Characterization of Engineered Pinholes in Dielectric Stacks of High-Performance Poly-Silicon Passivating Contacts

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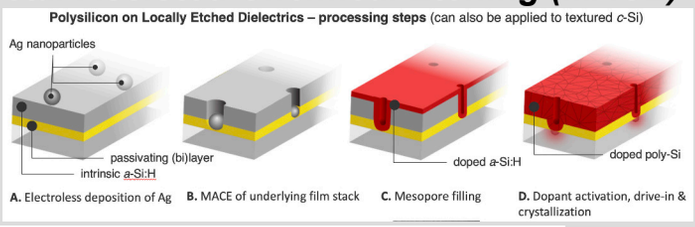
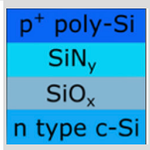
Abstract

- Poly-Si on thick dielectric(s) are passivating contact structures that require pinholes in the dielectric layer(s) for effective charger-carrier transport.
- Poly-Si on SiO_x contacts with thermally induced pinholes have enabled solar cells with > 26% efficiency, but additional thermal processing increases costs
- Pinholes can also be formed via metal-assisted chemical etching (MACE)
- Recently, poly-Si on dielectric(s) with MACE-induced pinholes have enabled certified efficiencies > 22.5% with Voc = 726–729 mV
- We need to determined how the structure and charge-carrier transport of MACE-induced pinholes relates to that of thermally-induced pinholes, then the MACE process may be controlled and optimized to a level that will attract industry adoption

Contact Formation Process Metal-Assisted Chemical Etching (MACE)

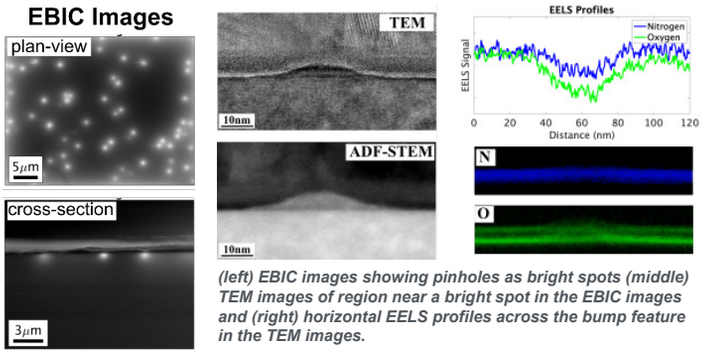


- In this work we study **P**oly-Si on **L**ocally **E**tched **N**itride and **O**xide (**PLENO**) passivating contact structures
- Electron beam induced current (EBIC), TEM phase contrast imaging, and STEM EELS composition mapping are used to determine the structural and chemical properties of MACE-induced pinholes



Salles, C. L. et al. In *AIP Conference Proceedings*, vol. 2487, no. 1, p. 020011. AIP Publishing LLC, 2022

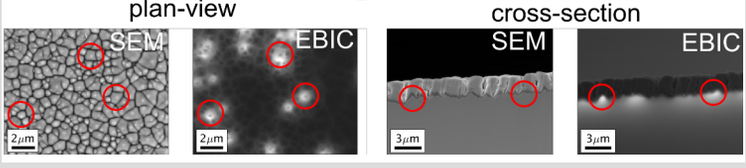
PLENO on Saw-Damage Etched Wafer



(left) EBIC images showing pinholes as bright spots (middle) TEM images of region near a bright spot in the EBIC images and (right) horizontal EELS profiles across the bump feature in the TEM images.

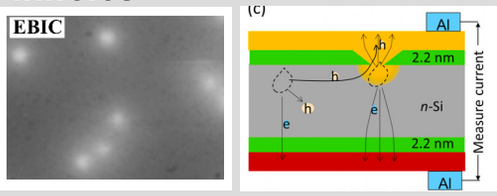
- EBIC images of pinholes in PLENO sample in plan-view orientation appear similar to EBIC images of thermally-induces pinholes
- STEM-EELS analysis reveals a decrease in both the SiO_x and SiN_y indicating pinhole formation in these layers resulting from the MACE process

PLENO on Randomly Textured Wafer

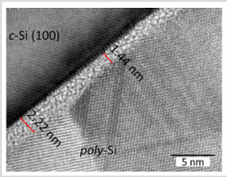


- EBIC images on PLENO sample with random texturing in plan-view orientation may suggest the pinholes are confined to specific pyramids
- In cross-section, the EBIC images suggest that the pinholes may form preferentially at or near the pyramid tips

Previous Work on Thermally-Induced Pinholes



EBIC guided FIB sample preparation

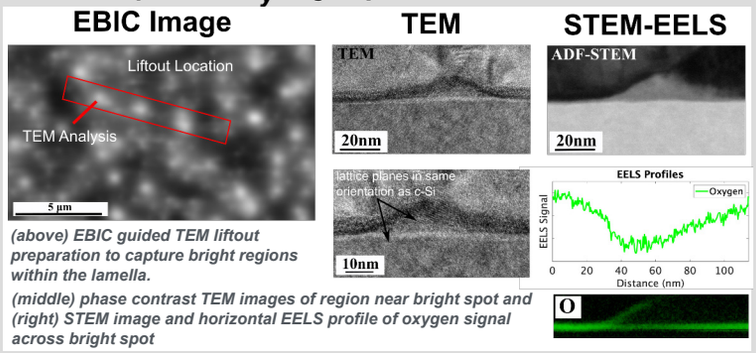


Thinning of SiO_x layer was observed near locations of higher charge-carrier collection in EBIC images

- Previous work has revealed localized regions with enhanced charge-carrier collection in polished poly-Si/SiO_x passivated contact structures, caused by either the presence of pinholes or local SiO_x thinning
- Pinholes in SiO_x layer enable charge-carrier transport on otherwise insulating SiO_x (>2nm)

Kale, A.S., et. al Applied Physics Letters, 2019, 114, (8), pp. 083902

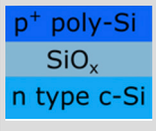
Correlative EBIC – TEM – STEM EELS PLEO (no SiN_y layer)



(above) EBIC guided TEM liftout preparation to capture bright regions within the lamella.

(middle) phase contrast TEM images of region near bright spot and (right) STEM image and horizontal EELS profile of oxygen signal across bright spot

- EBIC guided FIB used to target specific bright spots for TEM sample preparation
- Bump observed near the bright spot location exhibits lattice fringes in the same orientation as the c-Si substrate, suggesting epitaxial growth from the substrate during crystallization of the poly-Si
- A decrease in the oxygen signal is observed in horizontal EELS profiles across this feature indicating pinhole formation from the MACE process



Summary

- Enhanced local charge-carrier collection on MACE-processed PLENO on saw-damage etched wafers is similar to EBIC measurements of thermally-induced pinholes
- TEM and STEM-EELS analysis shows that the MACE process effectively creates pinholes not only in SiO_x, but also in SiO_x/SiN_y dielectric bilayers
- This is critical to enable transport through the thick SiOx/SiNy, which provides surface passivation and barriers to Boron in-diffusion
- **Inducing pinholes in thick dielectric layers with the MACE process results in similar charge-carrier transport behavior as observed for thermally-induced pinholes**
- **Recent certified efficiencies > 22.5% in solar cells with PLEO and PLENO contacts indicate the MACE process may provide a viable future direction for industrially produced solar cells with passivating contacts as long as MACE processing costs are minimized**

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