The importance of contact pattern in passivation layers for ultrathin $Cu(In,Ga)Se_2$ solar cells

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Nanofabrication for Optoelectronic Applications - INL

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Ultrathin devices require passivation of back contact

Several materials, contacts and fabrication show different outcome

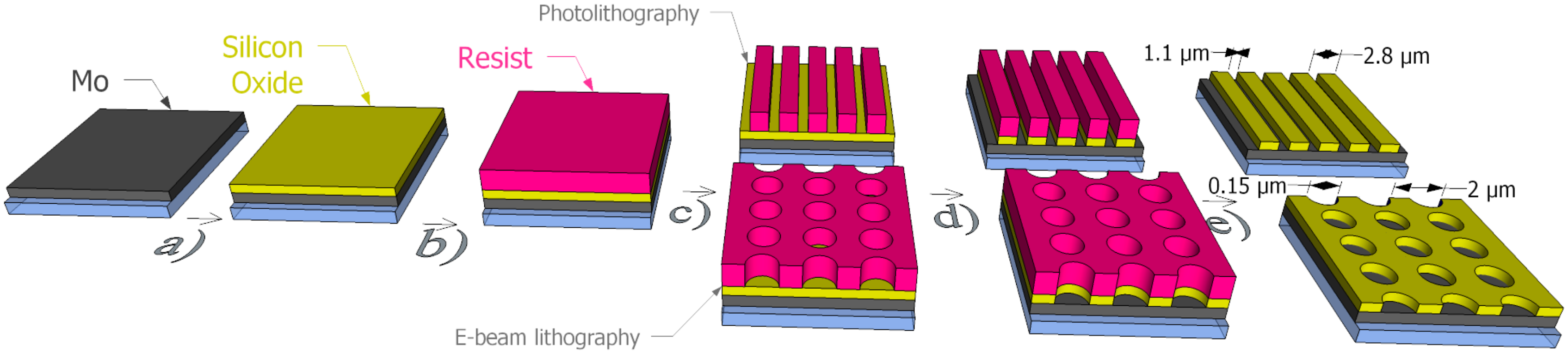
Line Contacts
Point contacts
Tunnelling barriers

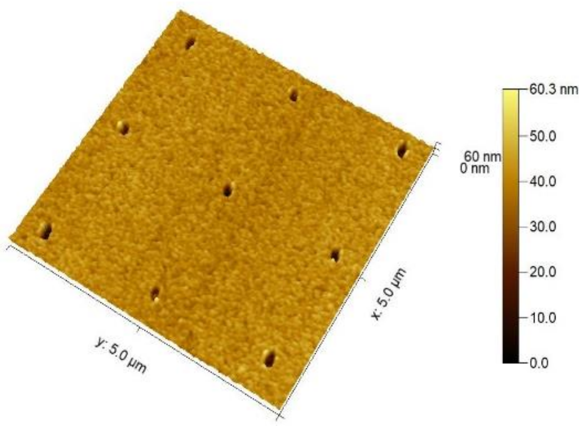
Lift-off Approaches
Optical Lithography
E-Beam Lithography
Nano-imprint

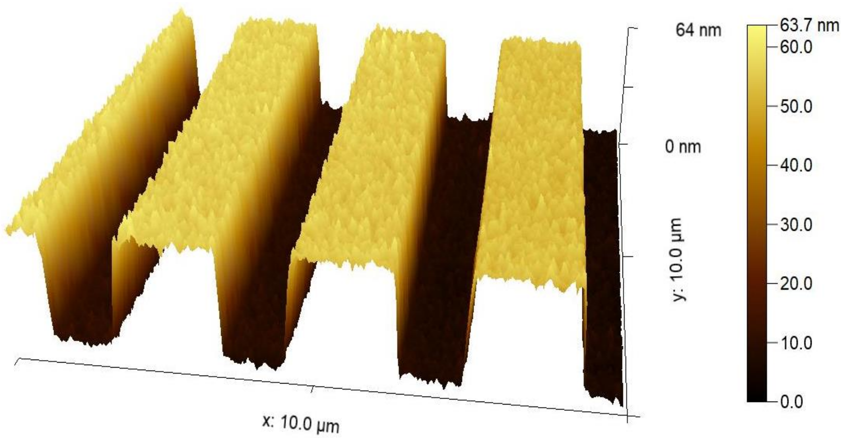
Materials:
Al_2O_3;
SiO_2;
HfO_2;
etc

Nanofabrication of line and point contacts

Optical and e-beam lithography







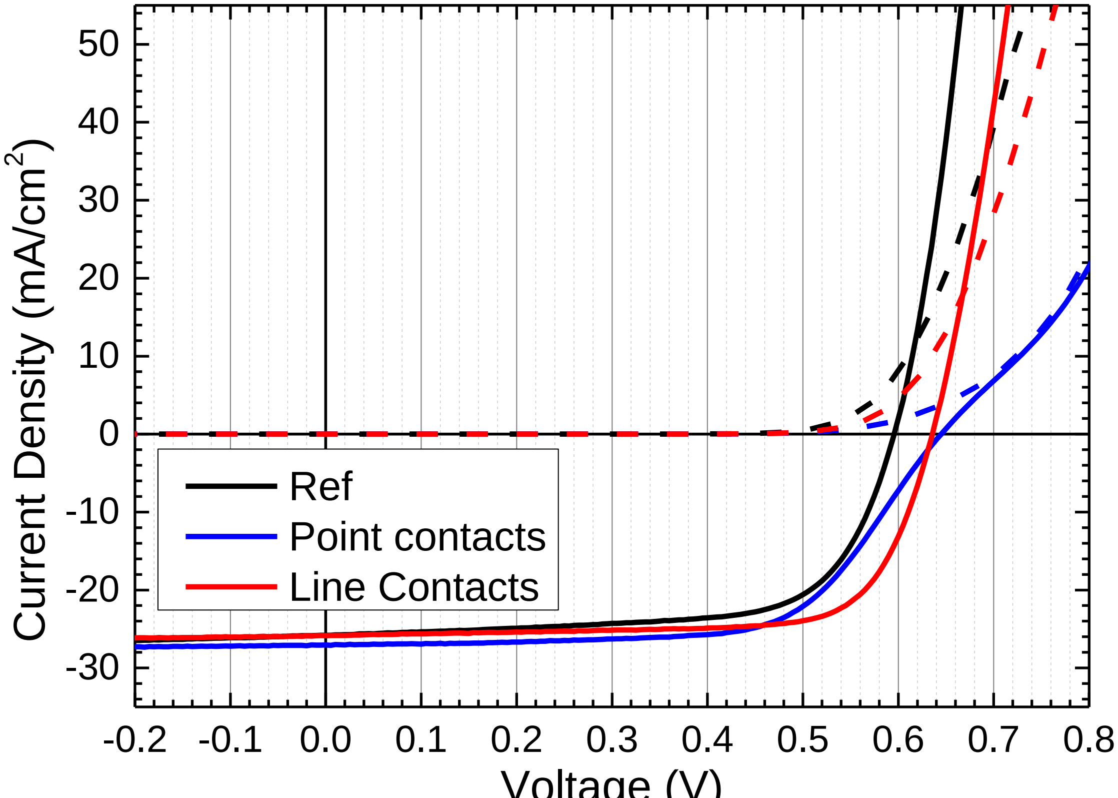
Line contacts: Passivation area 60%; 2.8 µm Pitch

Point contacts: Passivation area 99%; 2 µm Pitch

J-V analysis

Both patterns improve efficiency but with different benefits

Device	V_{oc} (mV)	EQE corrected J_{sc} (mA/cm^2)	FF (%)	Eff. (%)
Ref	585 ± 7	22.50 ± 0.44	66.9 ± 1.3	8.8 ± 0.4
Point Contacts	653 ± 13	24.23 ± 0.67	66.6 ± 2.6	10.5 ± 0.7
Line Contacts	639 ± 7	23.80 ± 0.21	74.7 ± 0.8	11.4 ± 0.2



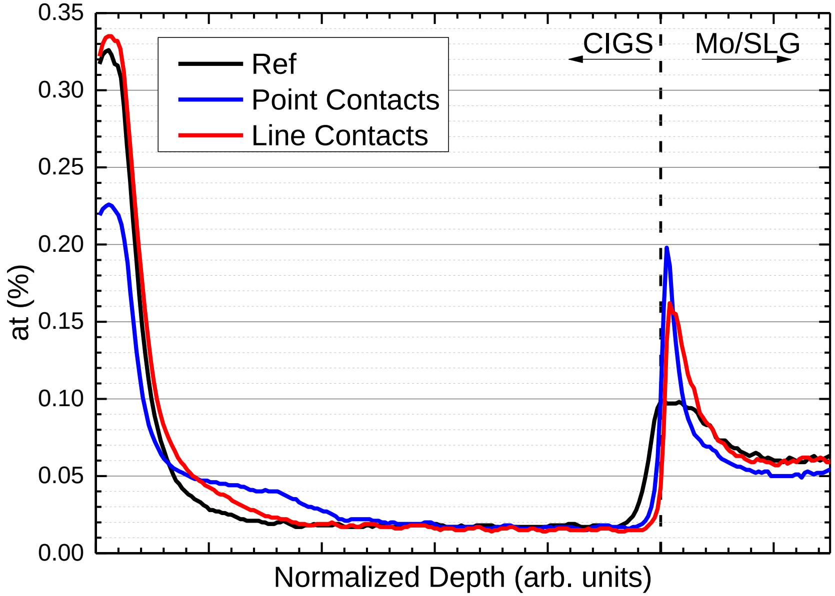
CIGS thickness 700 nm

Ga-flat profile

18 nm SiOx

Na distribution and admittance

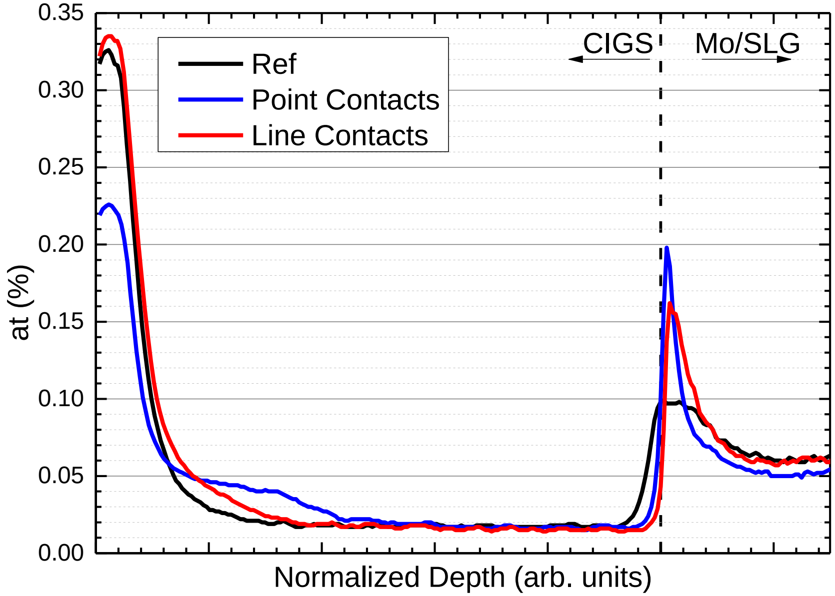
GDOES and Admittance give contradictory results



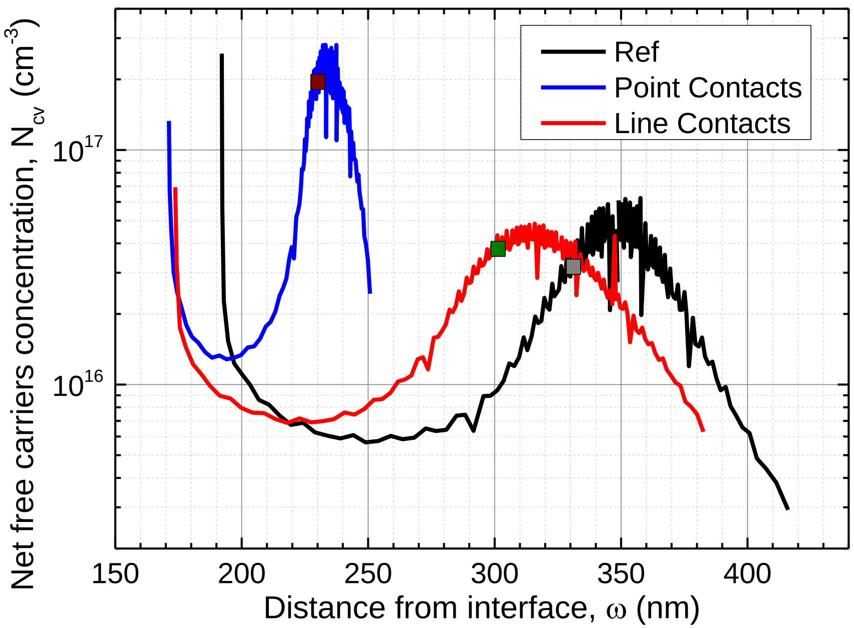
Na profile by glow discharge optical emission spectroscopy

Na distribution and admittance

GDOES and Admittance give contradictory results



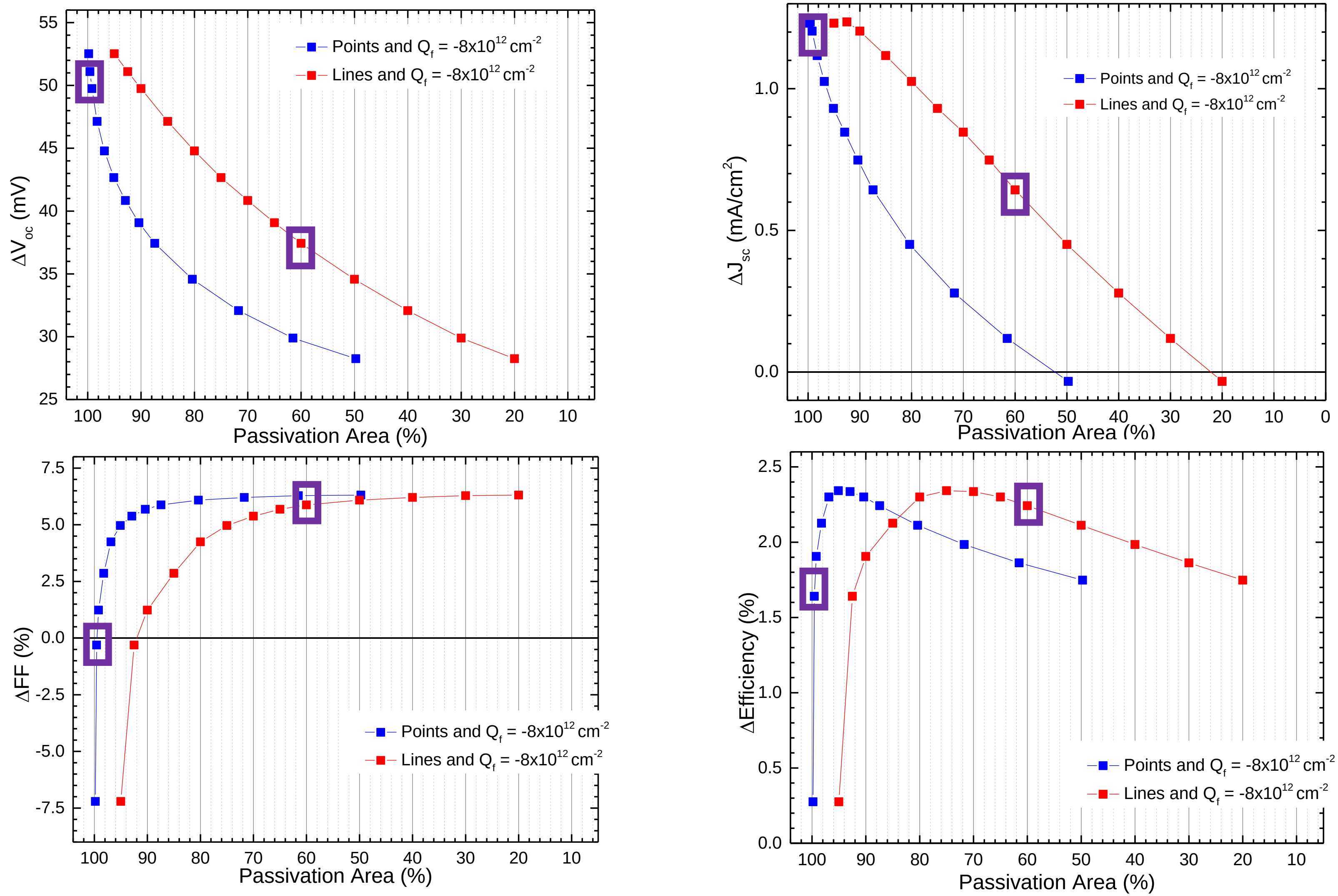
Na profile by glow discharge optical emission spectroscopy



Device	ω (nm)	N_{cv} (cm^{-3})
Ref	364 ± 35	(3.3 ± 0.4) x10^{16}
Point Contacts	228 ± 35	(20 ± 8) x10^{16}
Line Contacts	298 ± 7	(4.1 ± 0.4) x10^{16}

2D Simulations

Optimization heavily depends on CIGS and passivation properties

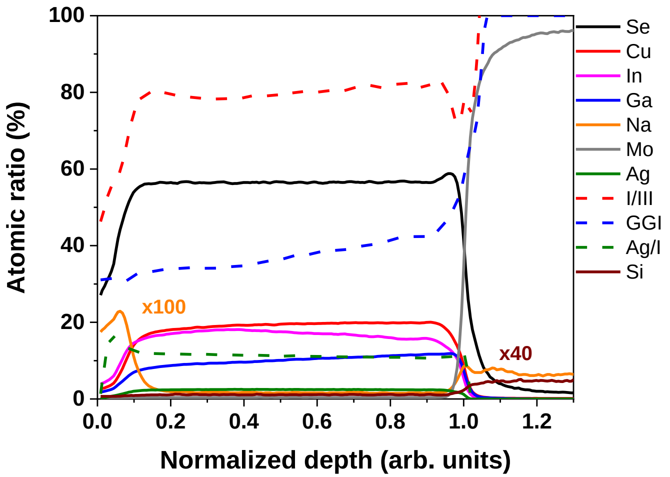


Comparison with graded profile and ACIGS

Grading provides more variability to references but also helps passivation

Device	V_{oc} (mV)	QE corr. J_{sc} (mA/cm²)	FF (%)	Eff. (%) QE corr.
REF	621 ± 85	25.63 ± 0.41	50.54 ± 15.82	8.83 ± 3.03
P-8 nm SiO_x	726 ± 3	26.20 ± 0.29	77.69 ± 0.23	14.77 ± 0.18
P-25 nm SiO_x	731 ±5	26.10 ± 0.44	73.10 ± 11.05	14.66 ± 0.17

ACIGS: 730 nm; linear Ga profile



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Comparison with best of CIGS

V_{oc} and FF on par with WR J_{sc} still has electrical and optical losses

	Voc (mV)	J_{sc}, simulated (mA/cm²)	FF (%)	Eff (%)	ΔJ_{sc}	E_g-V_{oc} (meV)
ZSW E_g= 1.11	741	37.8, 39.95	80.6	22.6	2.15	369
This work (best cell) E_g=1.23*	744	26.91, 30.62	77.2	15.5	3.71	486

No PDT, No AR, no back reflection increase
*bandgap estimated from composition, not EQE

Reference ZSW: Philip Jackson et al, P hys. Status Solidi RRL, 1–4 (2016) / DOI 10.1002/pssr.201600199

Solutions for performance increase

Individual solutions and integration with SiO_x is on-going

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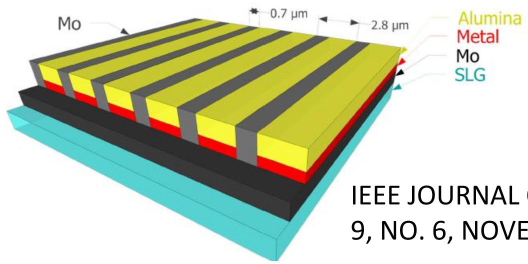
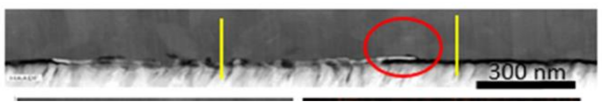
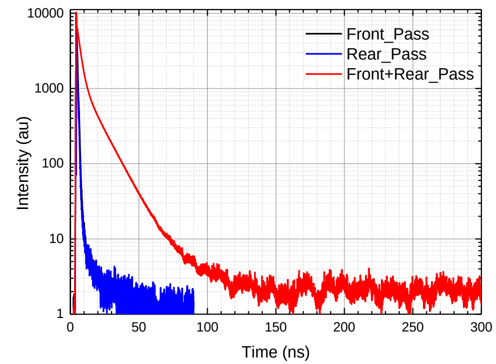
Decoupling of Optical and Electrical Properties of Rear Contact CIGS Solar Cells



IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 9, NO. 6, NOVEMBER 2019

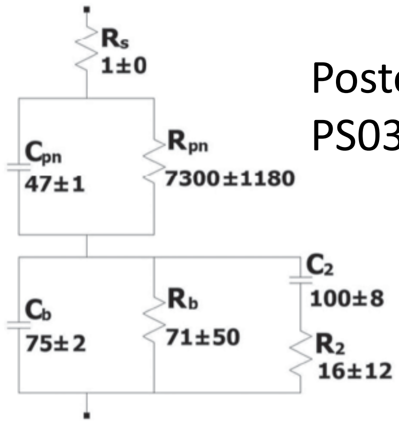


Effect of PDT and passivation



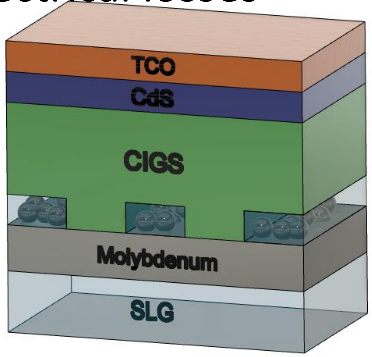
poster PS03-07

Analysis of lower bulk recombination channels for ultrathin devices



Poster PS03-04

J_{sc} increase by 18% without electrical losses



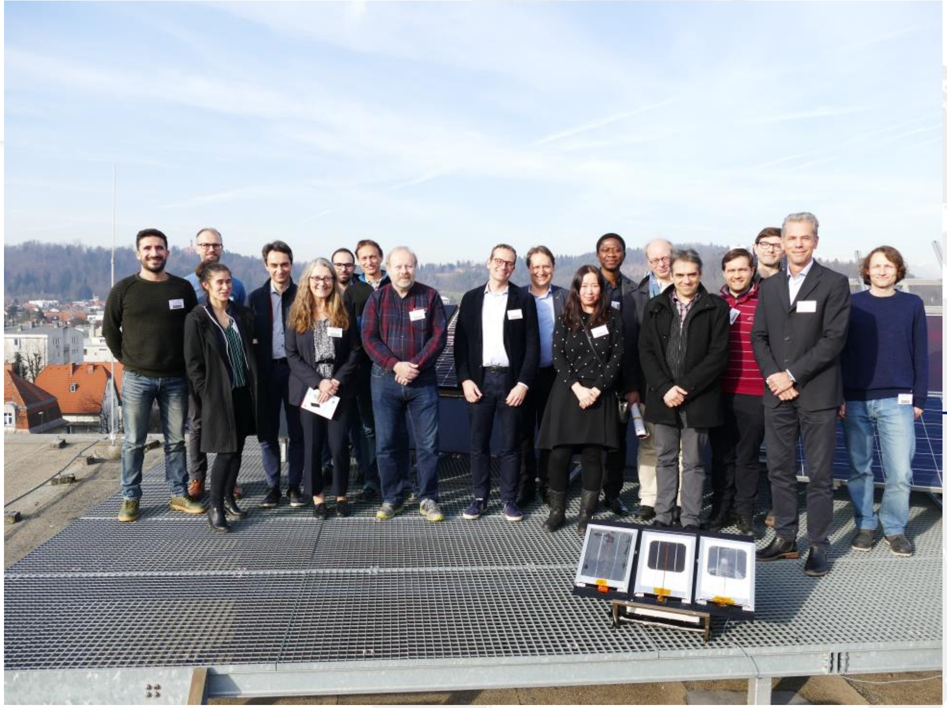
poster PS03-09

Front passivation
Poster: PS02-01

SiOx passivation
Poster:PS02-10

https://inl.int/micro-nanofabrication/nanofabication-optoelectronic-applications/

ARCIGS-M Consortium



NOA group at INL

P.M.P. Salomé Advanced Materials Interfaces, Volume 5, Issue 2, January 23, 2018

S. Bose et al, Thin Solid Films 671, pp. 77-84.

J. M. V. Cunha et al, IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 8, NO. 5, SEPTEMBER 2018.

730 nm CIGS with SiOx passivated rear contact - 15.5 % eff

	Voc (mV)	J_{sc} (mA/cm^2)	FF (%)	Eff (%)	E_g-V_{oc} (meV)
This work (best cell) E_g=1.23*	744	26.91	77.2	15.5	486

Thank you for listening!

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