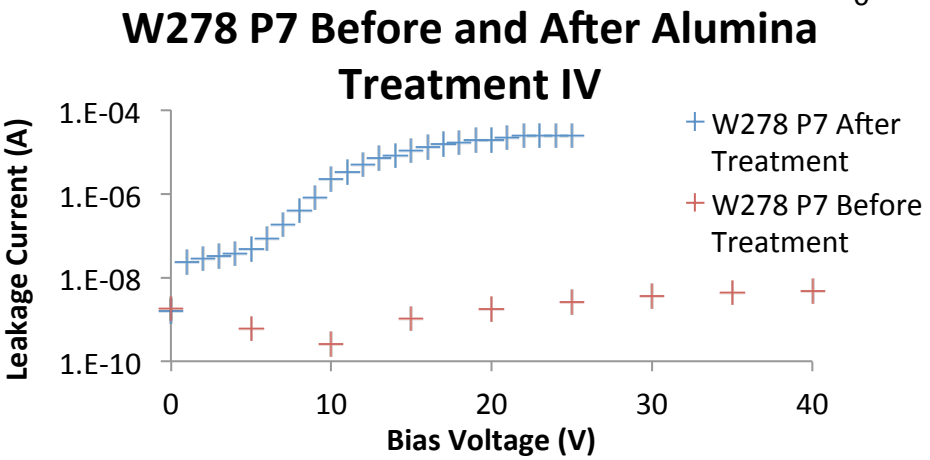


- Increased leakage current after alumina treatment

Alumina Effect on Inter-Strip Resistance

- W278 P7 showed increased inter-strip resistance by several orders of magnitude at low bias voltage after alumina treatment



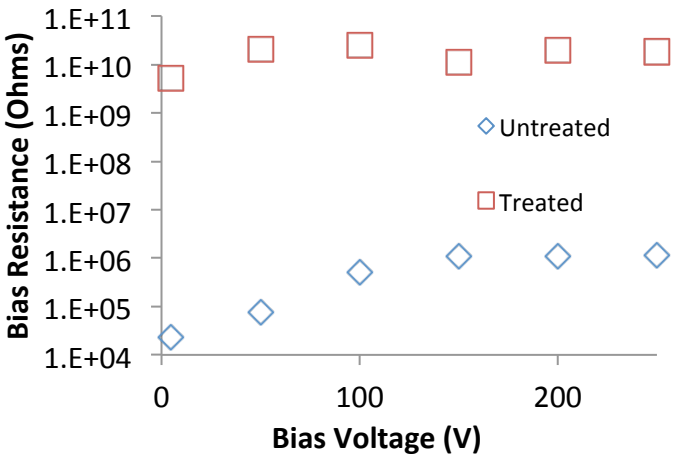


- W278 P7 also showed increased leakage current after treatment

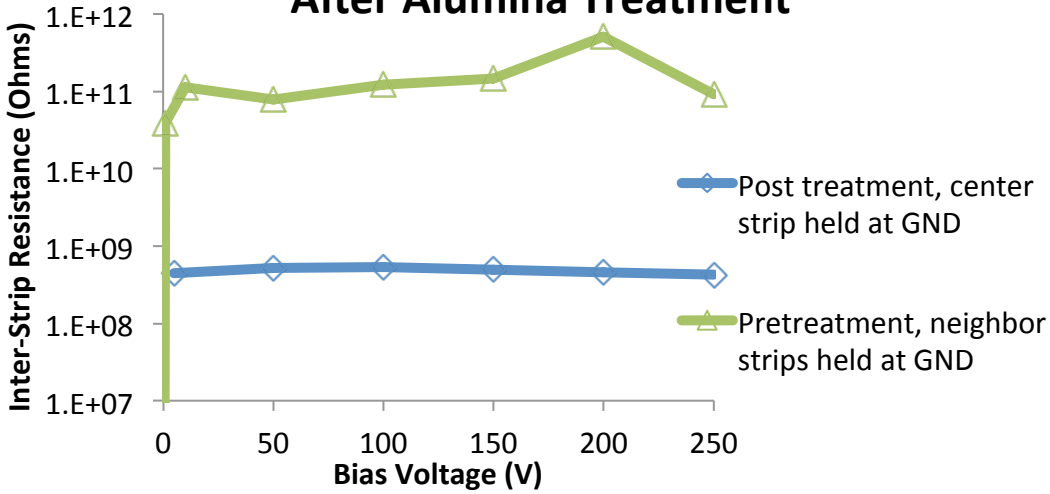
Detector Damage After Alumina Application

- Increased leakage current after treatment as shown before
- Possible source of damage is removal of SiO_2 or high temperature annealing
- W230 P7 showed increased bias resistance after alumina treatment
- W230 P7 had decreased inter-strip isolation after alumina treatment because it had p-spray applied before the treatment, but isolation was higher than a device with no isolation structures at all

Alumina Treatment Effect on Bias Resistance of W230 P7

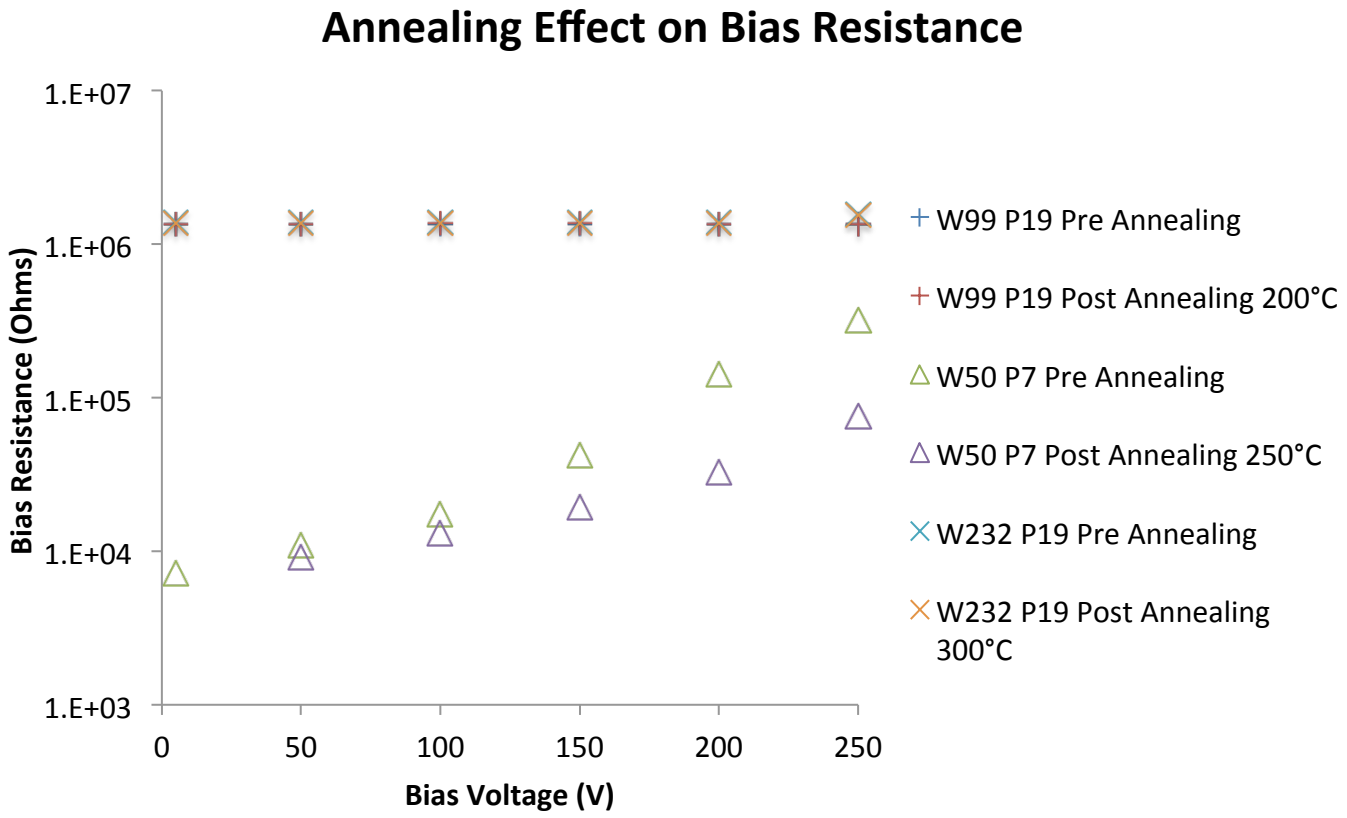


W230 P7 Inter-Strip Isolation Before and After Alumina Treatment



Elimination of Annealing Step as a Cause for Increased Bias Resistance

- Untreated ATLAS07 BZ1 sensors showed no change in bias resistance after being annealed up to 300°C



Future Work

- More treatments possibly with ATLAS12 sensors to see if we can reduce leakage current and not affect bias resistance value
- Applying alumina during detector manufacturing to reduce risk of damaging devices
- Radiation resistance studies to look at surface effects with different particles

Conclusions

- Devices without isolation structures showed increased inter-strip resistance at low bias voltages after treatment with alumina
- Removal of silicon oxide layer caused damage to the devices, e.g. increased leakage current and increased bias resistance value
- Sensor damage may be avoided if alumina deposition was part of the initial fabrication sequence before metallization because the devices could be annealed at higher temperature (>400°C)

Questions?