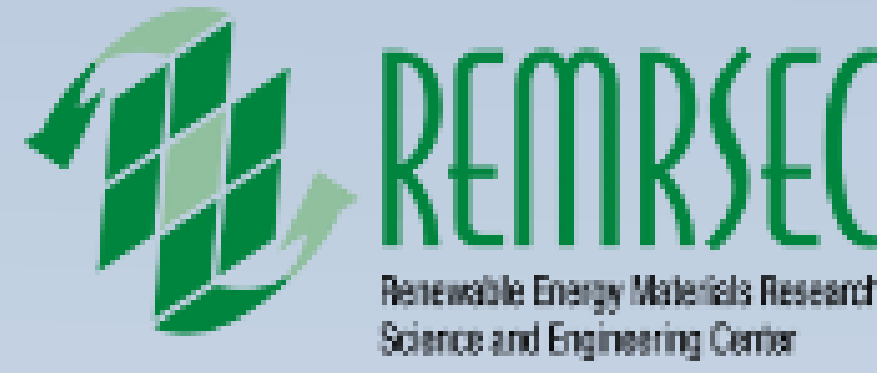


# Surface Characterization of Spalled Germanium Substrates



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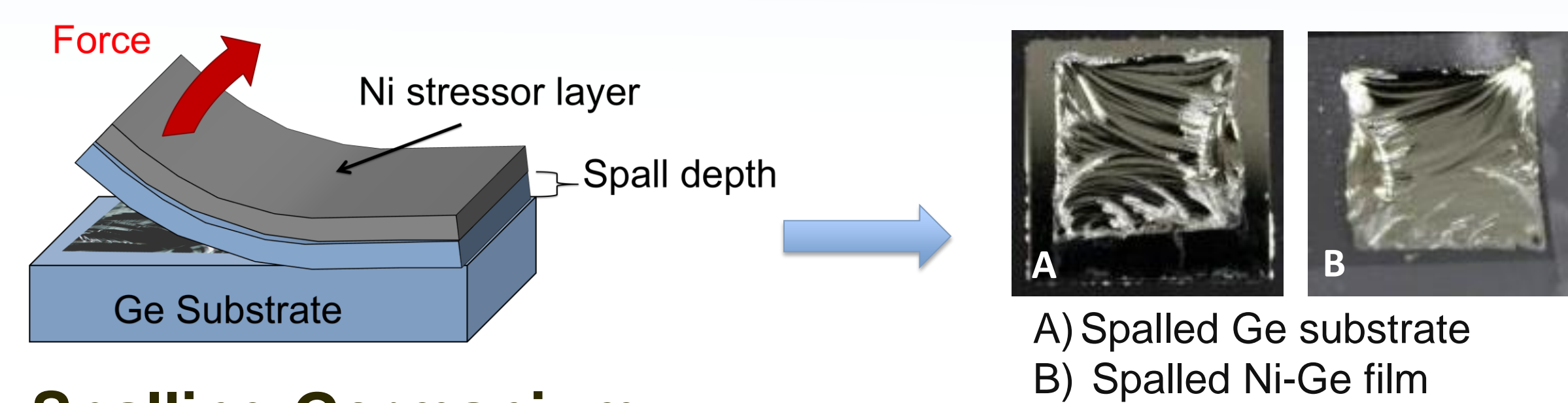
## Motivation

III-V photovoltaic devices display a significantly higher efficiency than commercially available solar cells. Germanium substrates on which III-V devices are grown represent a significant fraction of overall production costs. The solar cells can be removed from the Ge substrate through a process called spalling. Reusing the substrate after spalling requires highly controlled surface quality.

## Research Goal

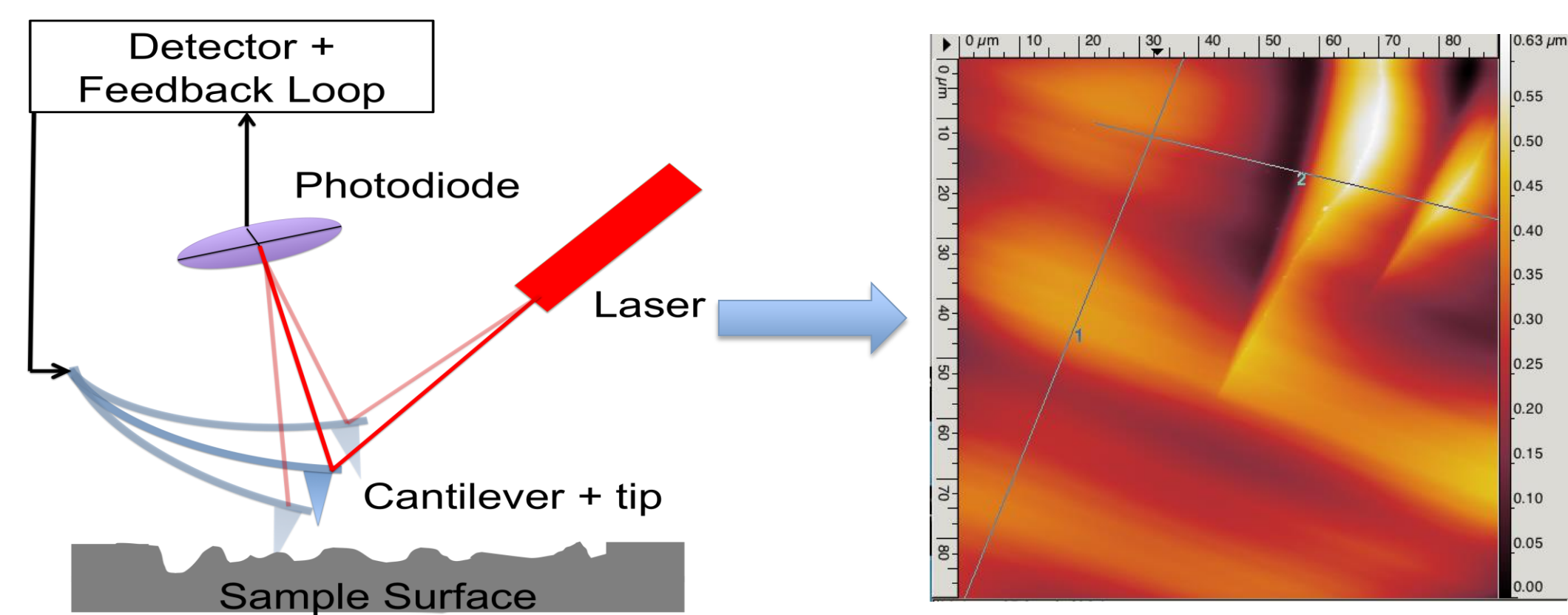
- Provide a baseline roughness for post-spalled Germanium substrates using atomic force microscopy.
- Determine trends between surface roughness and spalling parameters.
- Evaluate the effect of surface treatments on surface quality.

## Methods



### Spalling Germanium:

- An electro-plated Ni layer creates a strain mismatch that allows a fracture to propagate through the substrate at a certain depth.
- Spalled Ni-Ge film was mounted, polished, and used to optically measure spall depth.

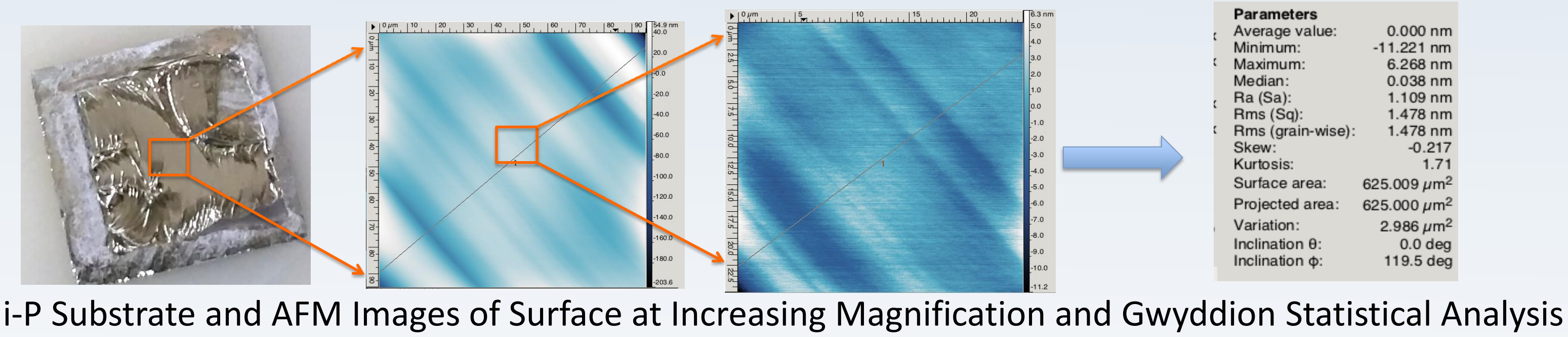
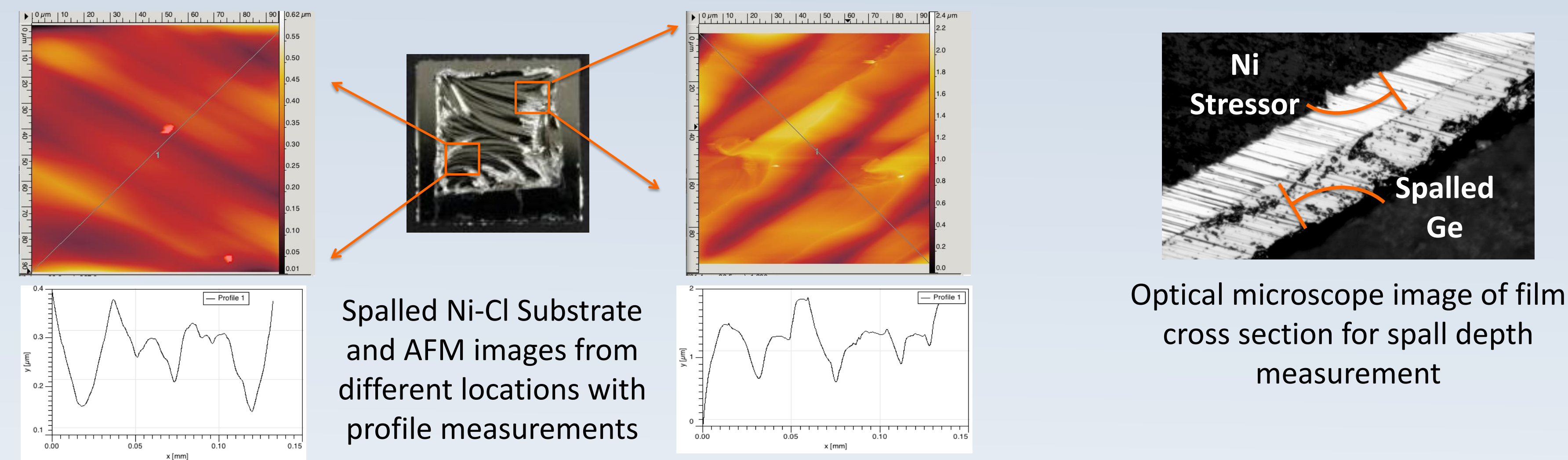


### Measuring Surface Roughness:

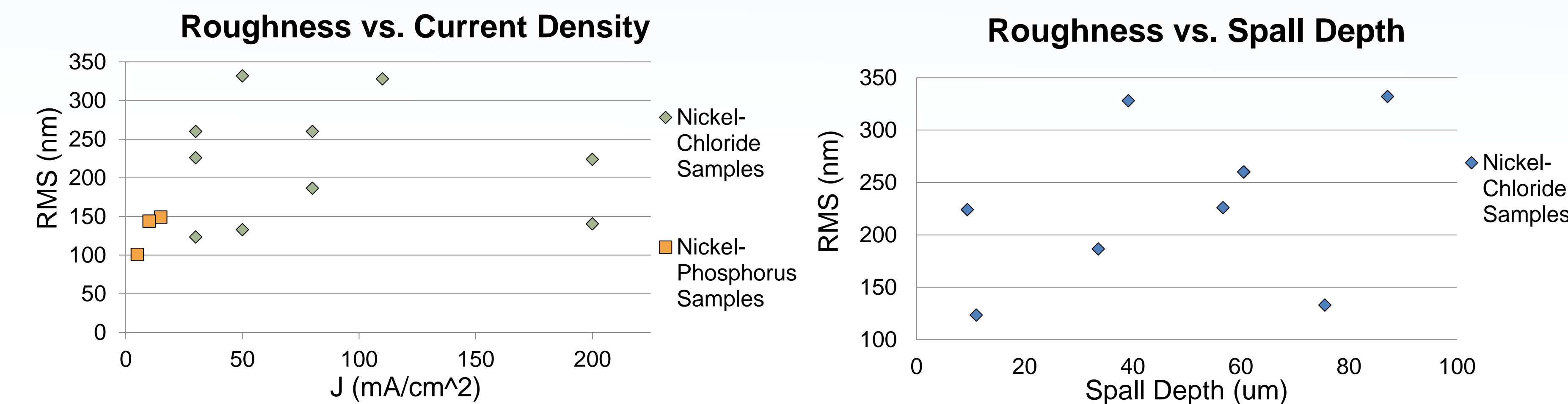
- Tapping mode AFM uses an oscillating cantilever to map out the surface of the spalled substrate. The image is then imported into an analysis software called Gwyddion.

## Effect of Applied Current Density on Roughness

- Two plating baths were used to electroplate Germanium substrates.
  - Ni-Cl: Nickel Chloride Hexahydrate, Boric Acid, DI Water
  - Ni-P: Nickel Chloride, Phosphoric Acid, DI Water

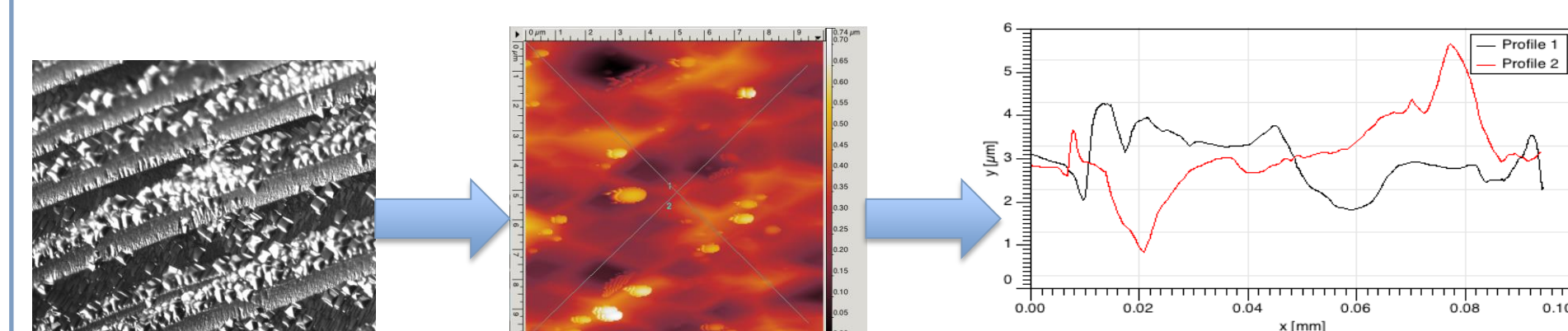
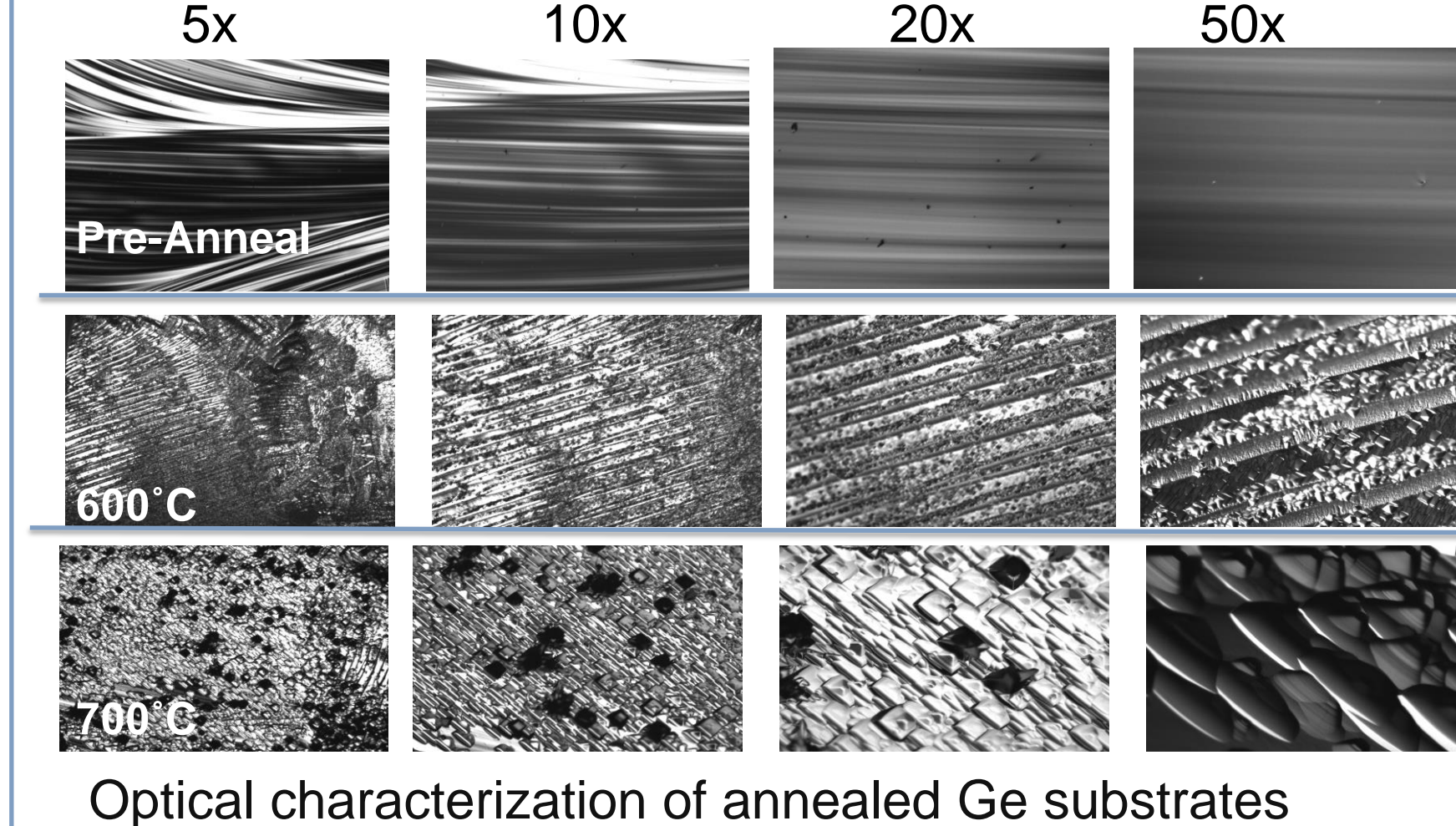


- Samples in the two baths were then spalled. A statistical RMS analysis of the substrate was done via AFM. The spalled film was cold mounted and a cross section measured under optical microscope to determine spall depth.

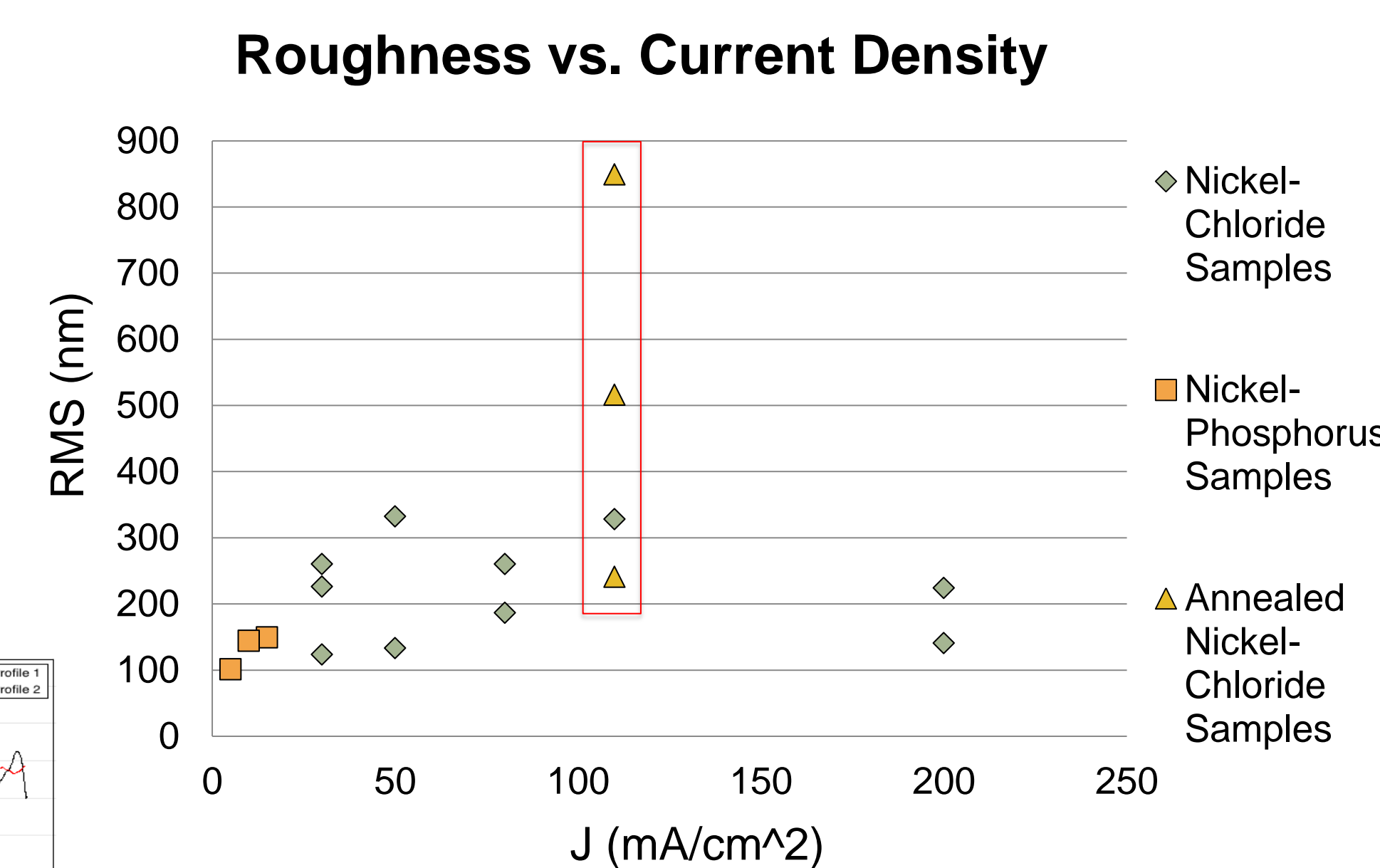


## Effect of Annealing on Roughness

- RMS roughness was measured before and after annealing at varying temperatures.



Optical, AFM, and profile scan of sample annealed at 600 °C in N<sub>2</sub> environment



## Results

- Spalled Ge using Ni-Cl bath tends to be rough.
  - Roughest areas measured up to 332 nm
  - Smoothest areas measured up to 8 nm
- Spalled Ge using Ni-P bath tends to be less rough.
  - Roughest areas measured up to 150 nm
  - Smoothest areas on the order of 3 nm
- There does not appear to be a correlation between spall depth and roughness.
- Annealed samples develop higher RMS and altered surface features compared to pre-annealed.
  - Roughest areas measured up to 849 nm
  - Smoothest areas on the order of 4 nm

## Conclusion

- Samples plated with a high current density in the Ni-Cl bath tended to have a high RMS.
- Samples plated in the Ni-P bath resulted in lower roughness.
- All samples displayed varied surface features, including flatter areas and areas of jagged peaks.
- Since spall depth does not effect roughness, other engineering parameters should be evaluated.
- Annealing in a N<sub>2</sub> environment is not a promising method of preparation for substrate reuse.
- Annealing samples at 600, 650, and 700 °C develops unexpected surface features.
- At 650 °C the Ge substrate began evaporating and formed undesirably rough pits.

## Future Work

- Chemical etchants are currently being investigated to refine the surface of spalled Ge for regrowth. These surfaces will need to be looked at more closely
- Ni-P bath and roughness at different current densities.
- Annealing in H<sub>2</sub> and diluted H<sub>2</sub>/N<sub>2</sub> atmosphere and measuring subsequent roughness

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