Effective Dielectric Passivation Scheme in Area-Selective Front/Back *Poly*-Si/SiO_x Passivating Contact Solar Cells

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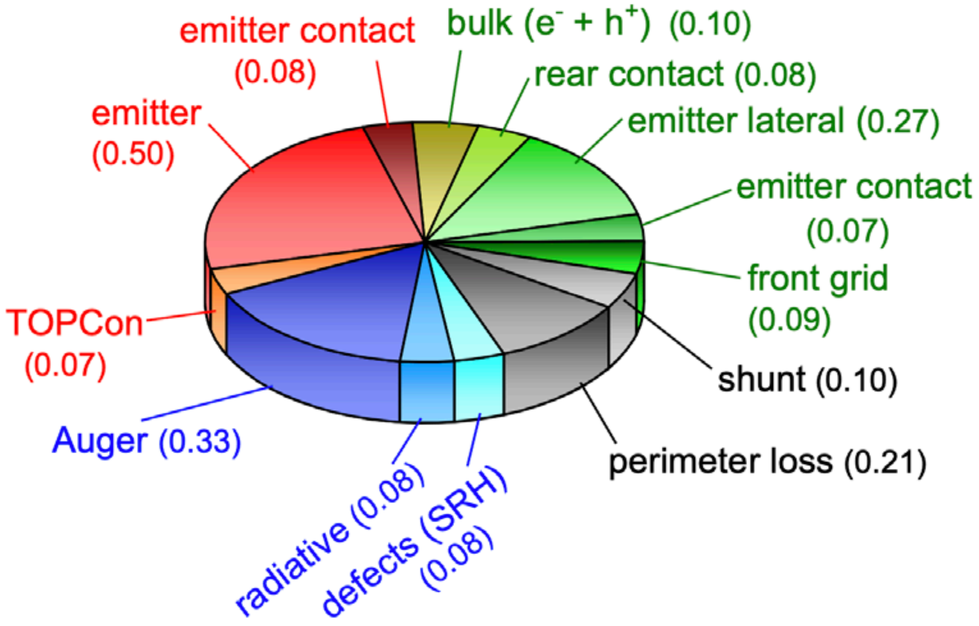
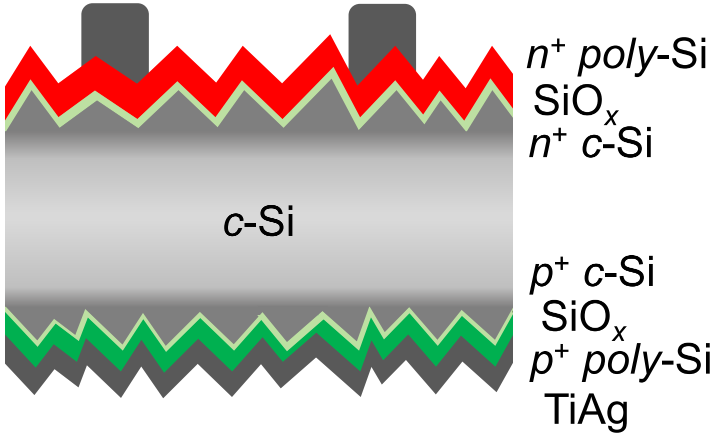
Challenges for Passivating Contacts as the Next Generation *c*-Si solar cells

- *Poly*-Si/SiO_x based passivating contacts have reached high efficiency in the past few years
- TOPCon with passivating contacts at the rear has largest recombination loss at the B diffused front surface[1]



- Front /Back *poly*-Si/SiO_x passivating contact[2]
  - Good front passivation
  - lean process



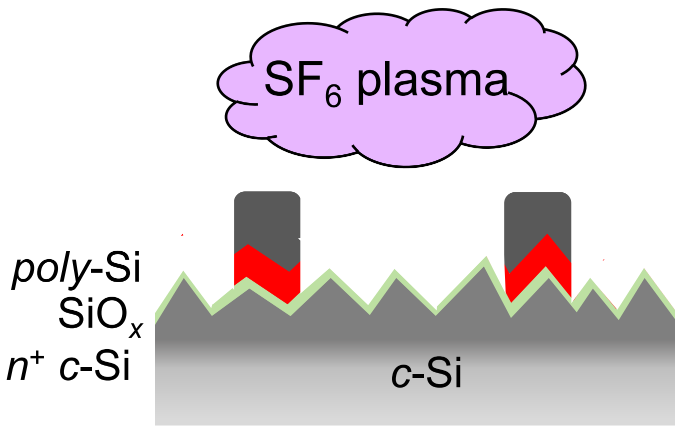
Metallization-induced degradation ⟷ parasitic absorption loss

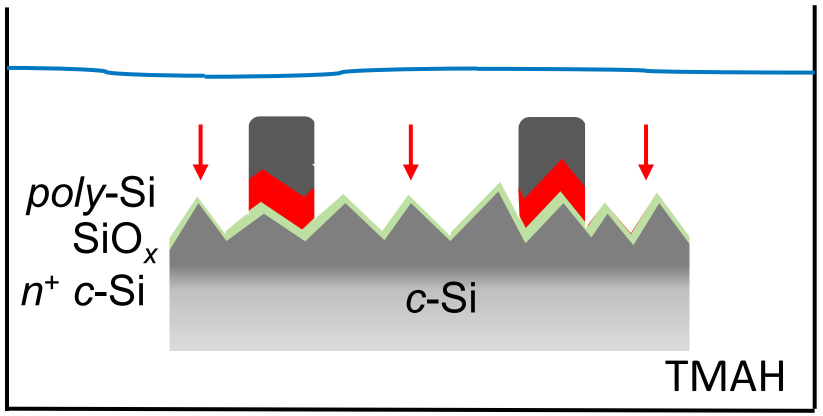
[1]. A. Richter *et al.*, in *36th European PV Solar Energy Conference and Exhibition*, Marseille, France, 2019

[2]. D. L. Young *et al.*, in *35th European PV Solar Energy Conference and Exhibition*, Brussels, Belgium, 2018

Improvement Device Performance by *Poly*-Si Removal and Re-passivation

- Area-selective thinning of front *poly*-Si with **pre-deposited** metal grid via dry and wet chemistry process[1-2]





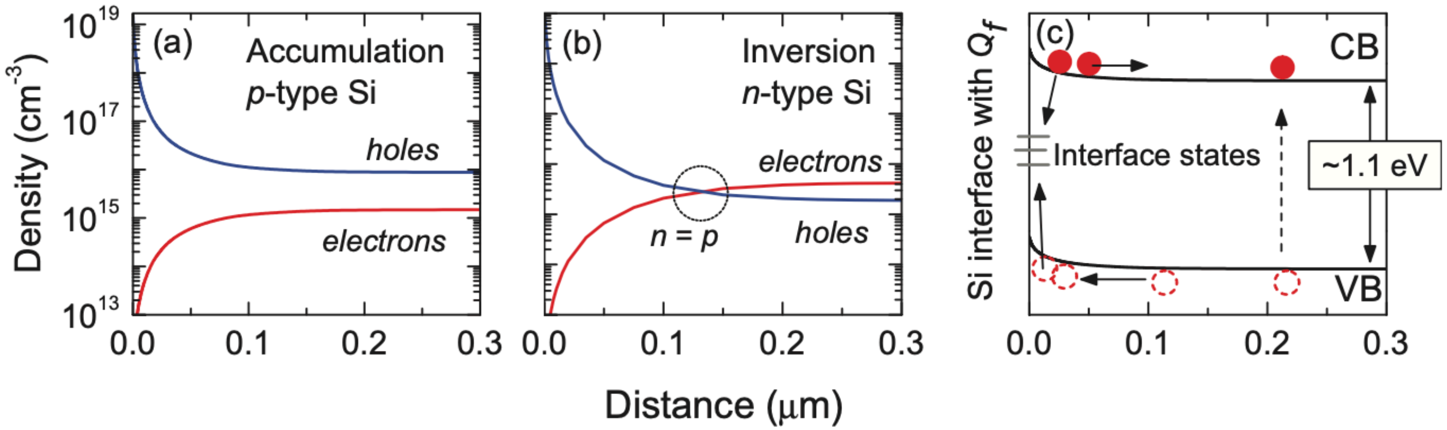
[1]. D. L. Young *et al.*, *Solar Energy Materials and Solar Cells,* vol. 217, p. 110621, 2020

[2]. K. Chen *et al.*, *Solar Energy Materials and Solar Cells,* Manuscript submitted for publication, 2021

Dielectric Surface Passivation in High-Efficiency Solar Cells

- To reduce surface recombination rate,
  - Reduce the number of defects states (**chemical passivation,** e.g Thermally grown SiO_2, atomic H)
  - Internal electric field - either e^- or h^+ (**field effect passivation**)

Al_2O_3 passivation



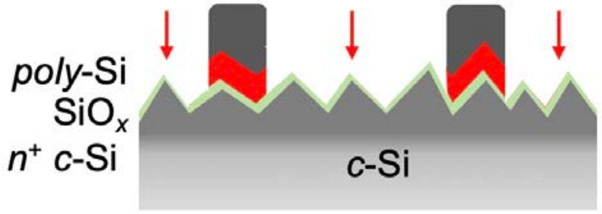
Dielectric films

- Al_2O_3: Negative fixed charge (ideal for *p*-type Si or p^+ emitter of *n*-type Si solar cells)
- SiN_x: Positive fixed charge (ideal for *n*-type Si or n^+ emitter of *p*-type Si solar cells)
- Various stacks (double or triple)

G. Dingemans *et al.*, *Journal of Vacuum Science & Technology A,* vol. 30, no. 4, p. 040802, 2012

Dielectric Surface Passivation on Front in-Diffused Unmetallized Region

- To determine the degree of field effect passivation with different *poly*-Si thicknesses
- To investigate the correct dielectric scheme on exposed **SiO_x/*n*+ in-diffused *c*-Si surface**



Etching Extent

- Partial *poly*-Si etch (20 nm *poly*-Si remained)
- Full *poly*-Si etch (stopped at SiO_x)
- Full *poly*-Si etch with SiO_x, bulk etch

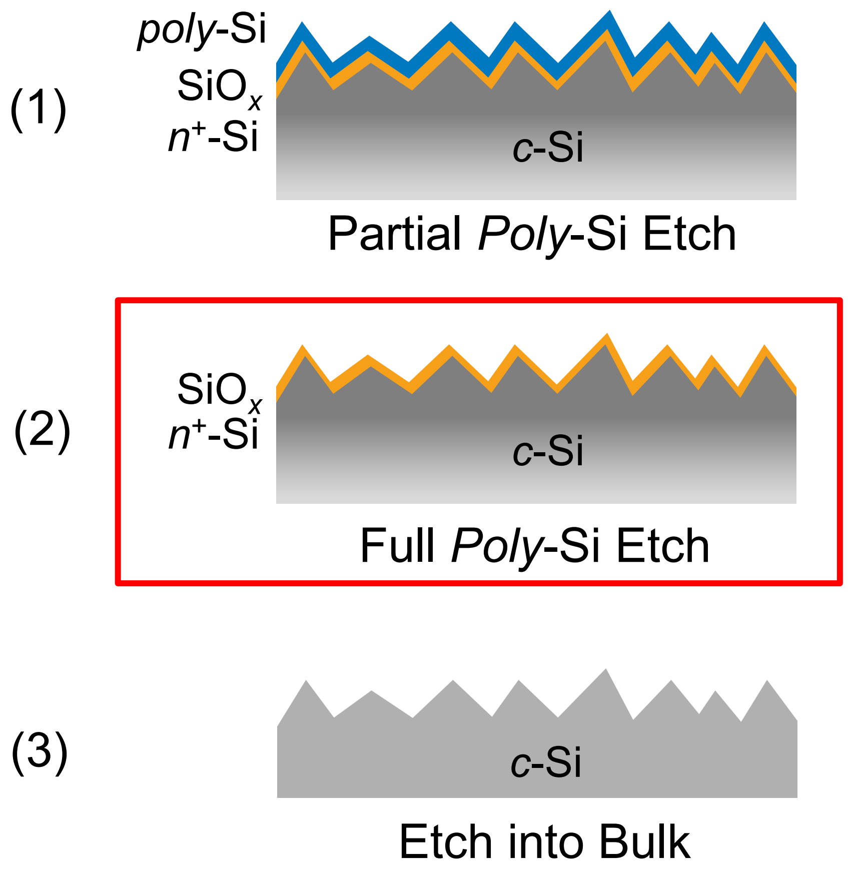
Dielectric Selection

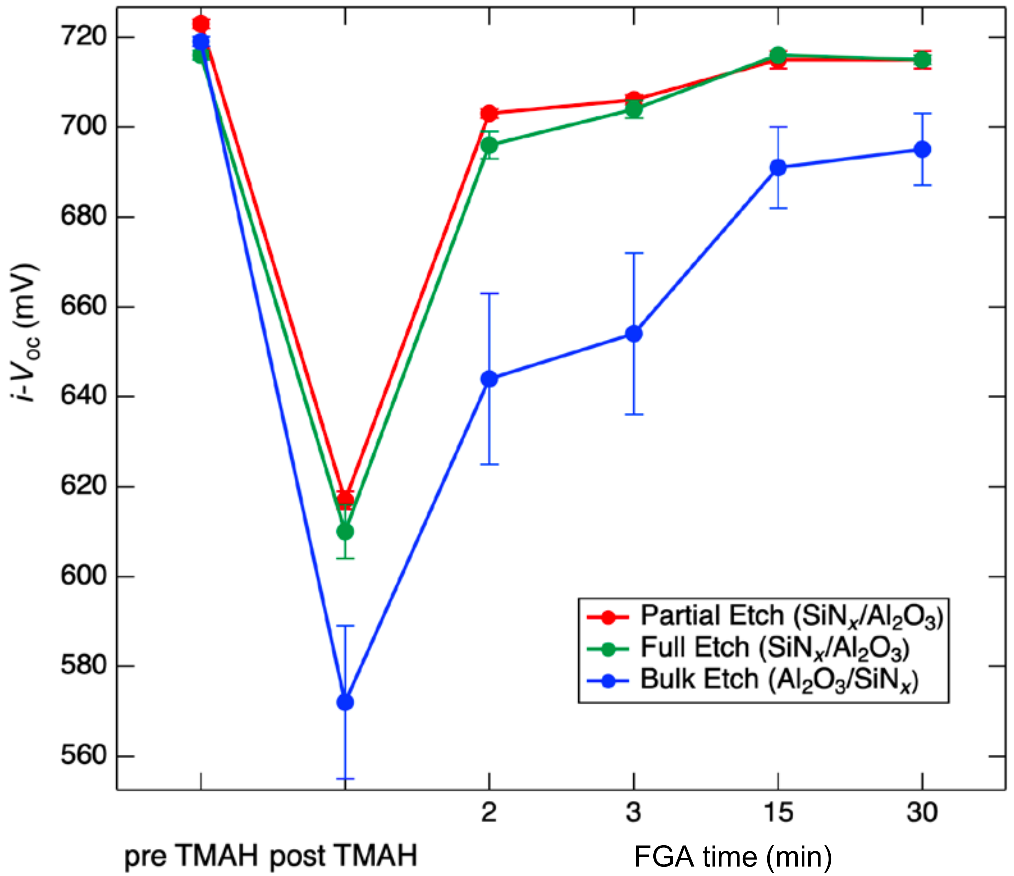
- SiN_x
- SiN_x/Al_2O_3
- Al_2O_3
- Al_2O_3/SiN_x
- $Al_2O_3/SiN_x/Al_2O_3$
- SiO_x (witness)

Device Implementation

- Best dielectric passivation scheme
- Explore optimal re-passivation anneal conditions

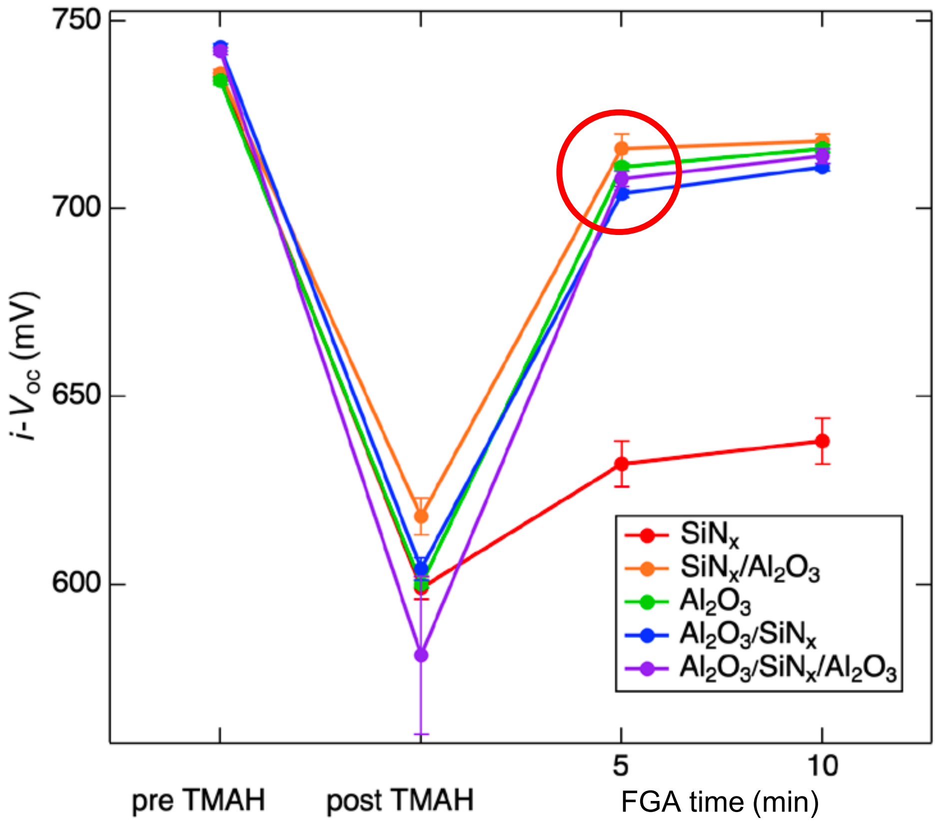
The Effect of Front *Poly*-Si Thickness on Passivation Quality

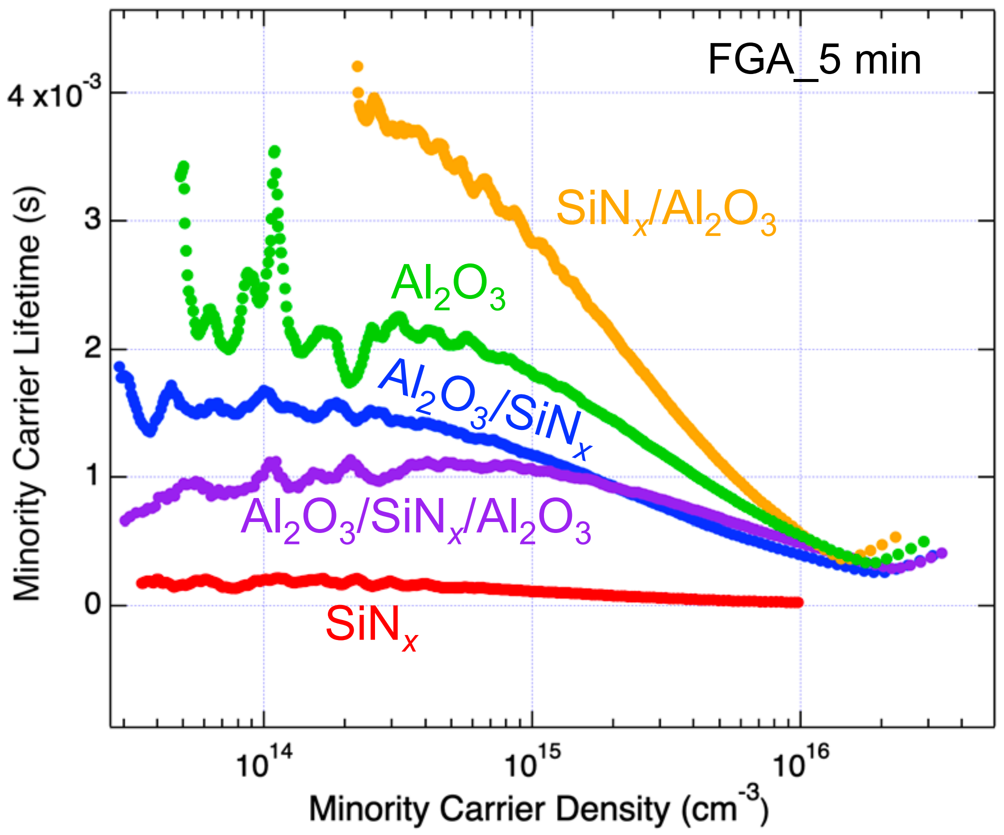




- Passivation was recovered for partial and full etch of *poly*-Si with SiN_x/Al_2O_3
- Complete *poly*-Si removal was chosen for device optimalization

SiO_x/n^+ *c*-Si: Injection-Level Dependent Minority Carrier Lifetime



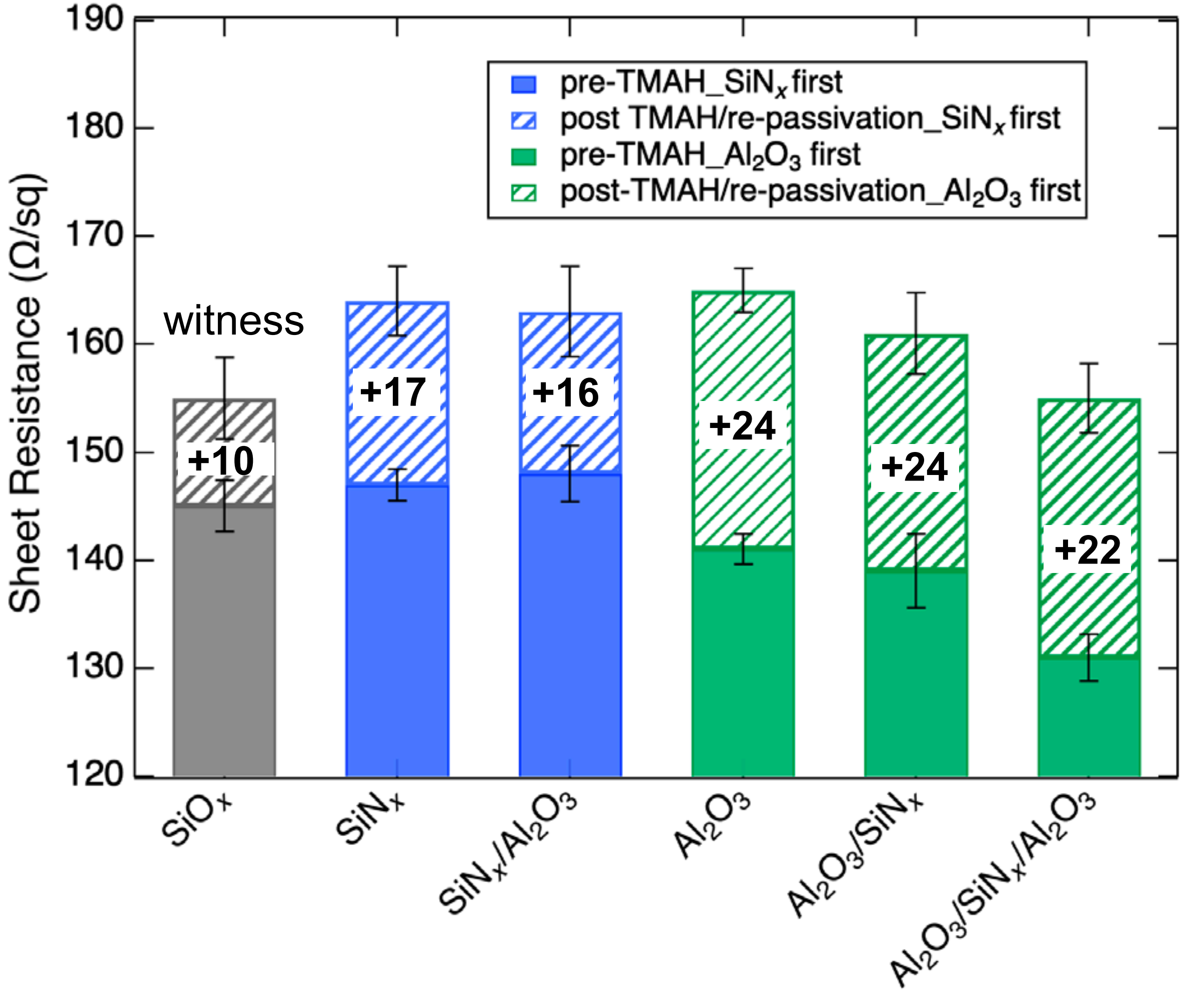


- All passivation schemes improved the passivation with increasing FGA time at 400°C
- SiN_x/Al_2O_3 has the best re-passivation quality (J_0 6.2 fA/cm^2 post 5 min FGA)
- All passivation with Al_2O_3 contacting SiO_x showed increased recombination evident from low lifetimes at low injection levels[1-2]

[1]. G. Dingemans *et al.*, *Journal of Applied Physics,* vol. 110, no. 9, p. 093715, 2011

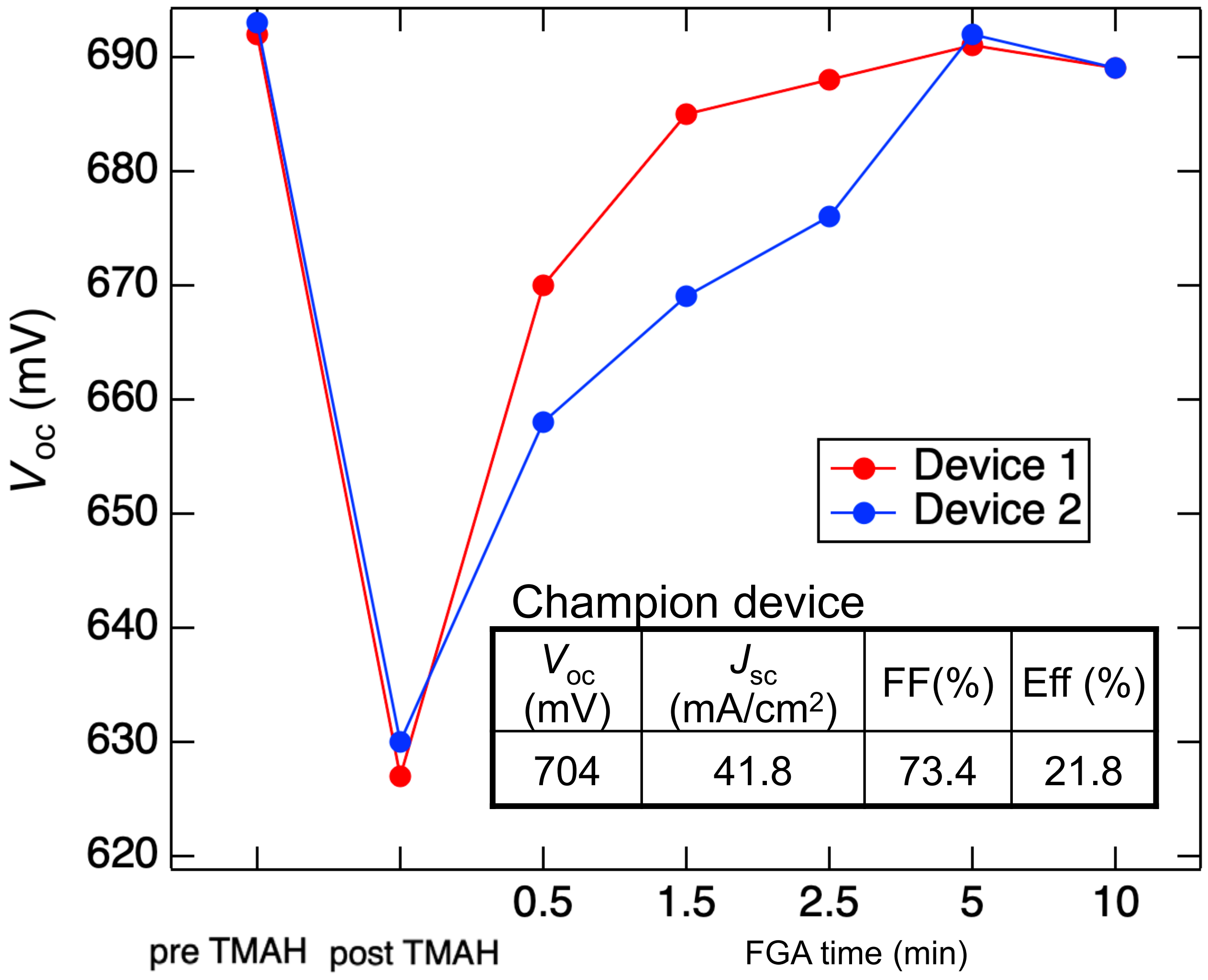
[2]. D. K. Simon *et al.*, *Solar Energy Materials and Solar Cells,* vol. 131, pp. 72-76, 2014/12/01/ 2014

TLM Measurements Reveal Near-Surface Charge Formation

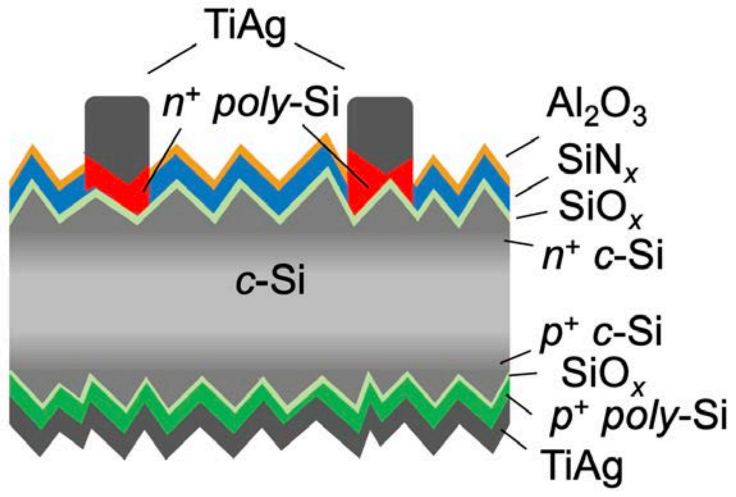


- All sheet resistances increased post TMAH indicating the removal of *poly*-Si
- Passivation schemes with SiN_x contacting SiO_x/*c*-Si showed less increase compared to Al_2O_3
- Al_2O_3 attracts minority carriers, thus contribute to the lowering of the doping concentration at the near surface

Implementation of Best Passivation Scheme in *Poly*-Si/SiO_x Device



V_{oc} (mV)	J_{sc} (mA/cm^2)	FF(%)	Eff (%)
704	41.8	73.4	21.8

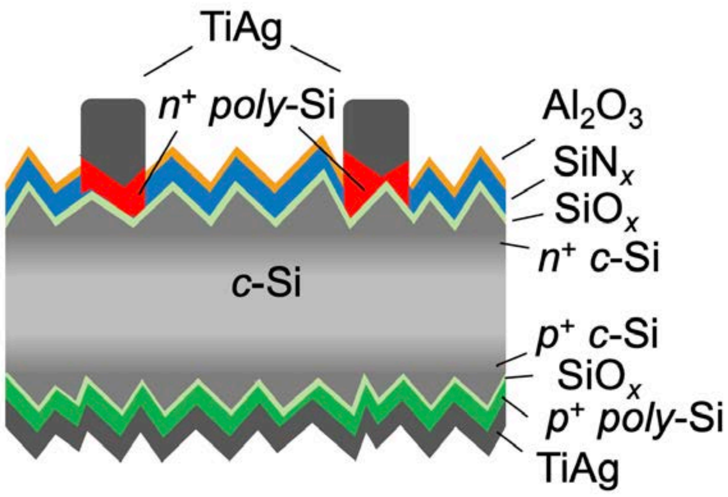


- SiN_x/Al_2O_3 dielectric scheme was used for device passivation
- Passivation recovered after an optimal FGA time at 5 min due to pre-existed metal contacts
- Best device performance yielded in **21.8%** device from 16% pre-processing

B. Nemeth *et al.*, *Journal of Materials Research,* vol. 31, no. 6, pp. 671-681, 2016

Conclusion and Acknowledgements

- Explored different dielectric passivation schemes on lifetime samples after removing *poly*-Si completely
- Showed that SiN_x/Al_2O_3 had the best passivation properties on SiO_x/n^+ *c*-Si in diffused surface
- Applied SiN_x/Al_2O_3 stack on *poly*-Si/SiO_x passivating contact device and showed large improvement in J_{sc}, with best device efficiency of 21.8%
- Future work: CV measurement of dielectric stacks to obtain Q_f and D_{it}



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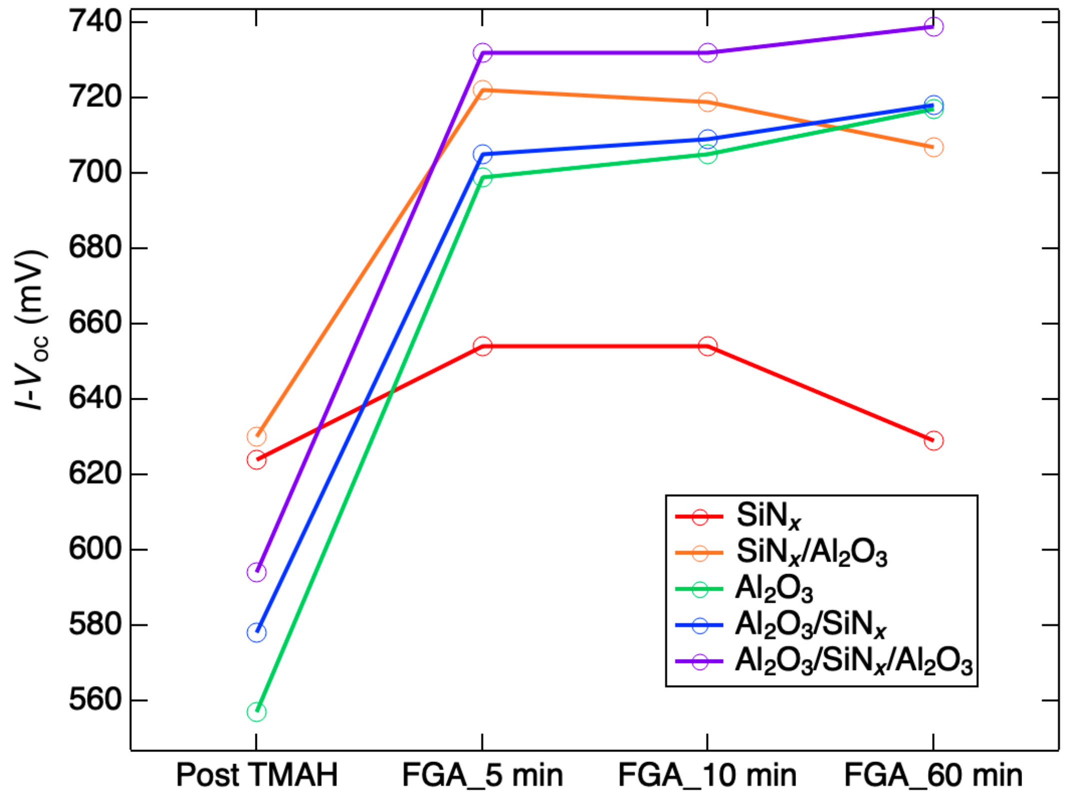
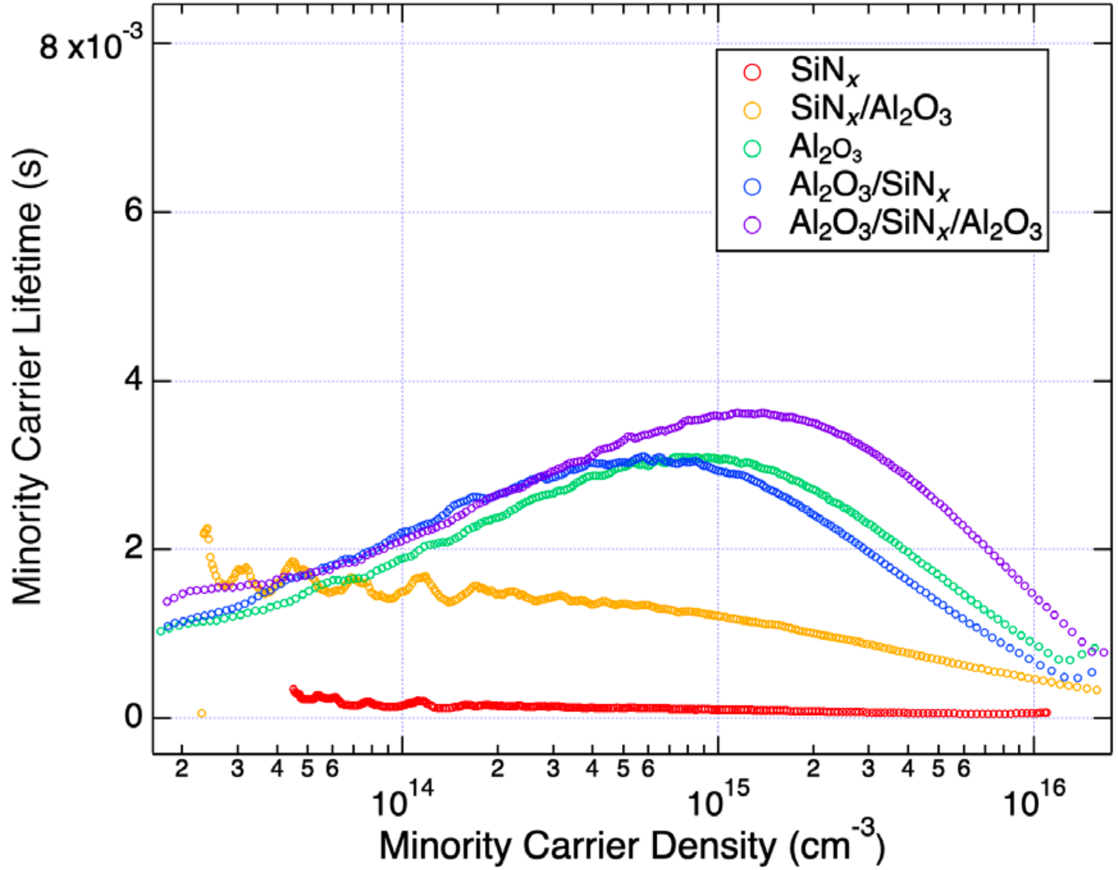
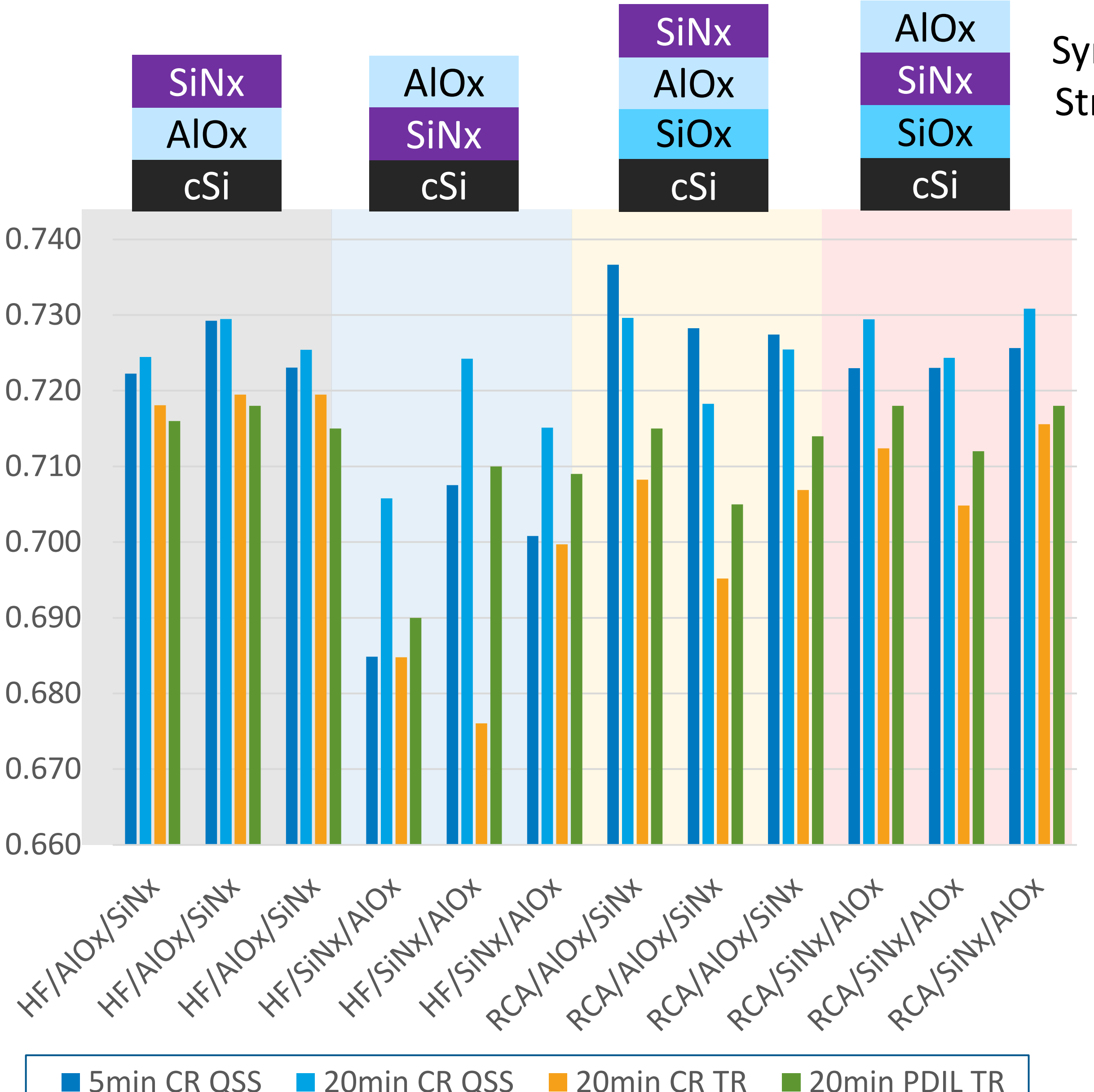
n-Cz *c*-Si bulk: Injection-Level Dependent Minority Carrier Lifetime





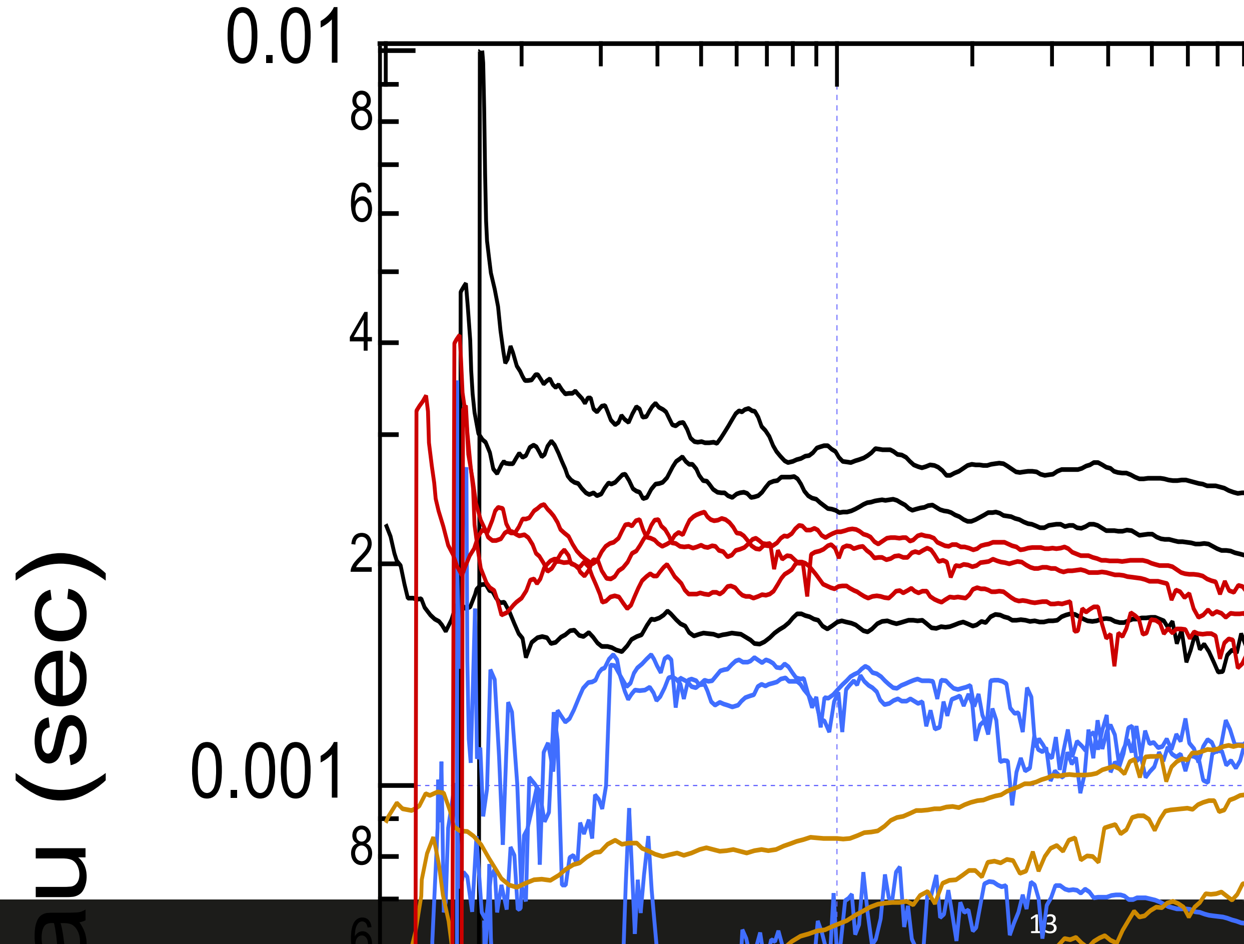
- Similar behavior as on SiO_x/n^+ region with improving passivation quality at longer FGA time
- SiN_x first schemes show de-hydrogenation with increasing FGA time
- $Al_2O_3/SiN_x/Al_2O_3$ reached high $i\text{-}V_{oc}$ of 739 mV at 60 min FGA

Passivate DSTXT nCz cSi ±HF, SiNx ↕ AlOx

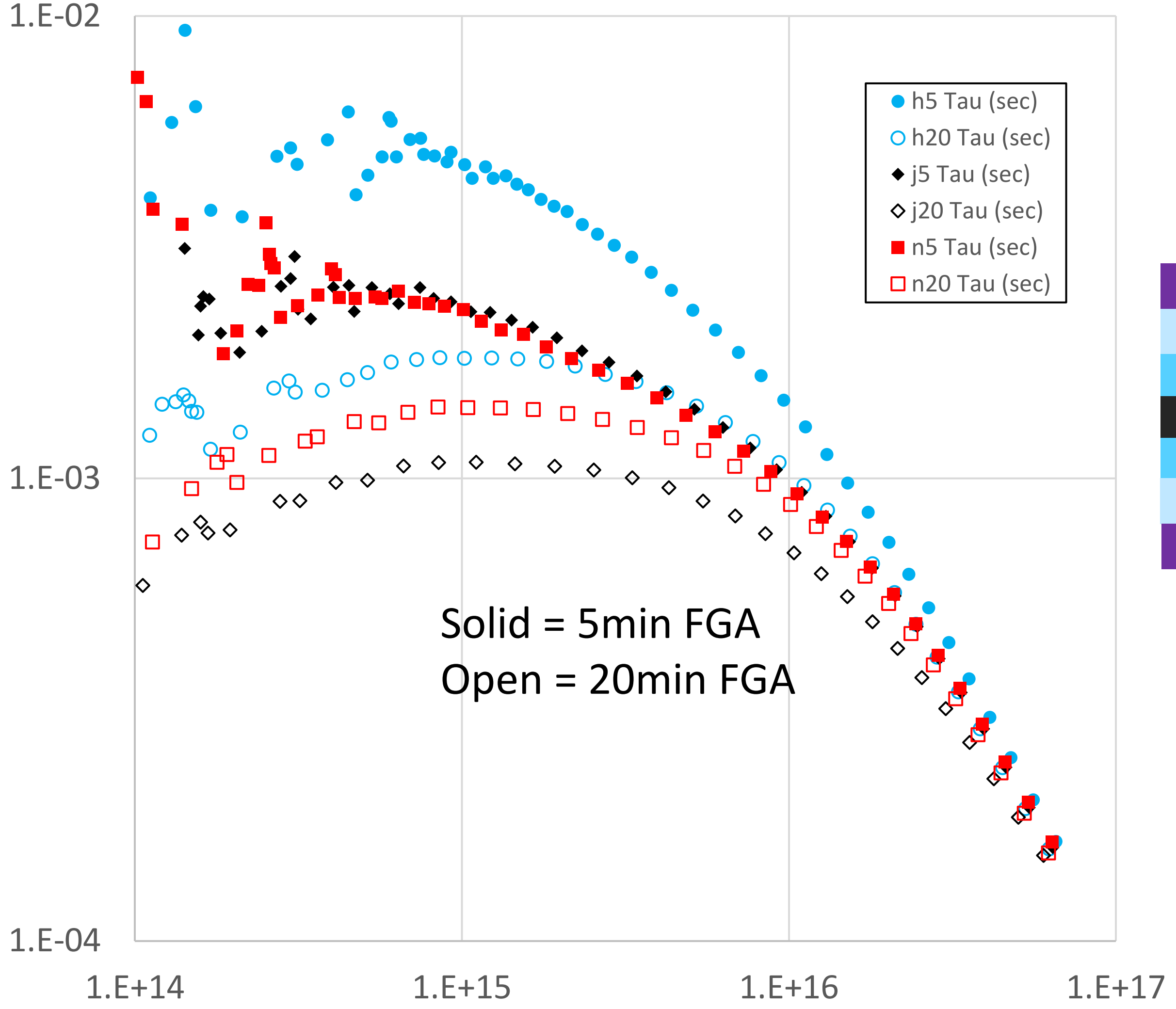


Symmetric Structures

- Si-N bond doesn't allow good passivation
- AlOx on HF cSi
  - forms SiOx (from HF cSi) interlayer with anneal
  - RCA SiOx has low injection lifetime decrease
    - Fixed charge development



5min vs 20min FGA SiNx/AlOx/RCA SiOx
Fixed charge ↑, inversion layer formed in nCz



The polarity of the fixed charge density is, however, of influence when considering the injection level dependence of the effective lifetime curves. The negative polarity of the fixed charge density in Al_2O_3 can provide an explanation of the injection level dependence of the effective lifetime for the passivated *n*-type *c*-Si wafers, as shown in Fig. 4. The

c-Si surface.[41,42] Consequently, the decrease of the effective lifetime at low injection levels for *n*-type *c*-Si wafers passivated by Al_2O_3 can most probably be attributed to bulk recombination losses in the depletion region near the *c*-Si surface induced by the negative fixed charge density in the Al_2O_3 film.

Hoex *et al.* J. Appl. Phys. **104**, 044903 (2008)

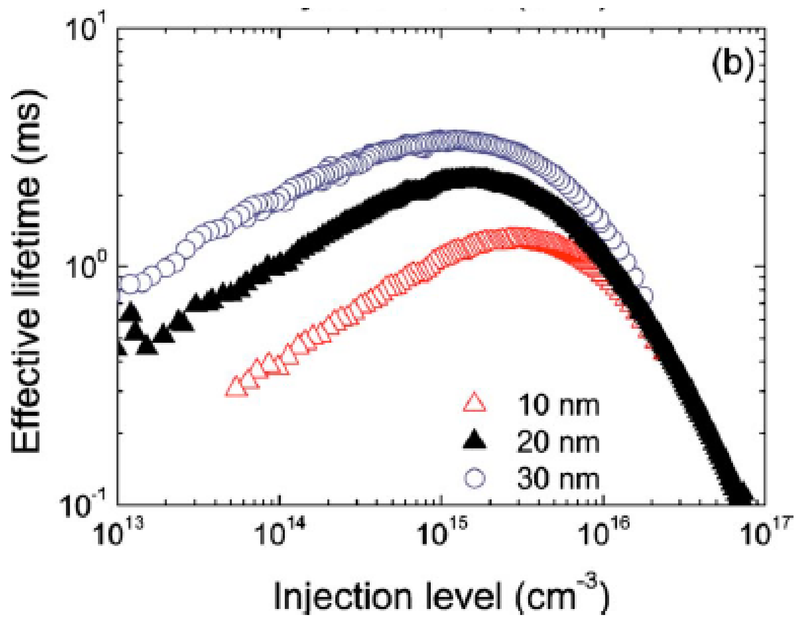


FIG. 4. (Color online) Injection level dependent effective lifetimes of *n*-type *c*-Si (1.9 Ω cm, ⟨100⟩, 275 μm) wafers symmetrically passivated by Al_2O_3

- As deposited means after n and p metal evaporation, but prior to TMAH
- 0 mins means after TMAH, SiNx and ALD deposition, but prior to FGA
- 32 was placed in between 31 and 34 during FGA (not enough time to heat up as shown in the next PL slide)

Pre TMAH full HF dip

4:30 n-side did not go hydrophobic

FGA time 31	Voc	Jsc	FF	Eff
As deposited	692	28.05	76.5	14.9
0 min	627	33.73	71.1	15.0
0.5 min	670	37.76	70.6	17.9
1.5 min	685	38.79	71.5	19.0
2.5 min	688	39.03	71.4	19.2
5 min	691	39.03	72.1	19.4
10 min	689	39.13	72.2	19.5

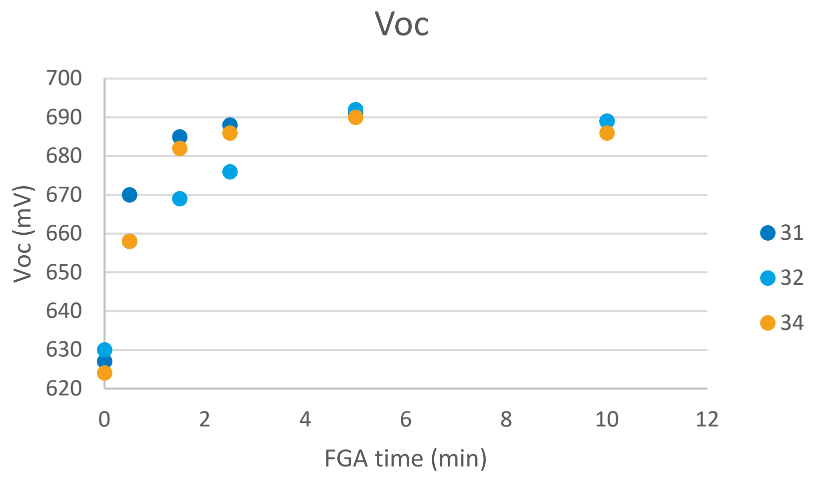
Pre TMAH partial HF dip

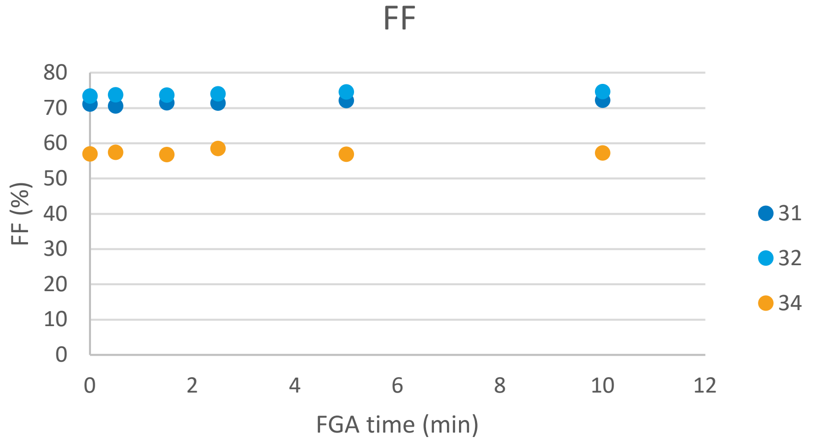
intended for one-side HF, but wafer dropped in container

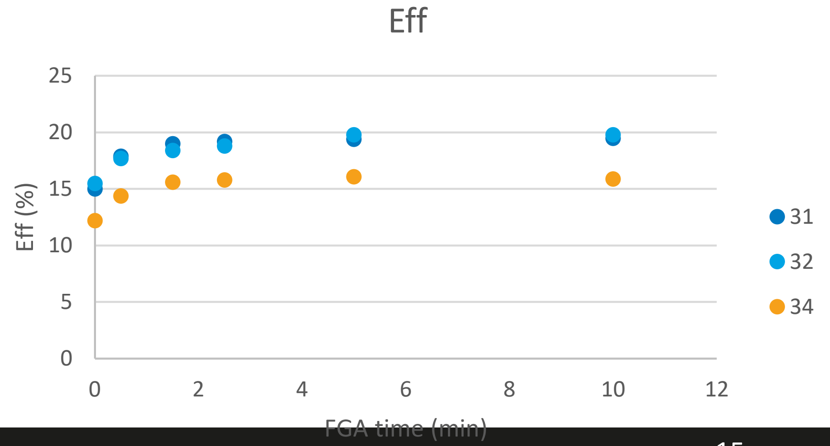
32	Voc	Jsc	FF	Eff
As deposited	693	27.94	76.9	14.9
0 min	630	33.50	73.4	15.5
0.5 min	658	36.47	73.8	17.7
1.5 min	669	37.37	73.7	18.4
2.5 min	676	37.65	74.0	18.8
5 min	692	38.34	74.6	19.8
10 min	689	38.48	74.7	19.8

Pre TMAH one side HF

34	Voc	Jsc	FF	Eff
As deposited	692	28.27	76.1	14.9
0 min	624	34.2	57.0	12.2
0.5 min	658	37.96	57.5	14.4
1.5 min	682	40.24	56.8	15.6
2.5 min	686	39.49	58.5	15.8
5 min	690	40.86	56.9	16.1
10 min	686	40.46	57.3	15.9







X-SEM to look for under-cut

	SiO_x	SiN_x	SiN_x/Al_2O_3	Al_2O_3	Al_2O_3/SiN_x	$Al_2O_3/SiN_x/Al_2O_3$
R_{sheet}_pre TMAH (Ω/sq)	145	147	147	141	139	131
R_{sheet}_post TMAH and re-passivation (Ω/sq)	155	164	163	165	161	155
ΔR_{sheet}	+10	+17	+16	+24	+24	+22

	SiO_x	SiN_x	SiN_x/Al_2O_3	Al_2O_3	Al_2O_3/SiN_x	$Al_2O_3/SiN_x/Al_2O_3$
R_{sheet}_pre TMAH (Ω/sq)	145	147	147	141	139	131
R_{sheet}_post TMAH and re-passivation (Ω/sq)	155	164	163	165	161	155
ΔR_{sheet}	+10	+17	+16	+24	+24	+22