Structure and Electronic Properties of Mesopores in Si PV Devices with PLEO Contacts

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PLEO Contact Structure - Motivation

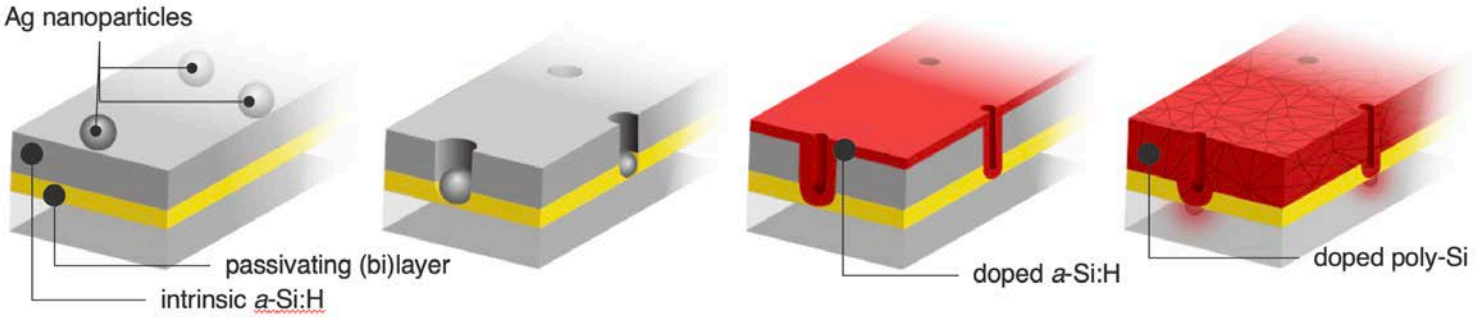
- Passivating contacts are expected to be implemented to > 50% of industrially manufactured Si PV within this decade
- Industry currently implements quantum-tunneling-enabled poly-Si contacts to the planarized rear of diffused emitter Si solar cells
  - Extremely sensitive to variations in SiO_x (< 1.7 nm) thickness – process yield issues
  - Alternative process involves thicker SiO_x (> 2.0 nm) that contains thermally induced (> 1000 ℃) discontinuities (i.e. pinholes) in SiO_x that is also sensitive to variations in SiO_x thickness – process yield issues, prohibitive thermal costs
  - Hole-selective contacts only achieve high-performance in pinhole-enabled poly-Si – demonstrated by ISFH's 26.1% IBC*

- Need a lower cost reproducible process for creating discontinuities in thicker dielectric layers
- Understanding the nanoscale structure of discontinuities is critical for process optimization

*Haase, F., oet al. *Solar Energy Materials and Solar Cells*, *186*, 184-193.

PLEO Contact Formation

Polysilicon on Locally Etched Dielectrics – processing steps (can also be applied to textured *c*-Si)



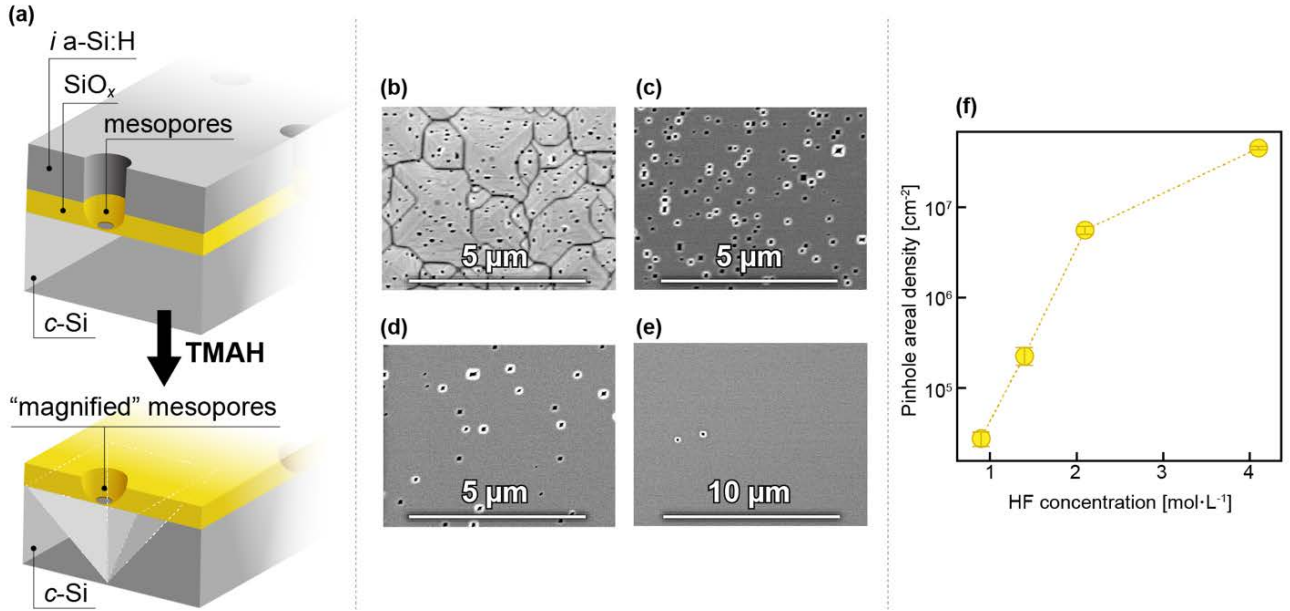
Lima Salles, C. et al., *Presented at European Photovoltaic Solar Energy Conference*. 2021.

- Development of pinhole-enabled poly-Si contact fabrication via room temperature process
- Pinhole formation achieved with metal-assisted chemical etching (MACE)
- Already used by Si PV industry to texturize *mc*-Si wafers
- May be applied to many different structures (e.g.: poly-Si/SiN_y/SiO_x, poly-Si/Al_2O_3 /SiO_x)

SolarTech in-line MACE tool

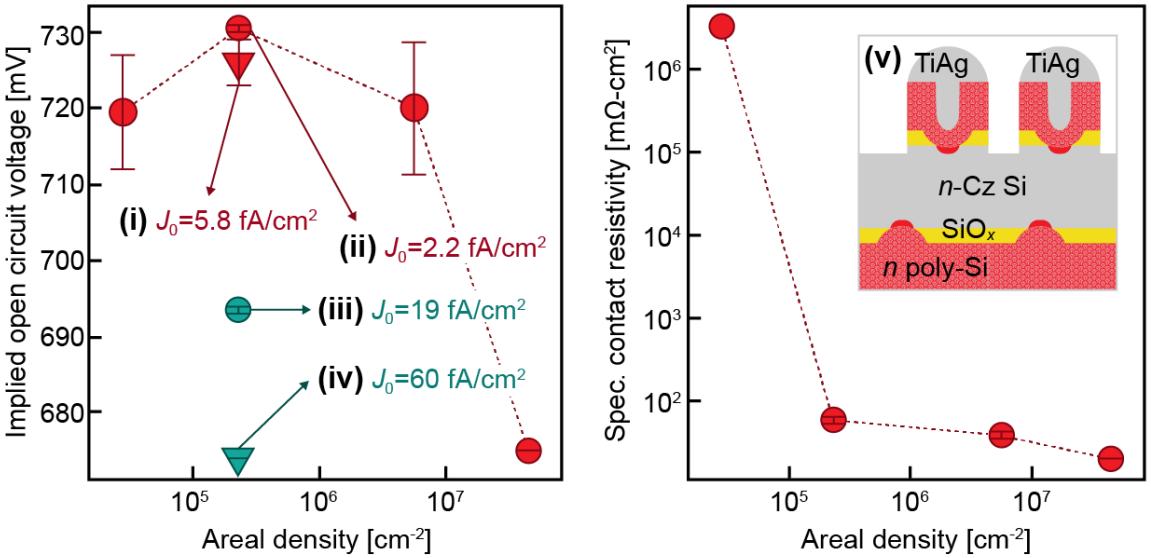
Jooss, W. et al., *33rd European Photovoltaic Solar Energy Conference and Exhibition*. 2017.

PLEO Characteristics



- TMAH etching to reveal disruptions in the SiO_x layer
- Density can be controlled by changing the solution concentration

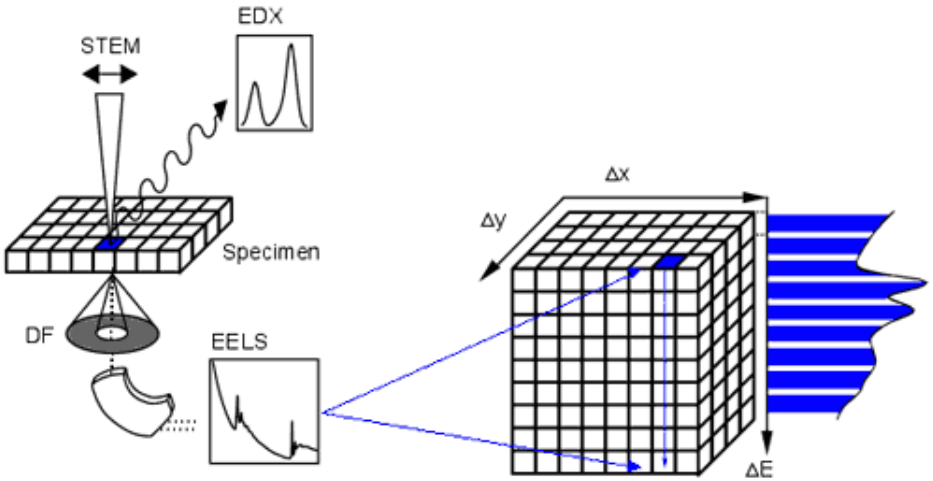
PLEO Characteristics

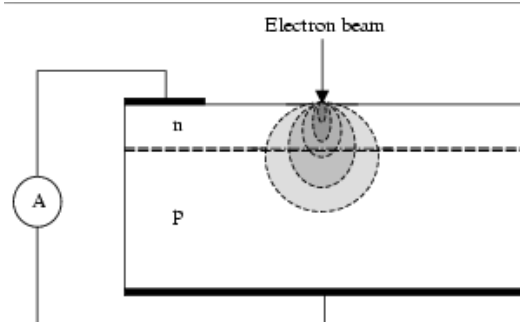


- iV_{oc} and contact resistivity are related to the density of pinholes in the SiO_x layer

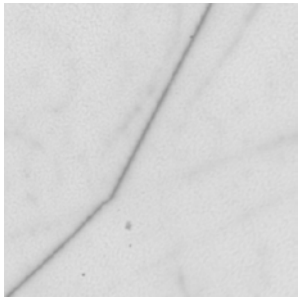
Measurements Used in this Work

- EBIC - Contrast analysis provides information about the local recombination/transport behavior
- S/TEM Imaging – atomic scale structural information
- STEM EELS – nanoscale composition information

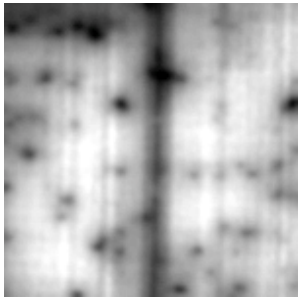




Grain Boundaries
Silicon



Misfits and Threads
III-Vs



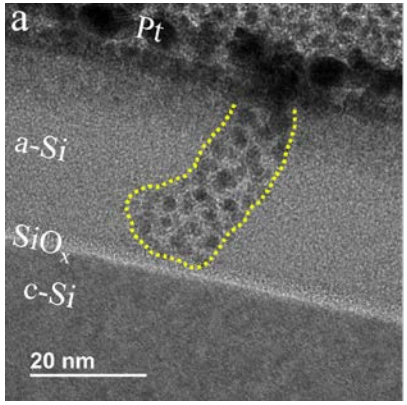
EBIC image showing recombination centers (dark regions)

Structural Measurements – Sample Preparation

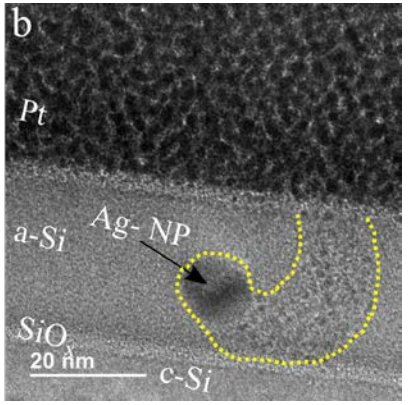
- Imaging voids
  - Can decorated with metals to produce image contrast
- Sputtering vs. FIB Pt deposition
  - Stronger contrast possible
  - Possible damage?
  - Complete filling?

FIB deposited e-beam Pt is the preferred method to decorate the mesopores

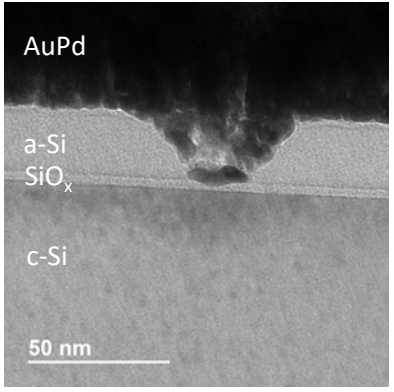
Decorated with FIB e-beam Pt



Not always vertically oriented

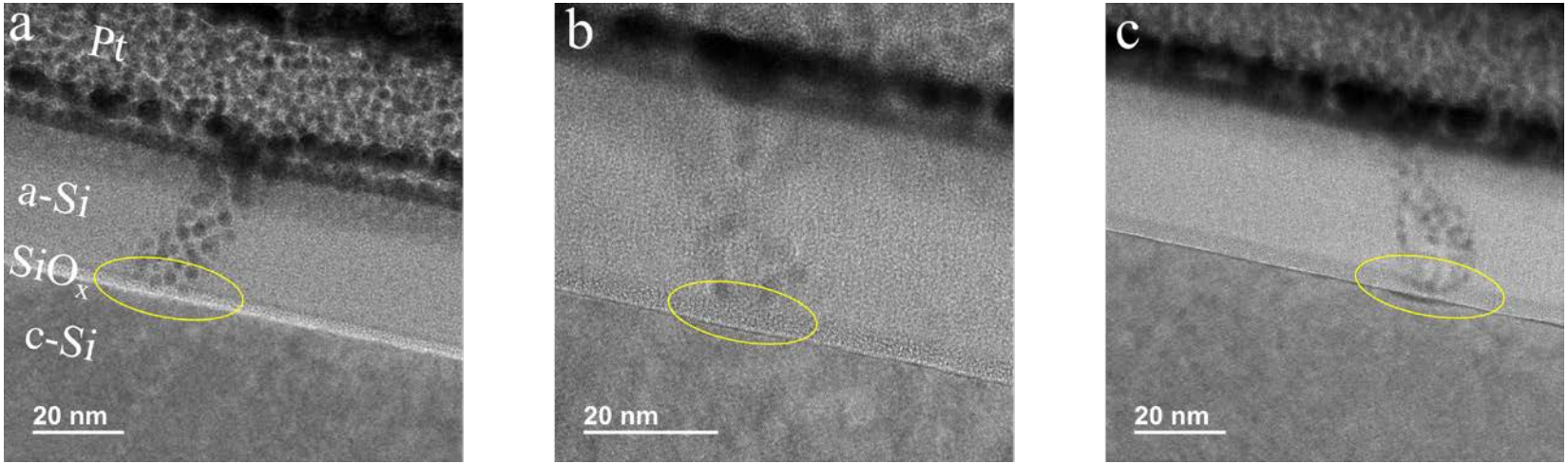


Decorated with sputtered AuPd



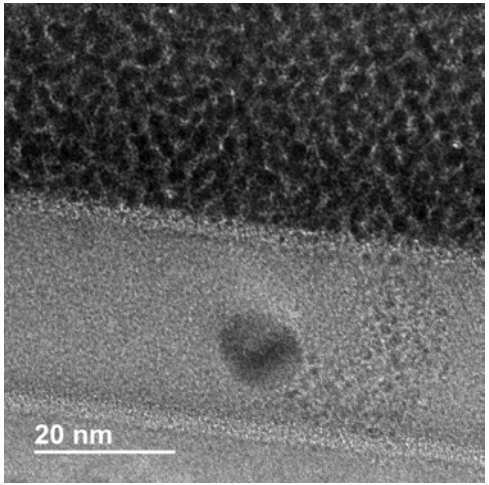
- In the image above the Ag particle was not washed away after the MACE process
- This image shows that the FIB Pt can fill the whole mesopore structure

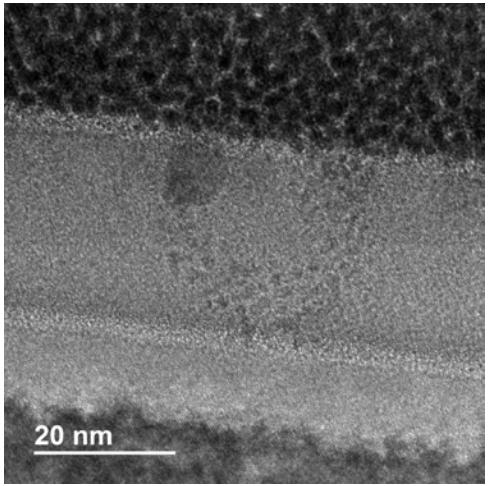
Structural Measurements – TEM Imaging

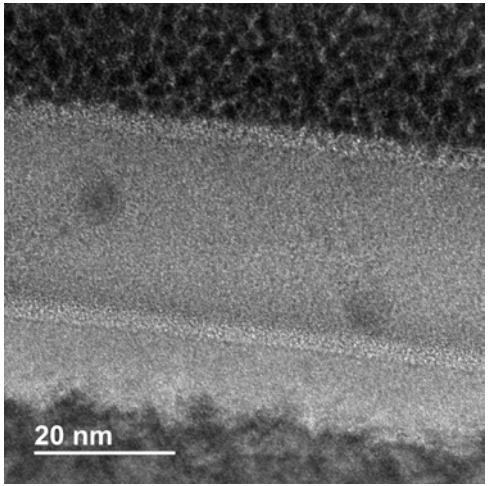


- The SiO_x under some mesopores appears intact
- The dimension of the etched portion of the SiO_x may be quite small
- Is the oxide being etched during the MACE process?

Structural Measurements – TEM Imaging



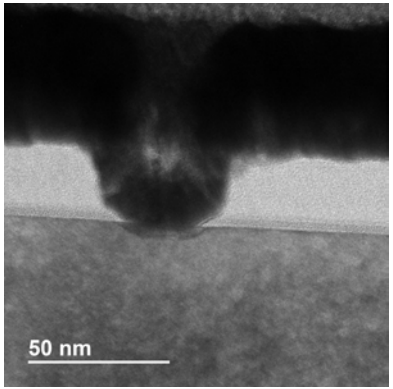




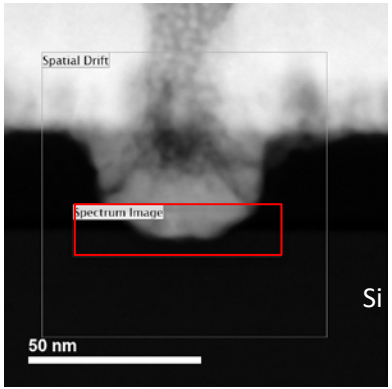
- In this case the SiO_x layer appears to be resistant to the MACE process
- Ag particles travel to the SiO_x then back into the a-Si layer

STEM EELS Mapping

Bright Field TEM

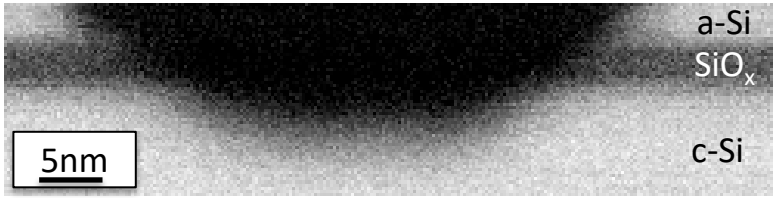


HAADF – STEM

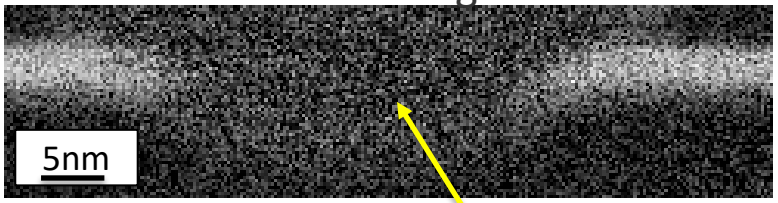


Areal Density
Elemental EELS Maps

Si L edge



O – K edge

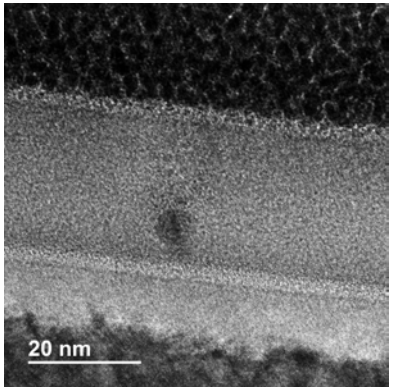


SiO_x clearly missing

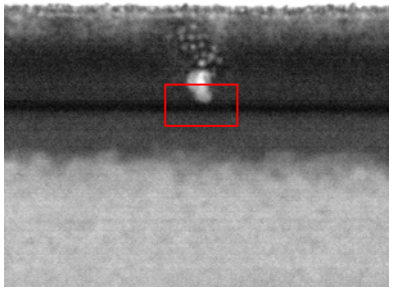
- Certain samples show metal coating clearly penetrating the layer stack
- Easily confirmed with EELS mapping
- What about less evident areas?

STEM EELS Mapping

Bright Field TEM



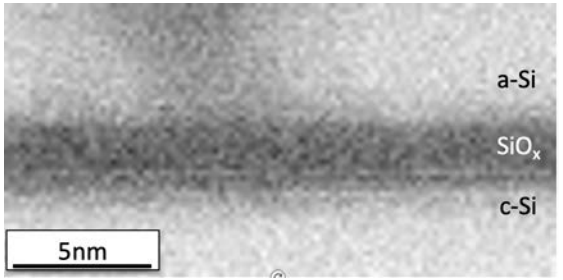
HAADF – STEM



- Oxygen profile over SiO_x layer under mesopore appears uniform
- Smaller etched area of SiO_x ?
- Not etched?

Areal Density Elemental EELS Maps

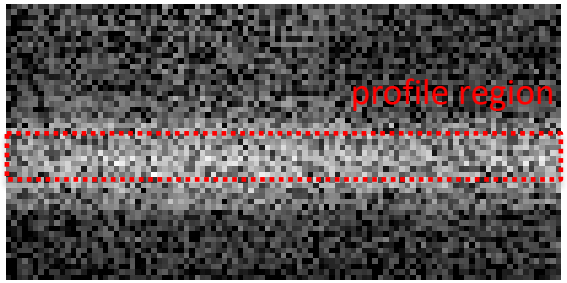
Si L edge

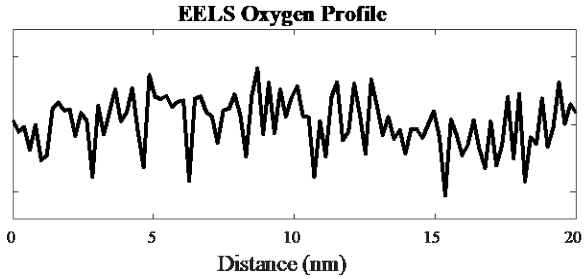


a-Si

c-Si

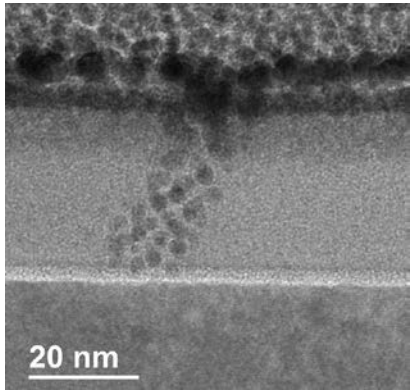
O – K edge



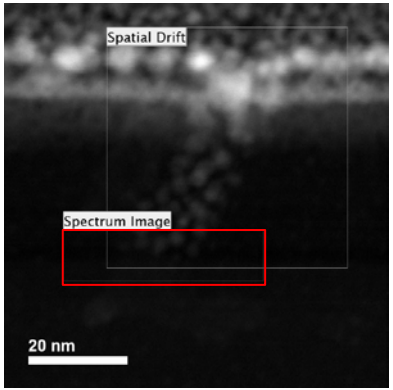


STEM EELS Mapping

Bright Field TEM

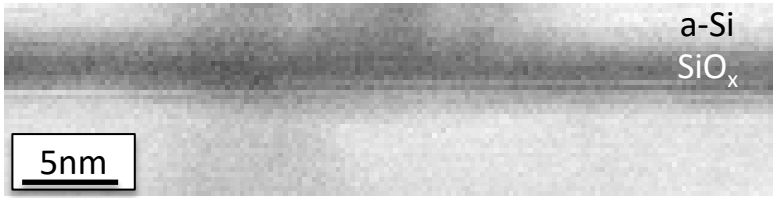


HAADF – STEM

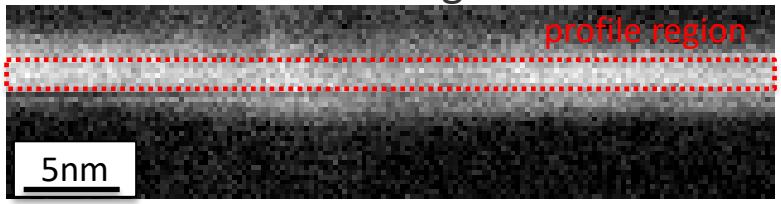


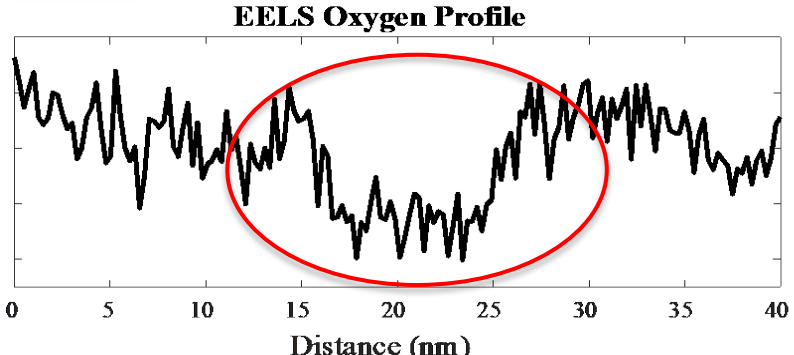
Areal Density Elemental EELS Maps

Si L edge



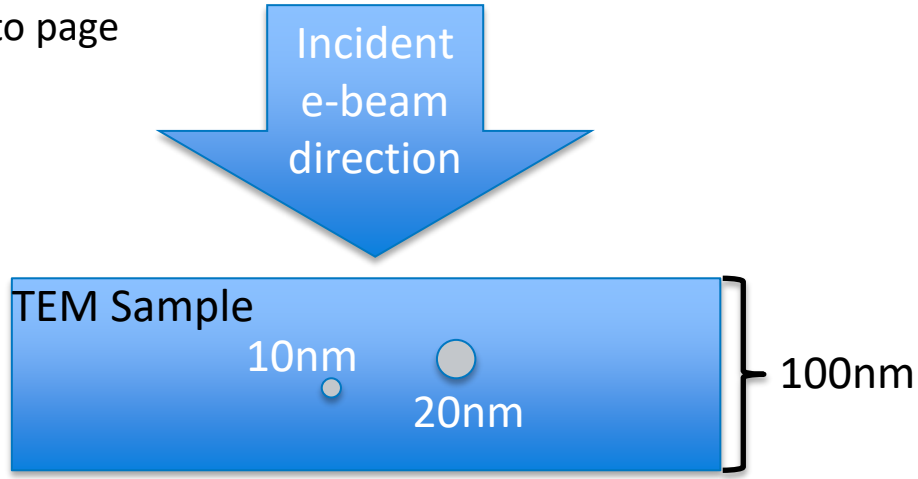
O – K edge





- Oxygen profile over SiO_x layer under mesopore exhibits a dip
- Due to etching of the SiO_x layer during the MACE process

TEM Imaging Geometry

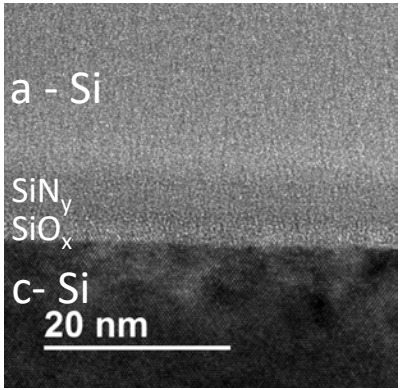


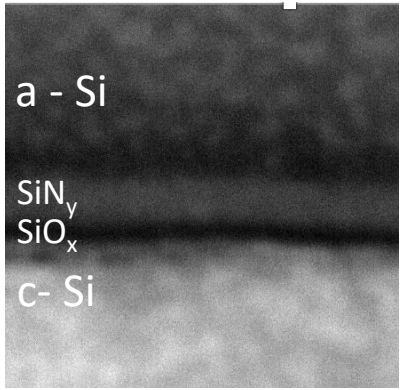
* Approximately to scale

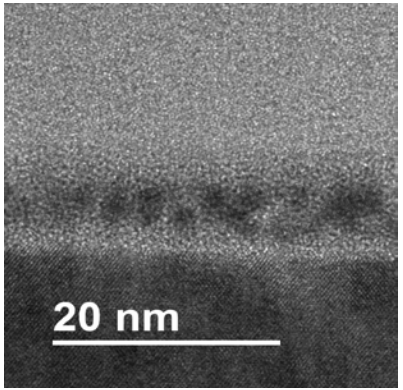
- Can be difficult to view small features with similar contrast due to sample dimensions
- Contributions to image formation from other areas may “wash out” the etched SiO_x regions

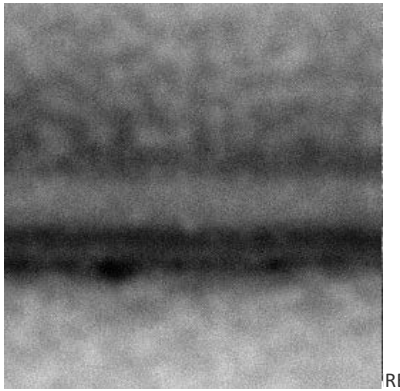
Additional Dielectric Layers - SiN_y

- poly-Si/SiN_y/SiO_x/c-Si layer stack
- Amorphous dielectric layers (and a-Si) can be difficult to distinguish in bright field and phase contrast images
- HAADF STEM imaging more effective to view these layers
- The SiO_x and SiN_y appear different in certain regions

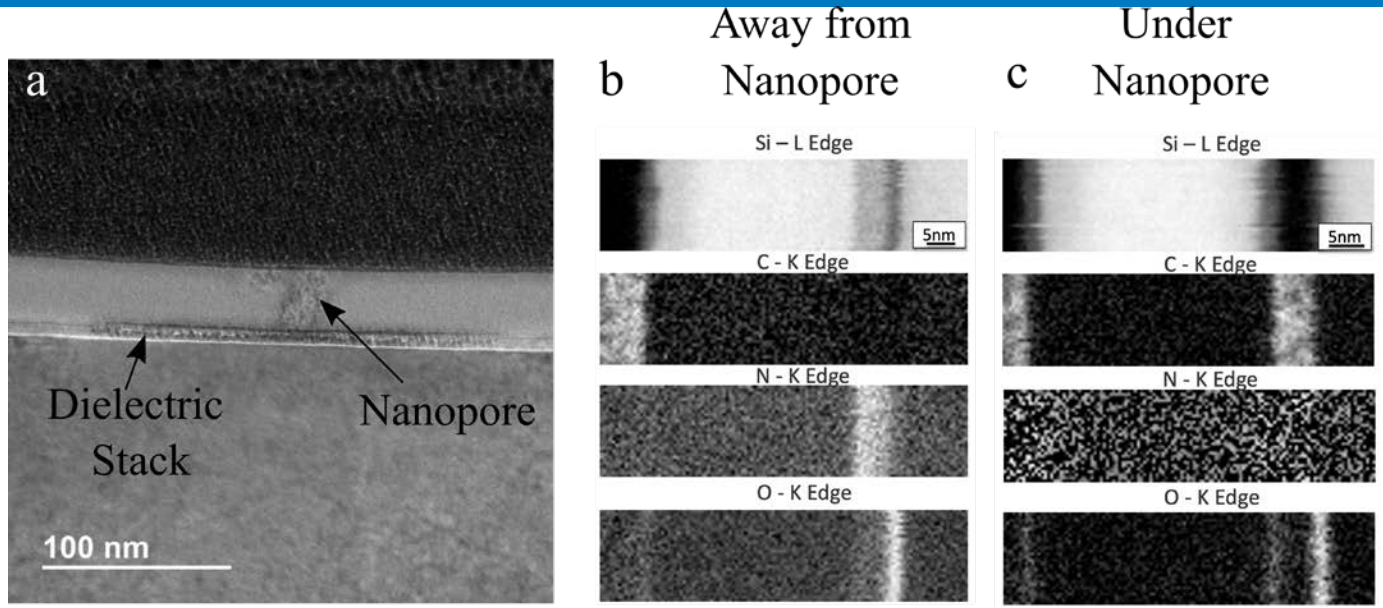








Additional Dielectric Layers - SiN_y



- Mesopores have similar dimensions as in other layer stacks
- The SiN_y layer under the mesopore and ~200nm wide appears different than the surrounding SiN_y
- EELS maps show a missing SiN_y layer replaced by a carbon rich layer

Summary

- Mesopores in a-Si/SiO_x/c-Si layer stack were imaged by decorating the pores with FIB deposited Pt
- The effect of the MACE process on the SiO_x varies, but may be related to mesopore size
- Adding more dielectric layers results makes the MACE process much more complex