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Imaging Doped Silicon Structures Using Low-Energy Electron Microscopy

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LEEM images of *n*-doped lines (0.25, 0.50, 0.80 μm width) within *p*-type background, 20 μm FOV

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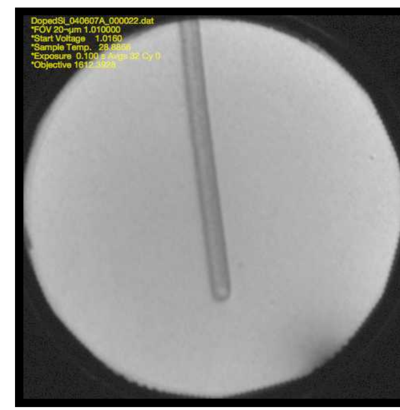
Motivation

As microelectronics feature sizes continue to decrease, there is a strong incentive to develop imaging techniques that offer both high spatial resolution and the possibility of high sample throughput.

High resolution → Electron based
High throughput → Non-scanning

Can we use the LEEM to image:

(a) Dopant distributions in semiconductor devices (with and without an oxide)? What is the contrast mechanism?



(b) Inversion layer, depletion region, etc. of biased devices?

Today's talk will focus on imaging *n*- and *p*-doped test structures with a thermal oxide and identifying the contrast mechanism.

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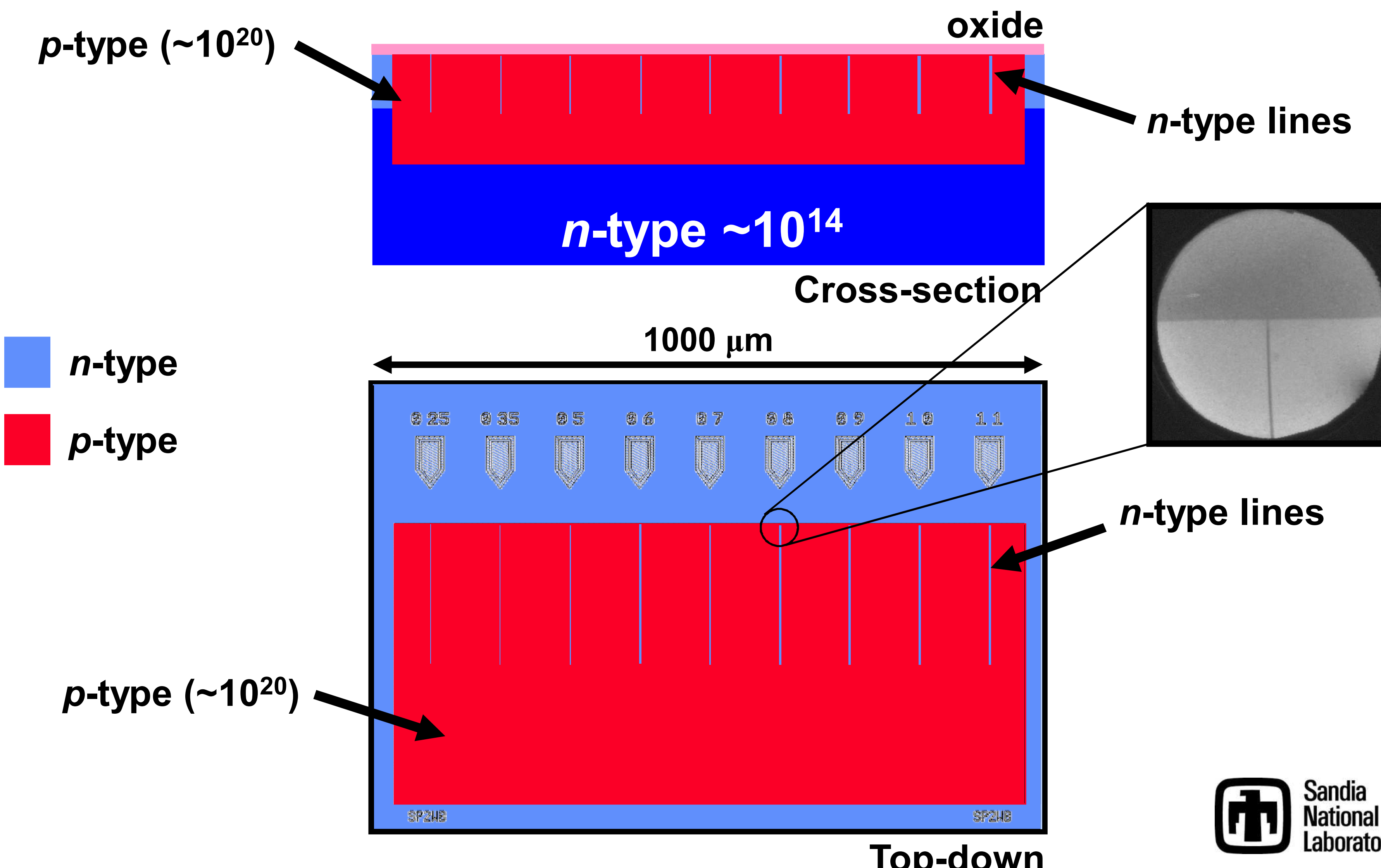
Top down test samples were fabricated with diode structures of varying widths



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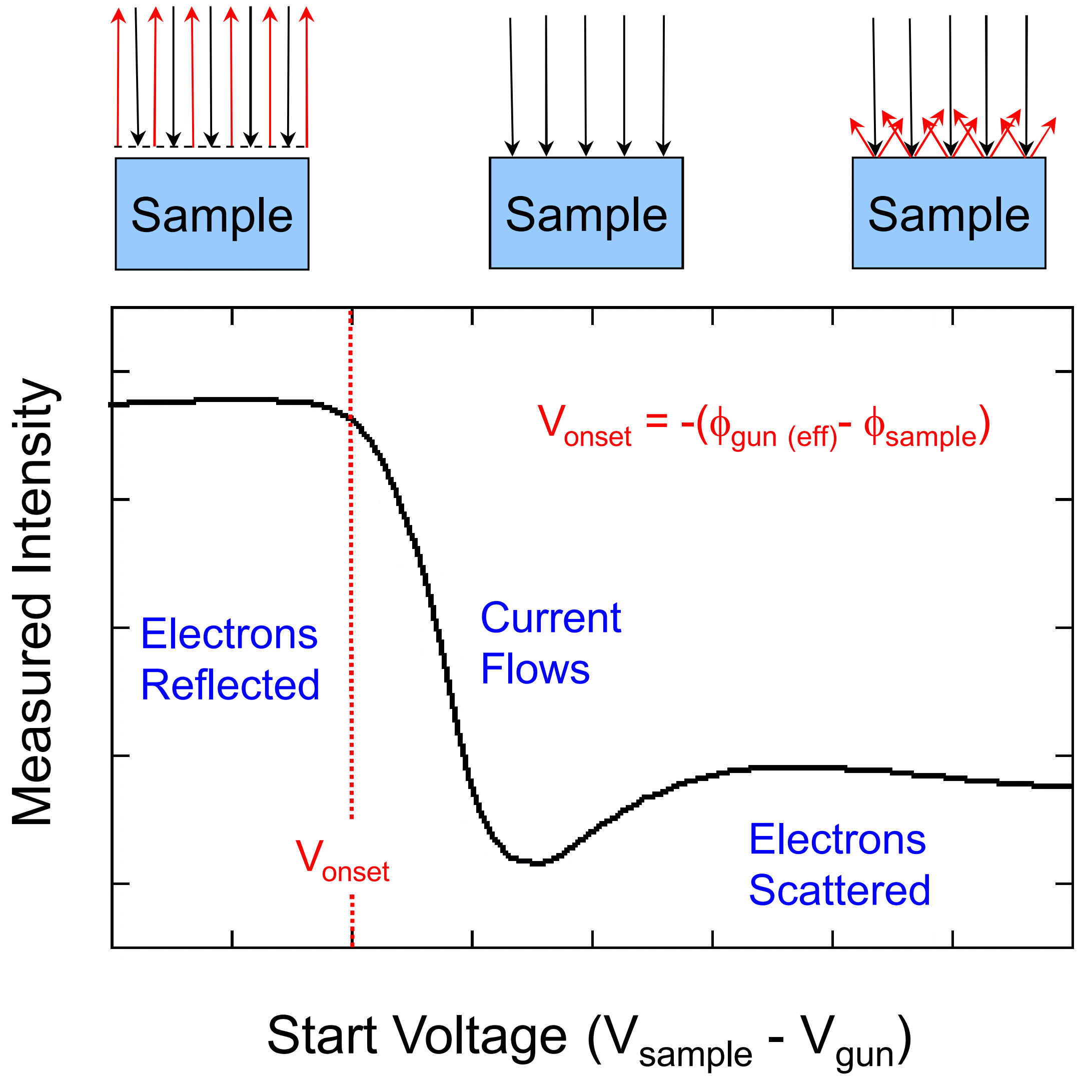
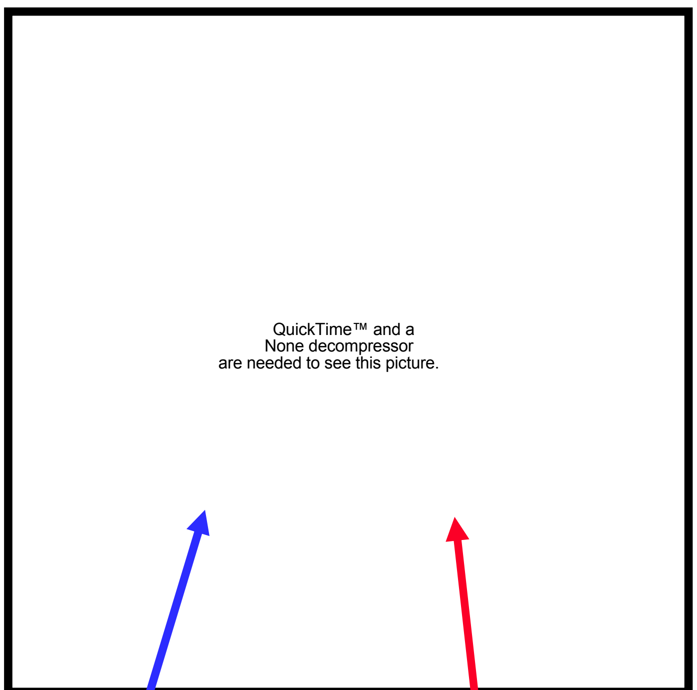
Reflected electron intensity depends on start voltage



I-V curves show a large separation, giving rise to contrast between *n*- and *p*-doped regions

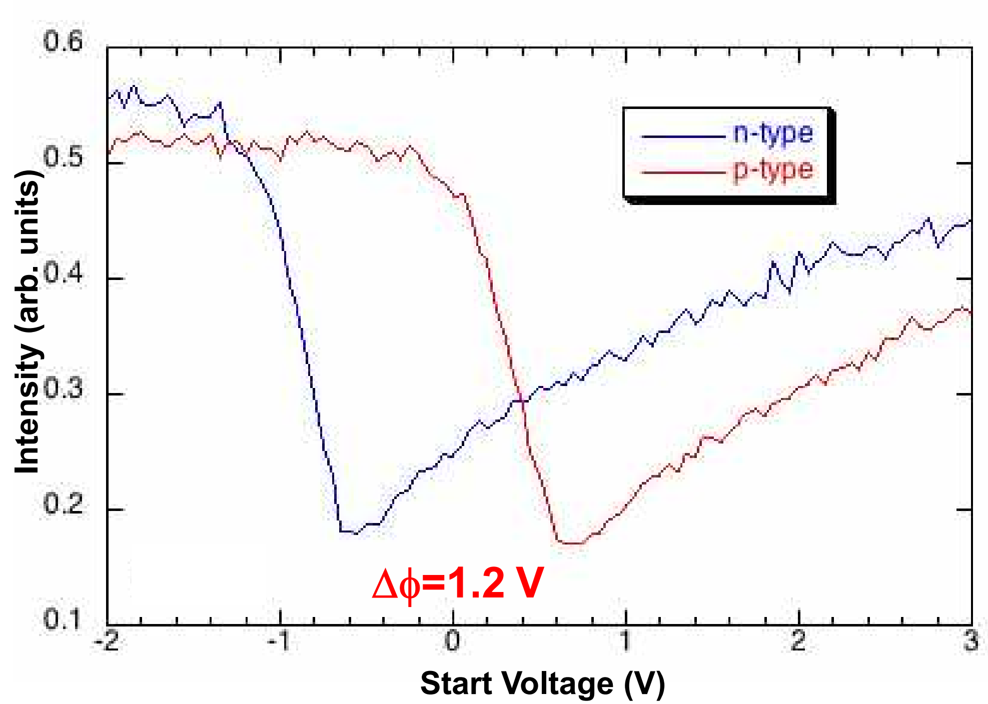


50 µm FOV

***n*-type**
oxide ~35A

***p*-type**
oxide ~50A

Contrast changes as a function of SV



- **The work function for *n*-type Si is smaller than that of *p*-type Si - onset voltage occurs at a more negative SV.**
- **True work function difference is not measured.**

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Samples with thermal oxide show charging effects during imaging

Translate sample under beam

QuickTime™ and a
None decompressor
are needed to see this picture.

***p*-type**
oxide ~50A

Start Voltage = 0V, 50 μm FOV

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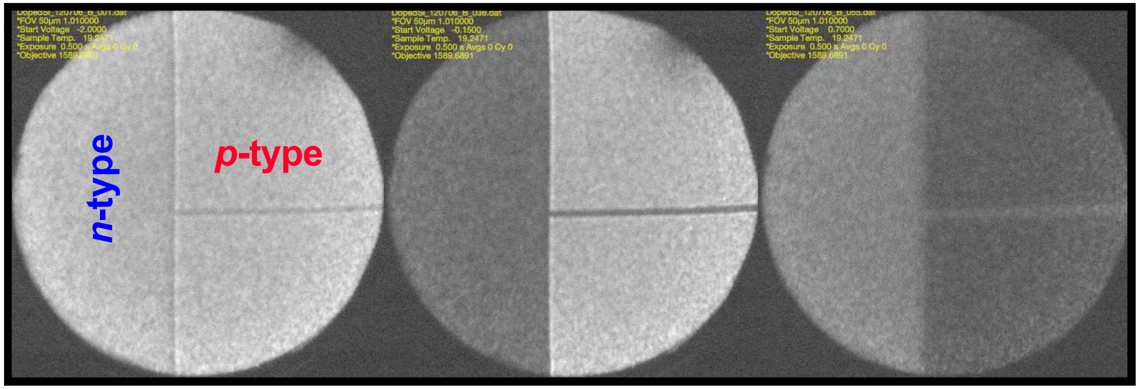
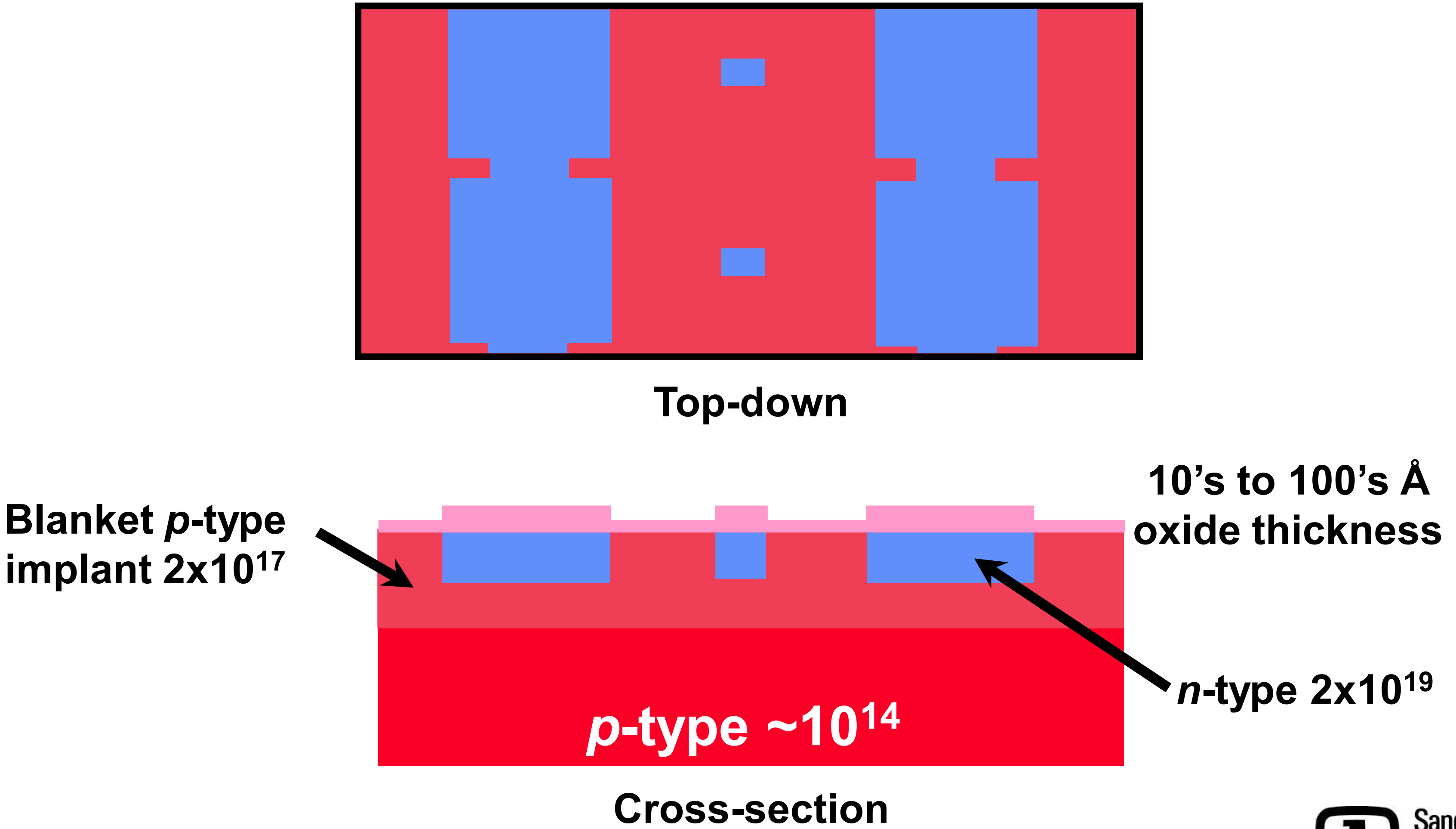
What is the contrast difference between the oxide-covered *n*- and *p*-doped regions due to?

- **Difference between *n*- and *p*-doping**
- **Difference in oxide thickness**
- **Difference in doping concentrations**

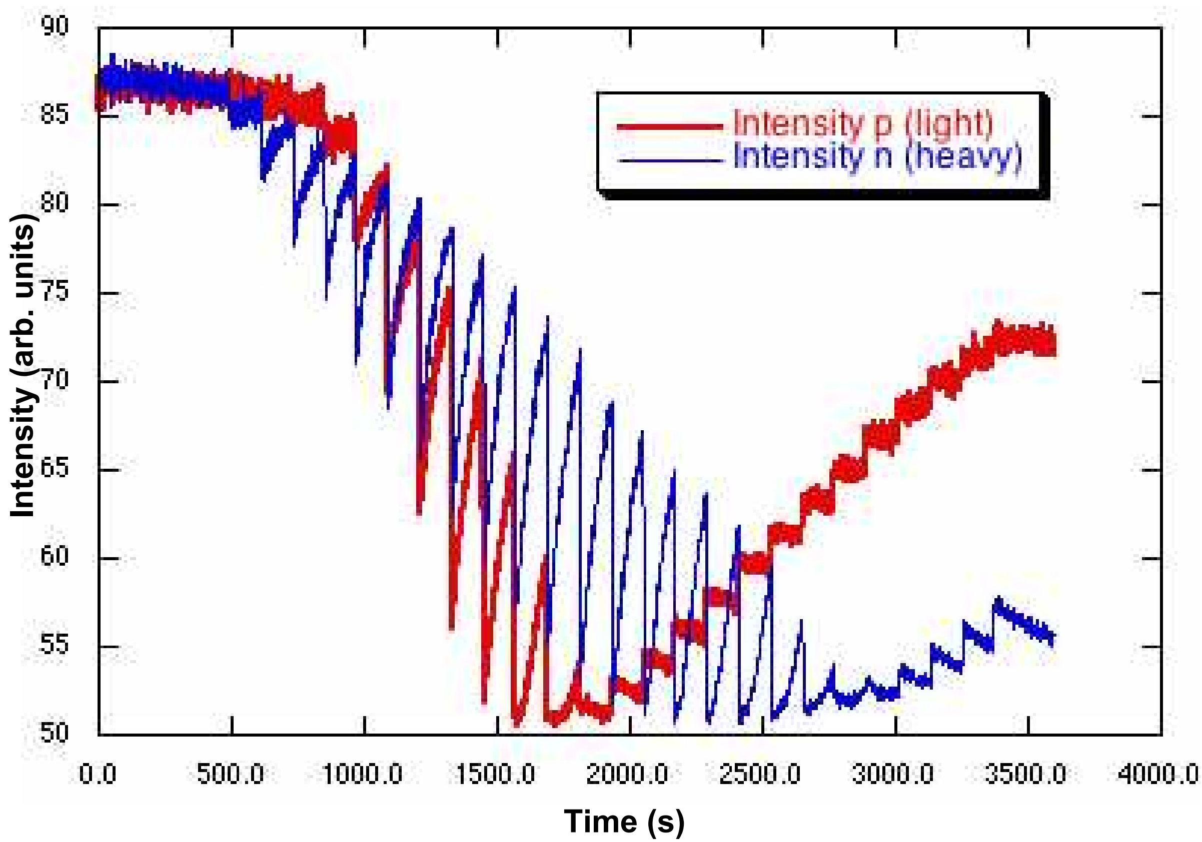


Measure intensity vs. start voltage for samples with varying oxide thickness (thin, medium, and thick).

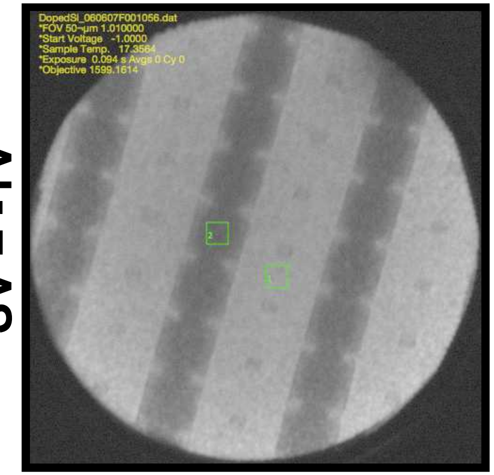
LEEM analysis was carried out on test samples with varying oxide thickness



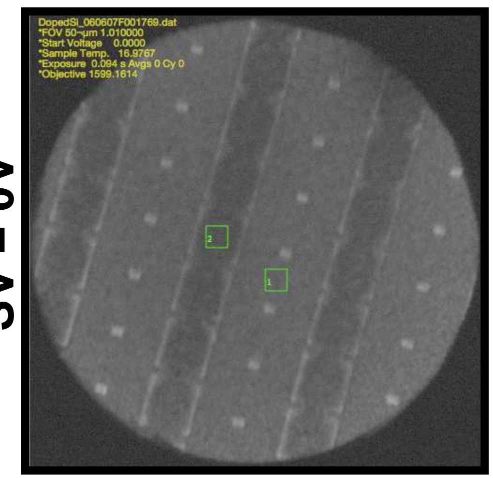
I-V curves are time dependent



SV = -1V



SV = 0V



Two effects contribute to changes in intensity.

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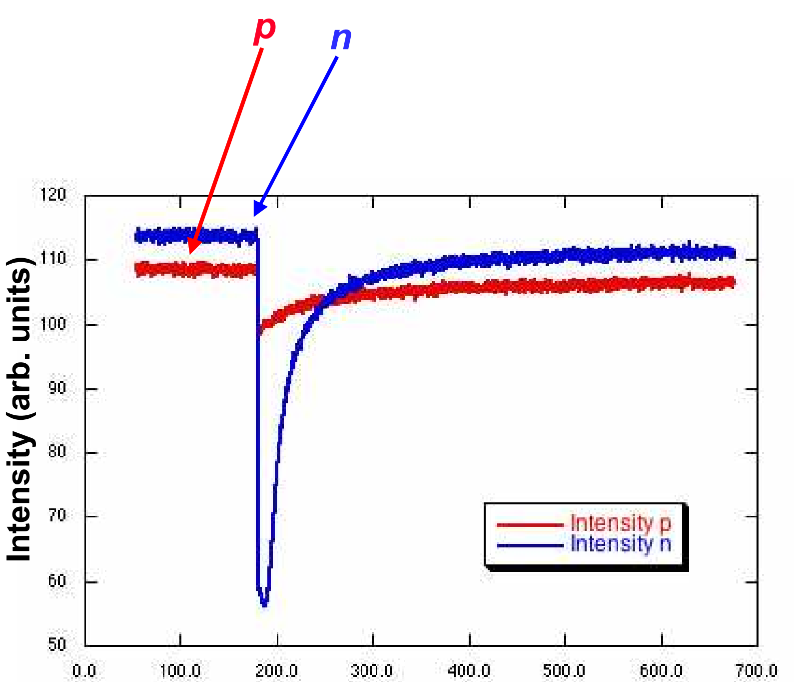
Charging curves depend on instantaneous increase in start voltage

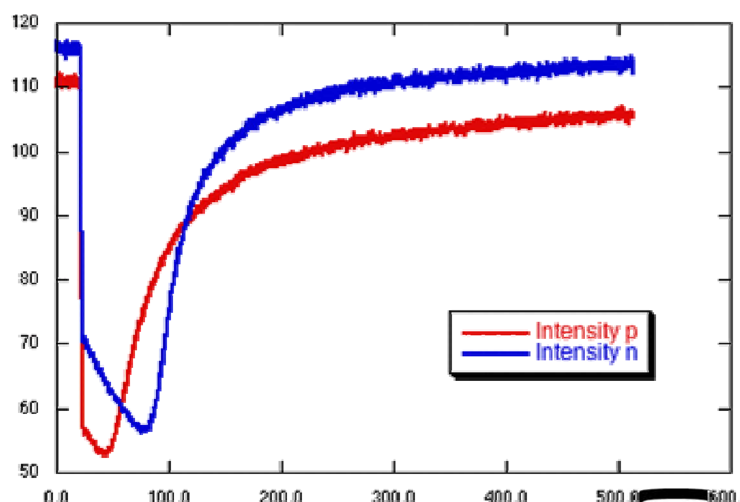
Increase from -3.0 V to -1.0 V

QuickTime™ and a decompressor are needed to see this picture.



Increase from -3.0 V to -0.2 V

QuickTime™ and a decompressor are needed to see this picture.



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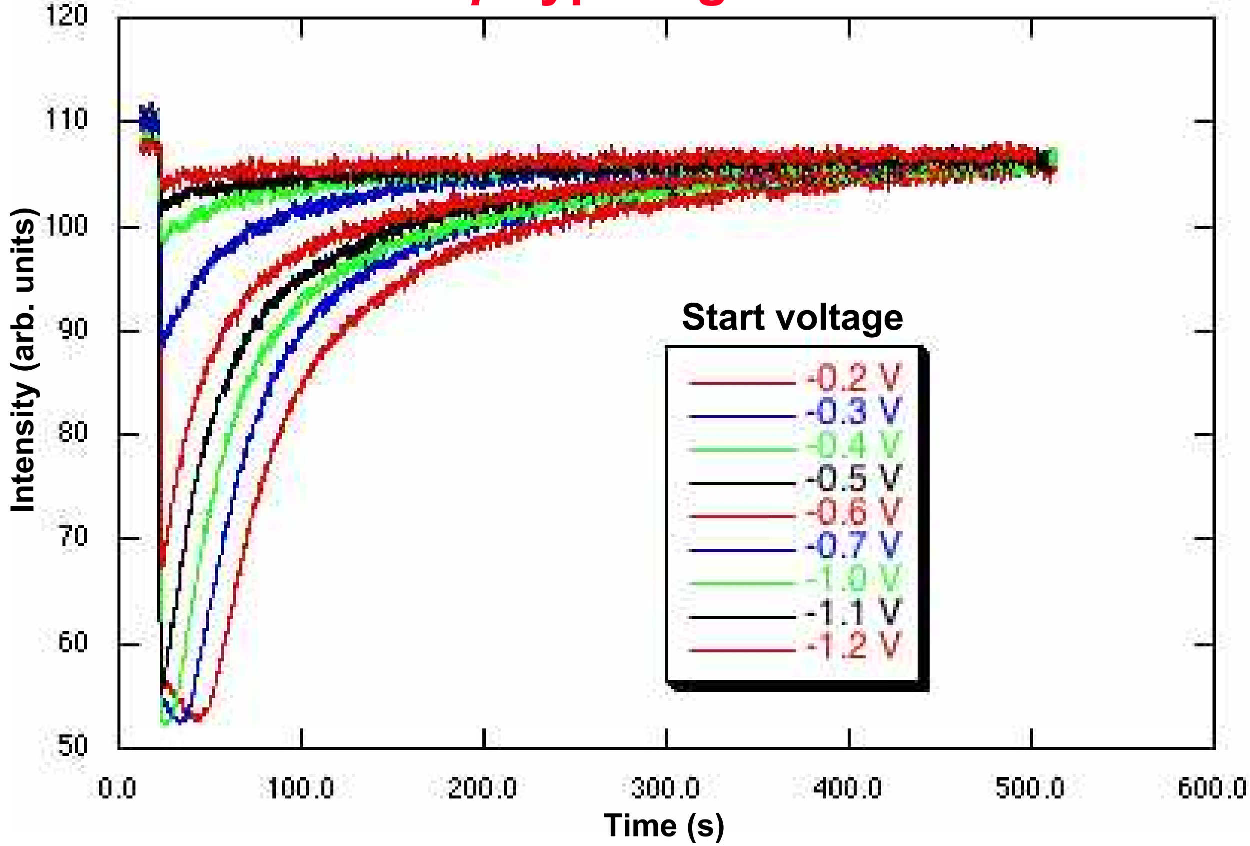
Measure a series of charging curves to obtain a pre-charging I-V curve

***p*-type region**



Begin each ΔSV measurement with a new (unexposed) region.

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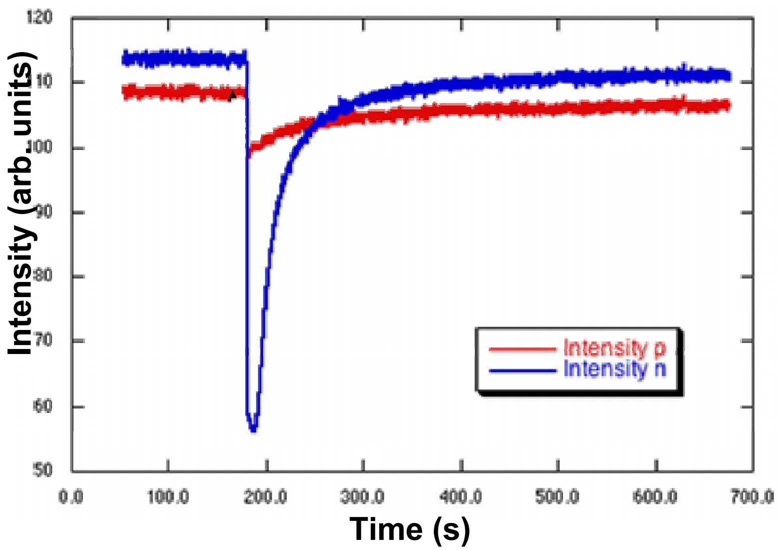
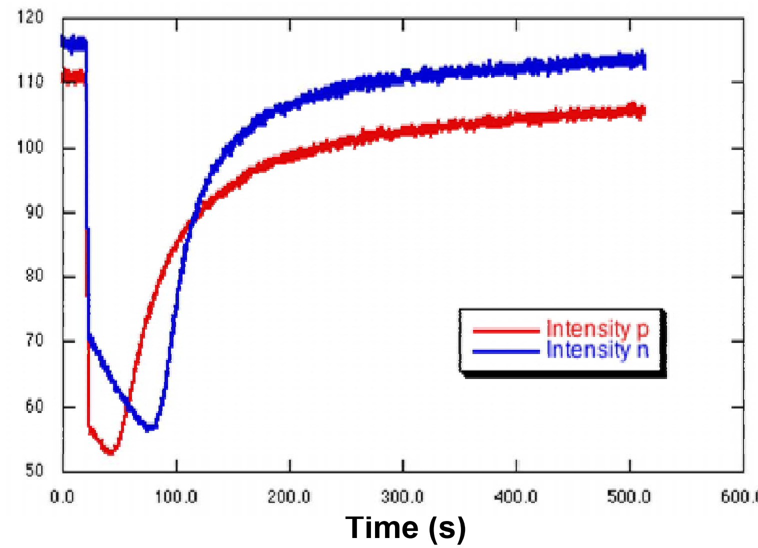
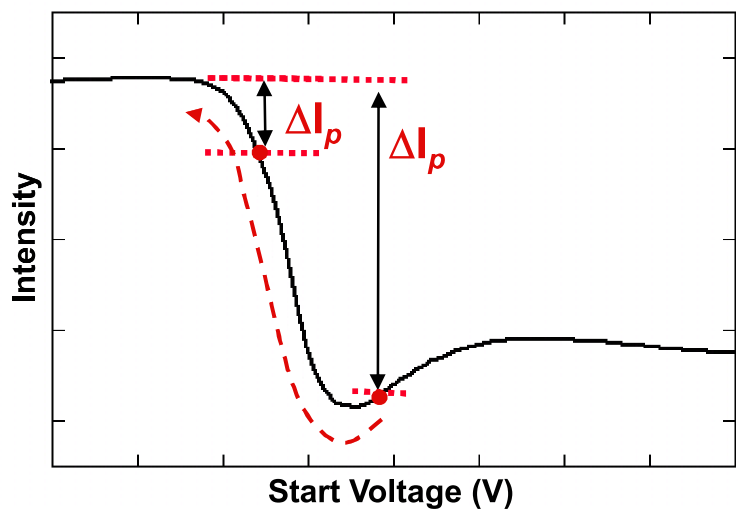
Intensity vs. time curves are the mirror image of intensity vs. start voltage curves



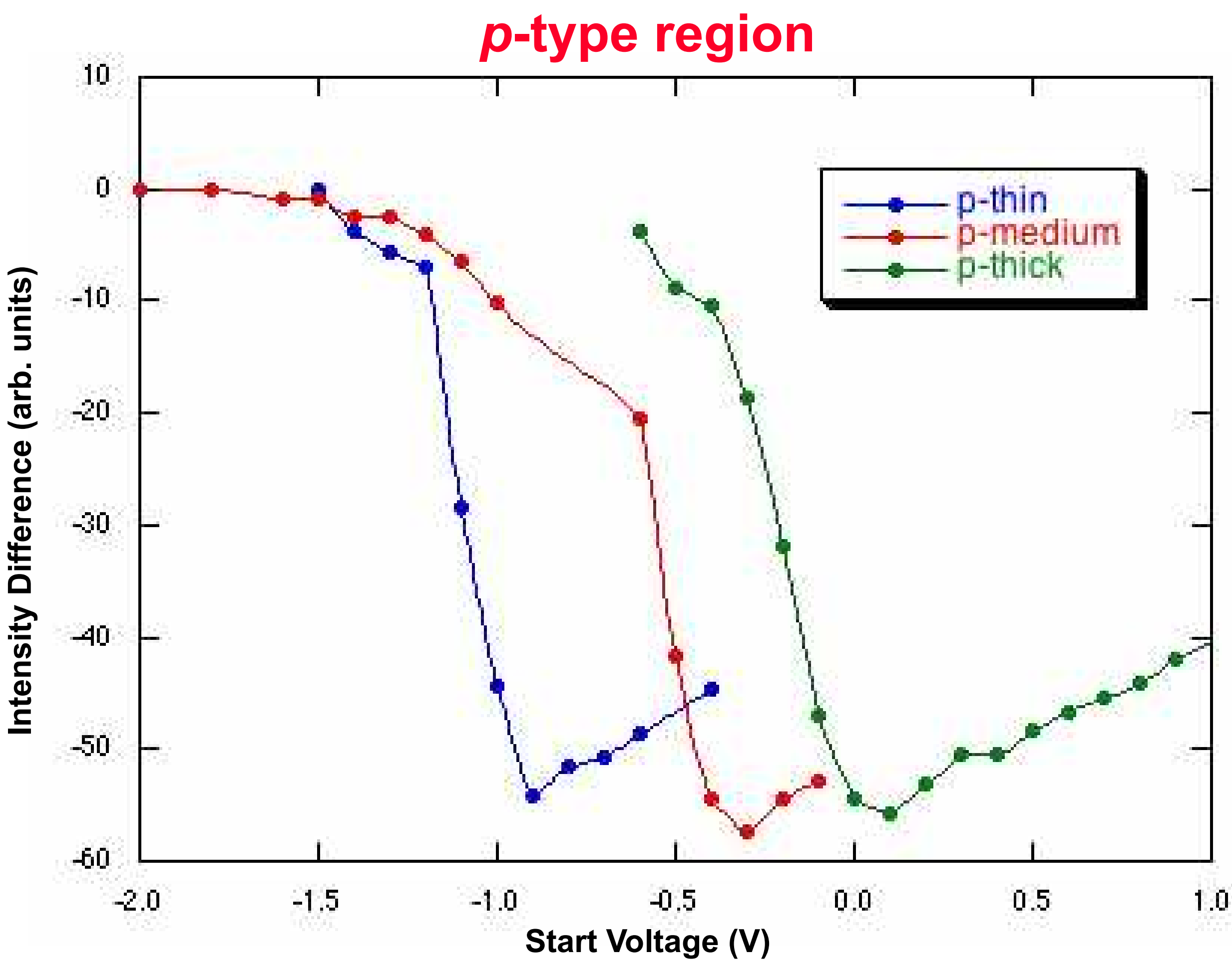


Intensity changes that occur after voltage increase follow the IV curve backwards.



Potential difference between gun and sample is the sum of the start voltage and the time-dependent charging potential.

Onset voltage of pre-charging I-V curve increases with increasing oxide thickness



Thin ~ 25A
Med ~ 40A
Thick ~ 110A

Contrast is dependent on oxide thickness.

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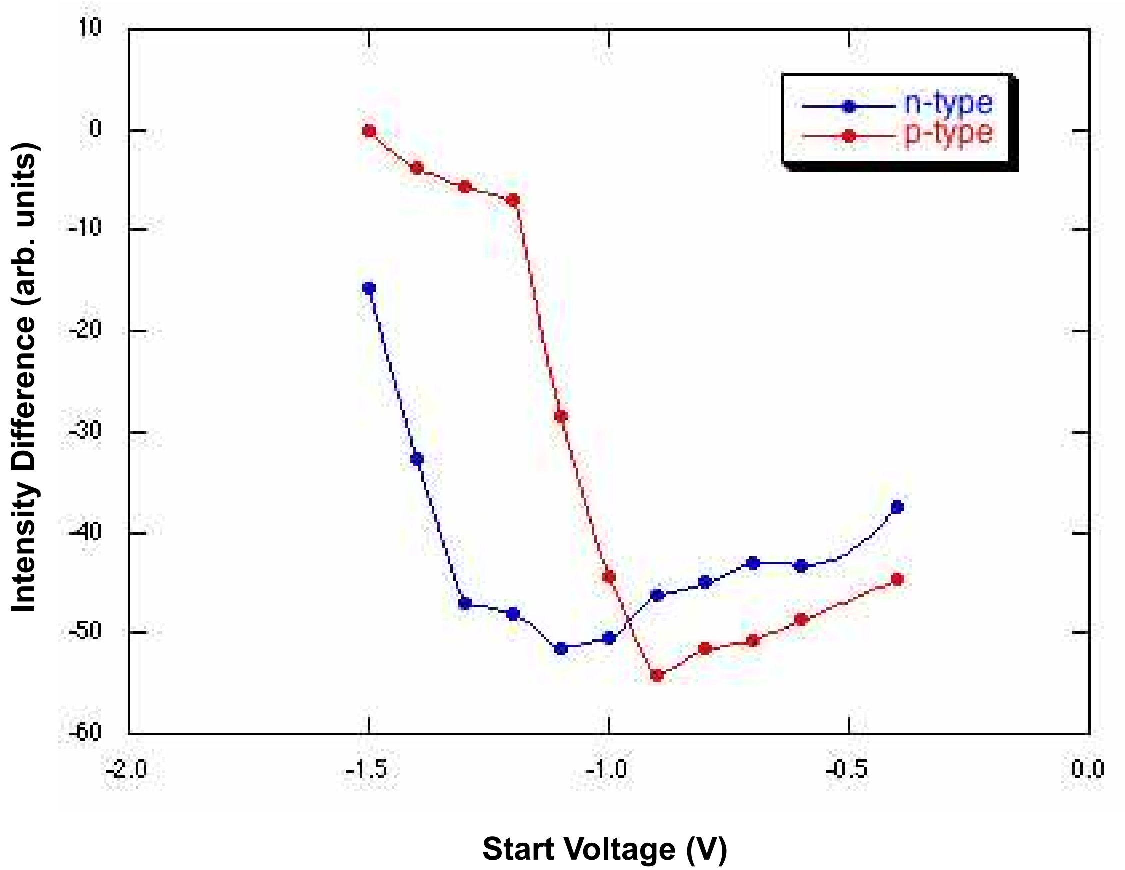
Samples with same oxide thickness, *n*-type onset occurs at a lower start voltage



Contrast is also dependent on doping.

Summary

LEEM provides high contrast images of *p*- vs. *n*-doping in Si test structures (with and without an oxide).

Onset for charge flow occurs first for *n*-type then for *p*-type (consistent with work function being lower for *n*-type region).

Oxide charges under LEEM electron beam.

Measurements of intensity versus time (with instantaneous SV increase) separates inherent reflectivity curve and oxide charging characteristics.

Onset for charge flow moves to more positive start voltage as oxide increases in thickness.

Contrast is due to charging and dopant differences.