Nafion Passivation of *c*-Si Surface and Edge for Electron Paramagnetic Resonance

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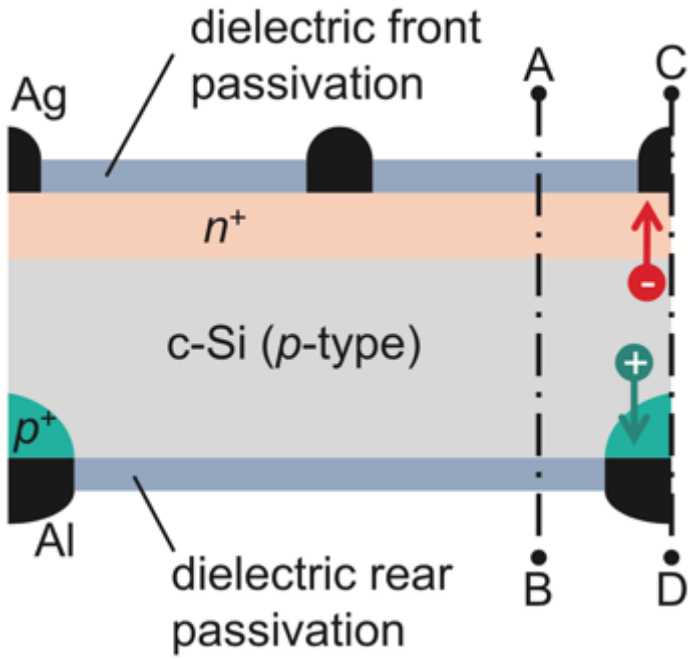
Bulk Silicon Study Requires Effective Surface Passivation

- Conventional passivation layers require high T processes
  - SiN_x, SiO_x, Al_2O_3, *a*-Si
- Negative bulk effects from elevated temperatures:
  - >850 °C: creates oxygen precipitates
  - 250–450 °C: activates bulk recombination centers, H diffusion, impurity gettering
- Time and energy-consuming

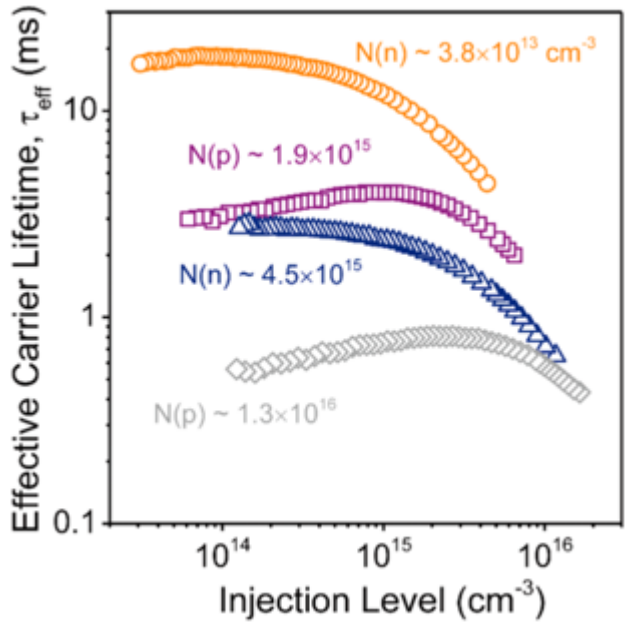


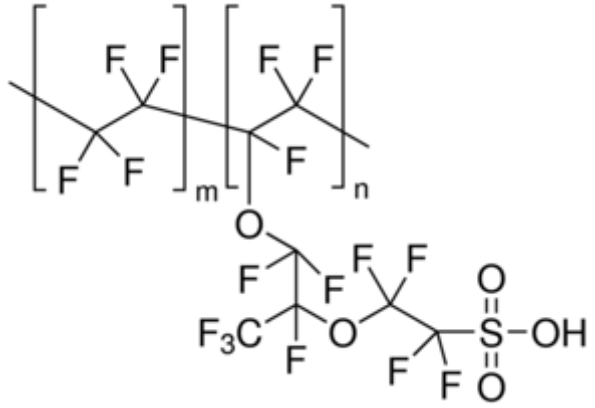
J. Schmidt *et al*., *Solar Energy Materials and Solar Cells,* vol. 187, pp. 39-54, 2018

Motivation for Room Temperature Surface Passivation

- Room temperature, low-cost alternatives to expensive deposition tools
- Some examples:
  - Acid, halogen-alcohol, benzyl-alcohol, **organic thin-film**
- Thin film passivation: easy handling and good short-term stability for bulk characterization such as lifetime and PL
- Poly(tetrafluoroethylene) based polymer was explored recently for passivation of *c*-Si[1-3]

[1]. D. Biro et al., *Solar Energy Materials and Solar Cells,* vol. 71, no. 3, pp. 369-374, 2002
[2]. J. Chen *et al.*, *ACS Applied Materials & Interfaces,* vol. 10, no. 51, pp. 44890-44896, 2018
[3]. W. Ji *et al.*, *ACS Nano,* vol. 13, no. 3, pp. 3723-3729, 2019





Nafion is a **room-T** technique, which is ideal for characterizing bulk defects using spectroscopy techniques such as Electron Paramagnetic Resonance (EPR)

Nafion Passivation Procedure at NREL

As sawn wafers

Saw damage removal

Piranha, SC-1 and SC-2 clean

Symmetric poly-Si/SiOx passivating contact structures

Tube furnace oxidation

PECVD n^+/p^+ a-Si:H deposition

Crystallization/dopant diffusion

HF dip

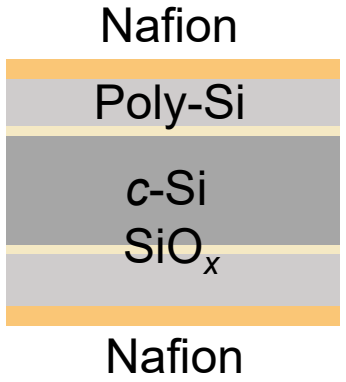
Nafion spin/dip coating

PL

Lifetime PCD

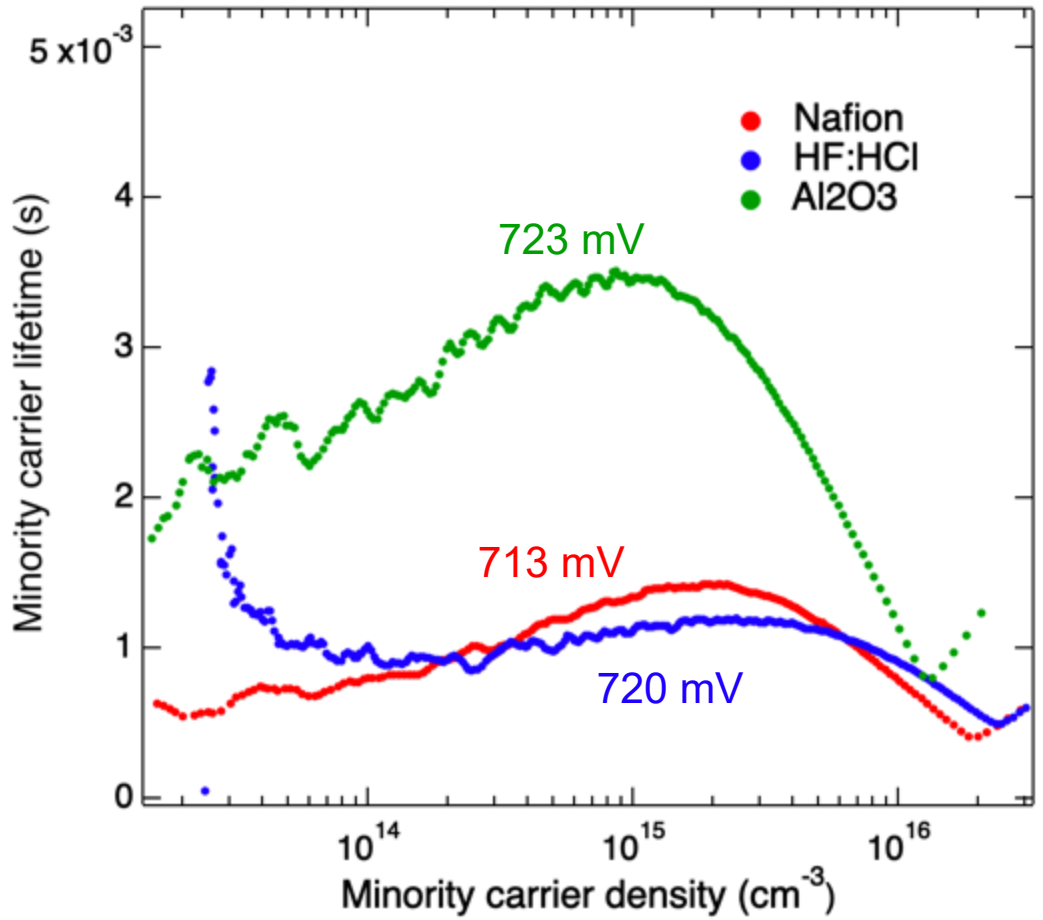
SEM

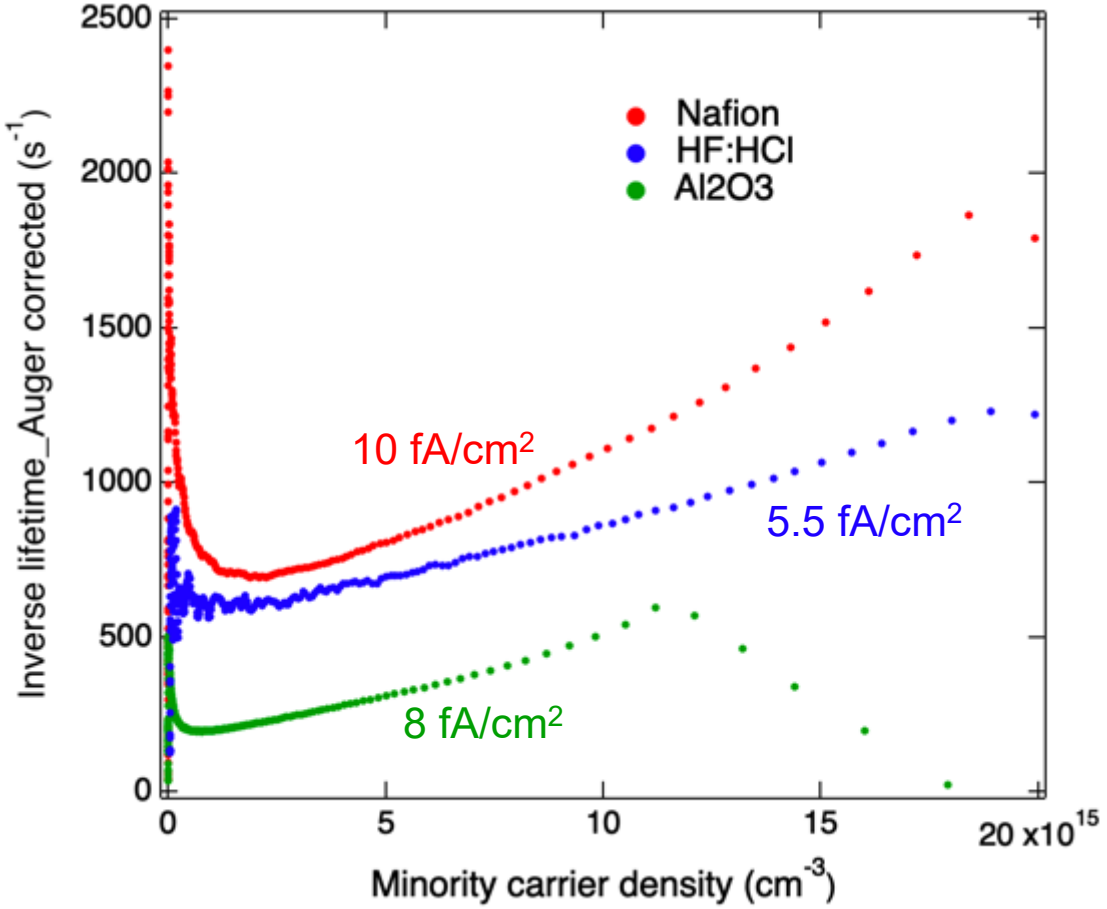
EPR



Passivation Results on *n*-type Cz Comparison

- Nafion passivation is comparable to HF:HCl liquid passivation in *n*-Cz wafer, but has a lower lifetime than Al_2O_3
- Slightly higher J_0 value was observed with Nafion dipcoat, but low enough for good passivation





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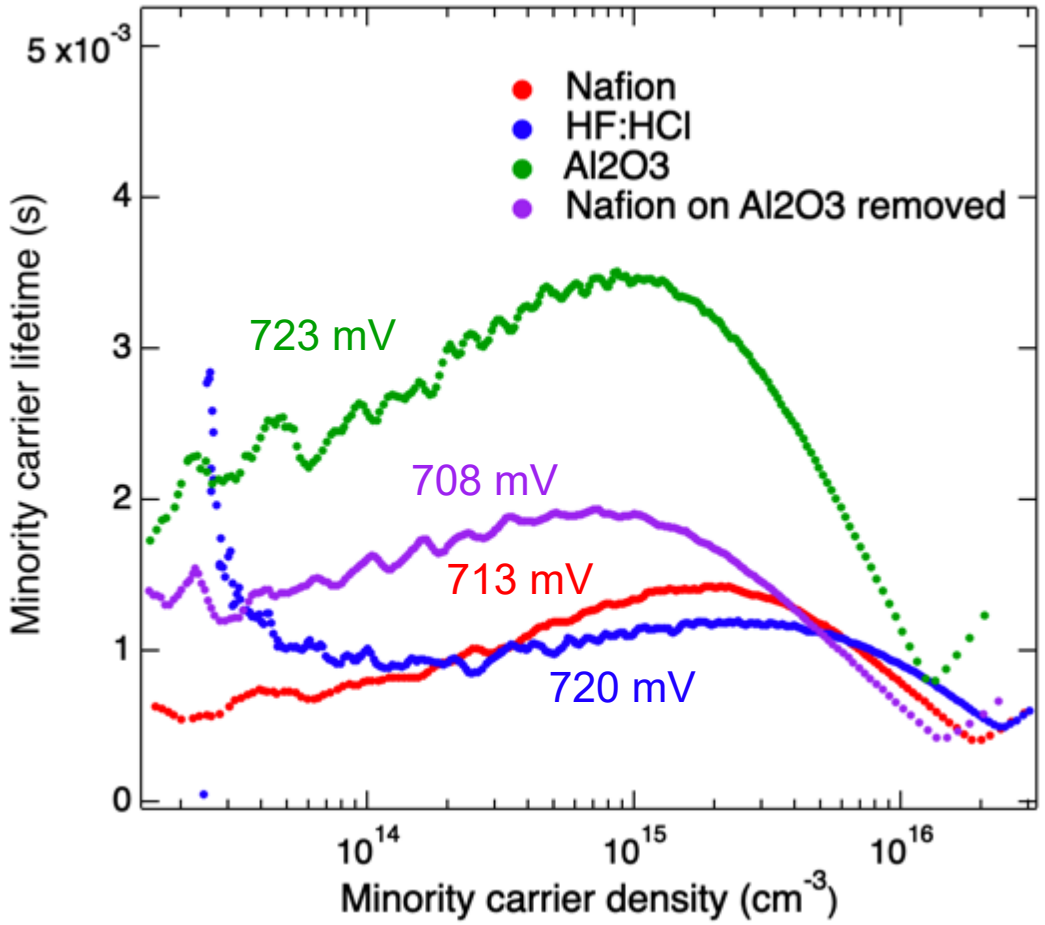
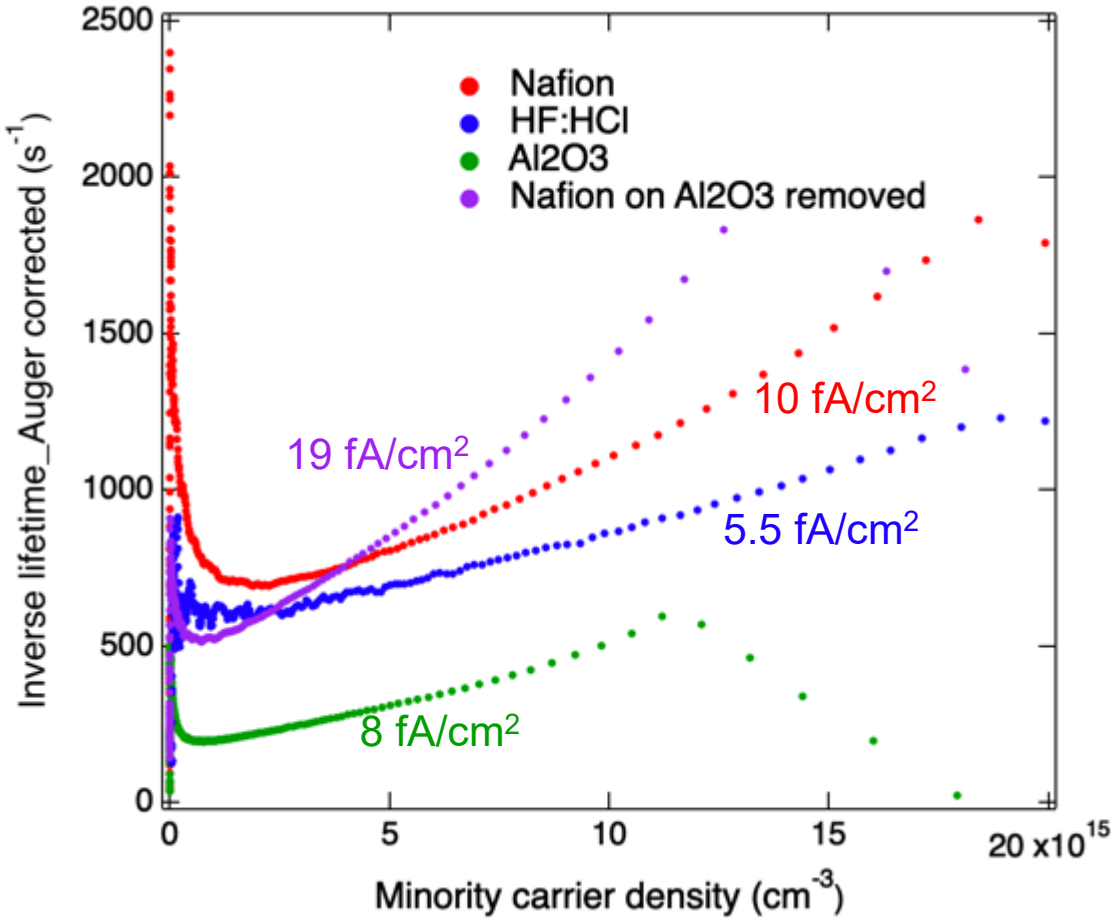
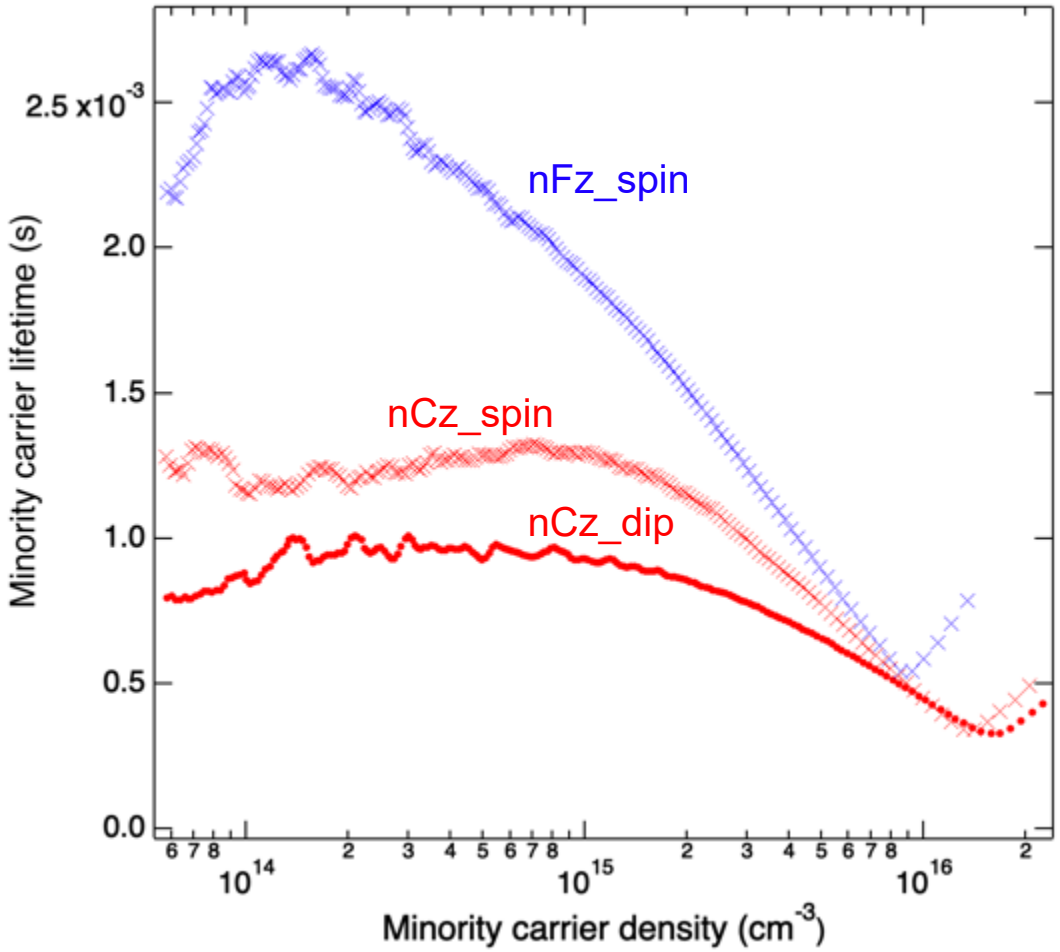


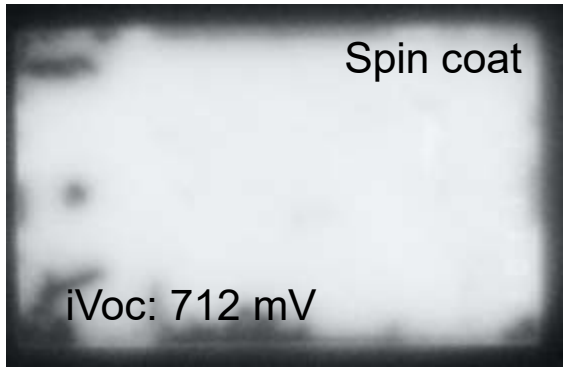


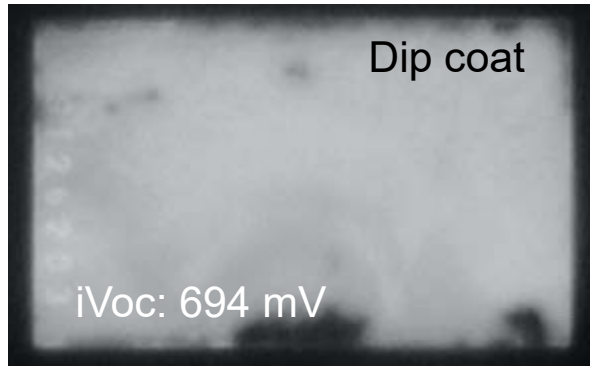
Passivation Results on Various Substrates

- *n*-type substrate has the highest passivation due to negative fixed charge from the strong Lewis acidity
- *n*- and *p*-type passivating contacts (200 nm *poly*-Si), and surface with oxide blocks field effect passivation
- Spin coating provided better uniformity and thinner films, which resulted in higher passivation quality

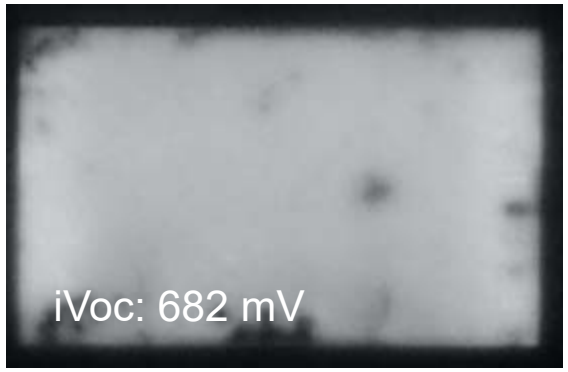


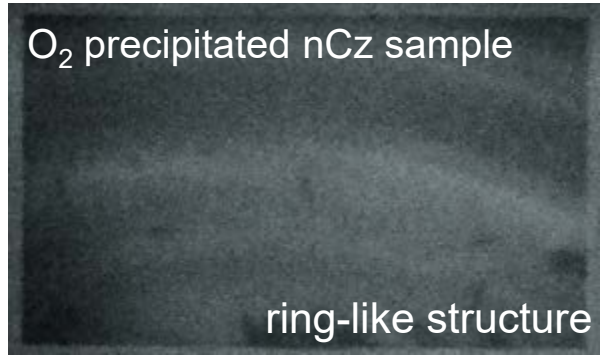
nCz





GaCz





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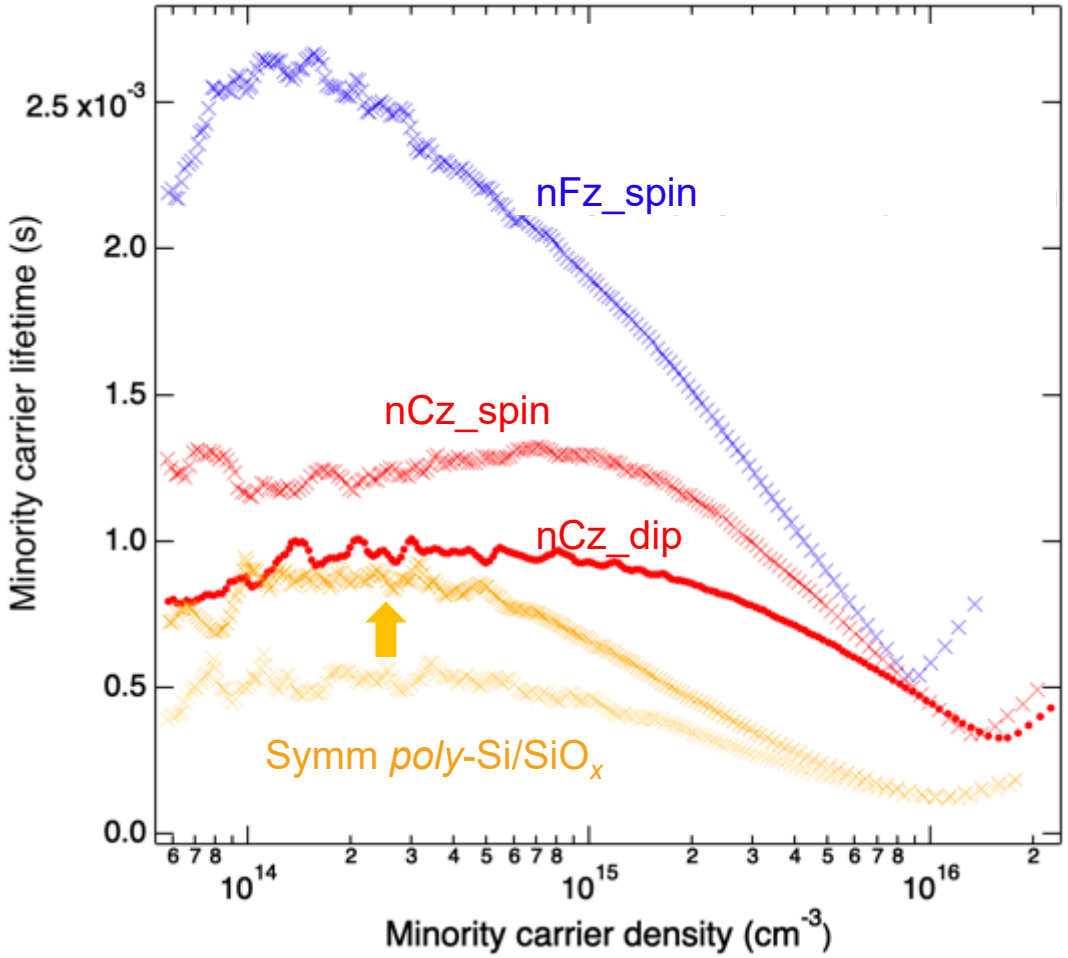
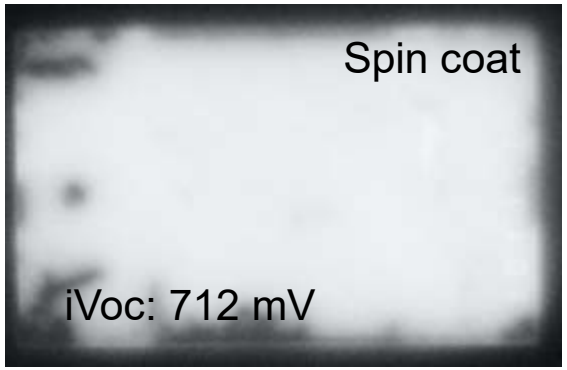
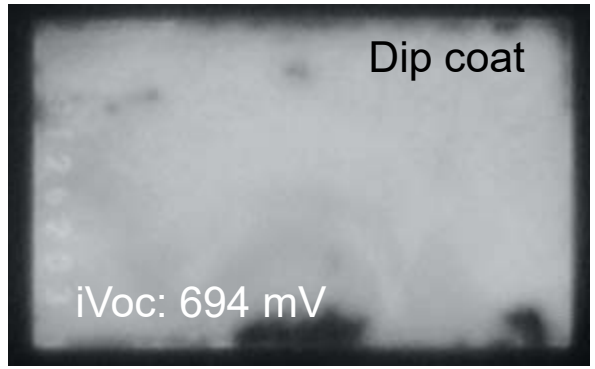
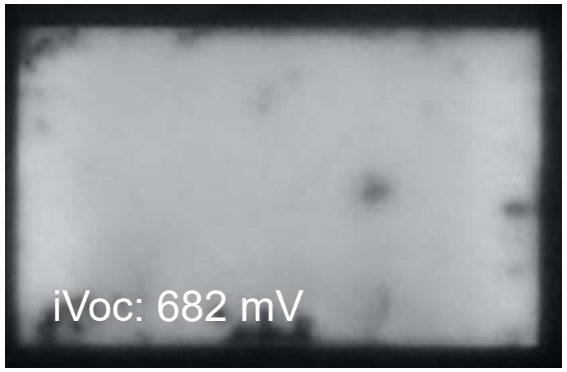


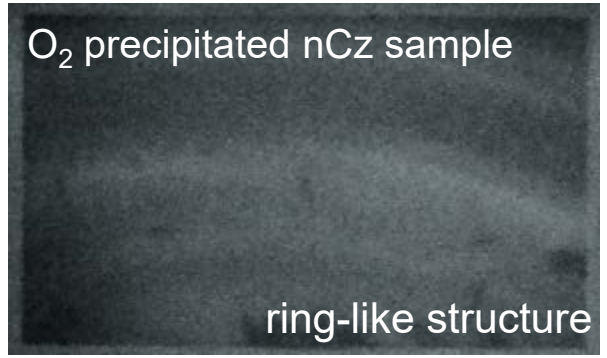
nCz





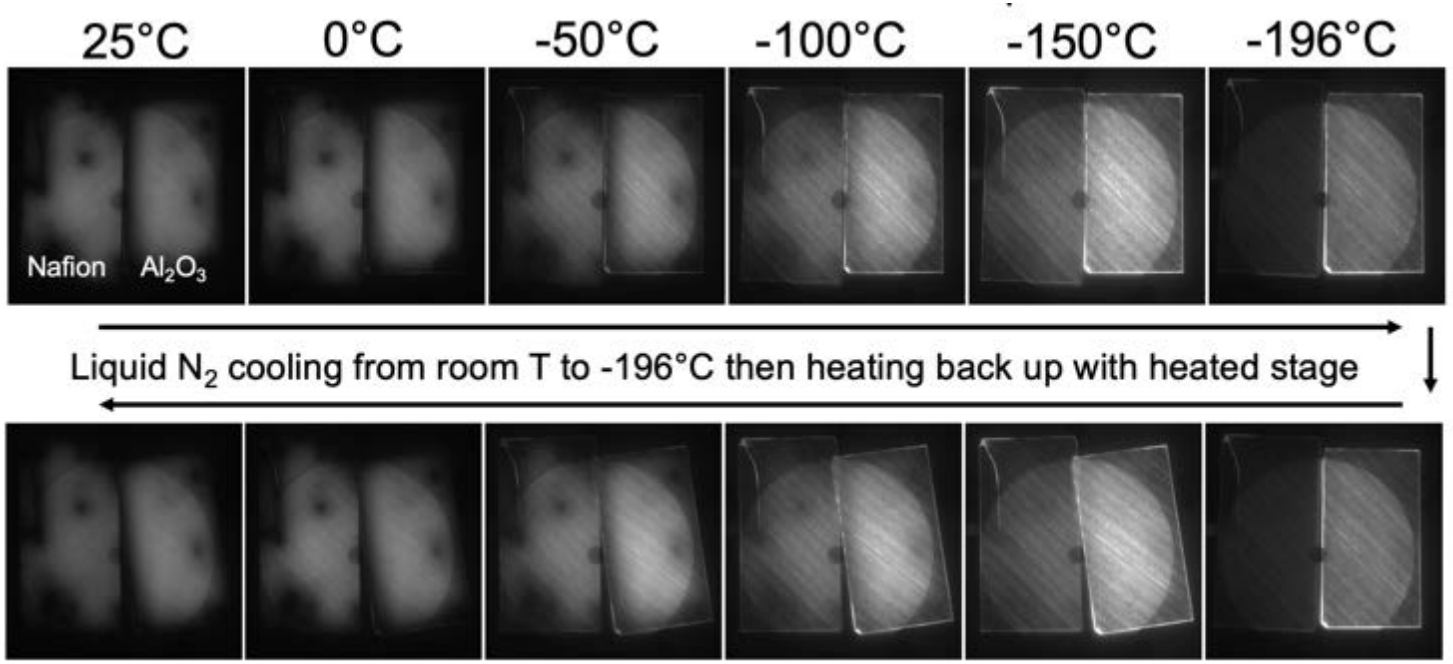
GaCz

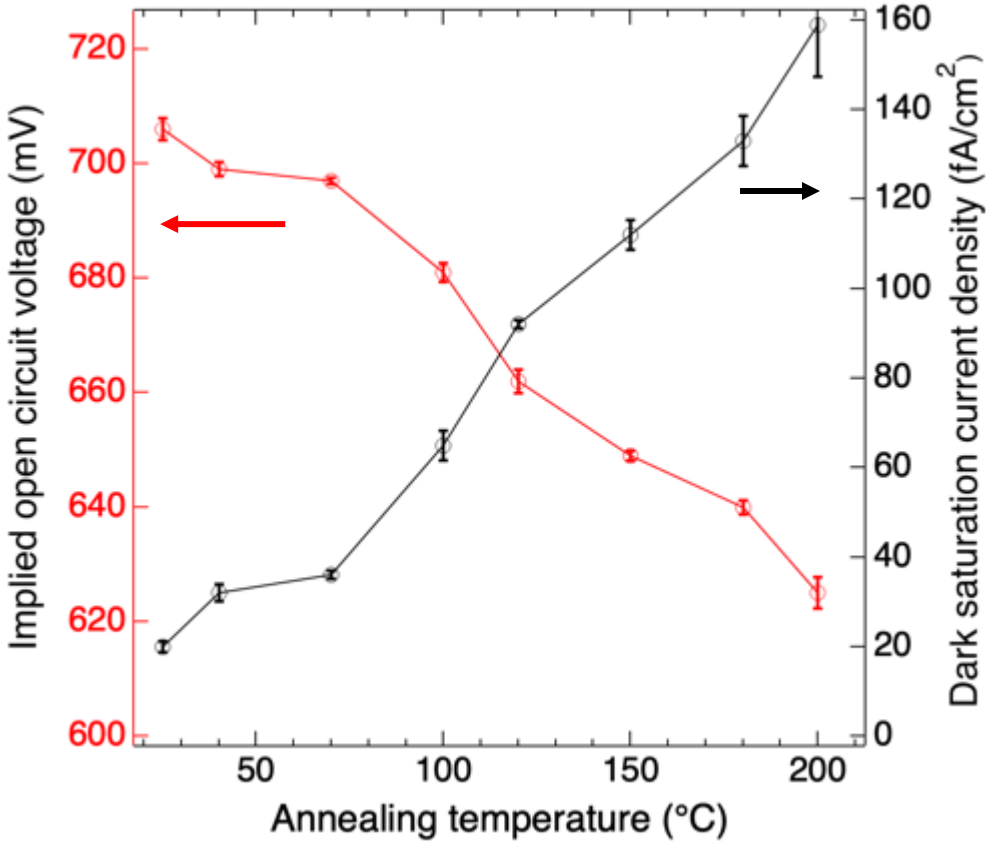




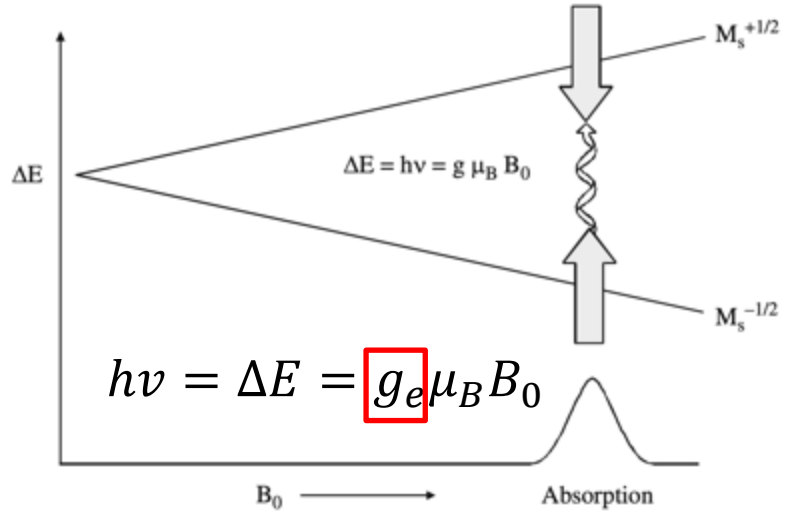
Temperature Dependency of Nafion Passivation

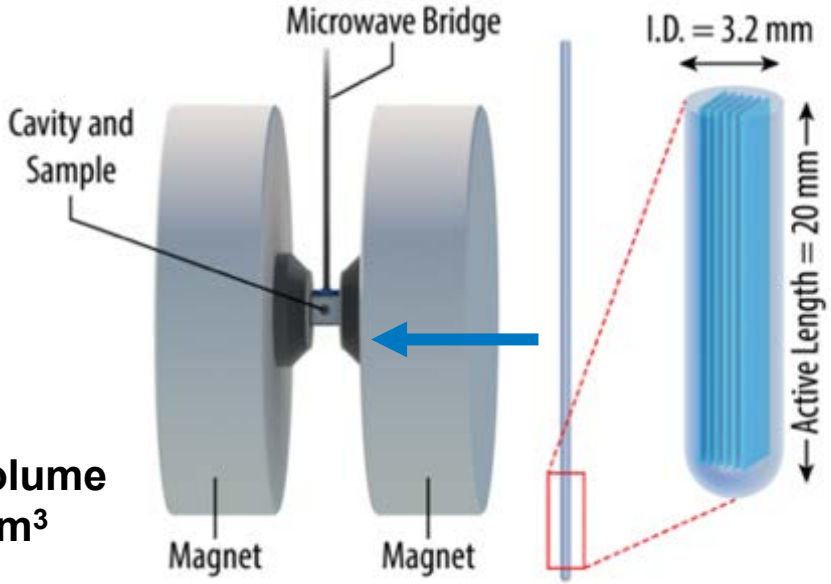
- Low T PL shows that Nafion can maintain a good passivation on *c*-Si samples up to -150°C, and the process can be reversed to room T with no passivation loss
- Nafion passivation decreases with increasing annealing temperature, but still remain some passivation at elevated T





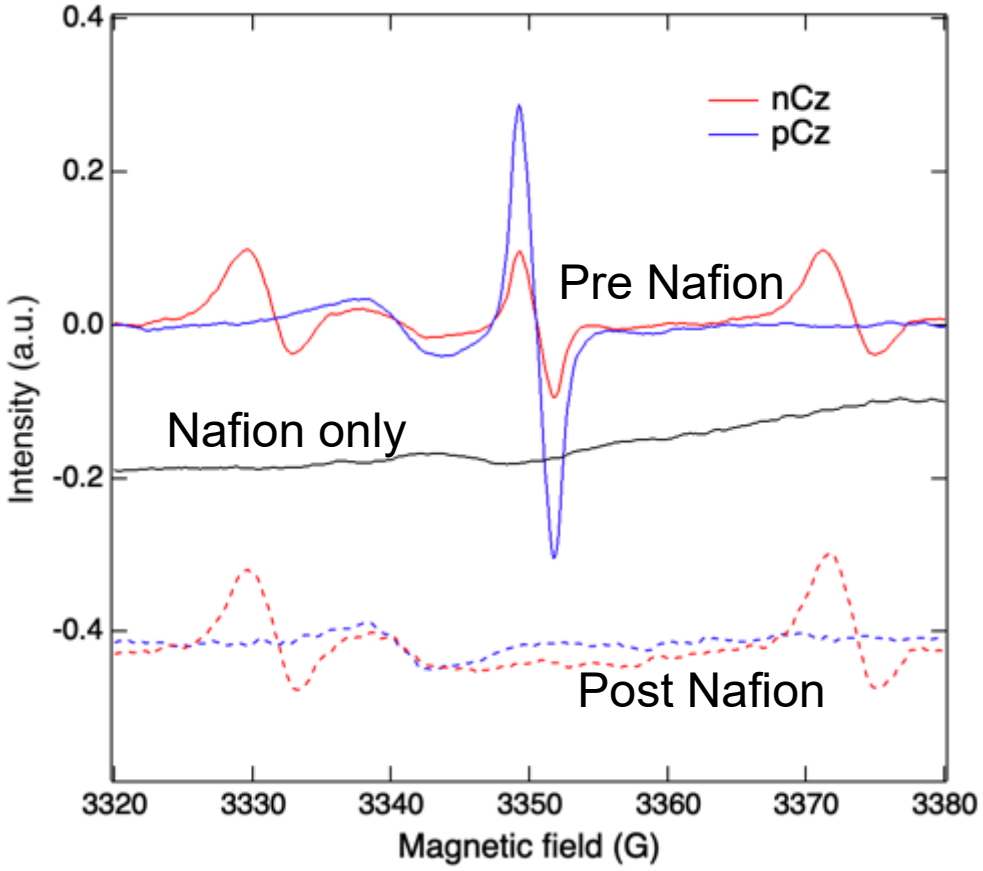
Electron Paramagnetic Resonance (EPR) of Nafion Passivation





Sample Volume ~0.01 cm³

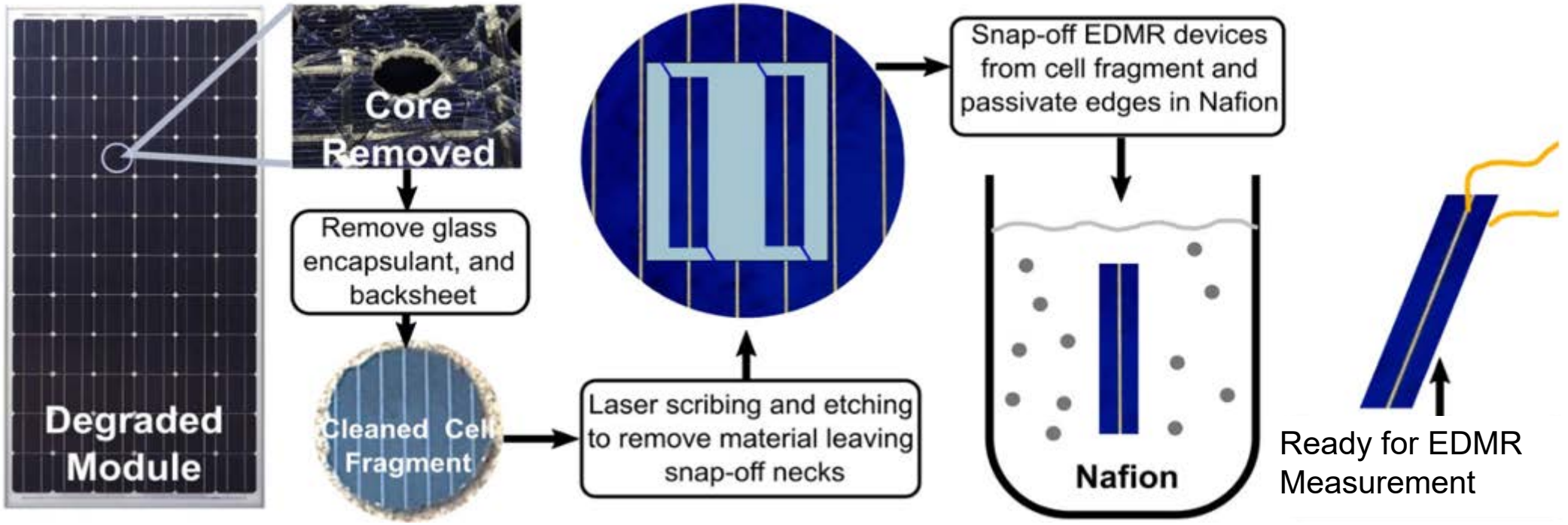
- We show for the first-time temperature study for Nafion down to 6K using EPR technique
- Both *n*Cz and *p*Cz samples have reduced peak ~3350G post Nafion



A. R. Meyer *et al.,* under review at *Joule,* (2022)

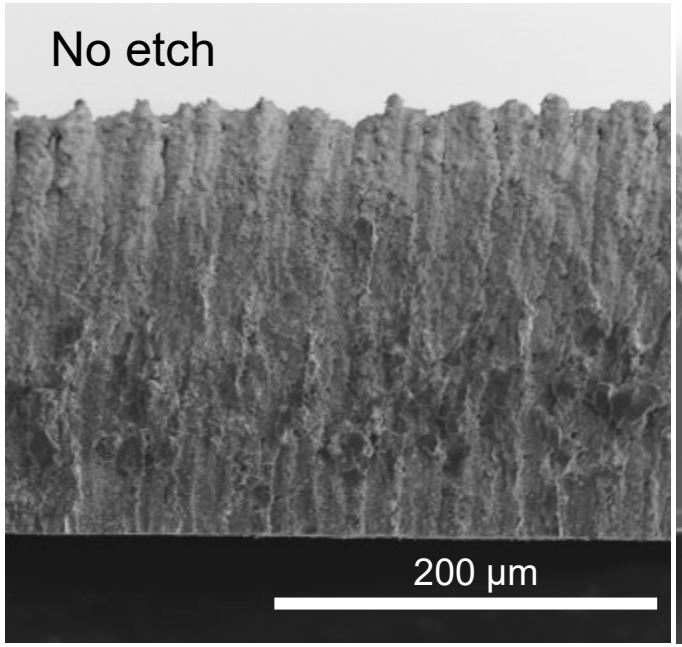
Nafion Passivation on Cell Fragment for EDMR Analysis

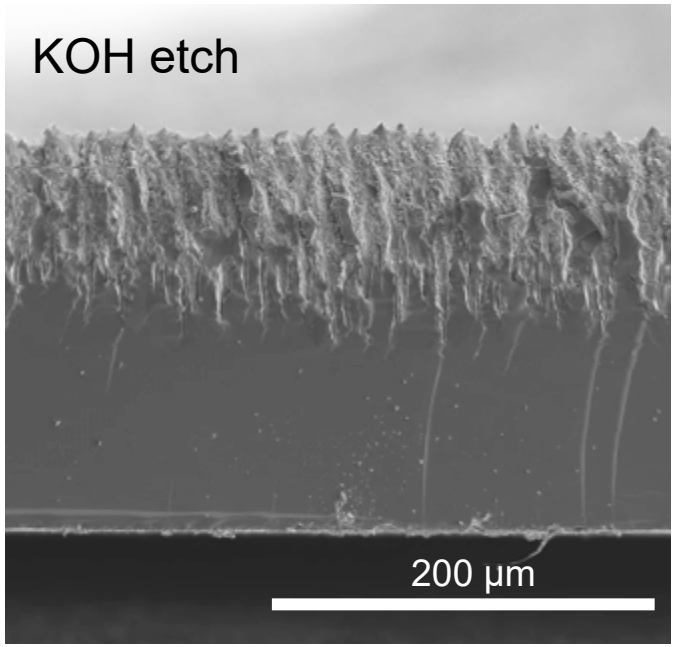
- Electrically detected magnetic resonance (EDMR) detects paramagnetic defects that affects the device's PV performance (sensitive to ~ 10^9 cm^{-3} defects)
- Laser-scribed small specimens are needed for characterizations such as EDMR

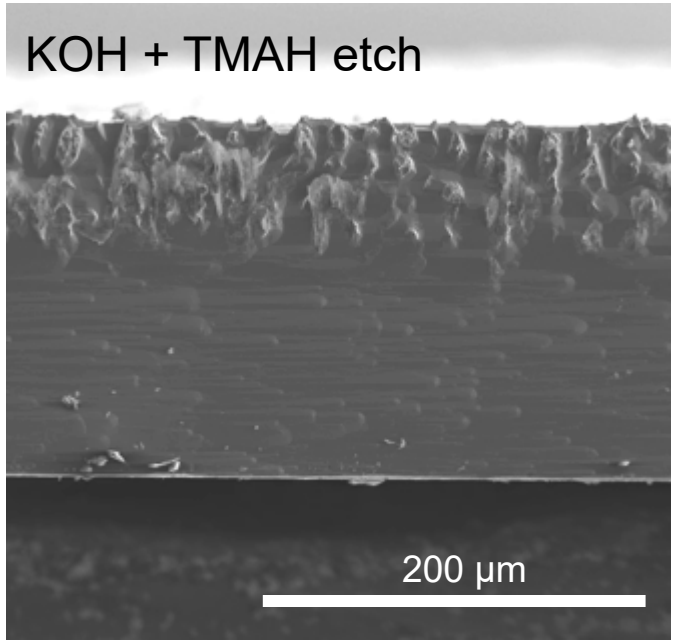


The Effect of Surface Morphology on Nafion Passivation Quality

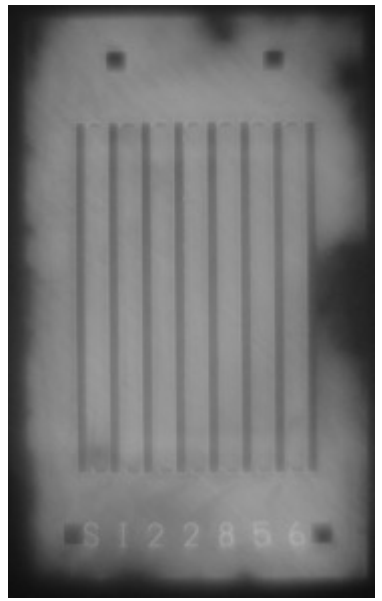
- Surface morphology is closely related to the Nafion passivation quality
- Pretreatment (alkaline etching and clean) is required before Nafion to remove edge damage







Prototype EDMR structure passivated with Nafion

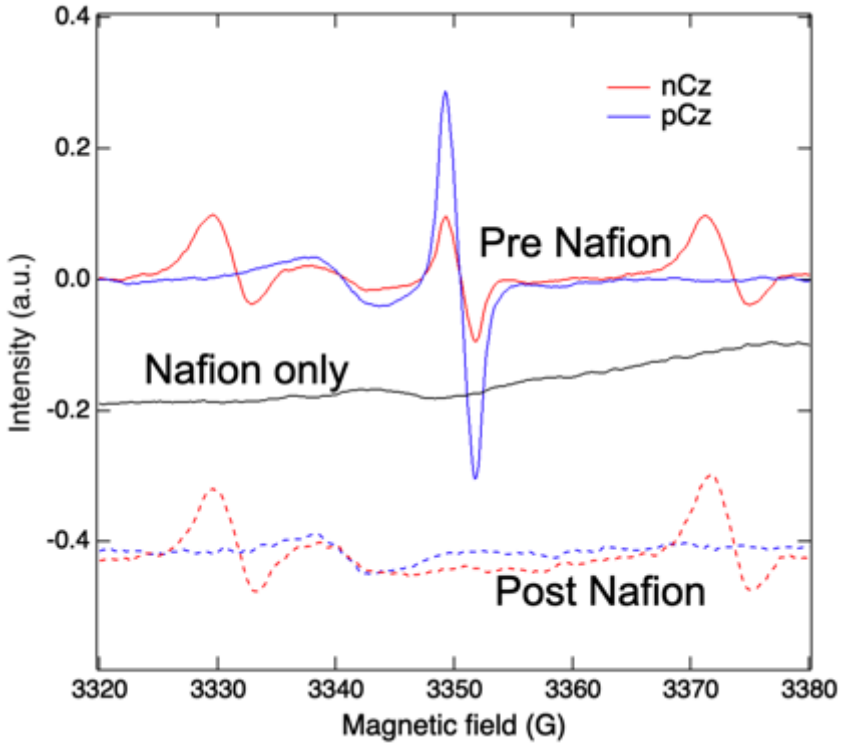


Summary and Conclusions

- Nafion is a promising room T, temporary passivation technique, which is ideal for bulk characterization of *n*-type *c*-Si
- Passivation can be used at low T with good passivation, and is compatible with cryogenic T of various characterization methods
- Surface etching of as-sawn *c*-Si is necessary before Nafion to obtain uniform passivation to sample edges

Advantages when introduced to PV applications:

- High throughput for wafer quality check
- Reduce process complexity and avoid hazardous materials
- Ideal for bulk degradation study



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Thanks for your attention! Questions?

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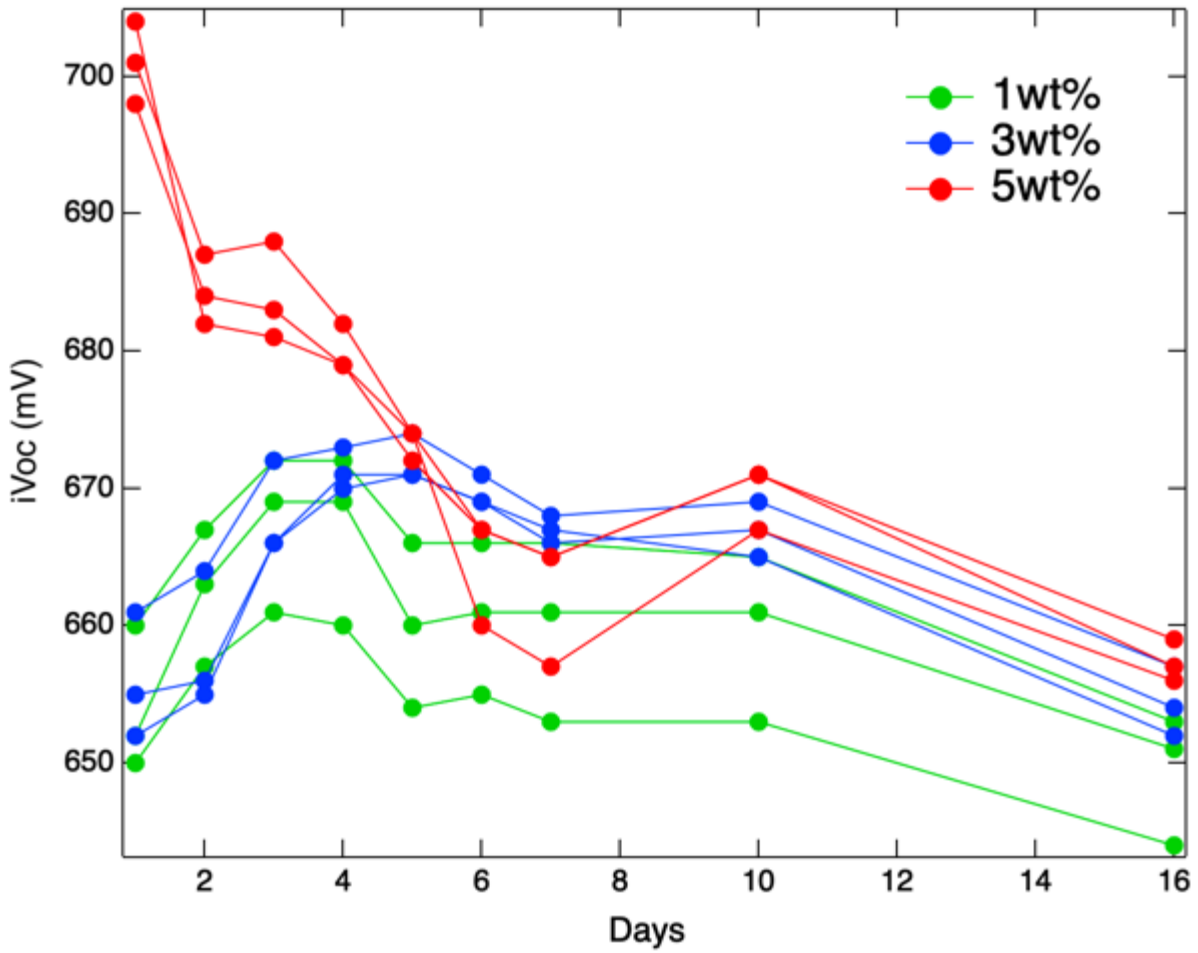
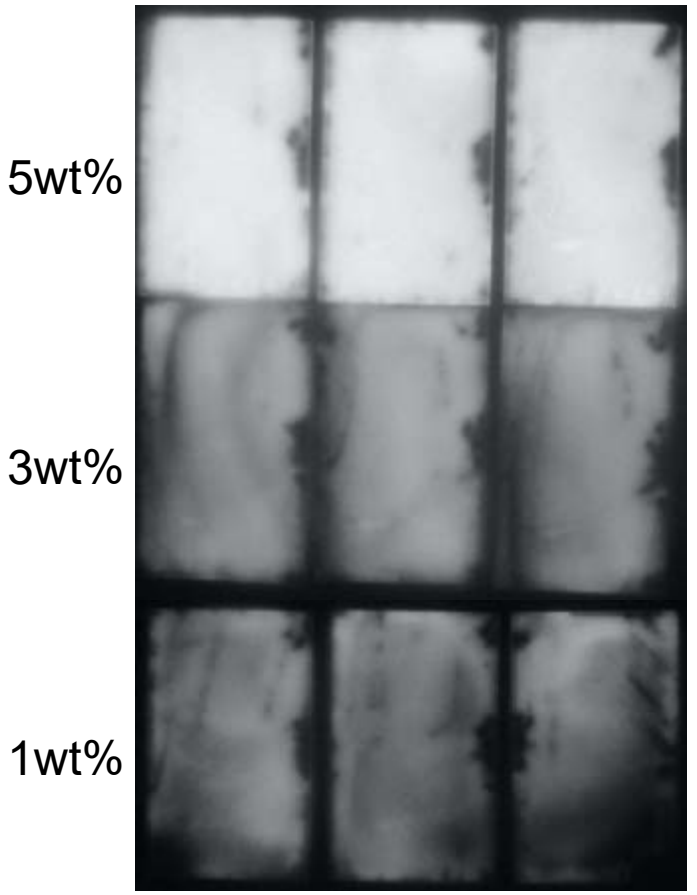
Nafion Degradation Test with Different Concentrations

- 5 wt% of Nafion has the highest passivation quality on the day of, but quickly degrades after a day
- Nafion diluted with ethanol samples have slightly lower passivation but remained some passivation overtime



Day 1



Dip coat

Humidity Effect on Nafion Passivation on *n*-type Cz

- Relative humidity between 48-70% has little effect on passivation quality