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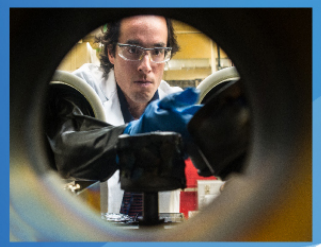


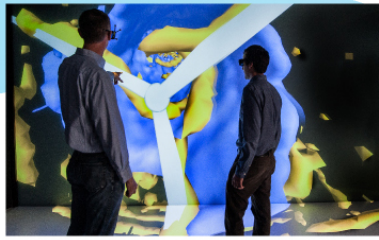

Approaches to Metallization for Poly-Si/SiO_x Passivated Contacts

M. Schnabel, W. Nemeth, S. Theingi, A. Kale, T.R. Klein, B.G. Lee, M.F.A.M van Hest, S. Agarwal, D.L. Young, P. Stradins

October 24th, Konstanz, Germany

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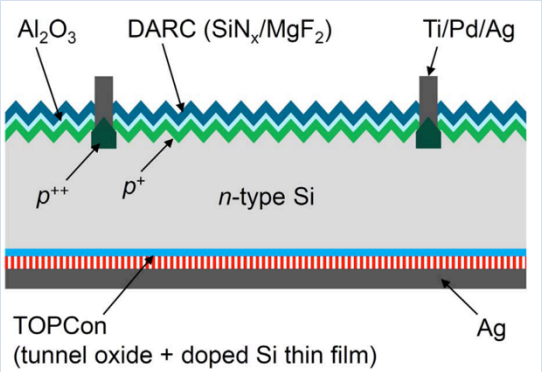
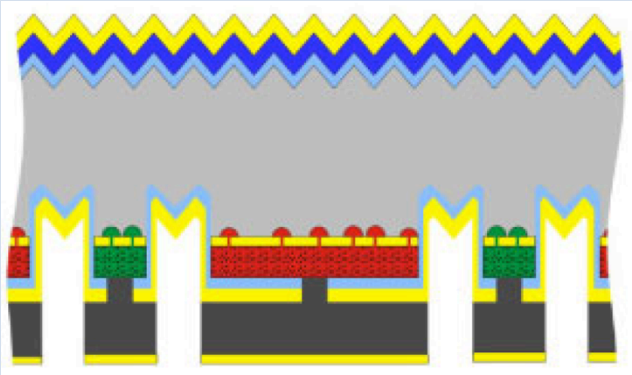
Why Poly-Si/SiO_x ?

Poly-Si/SiO_x passivated contacts on Cz Si are focus of Si PV research at NREL since 2013 [1,2].

FhG-ISE: TOPCon, 25.7% [3]	ISFH: POLO, 25.0% [4]
	
Used for BSF of front-back cell	Used for emitter and BSF in IBC cell

[1] Lee *et al.*, 40th IEEE PVSC (2014)
[2] Nemeth *et al.*, 40th IEEE PVSC (2014)
[3] Richter *et al.*, *Solmat*, Vol. 173, pp. 96-105, 2017.
[4] Haase, *et al.*, *JJAP*, vol. 56, p. 08MB15, 2017.

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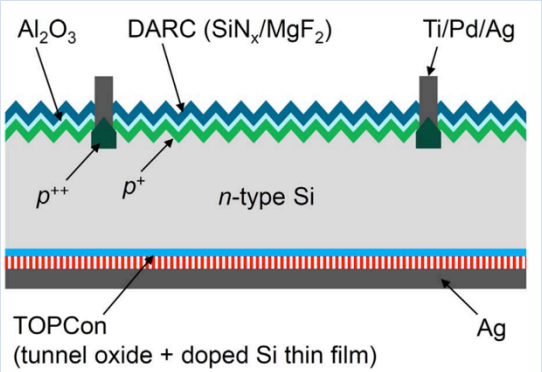	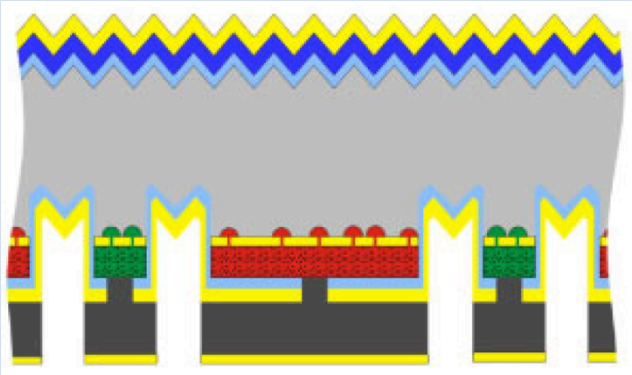
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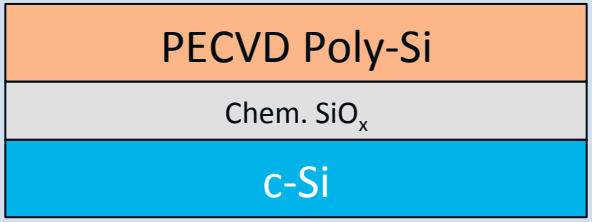
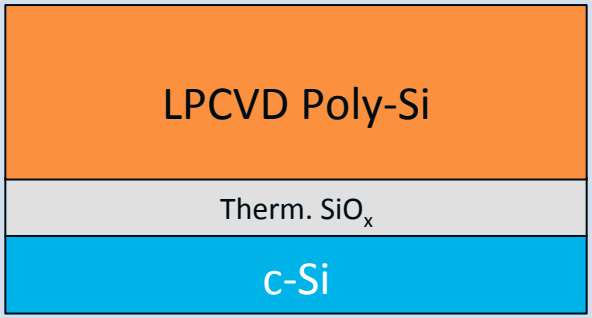
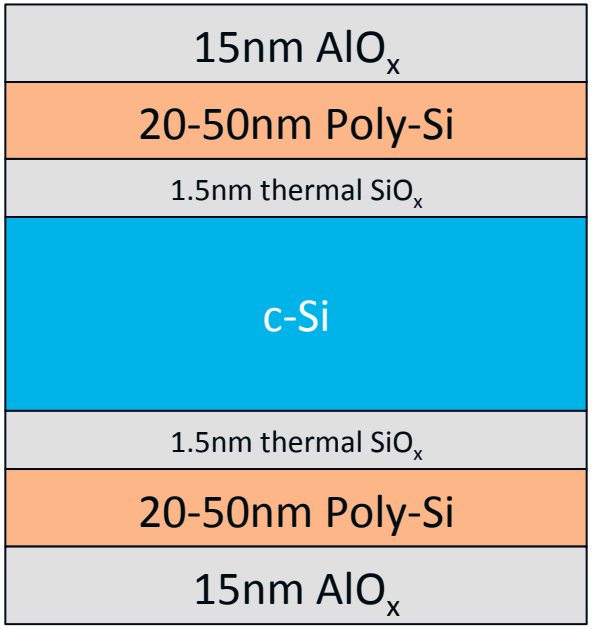
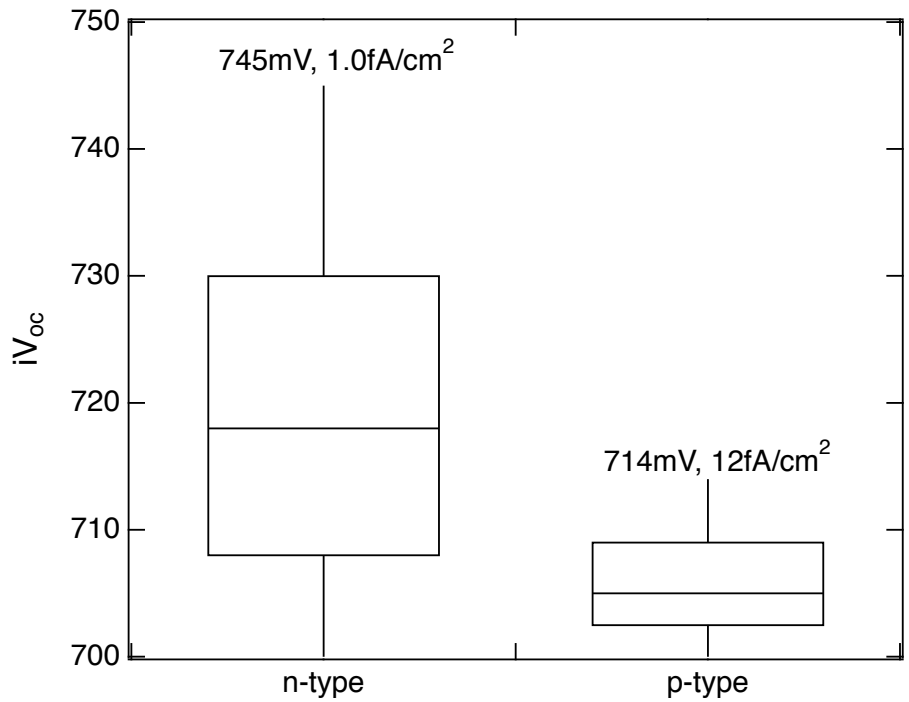
	

Poly-Si/SiO_x at NREL

1. RCA-cleaned Cz-Si
2. 1.5nm thermal SiO_x
3. 20-50nm PECVD a-Si:H
4. Crystallization, 850°C 30min
5. 15nm ALD AlO_x
6. FGA, 400°C 1h



Poly-Si/SiO_x at NREL



Before

After e-beam Ti/Ag/Pd

n-type

50ms

Outline

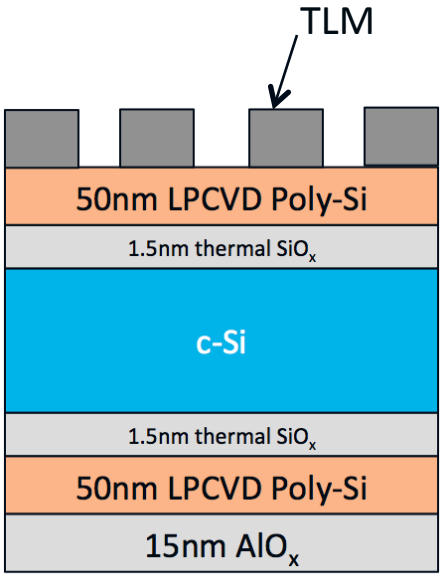
- Metal
- Spacer Layers
  - a-Si:H
  - TCO
  - Conducting Adhesive
- Summary

Metals

- Used in-situ doped LPCVD poly-Si
- Keep AlO_x on unmetallized side
- Initial iV_{oc}:
  - 735-740 mV (n-type)
  - 704-713 mV (p-type)

- Metals
  - 4nm Ti / 1µm Ag, thermal
  - 4nm Ti / 1µm Ag, e-beam
  - 1µm Al, e-beam
  - 1µm Al:1wt%Si, e-beam

- All metals 1µm thick, at 5A/s
- FGA: 200-400°C

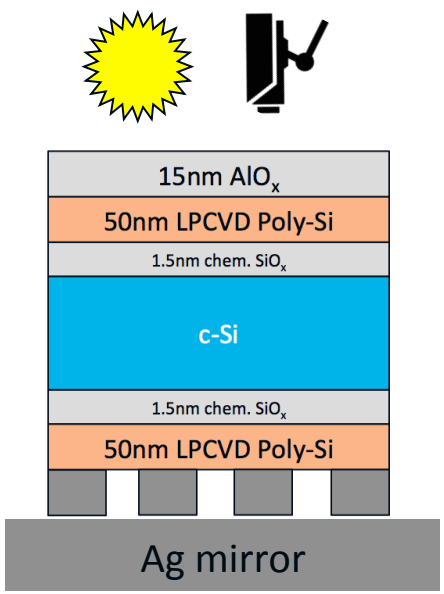


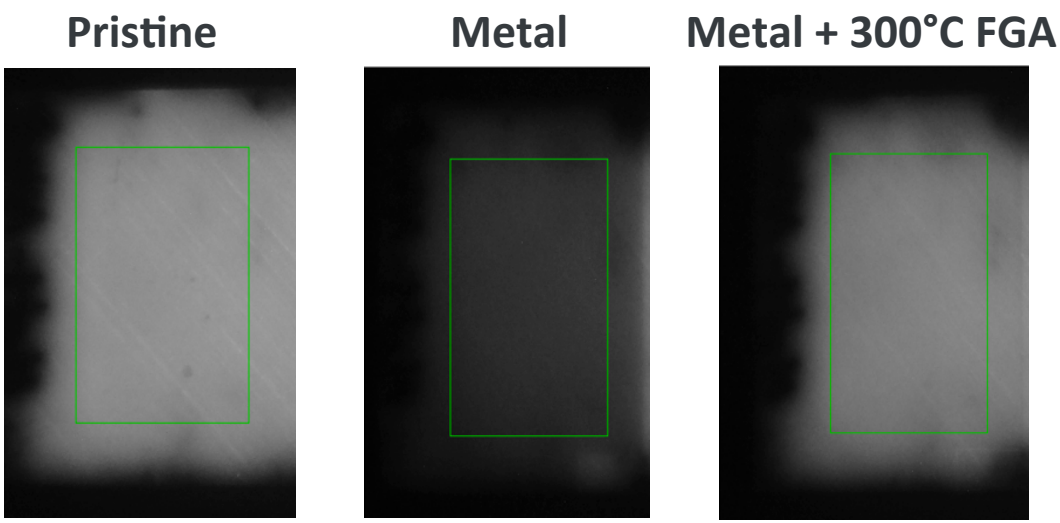
Metals – ΔiV evaluation

- Quantify metallization damage from PL via implied voltage loss, ΔiV, derived from PL intensity before and after metal:

$$\Delta iV = \frac{kT}{q}\ln\left(\frac{I_{after}}{I_{before}}\right)$$

- Measure on mirror to minimize effects of changing optics



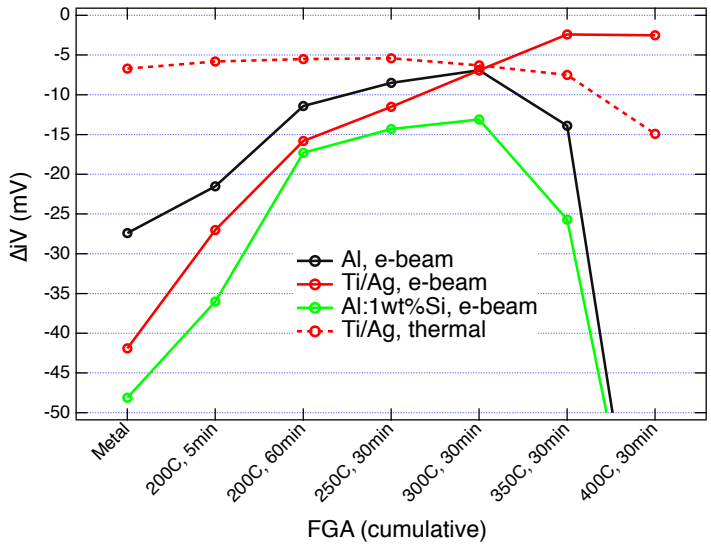


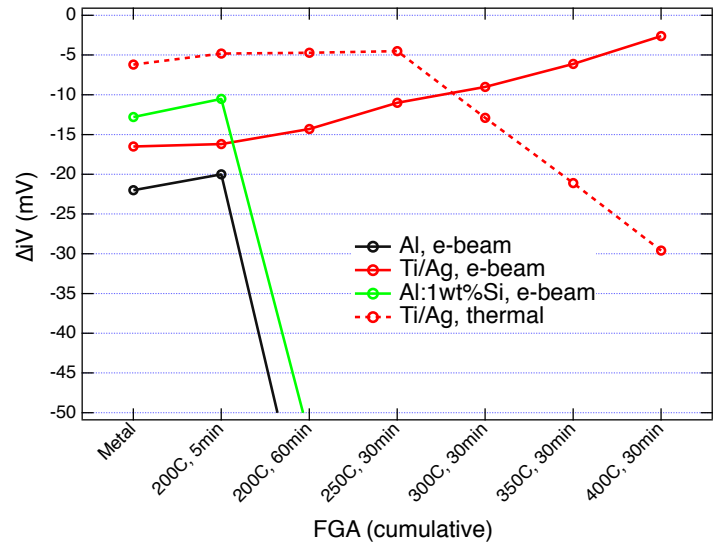
Metals

n-type

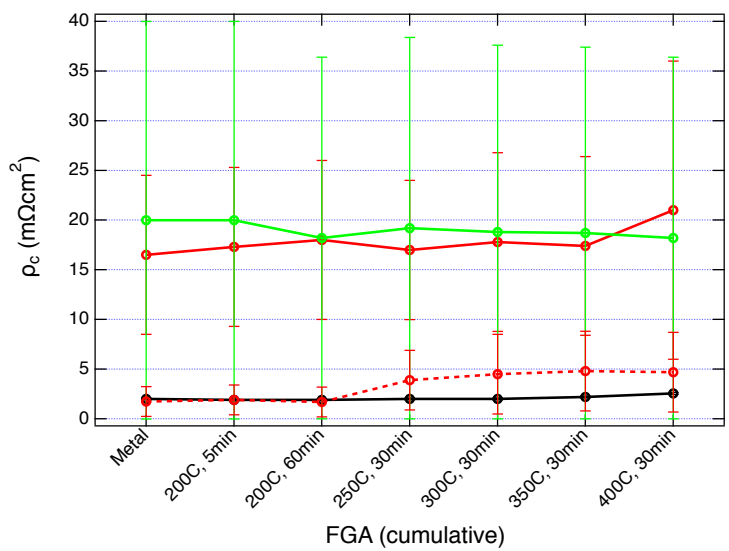
p-type

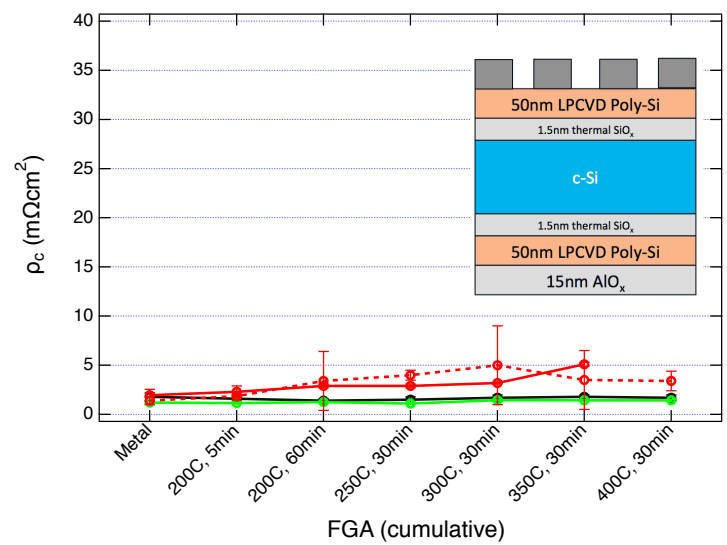
ΔiV





ρ_c



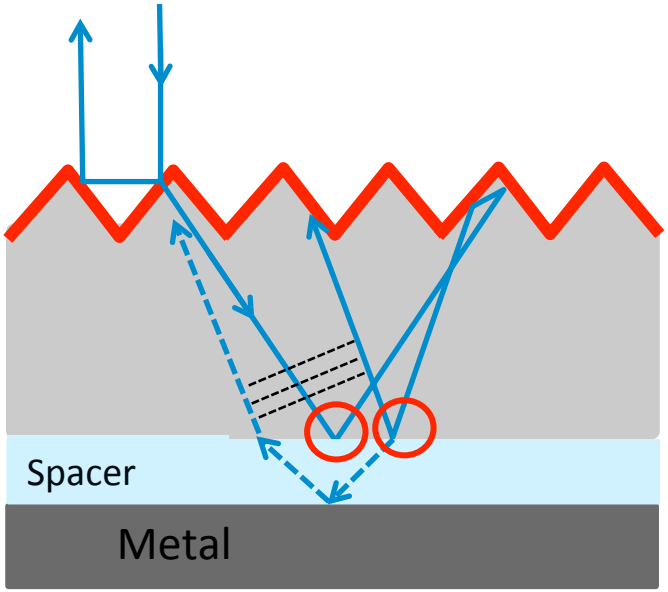


Metals - Conclusions

- Thermal evaporation less damaging
- E-beam damage of some metals anneals out
- Other metals kill contact before e-beam damage anneals out fully
- E-beam damage less severe for p-type (in ΔiV terms), but more prone to degradation upon FGA.

Spacers

- Metallization damage could be mitigated by spacer between poly-Si and metal.
- Can also improve light trapping
- Less sensitivity to reflectance of metal



<u>Calculated</u> maximum J_{SC} for 150µm Si wafer cell assuming perfect textured front ARC

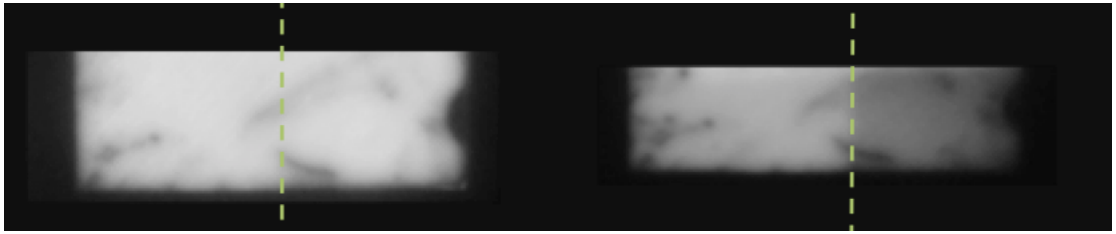
Back structure	Ag metal	Al metal
Flat rear, direct metal	41.58 mA/cm^2	41.15 mA/cm^2
Textured rear, direct metal	42.07	41.31
Textured rear, dielectric spacer (150 nm SiO_2)	42.61	42.50

Ben Lee, 2015

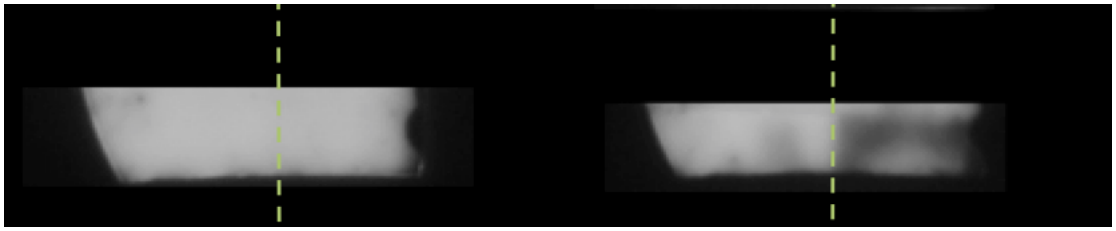
Spacers – a-Si:H

- Thin a-Si:H spacer reduces damage
- Attributed to covering of pinholes in poly-Si
- Negligible additional series resistance

n-type



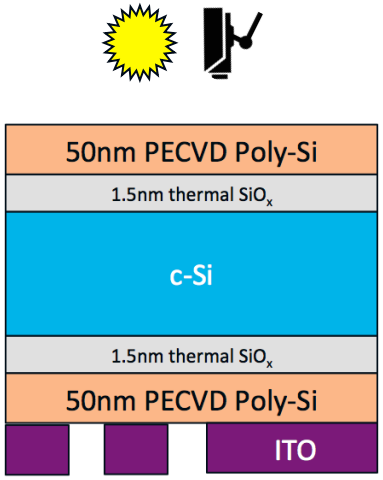
p-type



Nemeth *et al.*, 41st IEEE PVSC, Nemeth *et al.*, MRS Spring Meeting 2015

Spacers – thermal ITO

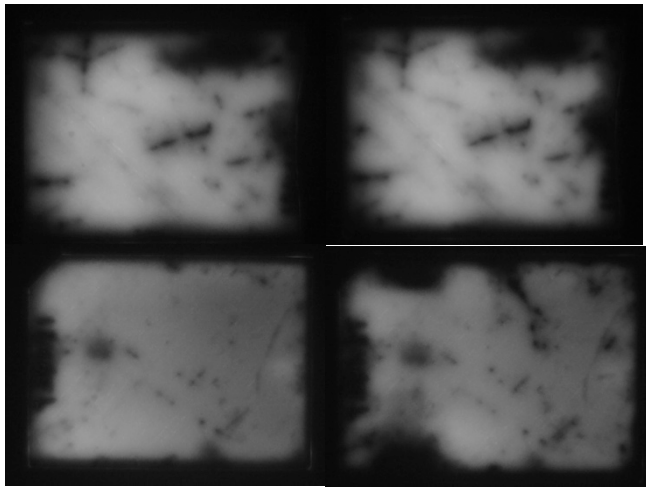
- Evaporation of In-Sn alloy in O_2 ambient.
- Deposition of ITO without sputter damage (ΔiV<5mV)
- Expected to shield metallization damage
- Contact resistivities somewhat high
  - 23 mΩcm^2 to n-poly-Si
  - 37 mΩcm^2 to p-poly-Si



Before ITO After ITO

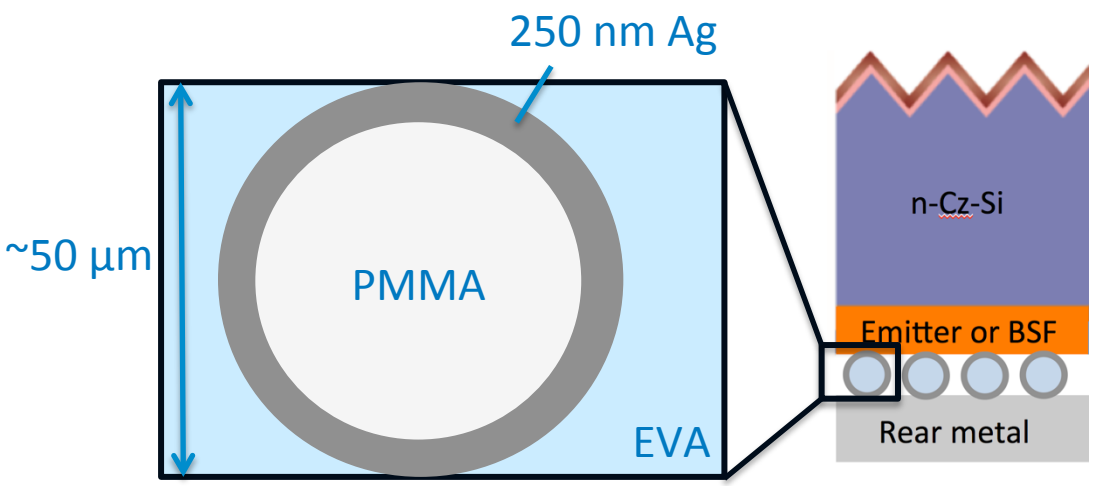
n-poly
733mV
0.1s

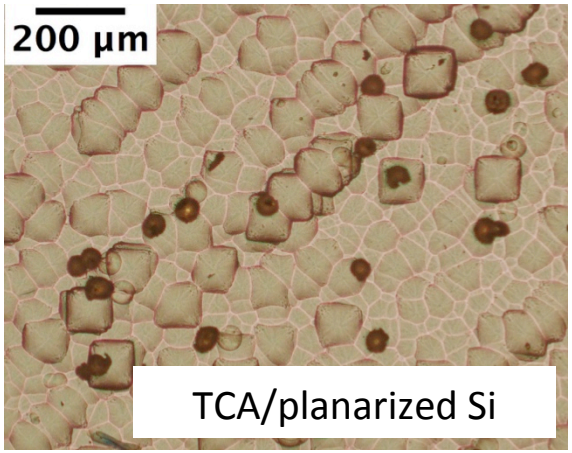
p-poly
667mV
1s



Spacers - Conductive Adhesive

- EVA with metal-coated microspheres [1,2]
- Bond metal to Si – Si doesn't see metal preparation
- A single sphere bridges conductive adhesive (CA)
  - anisotropic conductivity
  - can conform to rough surface
- 10 area% microspheres yields <0.4 Ωcm^2 between Ag surfaces

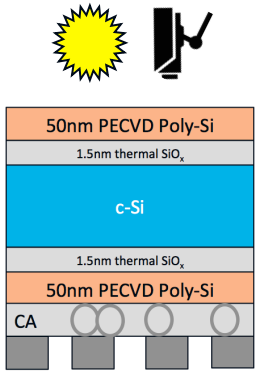


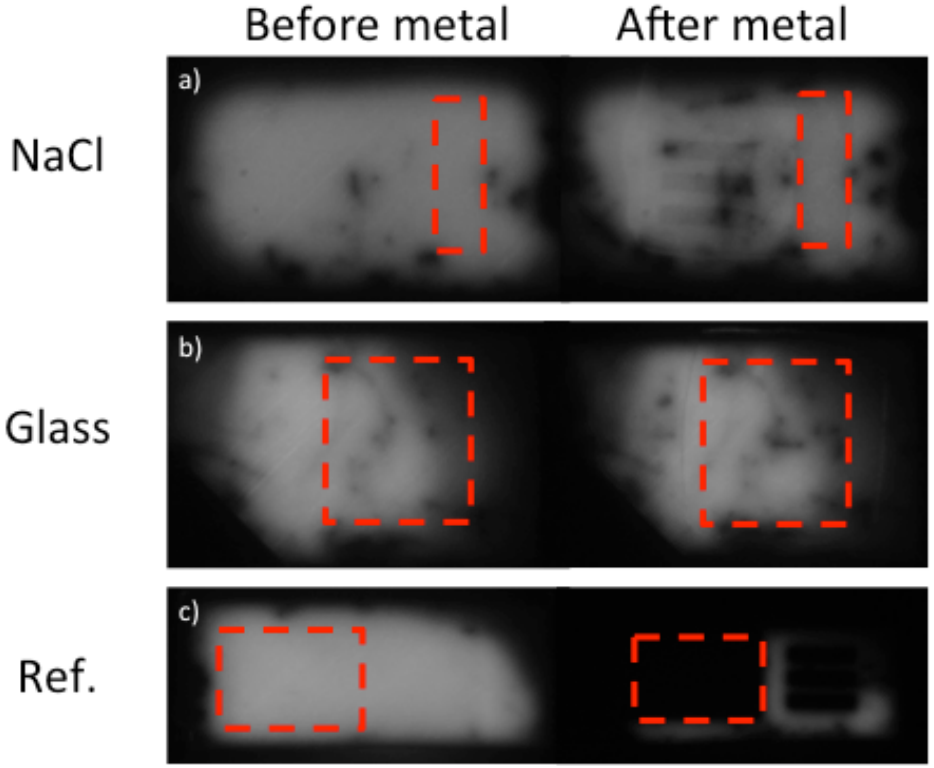


[1] T.R. Klein *et al.*, 44th IEEE PVSC, [2] M. Schnabel *et al.*, 44th IEEE PVSC

Spacers - Conductive Adhesive

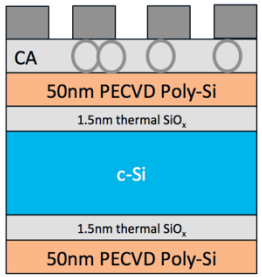
- PL imaging before and after metallization:
  - Ti/Ag/Pd stack, e-beam
- Metal transfer via NaCl and glass both maintain iV_{oc} (<5 mV change)
- Same e-beam process directly on passivated contact → 120 mV drop



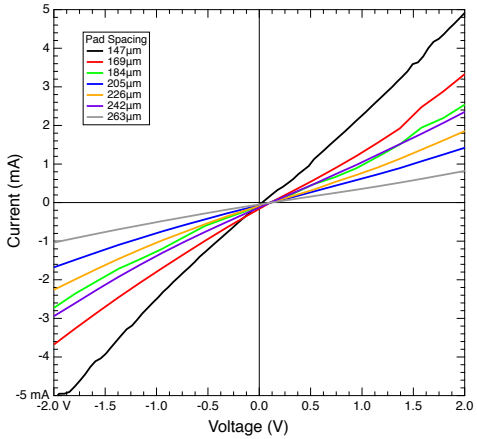


Spacers - Conductive Adhesive

- Ohmic IV curves



- ρ_c=4-6 Ωcm^2
- ρ_c≤1 Ωcm^2 feasible with more microspheres



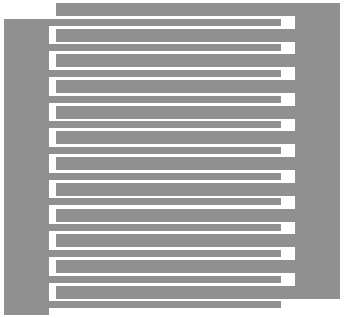
- $R_{c,\ sphere}$ = 3000-8000 Ω (~0.1Ω within sphere shell)
- ρ_c≤0.1 Ωcm^2 requires improvement of microsphere/poly-Si contact
  - Increase effective contact area

Area% MS	ρ_c
1%	6 Ωcm^2
4%	4 Ωcm^2

Spacers - Conductive Adhesive

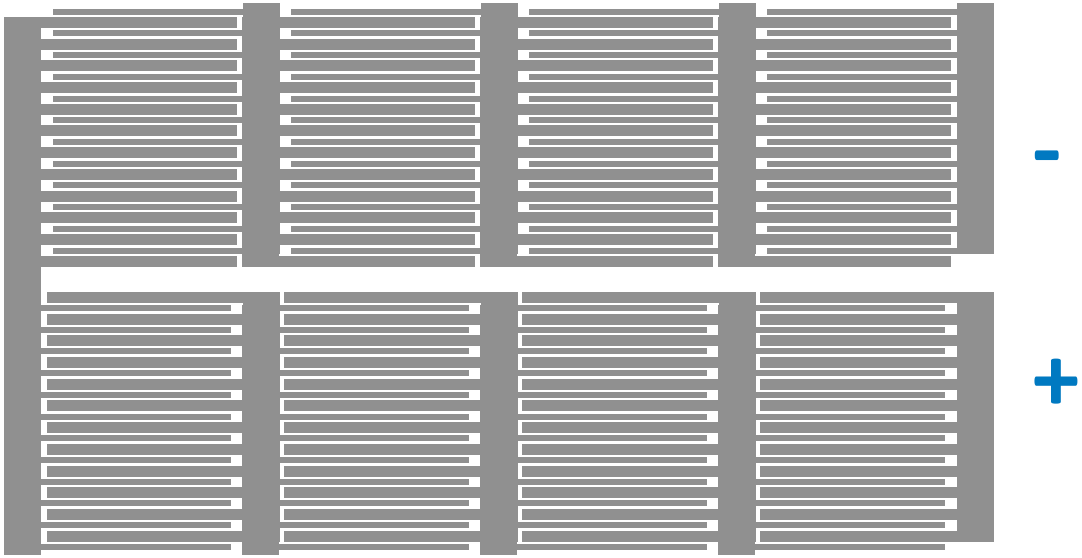
- Pattern all metal for metallizing back-contact solar cells, and for interconnecting them, onto a backsheet
- Use CA to attach non-metallized cells. No shunts if area% low
- Creates opportunity for cheaper, and more efficient modules

Doping on rear side of back contact cell



Metal on rear side of 1 such cell

Metal + Series Connection for 8 cells.



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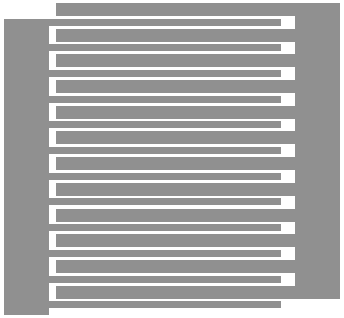

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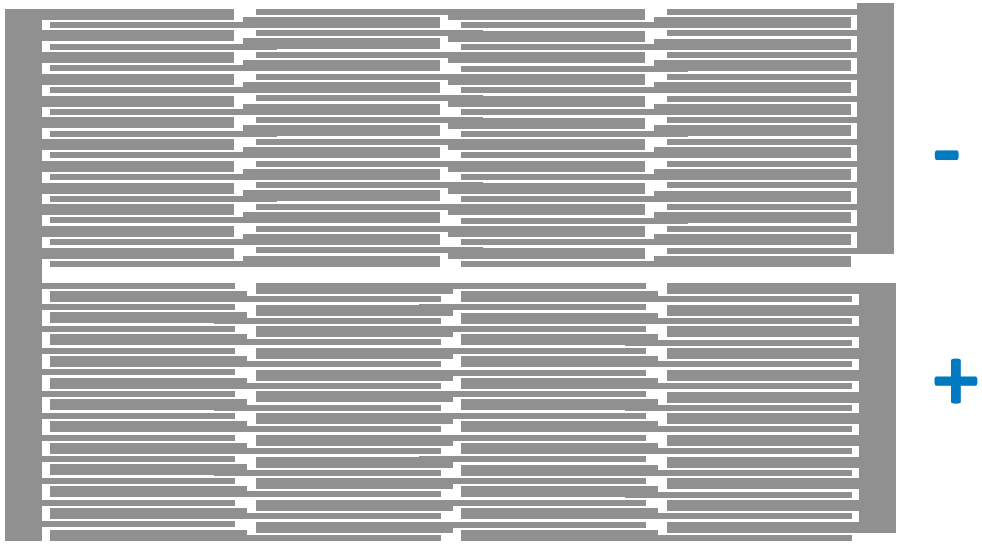

Conclusion

- Thermal evaporation preferable to e-beam
- Some e-beam metals can work
  - Key factor is whether damage is annealed out before metal kills the contact
  - p-type fails sooner upon FGA
- Poly-Si can be shielded from direct metal contact with spacers
- Spacers can provide additional benefits
  - Improved optics
  - Streamlined module processing

Thank you for your attention

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