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Sandia National Laboratories

Visible Light LVP on Bulk Silicon Substrates

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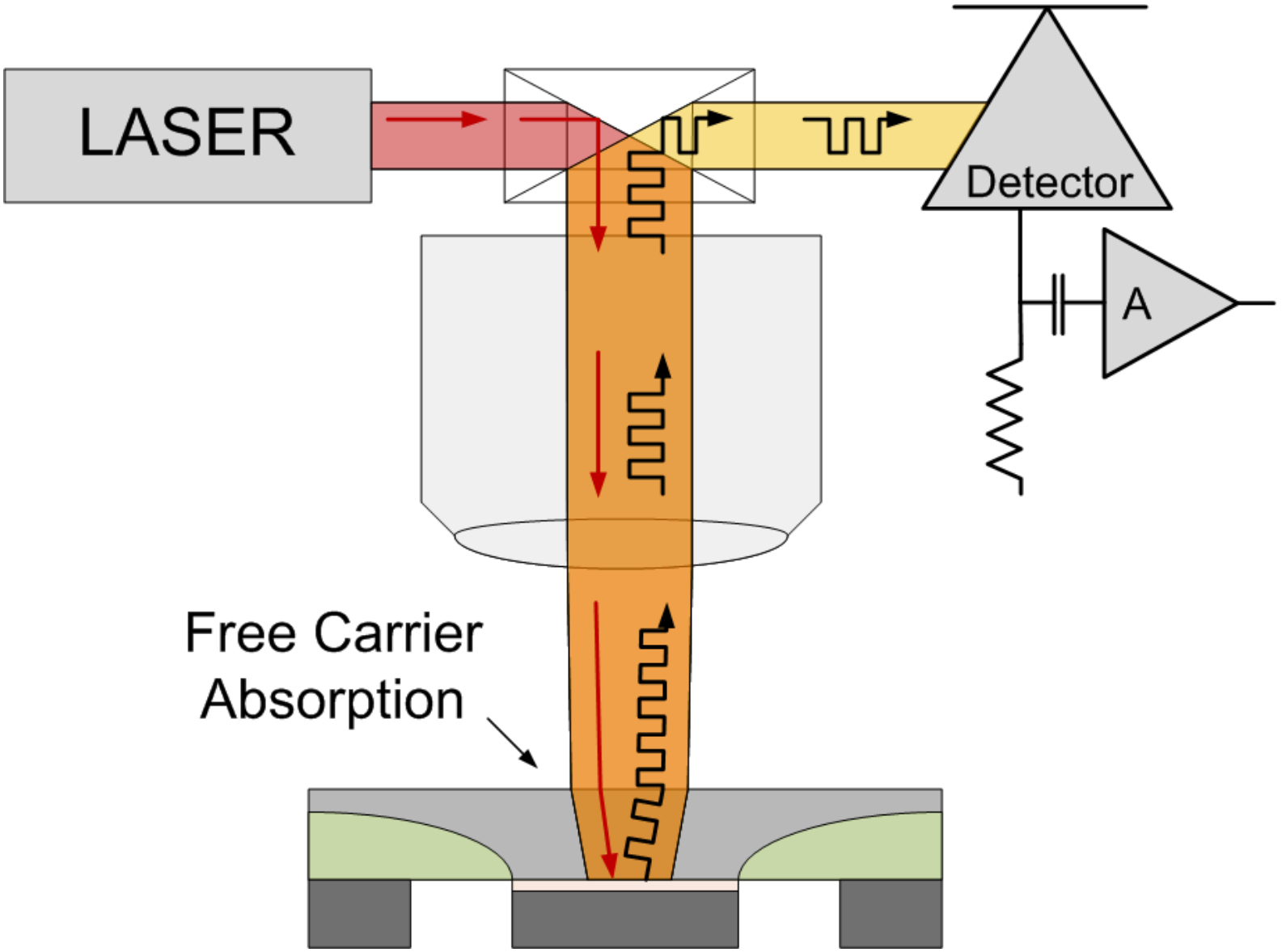
Purpose

- Describe backside bulk Si Visible Light LVP using visible light sources
- Discuss bulk Si substrate Ultra-Thinning
- Demonstrate Visible Light LVP on multiple bulk Si technology nodes
- Discuss planarity and process improvements to ultra-thinning

Outline

- Brief LVP Background
- Ultra-Thinning
- Visible Light Resolution and Transmission
- Visible Light VLP Bulk Si Case Studies
  - 90 nm
  - 40 nm
- Sample Preparation
- Metrology
- Improved Ultra-Thinning
- Conclusion

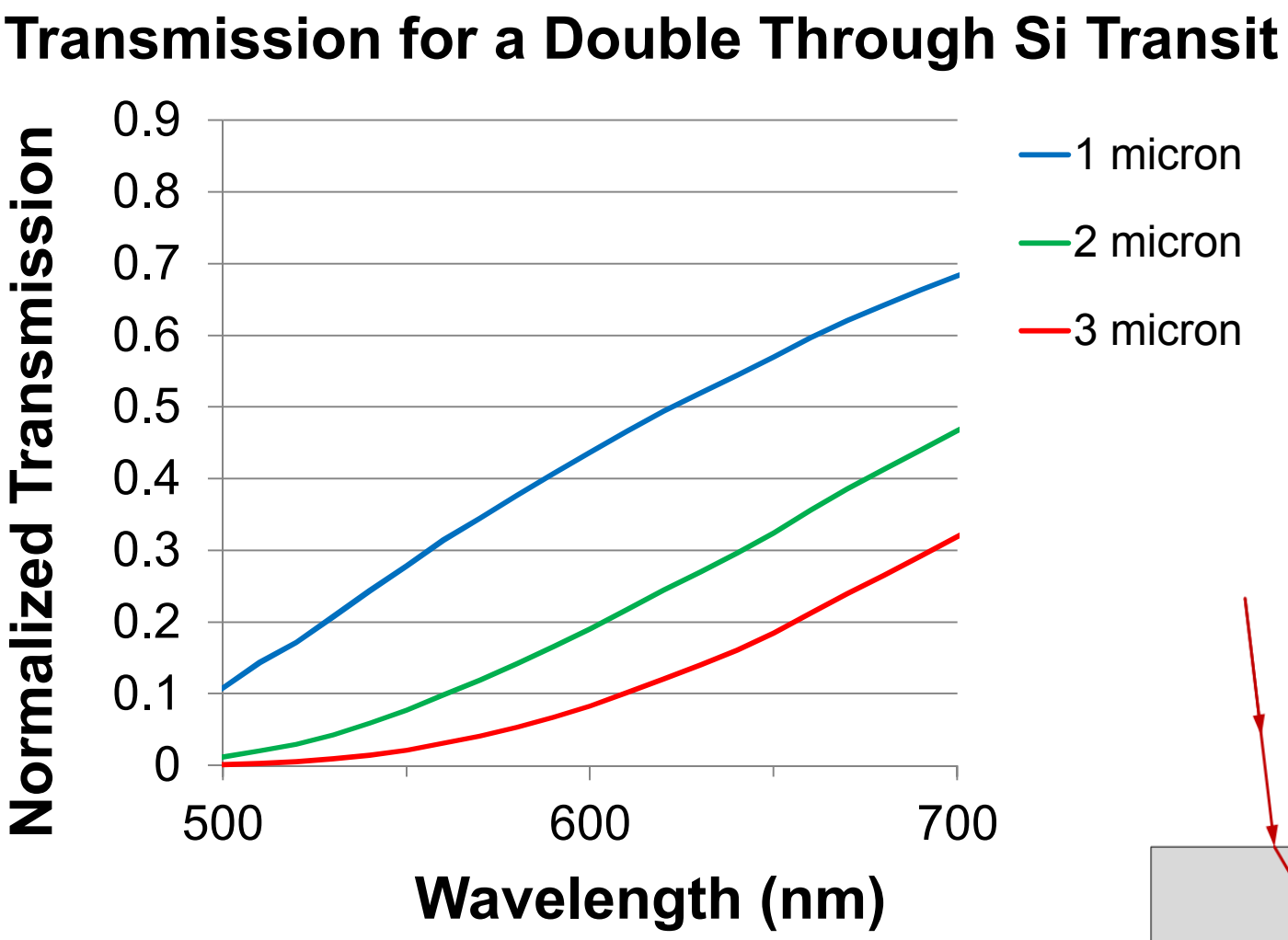
LVP Basics

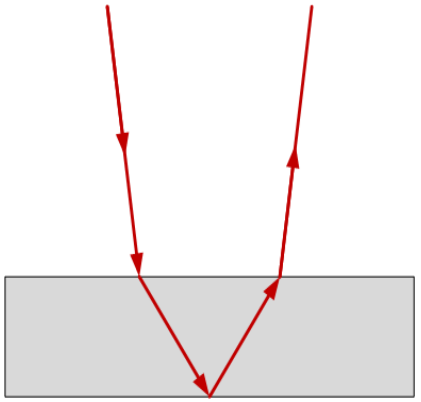


IR and Visible LVP

- IR
  - Advantages
    - Silicon Transparency
    - Straightforward backside sample preparation
  - Limitations
    - Long wavelength spatial resolution
    - Resolution enhancements becoming difficult
- Visible light advantages
  - Shorter wavelengths / Enhanced spatial resolution
  - Increased thinning possible
  - New resolution enhancement realm

Visible Light Transmission





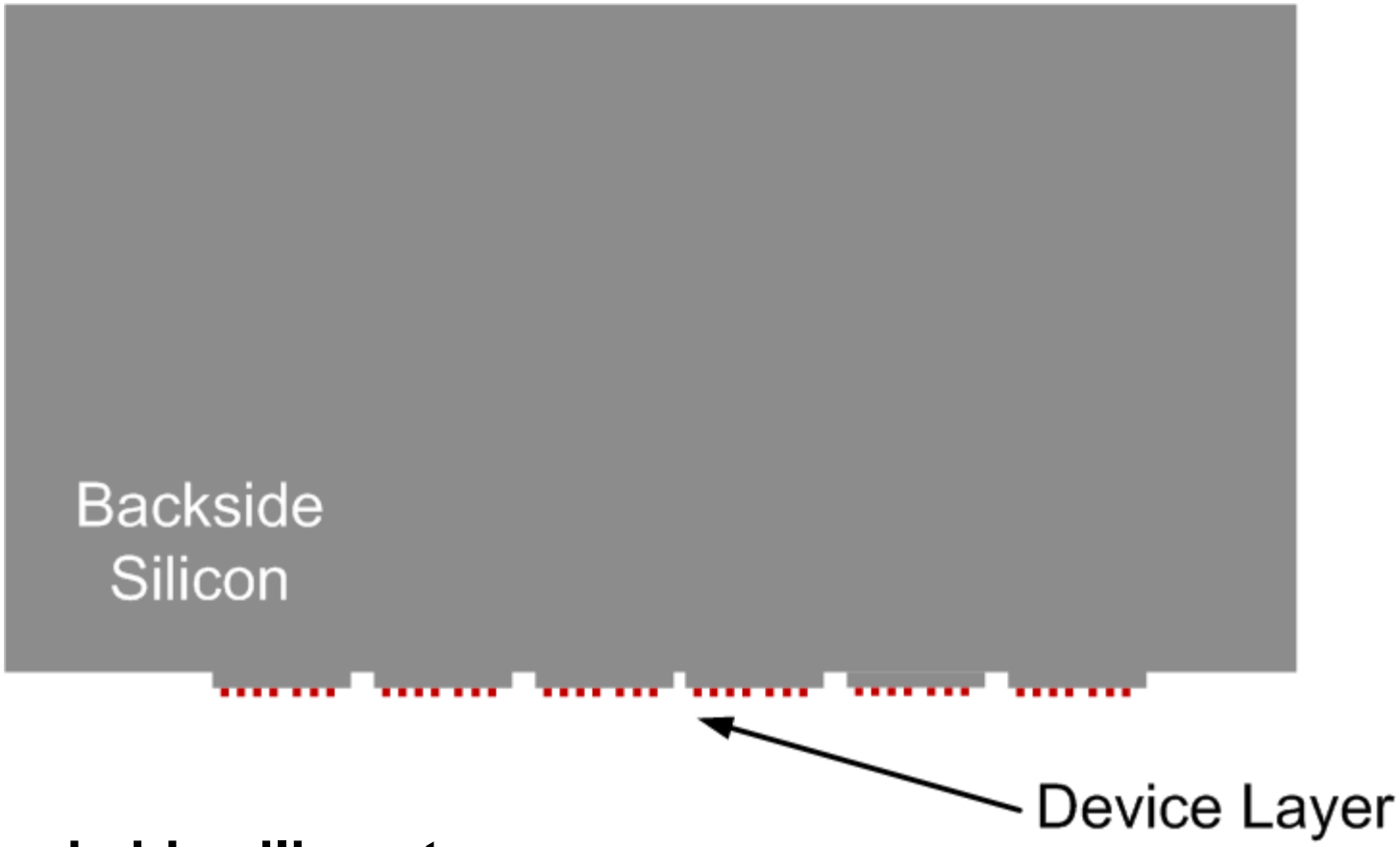
Visible Light Resolution

- **Rayleigh Criteria**

$$D = \frac{0.61\lambda}{NA}$$

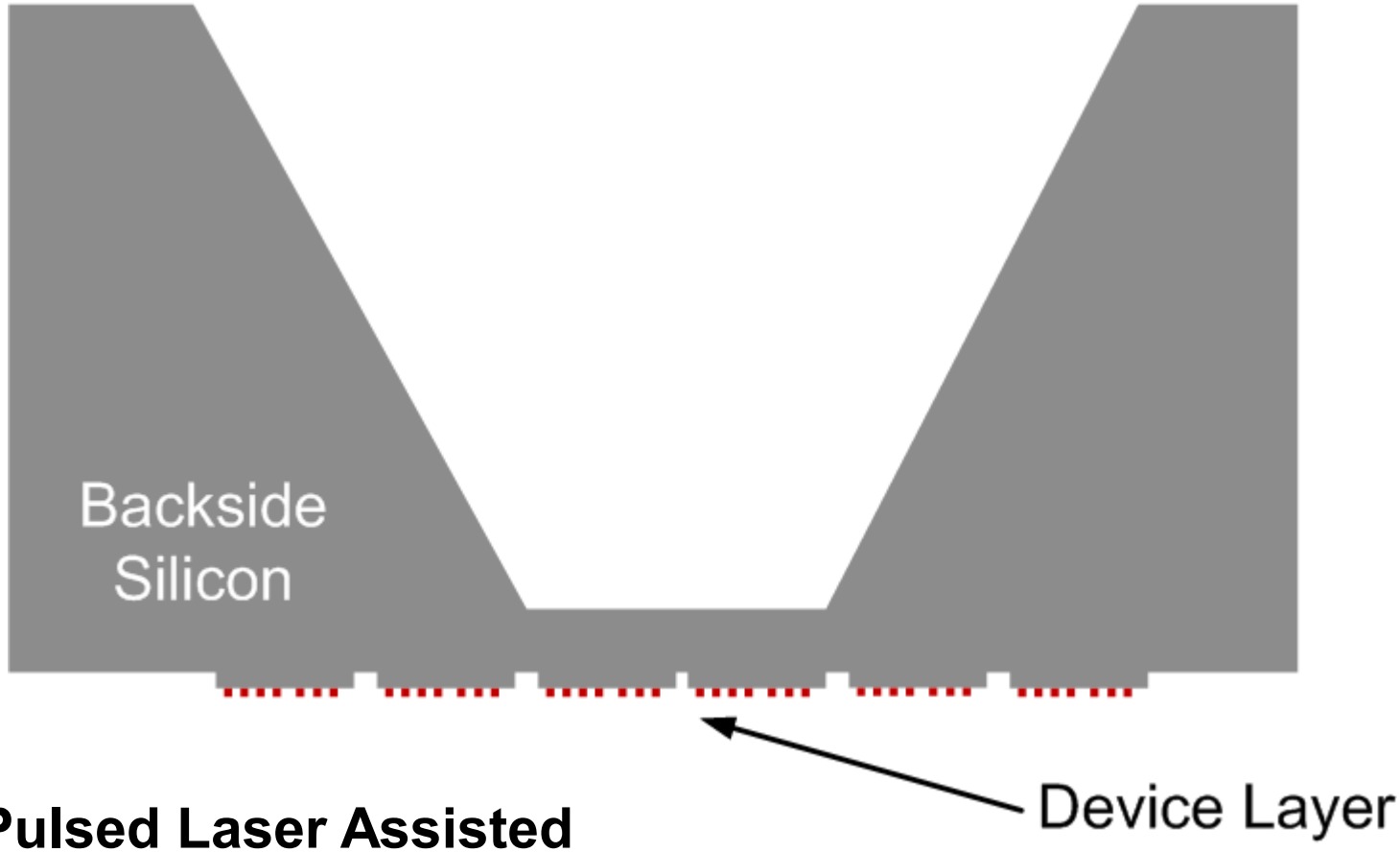
Lens Type	λ (nm)	NA	D (nm)
Air Gap	633	0.9	429
	532	0.9	361
1.4 Oil	633	1.4	276
	532	1.4	232
2.6 SIL	1320	2.6	305
	1064	2.6	246

Ultra-Thinning



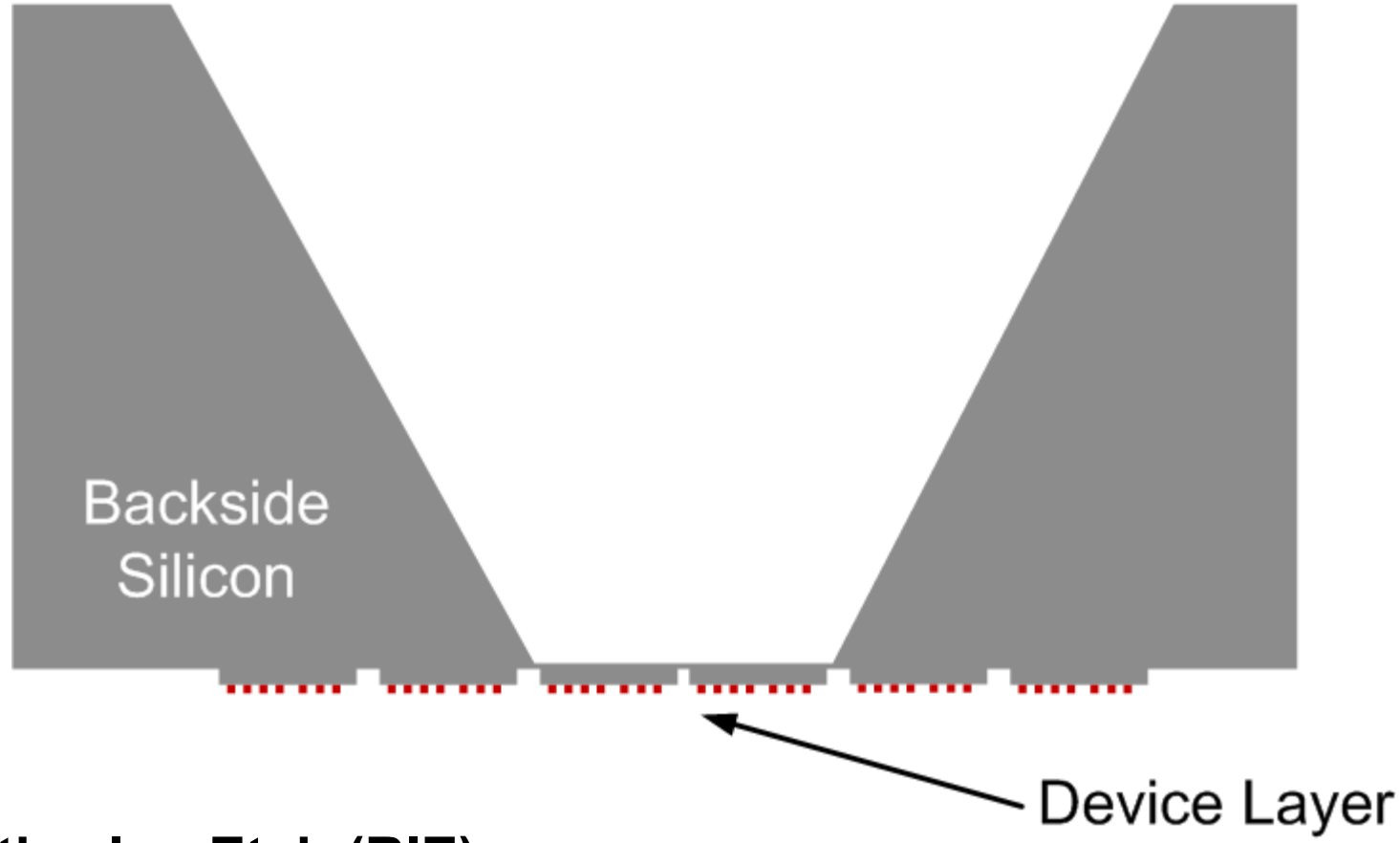
Lap backside silicon to ~ 100 µm

Ultra-Thinning



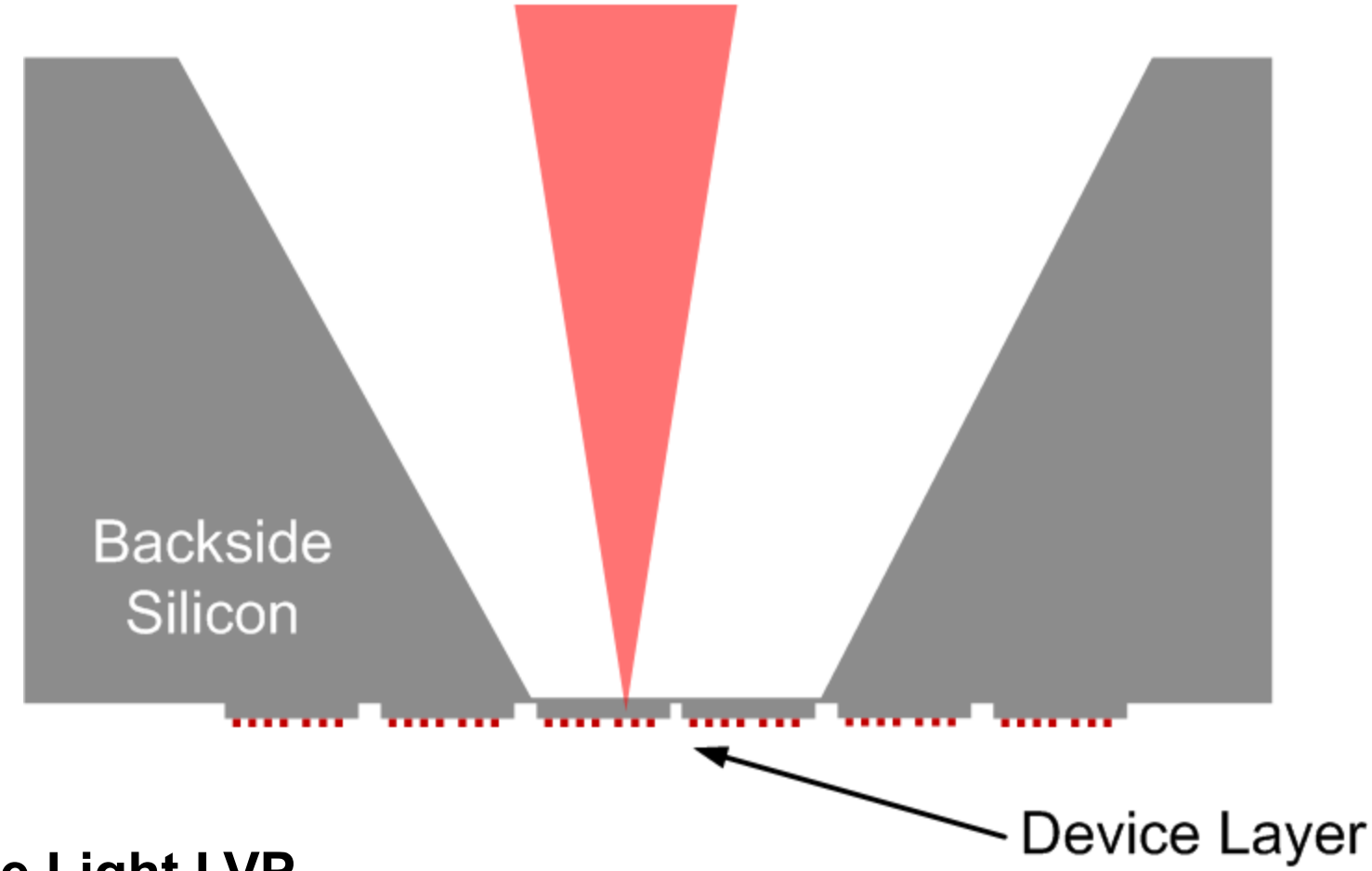
Use Pulsed Laser Assisted Chemical Etch (PLACE) to selective thin silicon to ~ 5 µm.

Ultra-Thinning



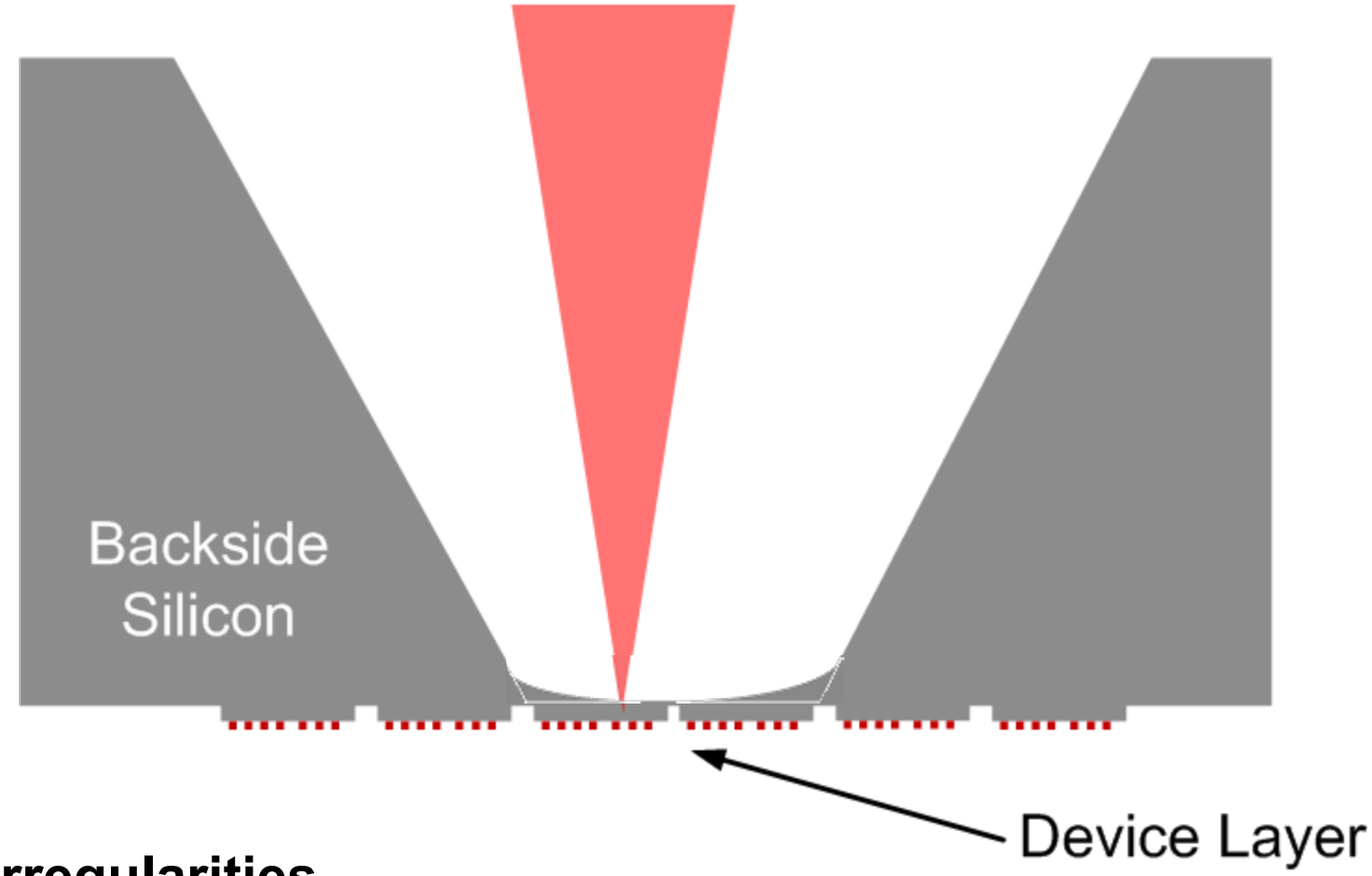
Reactive Ion Etch (RIE)
to ~ 1 µm

Ultra-Thinning



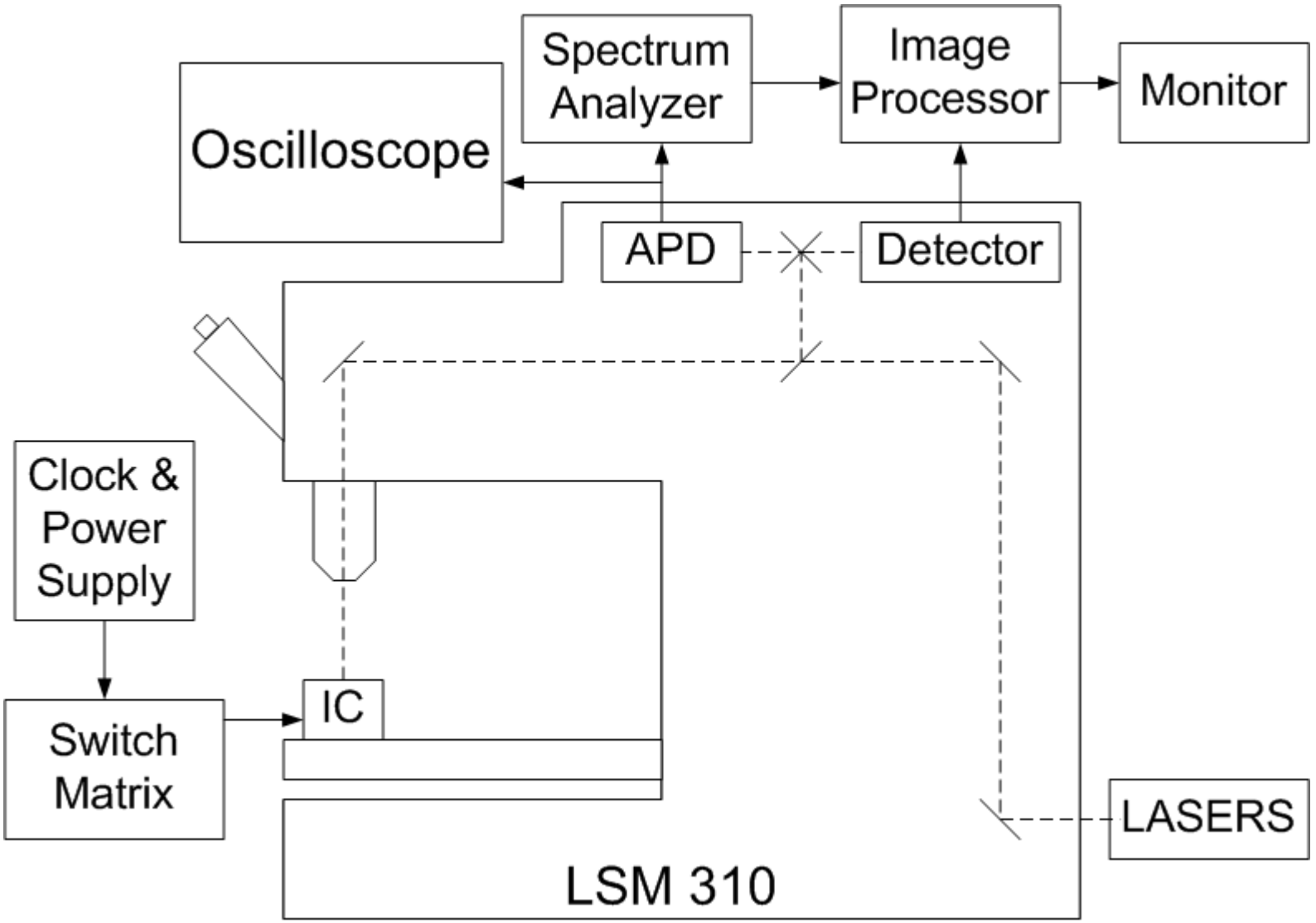
Visible Light LVP

Ultra-Thinning

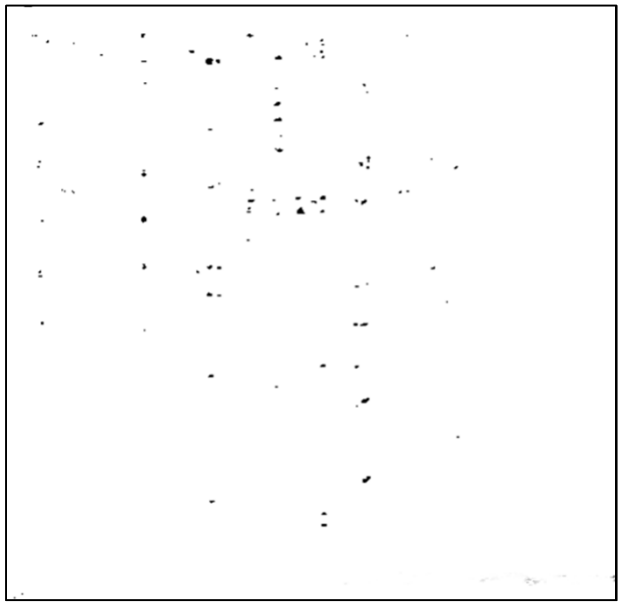


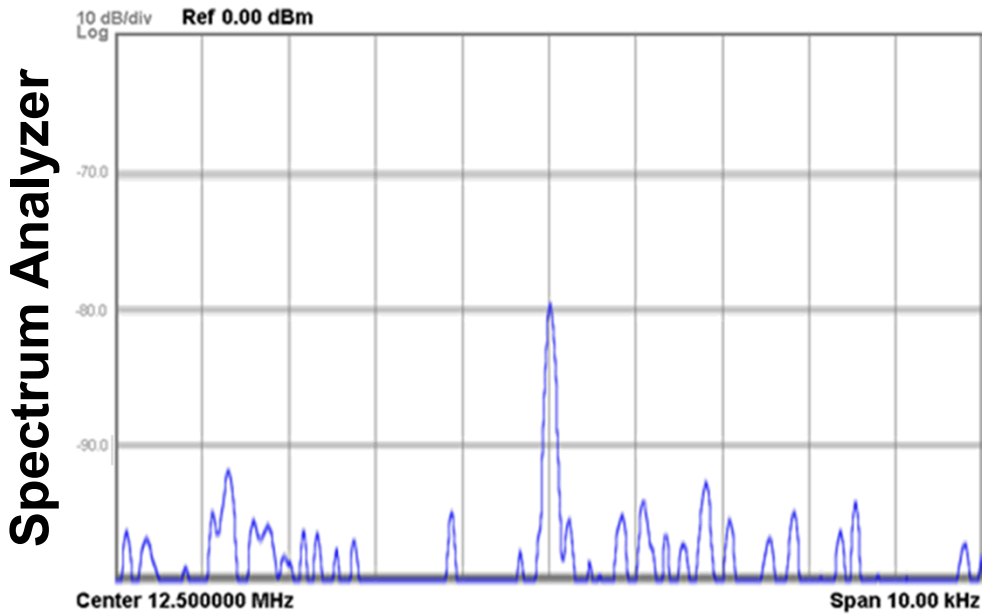
Etch Irregularities

LVP Framework



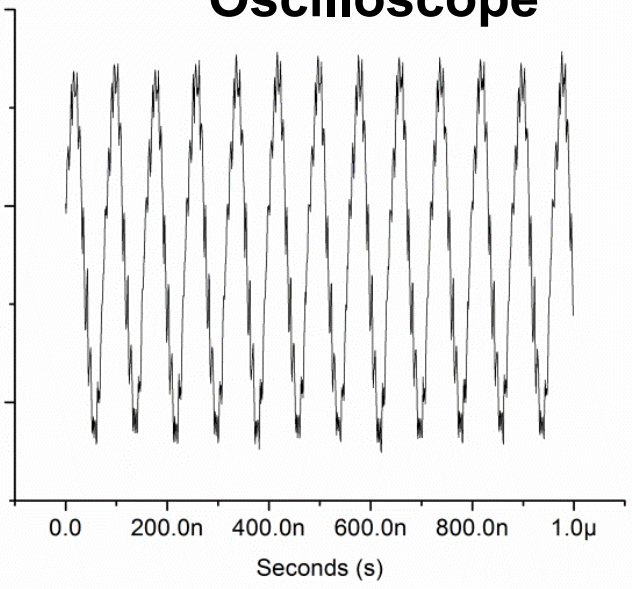
90 nm Bulk Si





Presence of LVP Signal

Oscilloscope



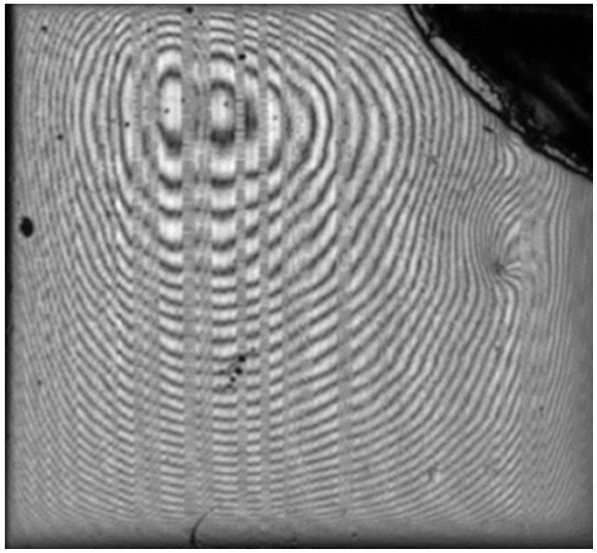
Scope Averaging to capture LVP Signal

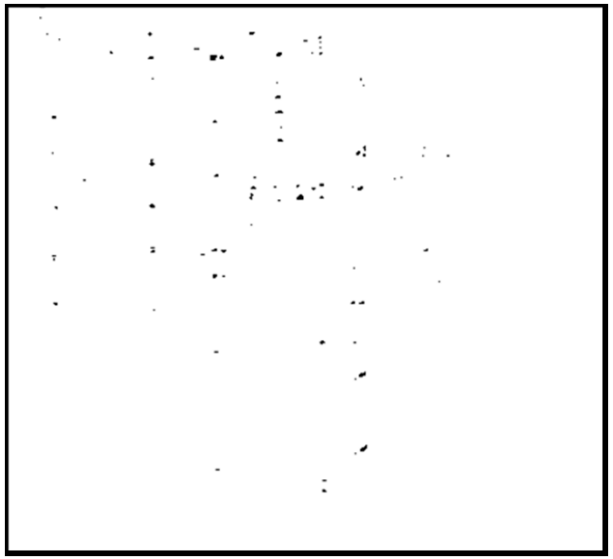
633 nm 50x Obj.

Signal Directly from APD Module

90 nm Visible Light LVI

633 nm

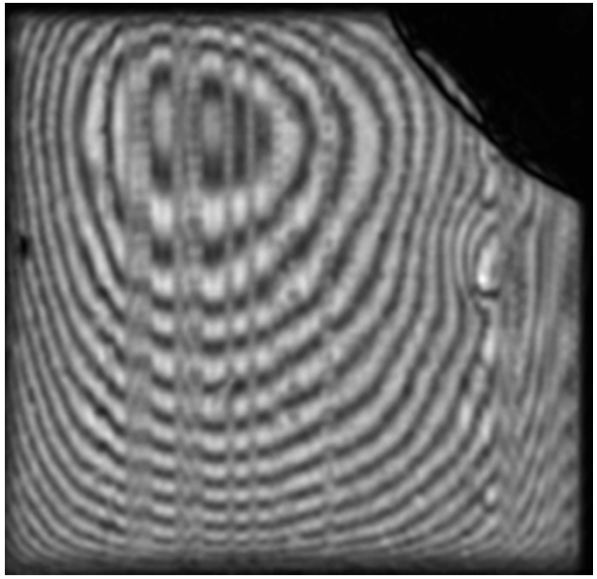


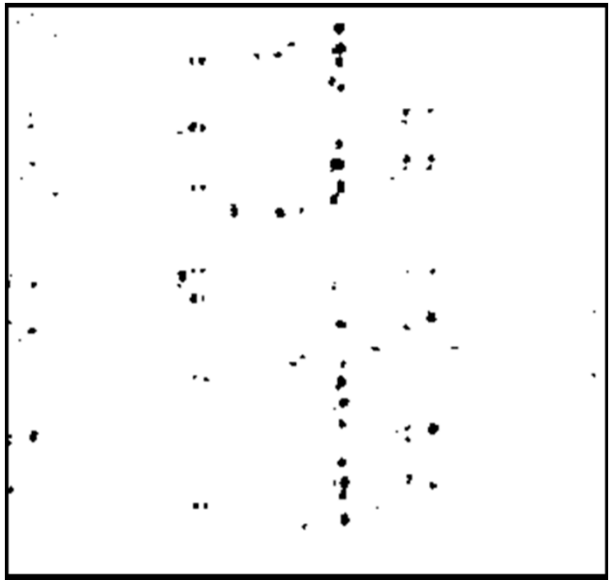


10x Obj.

Signal from APD fed into zero spanned Spectrum Analyzer

1320 nm

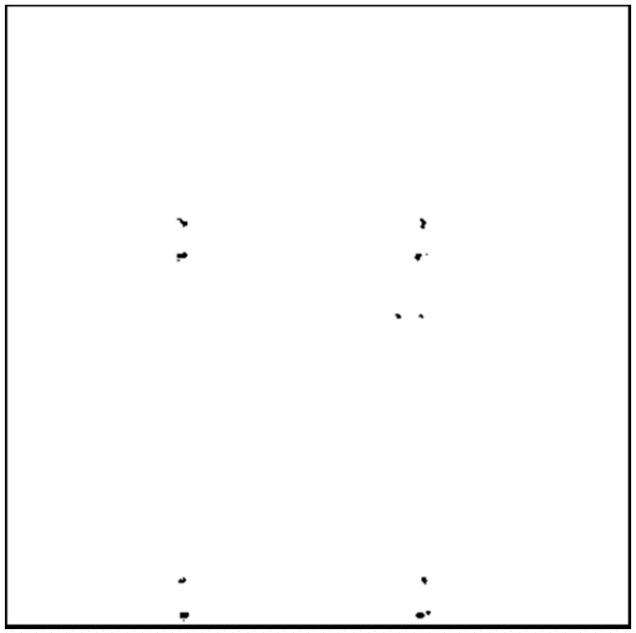


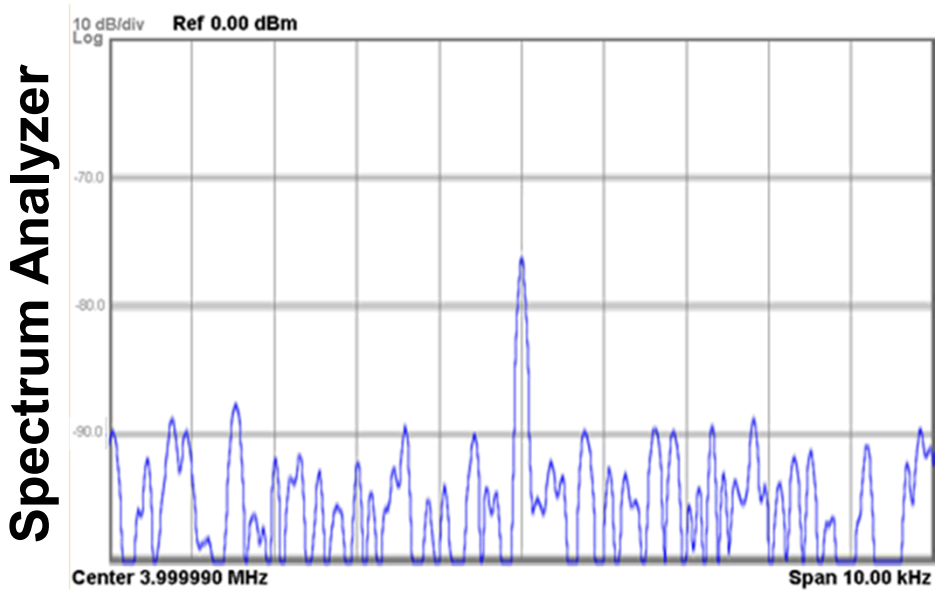


20x Obj.

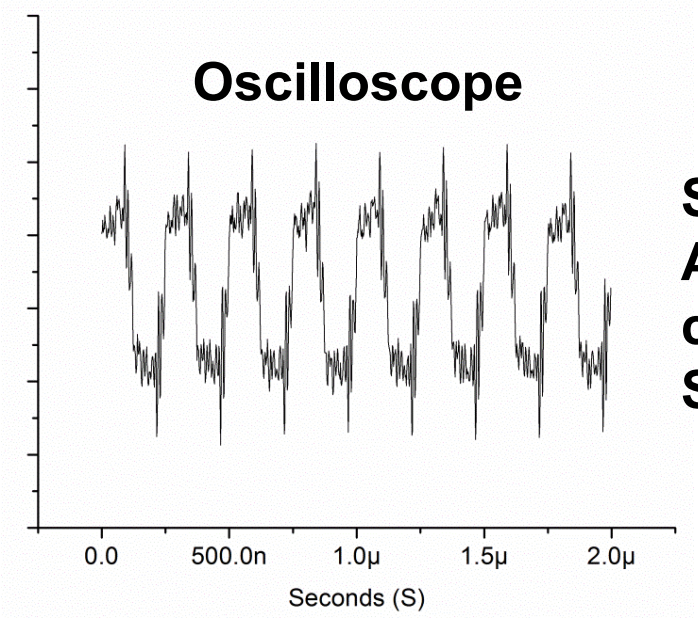
Video Out from Spectrum Analyzer fed into frame buffer

40 nm Bulk Si





Presence of LVP Signal



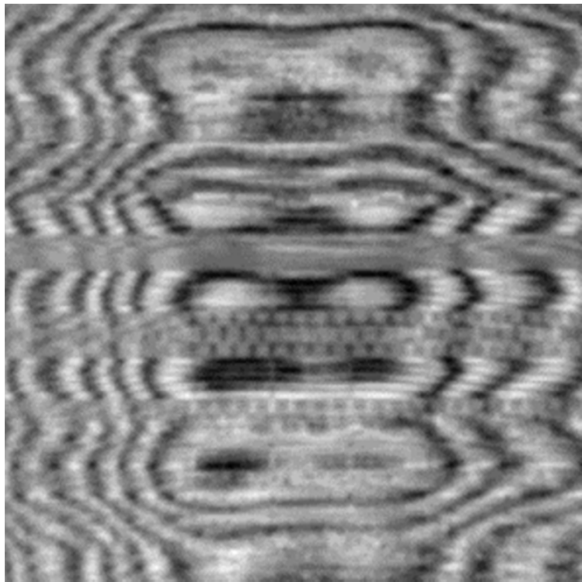
Scope Averaging to capture LVP Signal

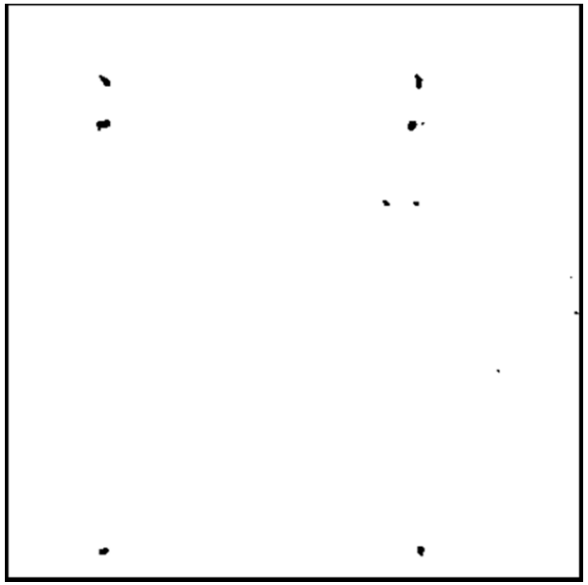
633 nm 10x Obj.

Signal Directly from APD Module

40 nm Visible Light LVI

633 nm

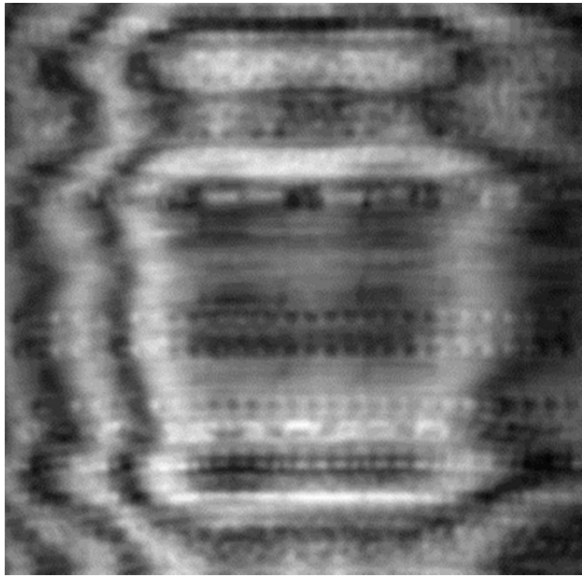


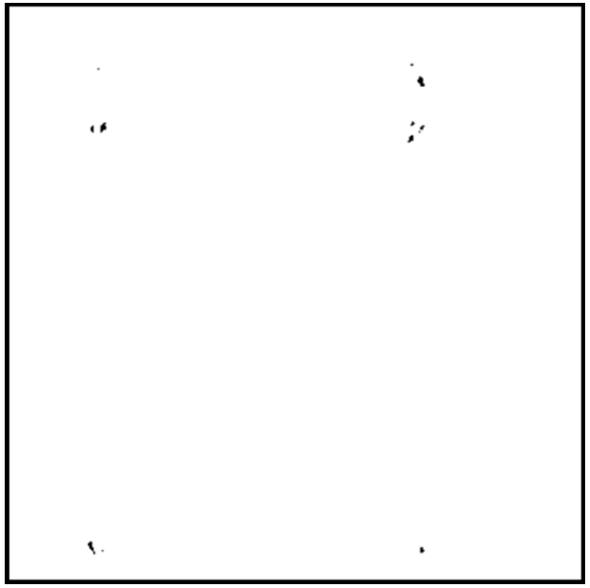


10x Obj.

Signal from APD fed into zero spanned Spectrum Analyzer.

1320 nm



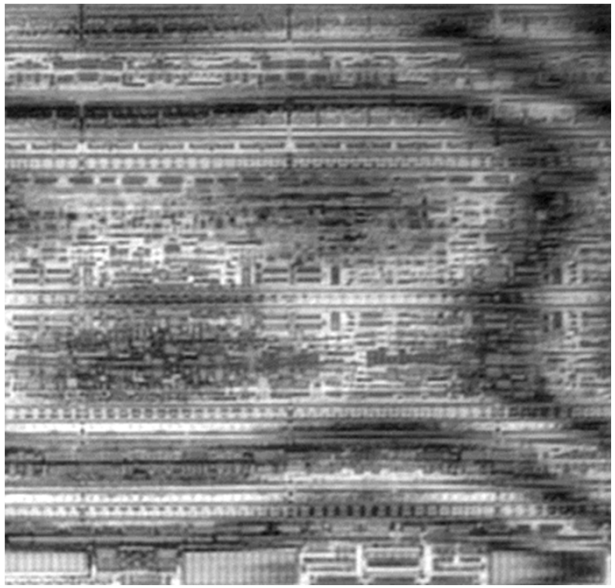


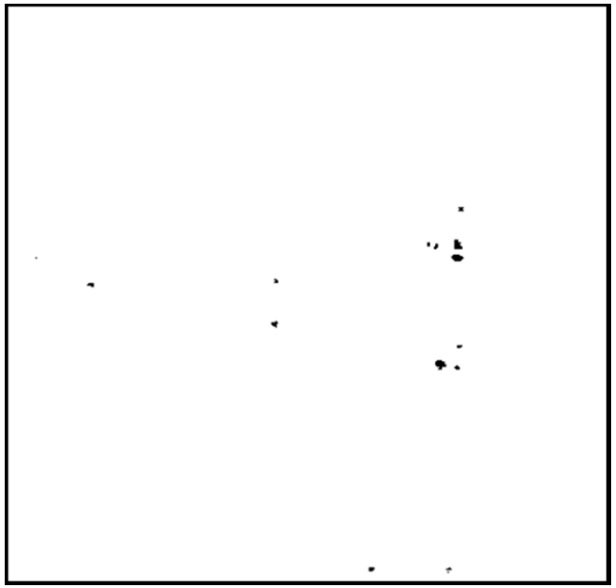
50x Obj.

Video Out from Spectrum Analyzer fed into frame buffer

45 nm Visible Oil vs. IR SIL LVI

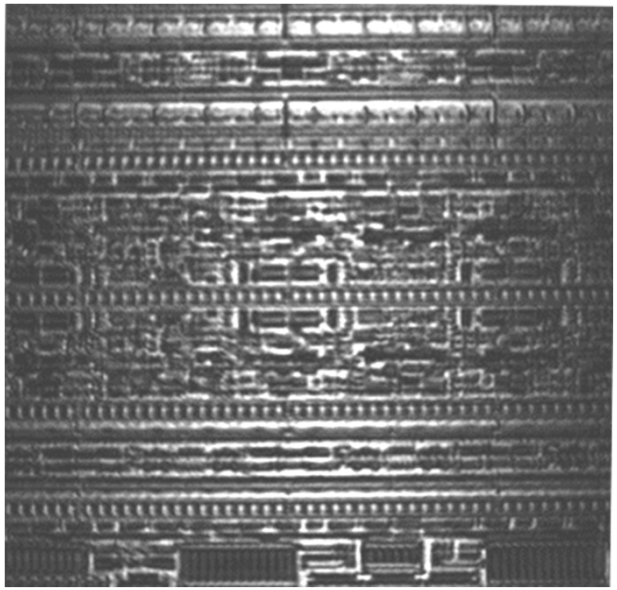
633 nm

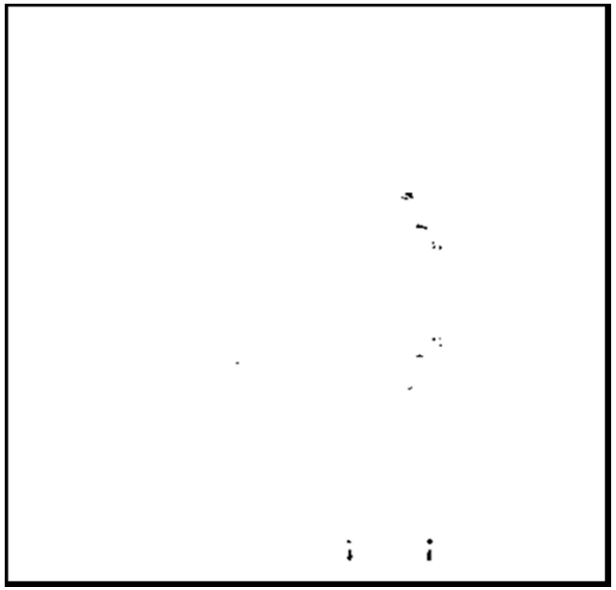




UTLVP
1.4 NA OIL

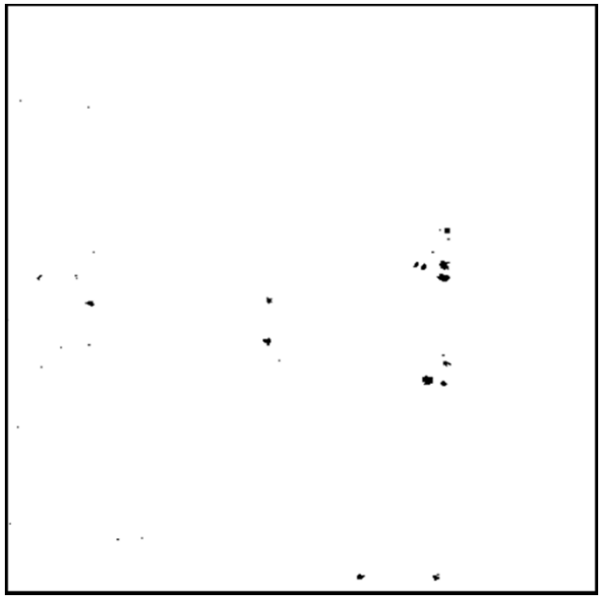
1320 nm

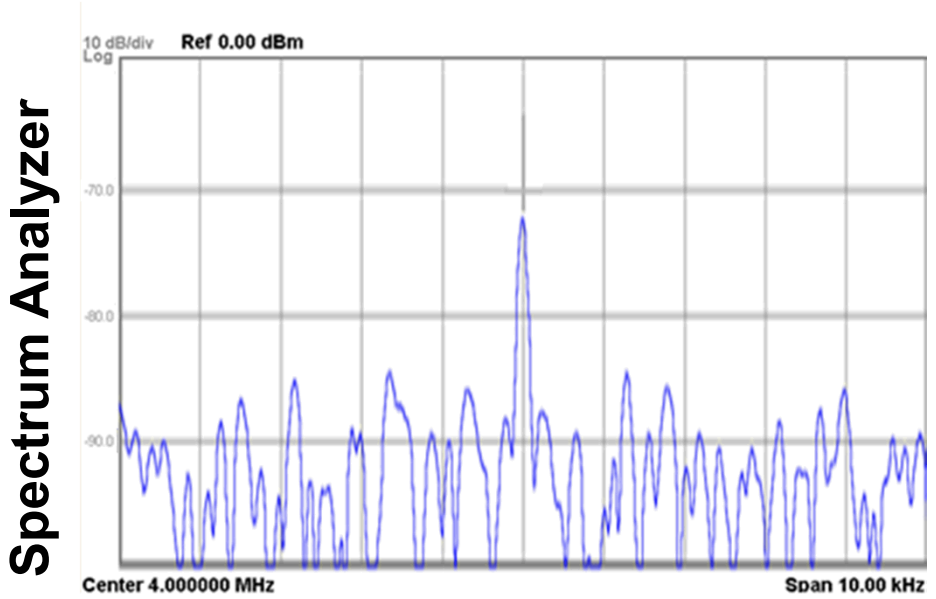




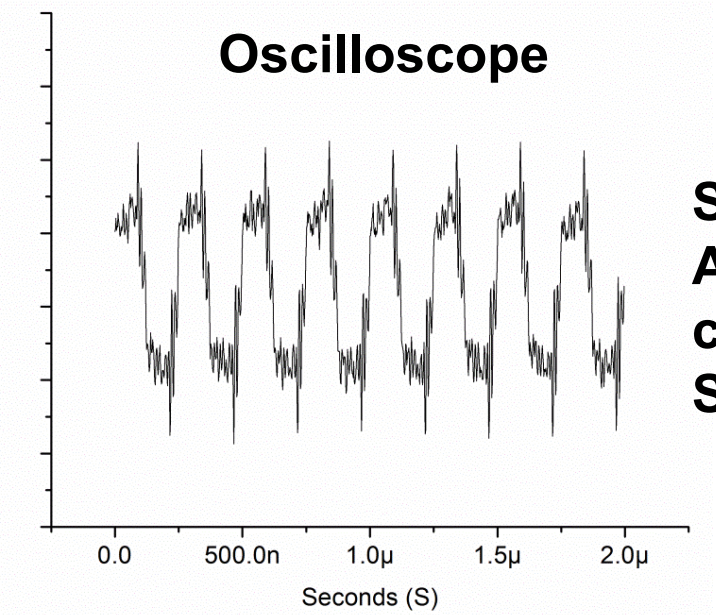
LVP
2.6 NA SIL

40 nm Visible LVP with Oil Immersion





Presence of LVP Signal

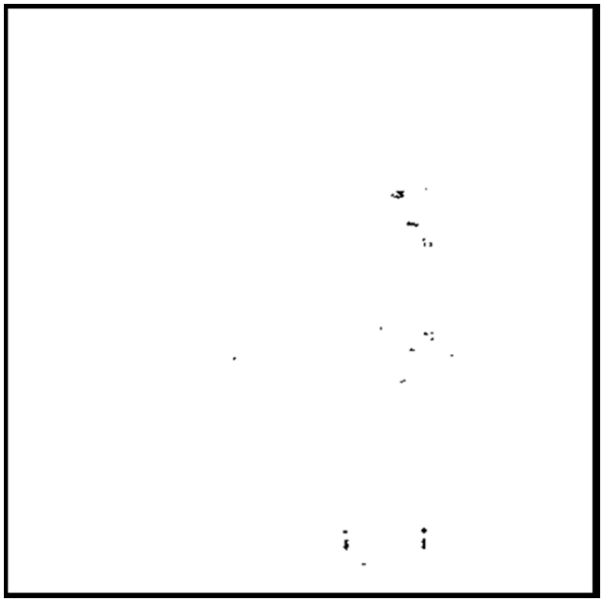


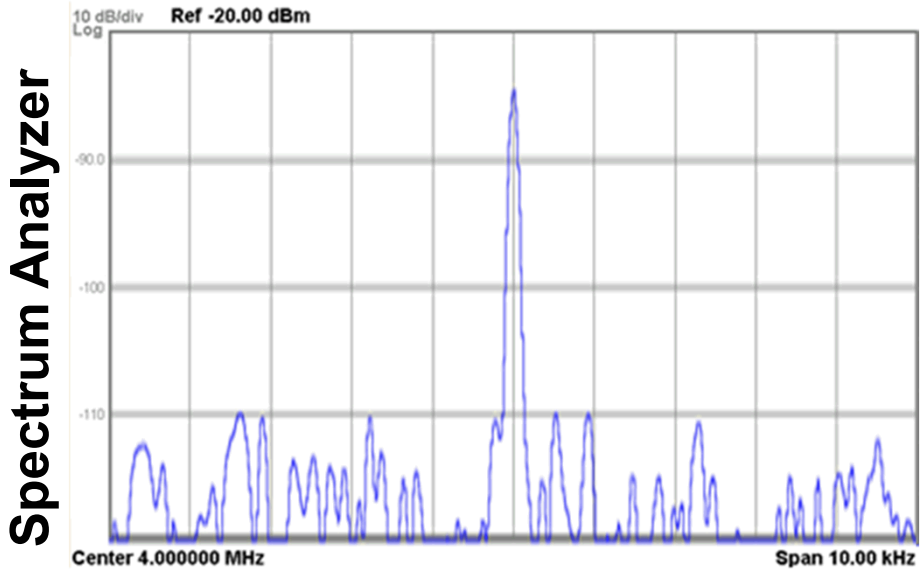
Scope Averaging to capture LVP Signal

633 nm 63x 1.4 NA Obj.

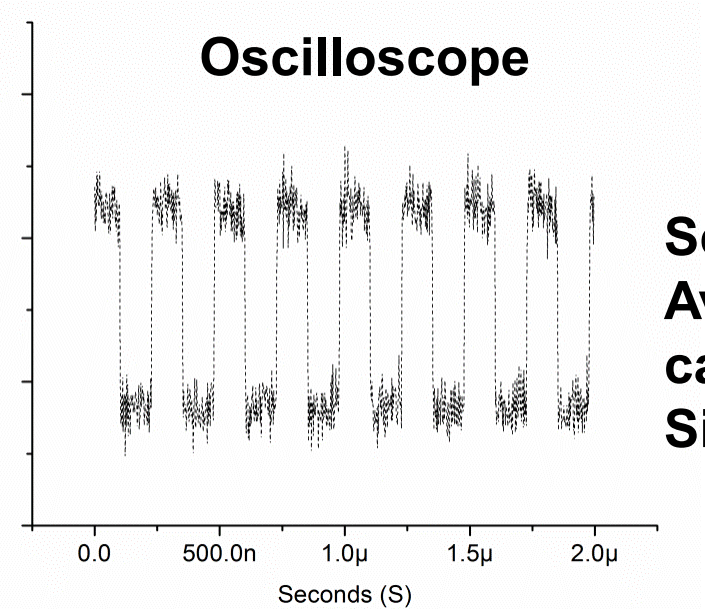
Signal Directly from APD Module

40 nm Conventional LVP with SIL





Presence of LVP Signal

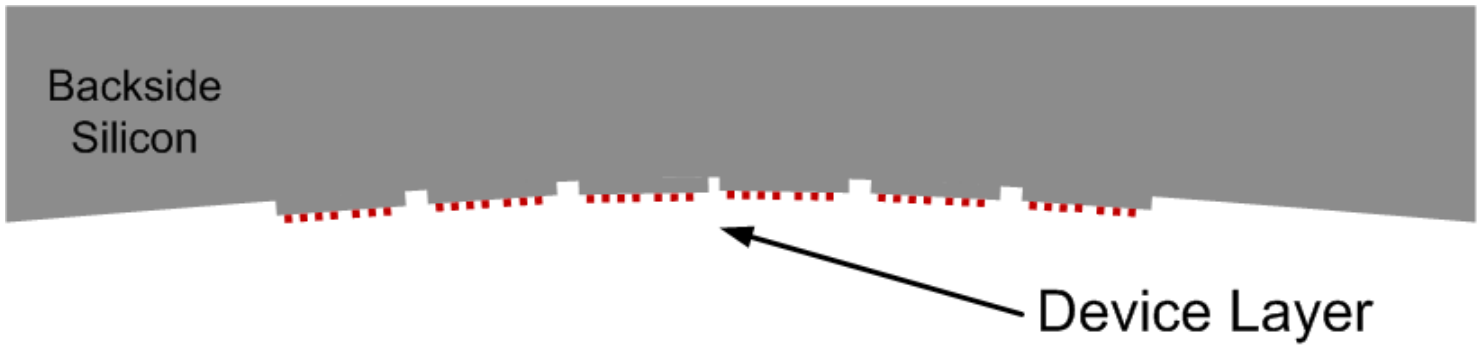


Scope Averaging to capture LVP Signal

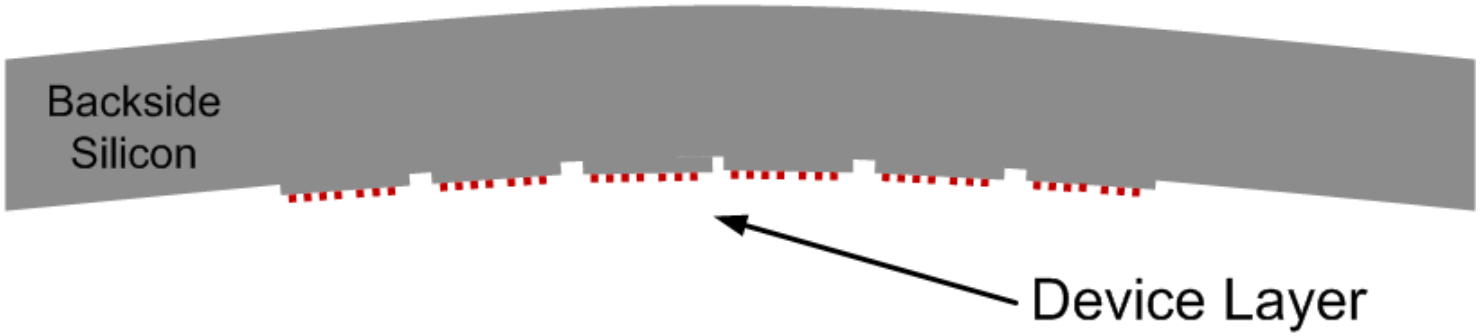
1320 nm 300x 2.6 NA Obj.

Advanced Sample Preparation

Advantages of Conformal Backside Substrate Removal



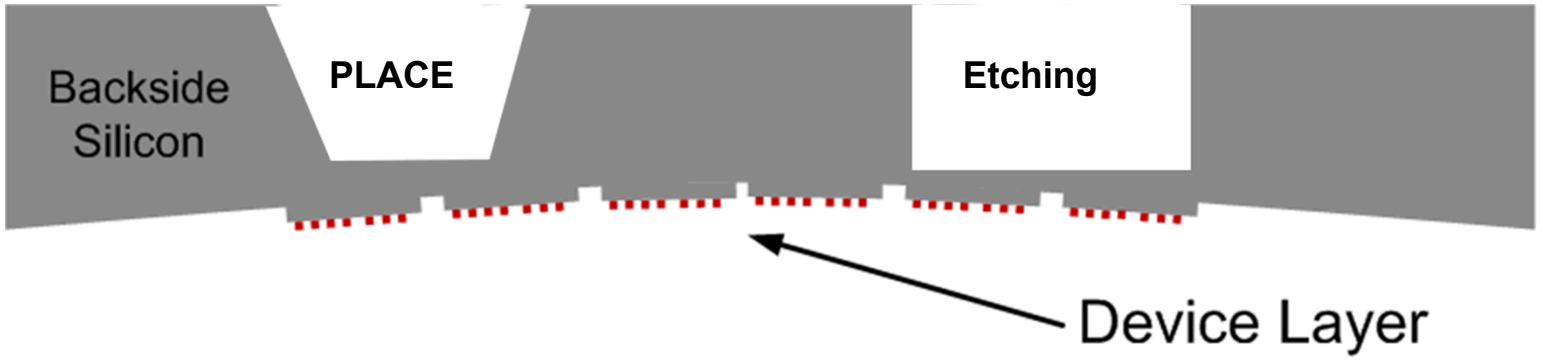
Lapping



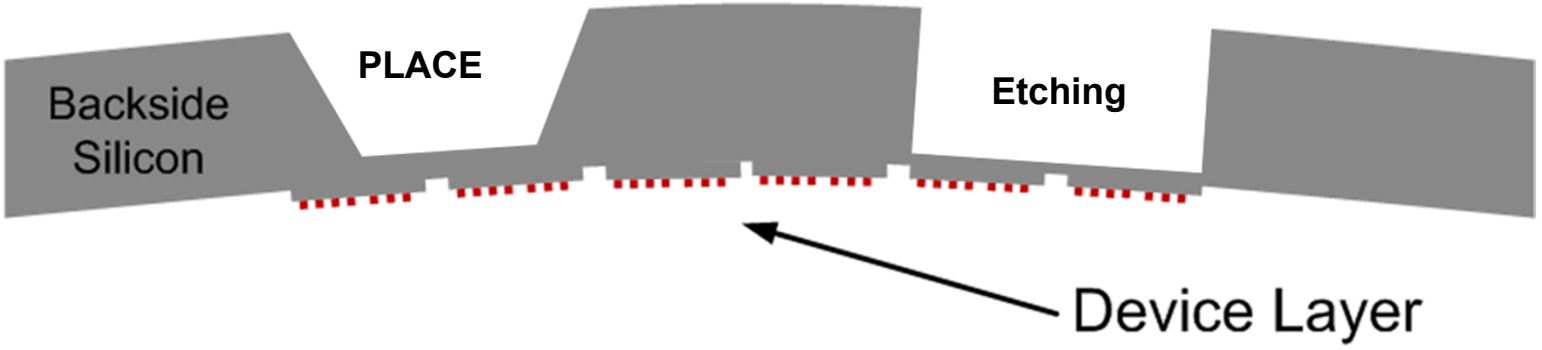
Adaptive Milling

Advanced Sample Preparation

Final results greatly affected by initial thinning process

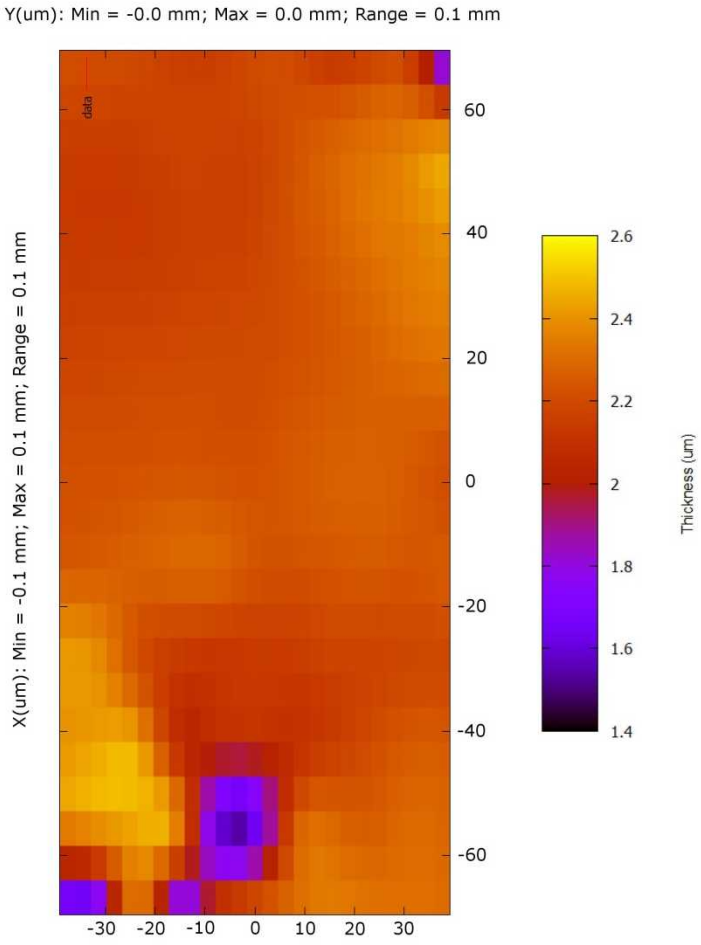


Lapping

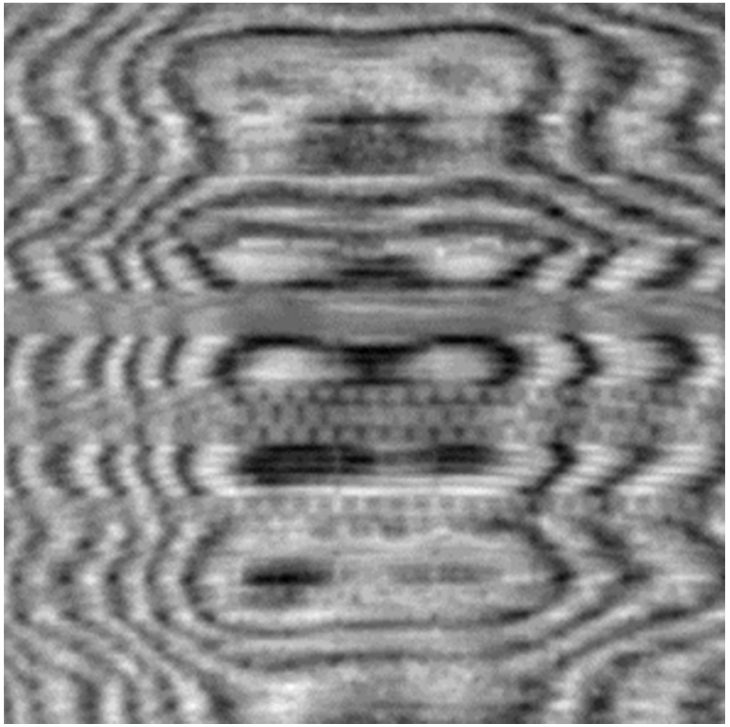


Adaptive Milling

Metrology

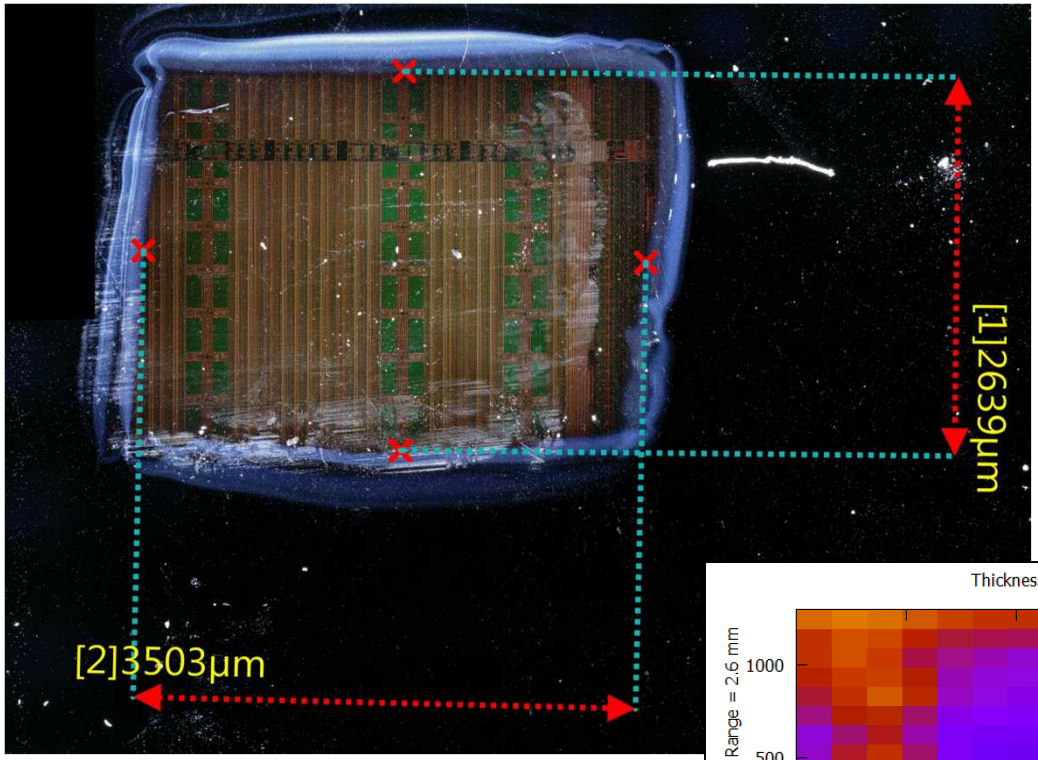


Bulk silicon metrology tools do not accurately measure UT silicon membrane thicknesses

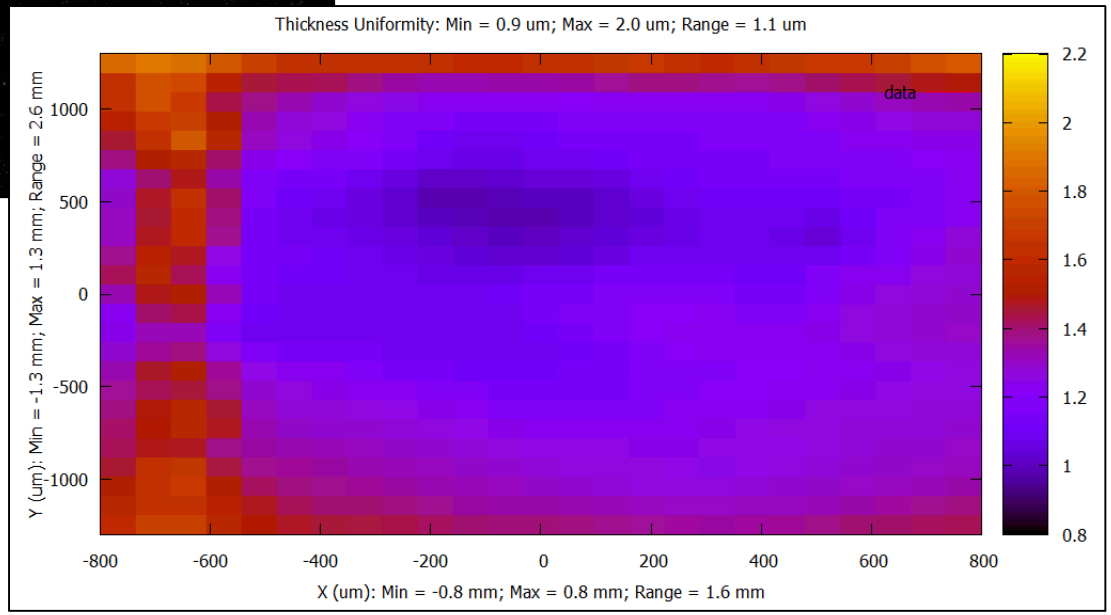


Visible light based metrology tools overcome this limitation

Improved Ultra-Thinning

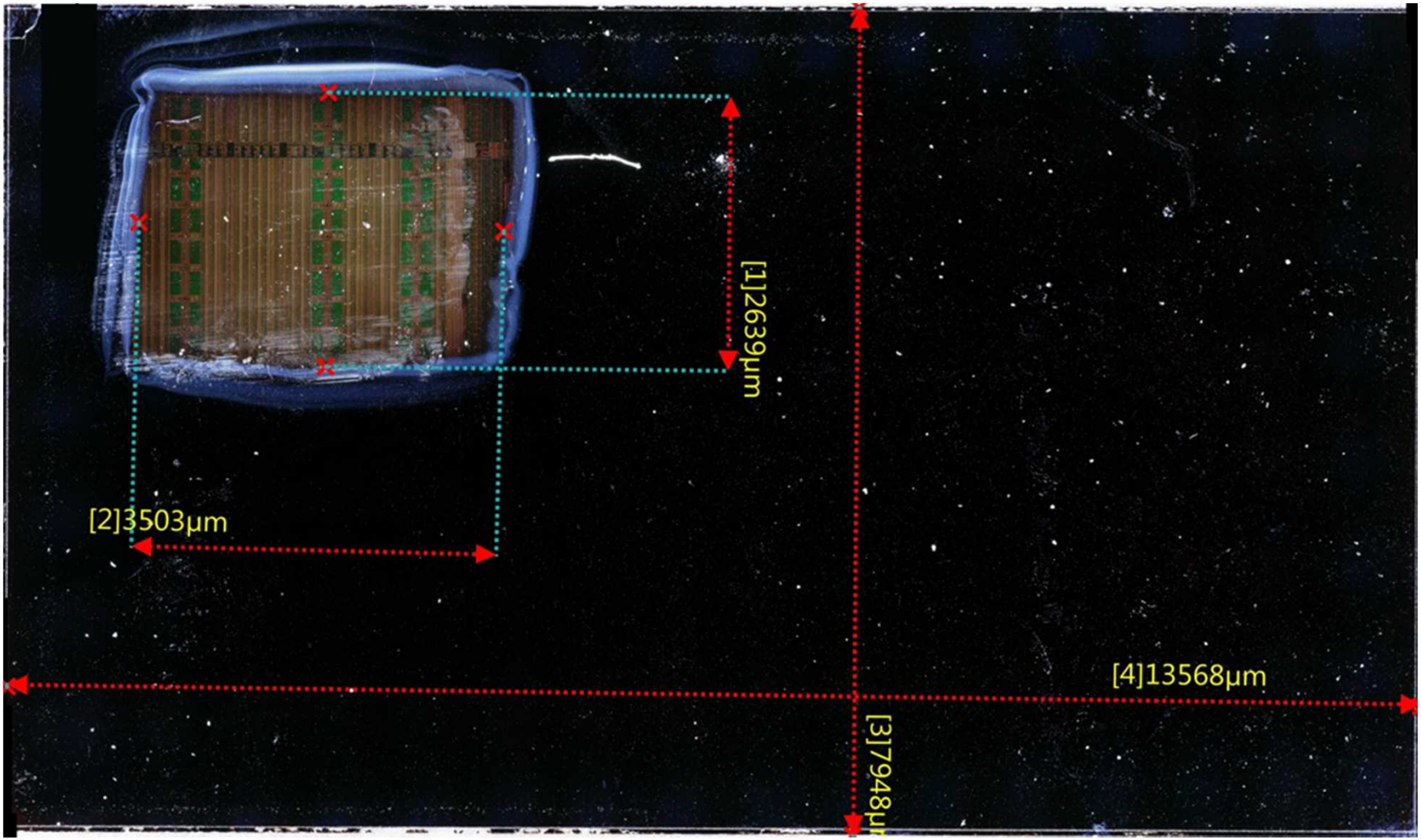


Combination of Conformal Milling and RIE Etch creates large uniform silicon membrane

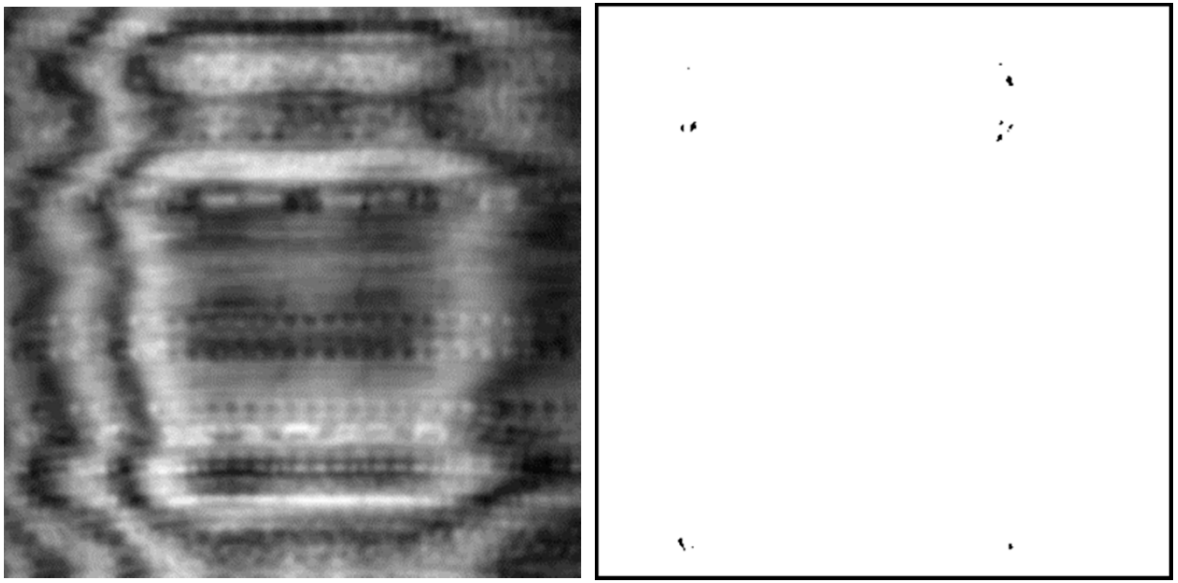


Visible light metrology tool accurately maps thickness of membrane

Improved Ultra-Thinning

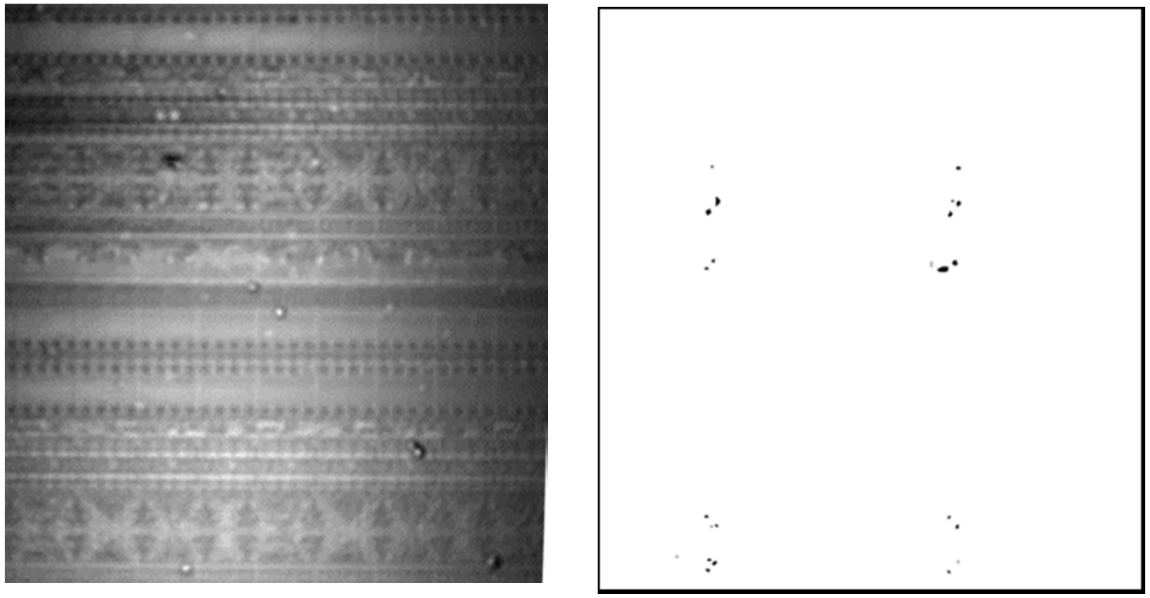


Improved Ultra-Thinning LVI



1320 nm

Initial Thinning



1320 nm

Improved Thinning

50x
Objective

Conclusions

- **Demonstrated bulk Si visible light LVP**
  - **Desired for improved spatial resolution**
  - **Relatively straightforward to implement**
  - **Demonstrated waveforms and imaging**

- **Requires Backside Ultra-Thinning**
  - **Effective bulk thinning process established**
  - **PLACE can produce superior samples**

- **Extend LVP to smaller SOI and bulk nodes**