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Electrical Analysis of Pulsed Laser Annealed *Poly*-Si:Ga/SiO$_x$ Passivating Contacts

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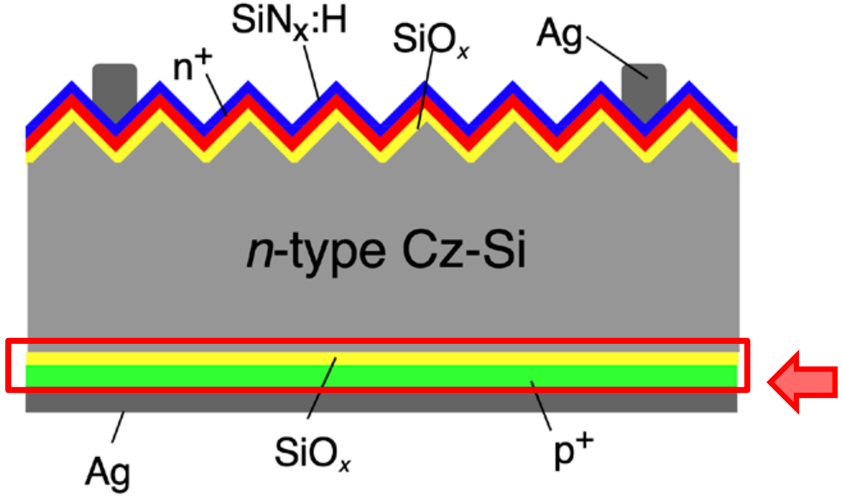
SiliconPV 2022

This work is supported by the U.S. DOE under Contract No. DE-AC36-08GO28308 and agreement Number 34359, and by the University of Padova (grant UNIPD-ISR 2017 'SENSITISE')

Further Improving *Poly*-Si/SiO$_x$ Passivating Contacts Performance



Double sided passivating contacts

Need to overcome low solid solubility of Ga in Si: ~10^{19} cm^{-3}

Compared with B: ~10^{20} cm^{-3}

- Double sided passivating contacts aim at better front passivation
- Lower passivation quality of B-doped *p*-type *poly*-Si based contacts compared to P-doped contacts

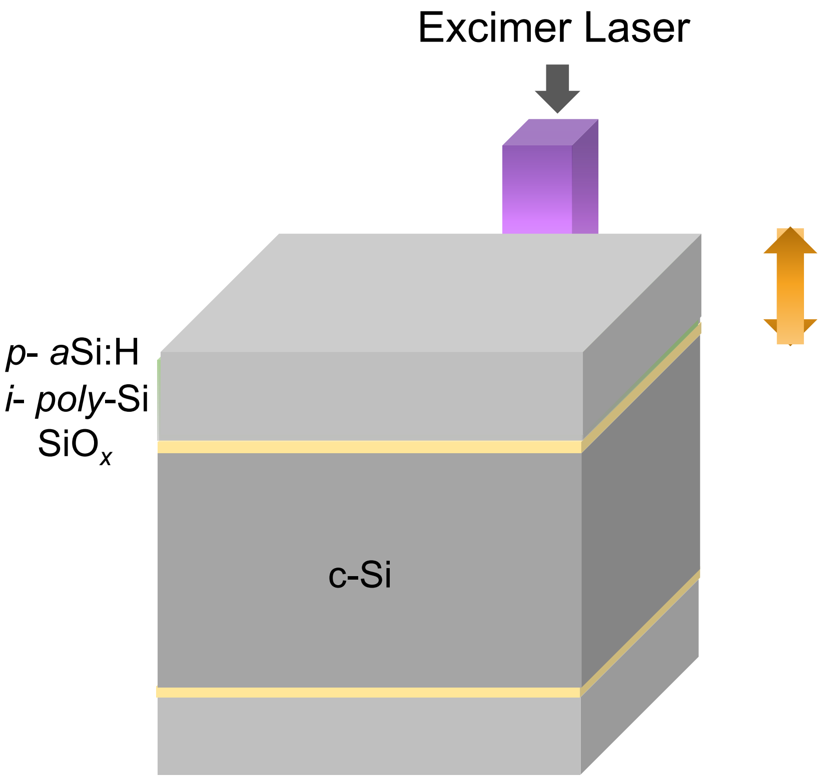
Textured *poly*-Si/SiO$_x$ passivating contacts
- *n*-type (P-doped): iV_{oc} ~730 mV (J_0 <5 fA/cm^2)
- *p*-type (B-doped): iV_{oc} ~700 mV (J_0 ~ 20 fA/cm^2)

Poly-Si: Ga/SiO$_x$ passivating contacts

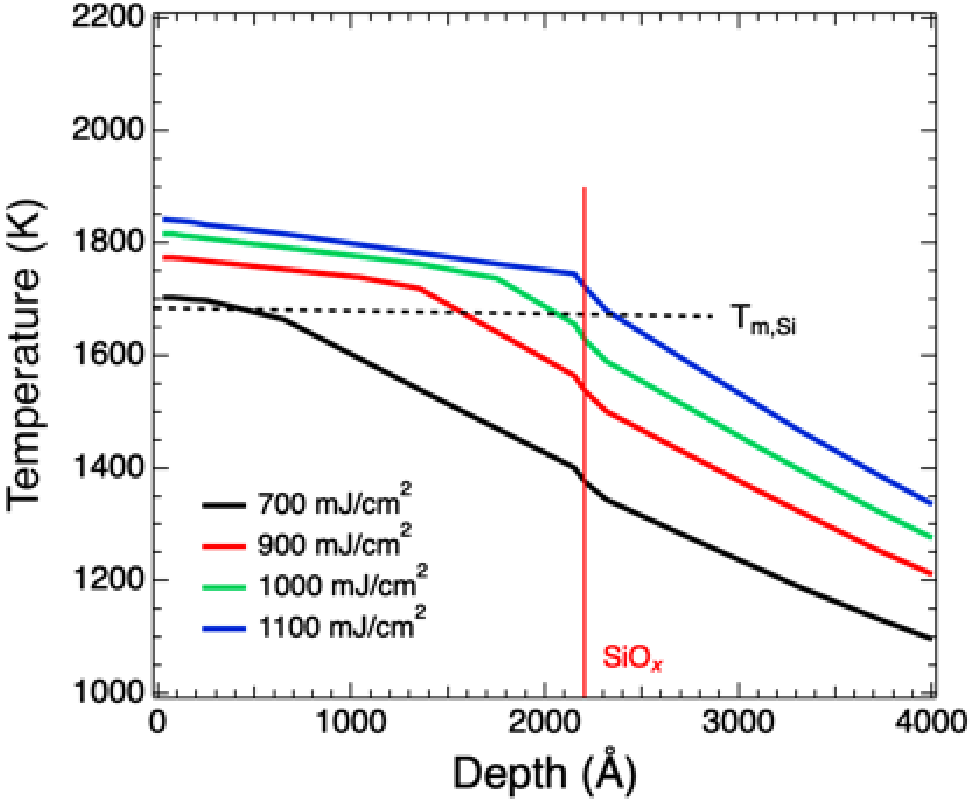
- Ga advantages:
  - high diffusion coefficient in SiO$_x$ and high segregation coefficient (k= Si:SiO$_x$)
- High iV_{oc} > 730 mV was shown on Ga doped *poly*-Si/SiO$_x$/*n*-Cz structure, but had high contact resistivity

D. L. Young *et al.*, *IEEE Journal of Photovoltaics,* vol. 7, no. 6, pp. 1640-1645, 2017

Process of Pulsed Laser Melting (PLM)

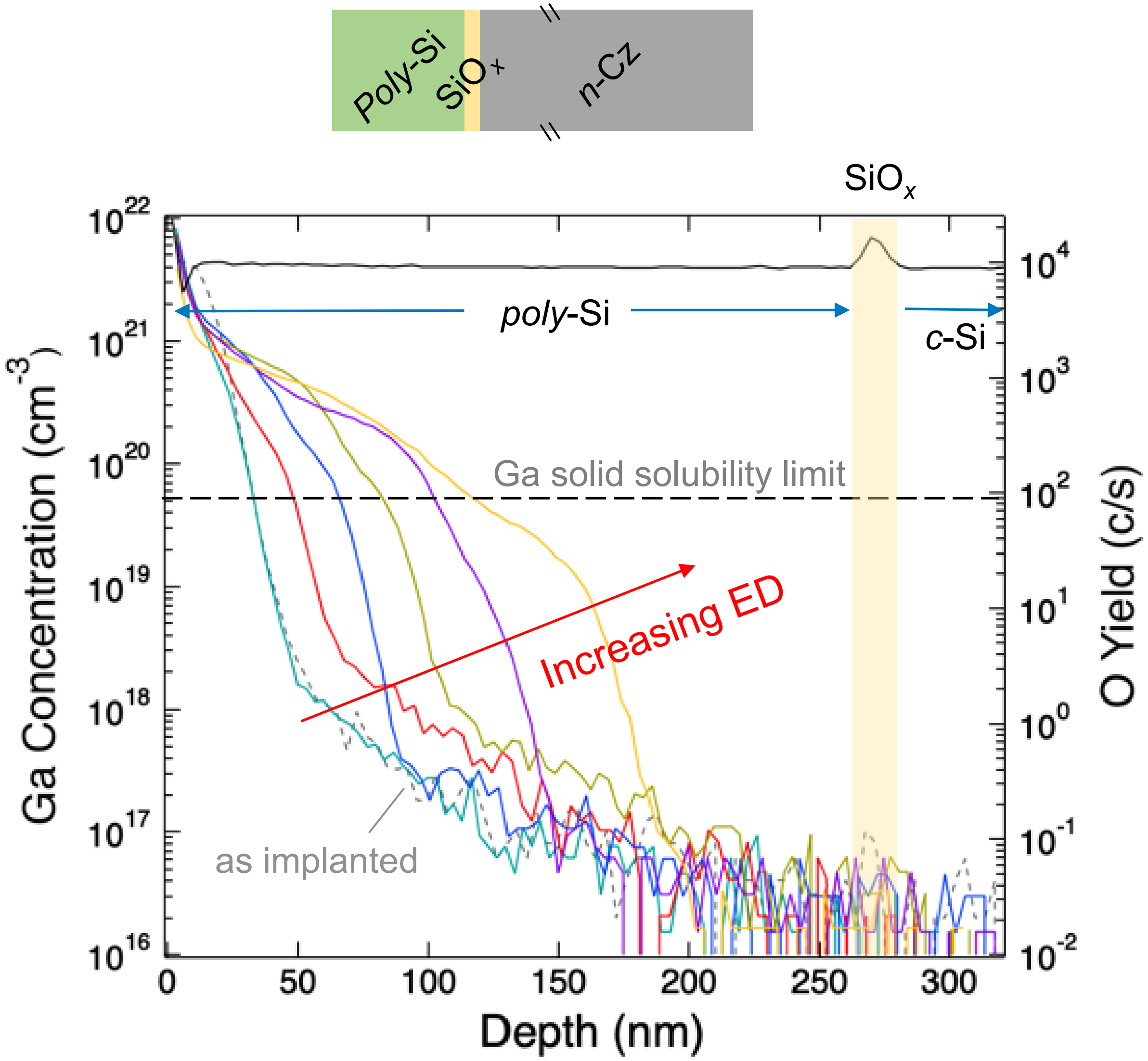


Simulated Maximum Melt Depth Plot



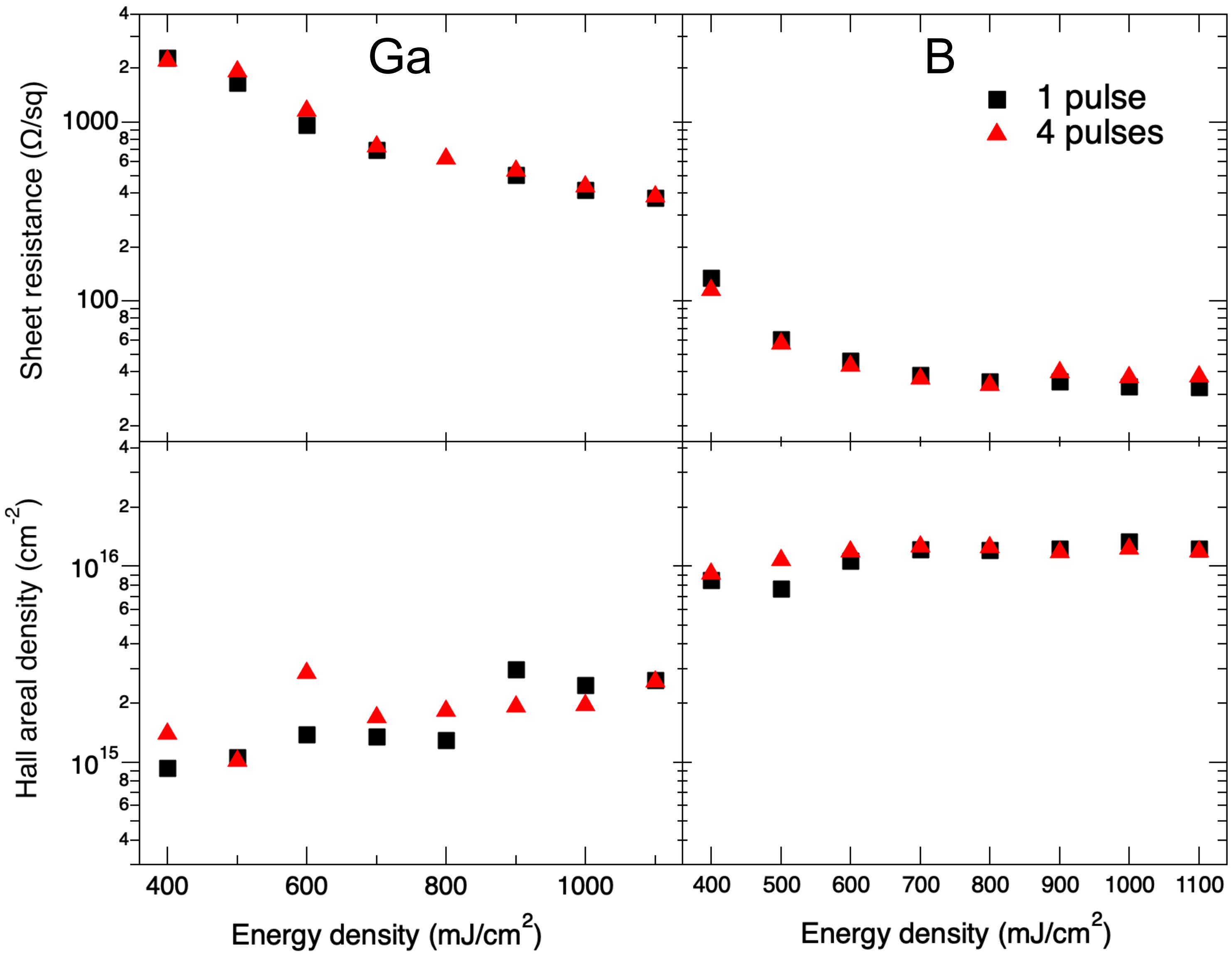
- KrF excimer laser with λ=248 nm, 22 ns was used to achieve non-equilibrium (hyper) doping
- Higher laser energy density (ED) resulted in deeper dopant penetration within *poly*-Si

Experimental Results: Dopant Distribution Profile of Ga



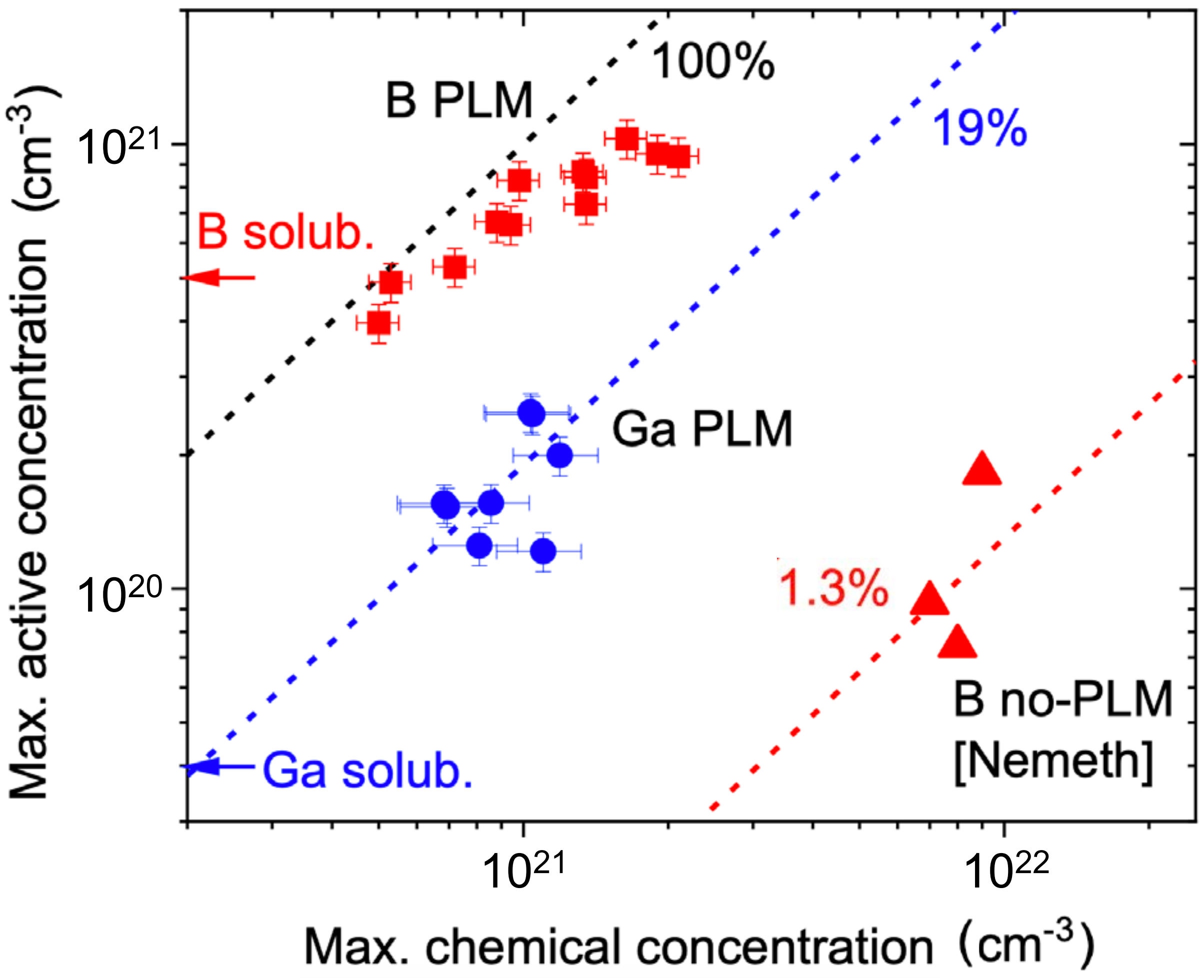
- Increase in energy density (ED) resulted in a deeper dopant profile inside *poly*-Si
- Pulsed laser melting (PLM) can easily tune the dopant diffusion profiles
- SIMS reveals high Ga doping concentration above the solid solubility limit in Si

Electrical Measurement on Laser Annealed Samples



- Van der Pauw (VdP) - Hall measurements show more in-diffusion of dopants with increasing ED
- High hole areal density of $7-13 \times 10^{15}$ cm^{-2} reached for B; $0.9 - 3 \times 10^{15}$ cm^{-2} for Ga

Active Doping Concentration Analysis

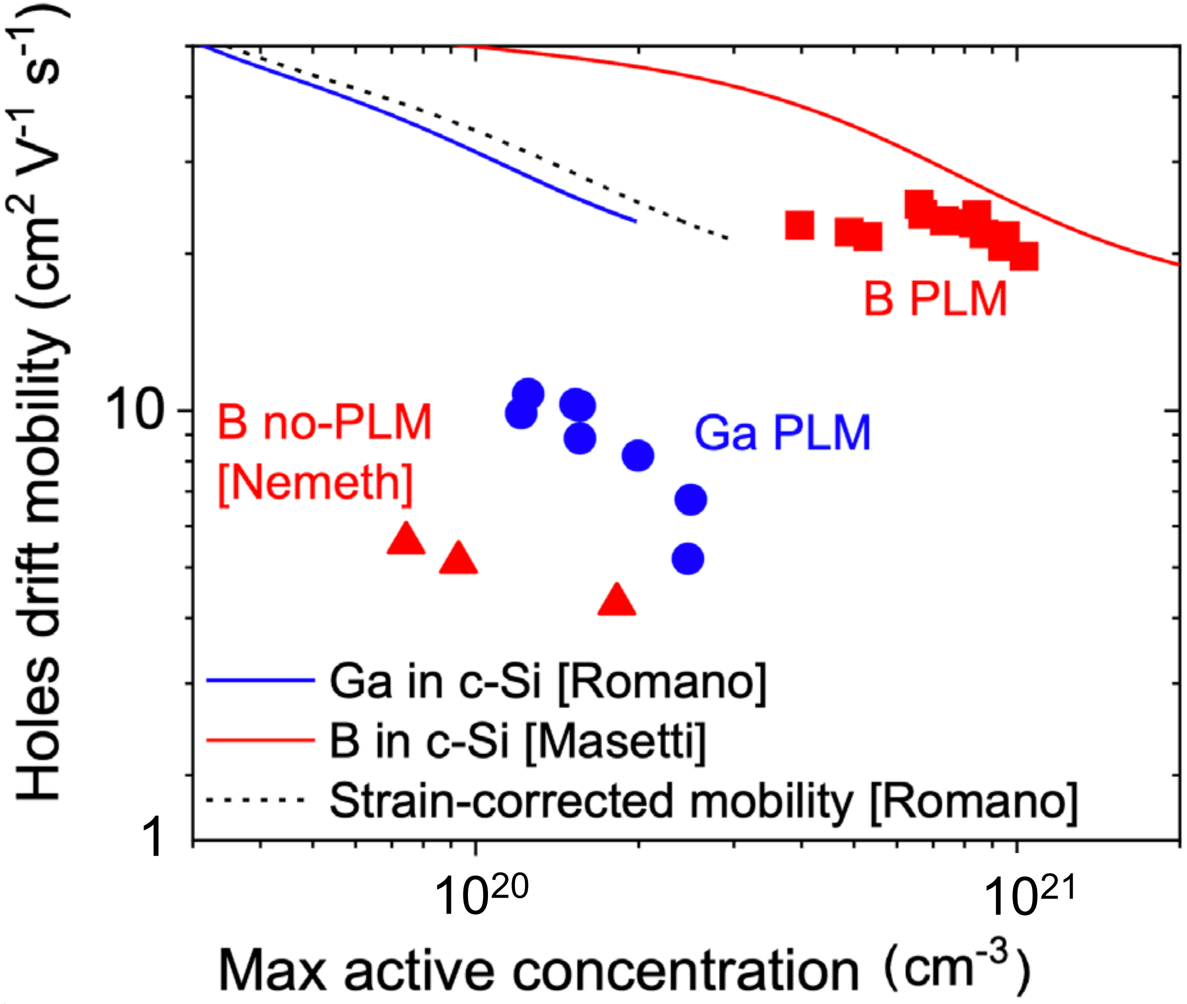


- Both Ga and B achieved higher active doping concentration than their solid solubility limits in Si after pulsed laser anneal (PLM)

- Conventional furnace anneal has much lower activation compared to PLM

- B doped PLM sample reached ~100% dopant activation; Ga doped sample has lower activation, but is still six times higher than its solubility limit in Si

Hole Drift Mobility Analysis



- Hole drift mobilities calculated as $\mu_D = 1/R_s\, e\, p_H r_H$

- B PLM data is between the values reported in literature for B in *c*-Si, and the strain-corrected curve[1-2]

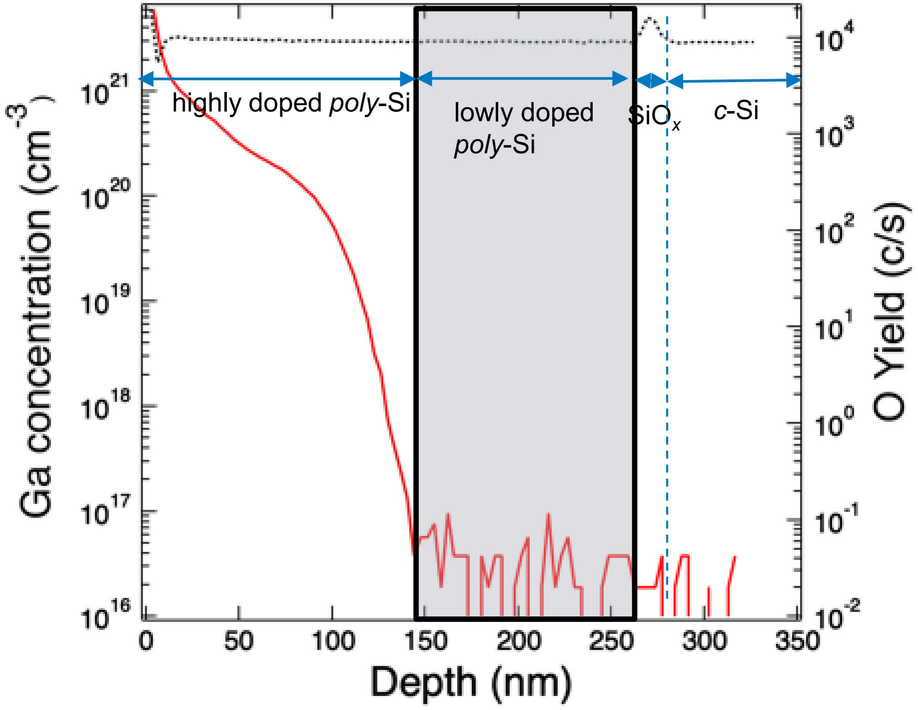
[1]. G. Masetti *et al.*, IEEE Transactions on Electron Devices, vol. 30, no. 7, pp. 764-769, 1983

[2]. L. Romano *et al.*, Physical review letters, vol. 97, p. 136605, 2006

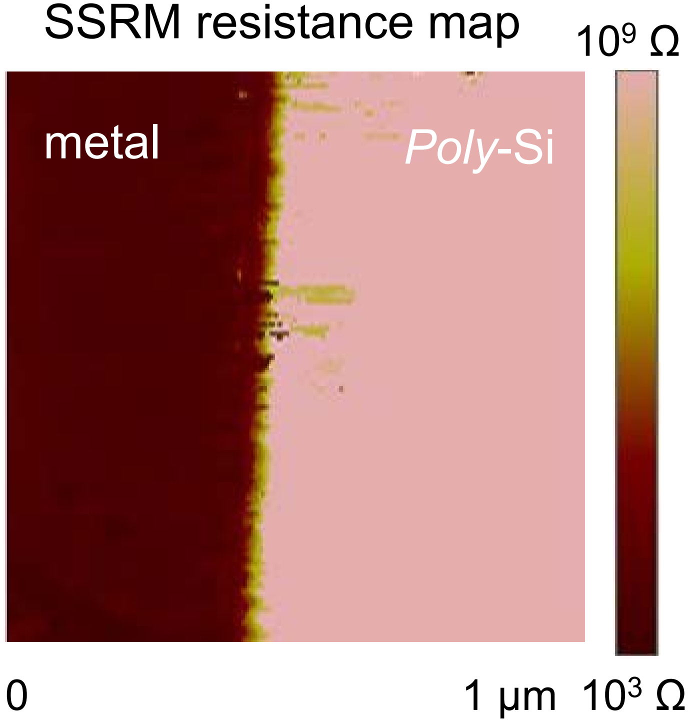
- Ga PLM data is lower than *p*-type mobility in *c*-Si (lower activated fraction of Ga, and additional scattering channels…)

- Mobility analysis shows PLM values are ~3× higher than conventionally furnace annealed PECVD *poly*-Si values

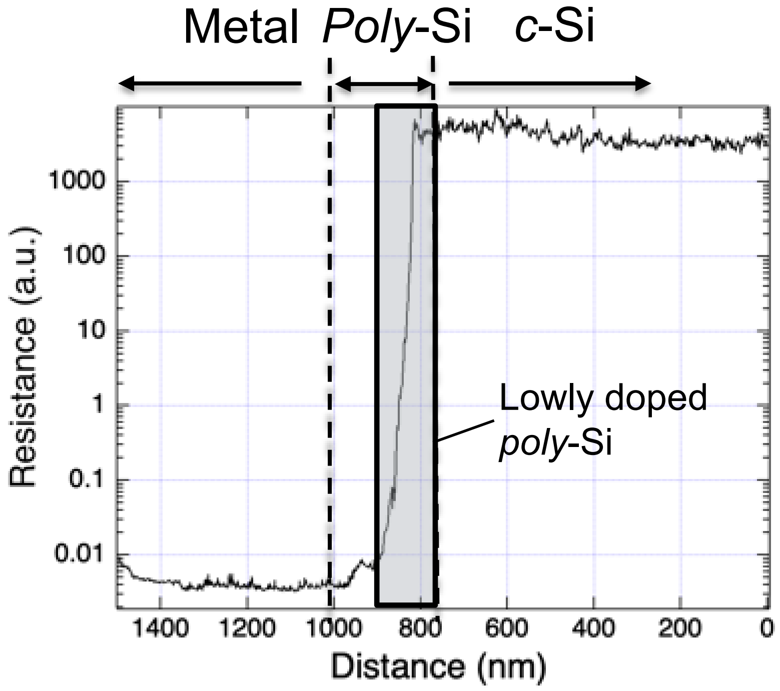
Investigation on Lowly Doped *Poly*-Si But Conducting Contacts

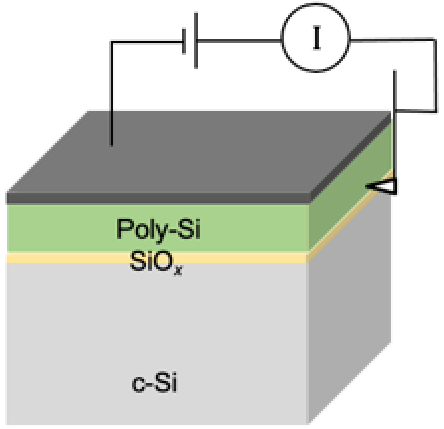


SIMS profile of best laser condition



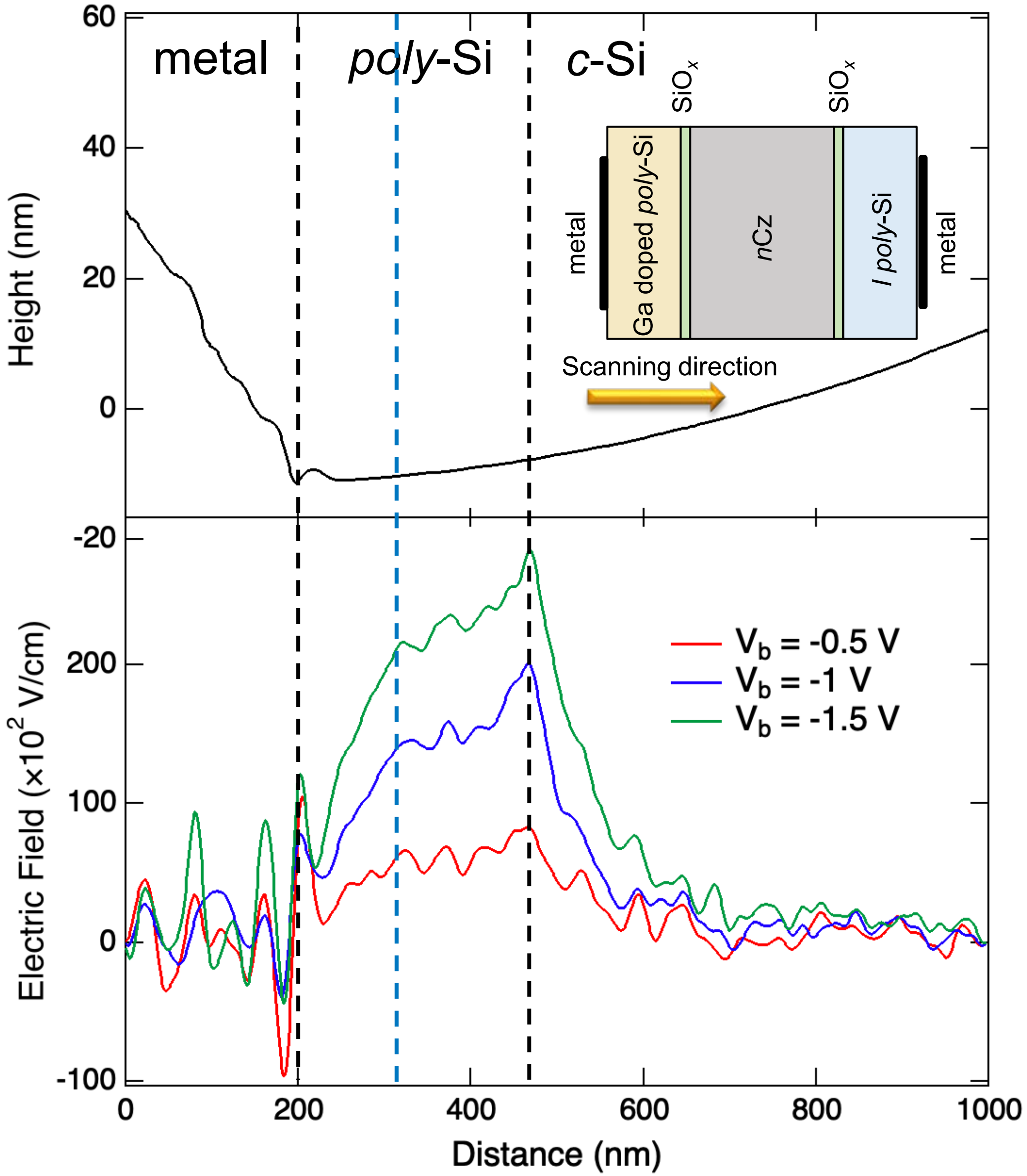
SSRM resistance map





- Metal-*poly*-Si-*c*-Si contact resistivity ~ **35.5±2.4 mΩ·cm²** using diode method
- Scanning spreading resistance microscopy (SSRM) reveals 100 – 150 nm low resistivity (highly-doped) region in *poly*-Si

Kelvin Probe Force Microscopy (KPFM) Investigation

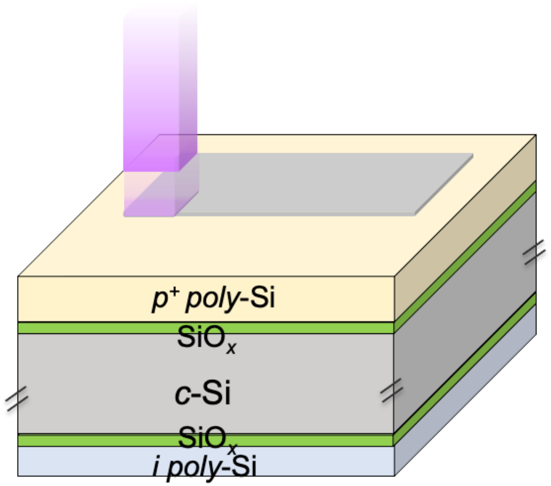


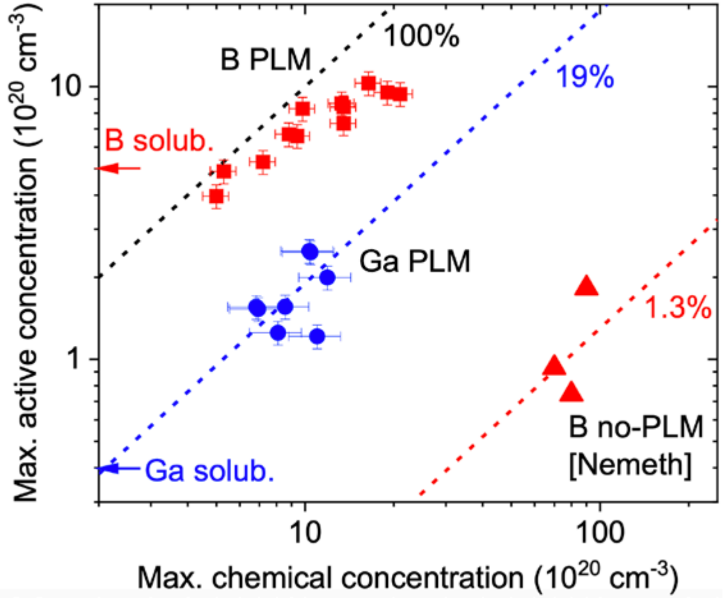
- KPFM measurement to map the electric field across the *p*-*n* junction
- AFM height profile is used to identify between the metal and *poly*-Si region
- Electric field profile shows the transition from *p*- to *n*-type and the shape of curves indicate the carrier concentration profile around the *p*-*n* junction
- Most of the depletion region lies within *poly*-Si

We speculate that the low contact resistivity is due to the large drift and diffusion current through the diode

Summary and Conclusions

- Hyper-doping of Ga and B in *poly*-Si via pulsed laser melting
- Detailed active dopant concentration and mobility analysis reveal that B is nearly 100% activated, with a maximum concentration ~10^{21} cm^{-3}; Ga is ~19% activated with an active dopant concentration of ~2×10^{20} cm^{-3}
- Low contact resistivity of 35.5 mΩ·cm^2, with minimal contact resistivity at the metal-to-semiconductor interface
- Our *poly*-Si:Ga/SiO_x/*n*Cz passivating contact benefit from drift and diffusion current through *p*-*n* junction for low contact resistivity
- Pulsed laser melting can provide high activation and can be extended to other applications in semiconductor industry





Acknowledgements

NREL Silicon Photovoltaic Team

- Dr. Paul Stradins
- Dr. David L. Young
- Bill Nemeth
- San Theingi
- Vinnie LaSalvia
- Matthew Page
- Markus Kaupa
- Dr. Chun-Sheng Jiang
- Dr. Harvey Guthrey
- Dr. Steven Harvey

Dr. Sumit Agarwal’s Research Group:

- Abigail R. Meyer
- Matthew B. Hartenstein
- Caroline Lima Salles
- Xue Wang
- Andrew Kaye
- Dirk Steyn
- Chirag Mule
- Mahesh Patil

University of Padova:

- Matteo De Tullio
- Dr. Francesco Sgarbossa
- Dr. Enrico Napolitani

Thanks for your attention! Questions?

U.S. Department of Energy

Funding provided by U.S. DOE under Contract No. DE-AC36-08GO28308 and by U.S. DOE Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office under Agreement Number 3435. Additionally, this work was partially supported by the University of Padova (grant UNIPD-ISR 2017 ‘SENSITISE’).

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NREL/PR-5900-82474

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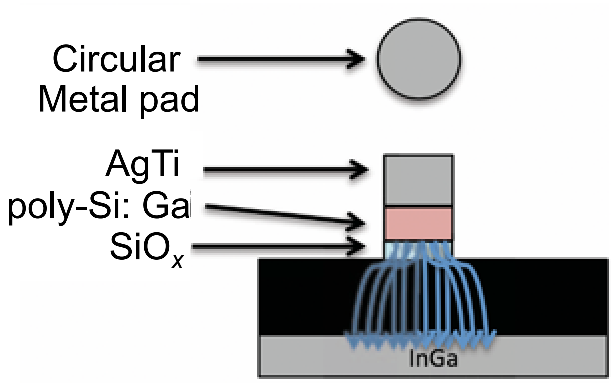
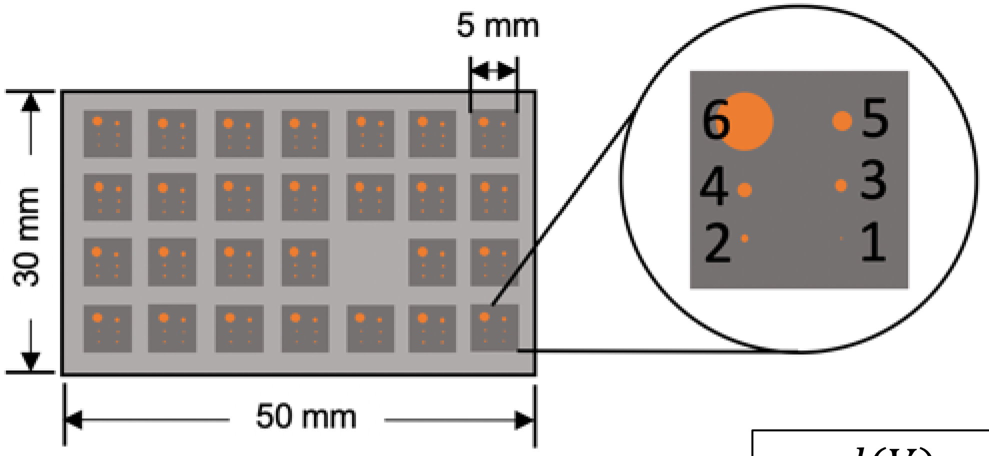
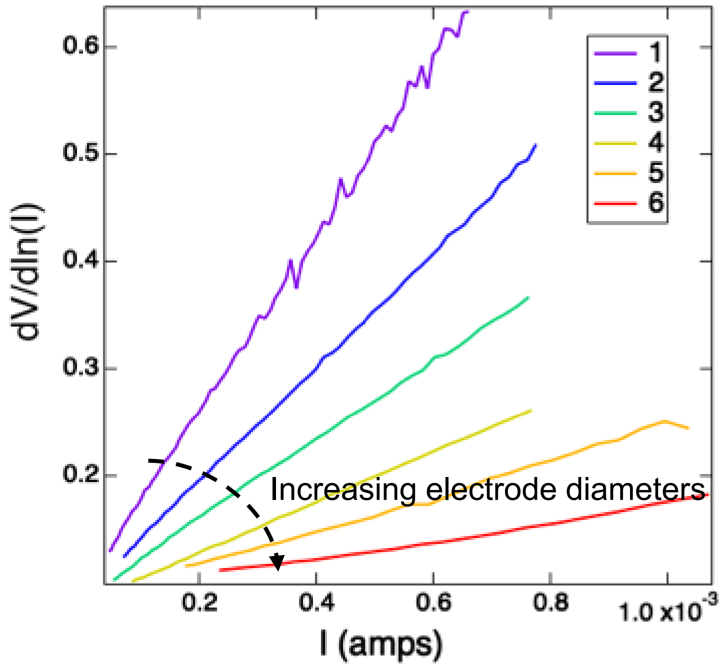
Diode Contact Resistivity Measurement on *Poly*-Si: Ga/SiO$_x$ Samples

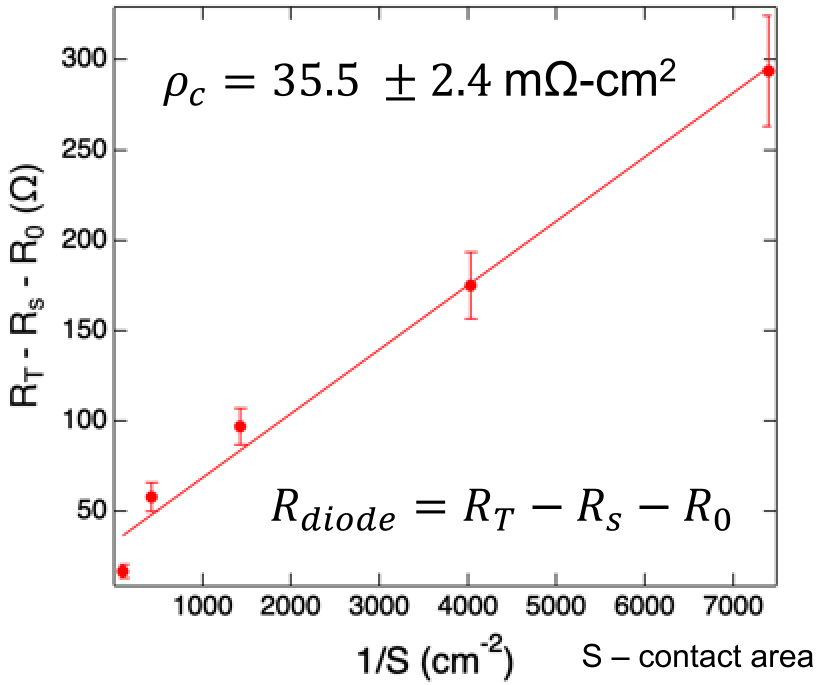
Reactive ion etching in SF$_6$





$$\frac{d(V)}{d(lnI)} = R_T I + \frac{nkT}{q}$$



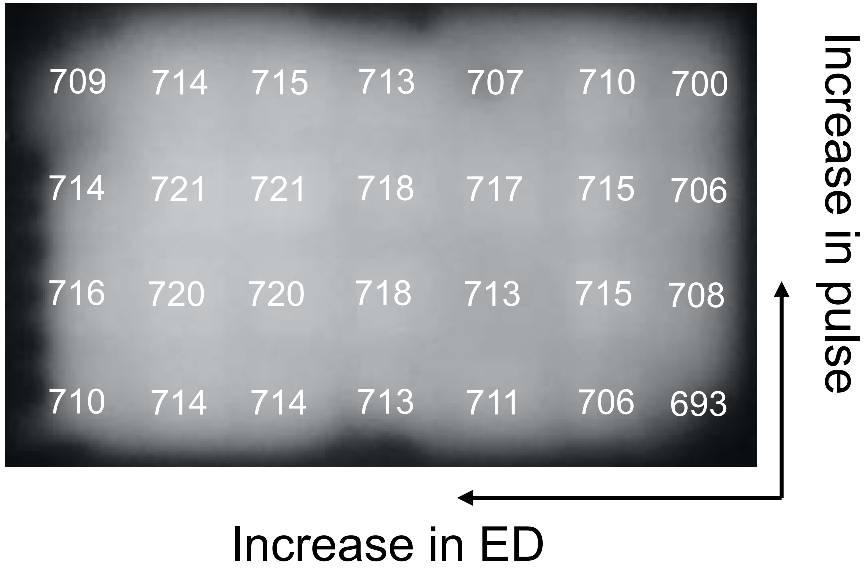


- Contact resistivity of **35.5±2.4 mΩ·cm²** achieved
- Metal-to-poly-Si contact resistivity **0.9 mΩ·cm²**

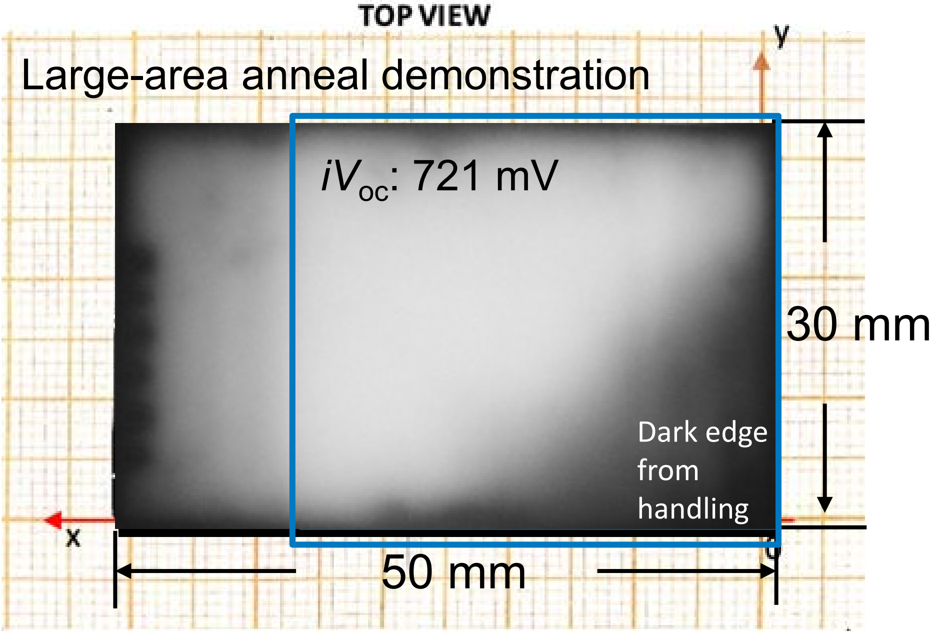
W. Wang *et al.*, *IEEE Journal of Photovoltaics*, vol. 9, no. 4, pp. 1113-1120, 2019

Quantifying Passivation Quality with Photoluminescence

iV_{oc} values (mV)



709	714	715	713	707	710	700
714	721	721	718	717	715	706
716	720	720	718	713	715	708
710	714	714	713	711	706	693



Large-area anneal demonstration

iV_{oc}: 721 mV

Dark edge from handling

- PL images were taken with various exposure times and PL intensity was compared with a large-area witness for Sinton lifetime measurement
- Highest iV_{oc} of 721 mV was achieved with 900 mJ/cm^2 and 4 pulses (J_0 of 12.8 fA/cm^2)

Figure 8

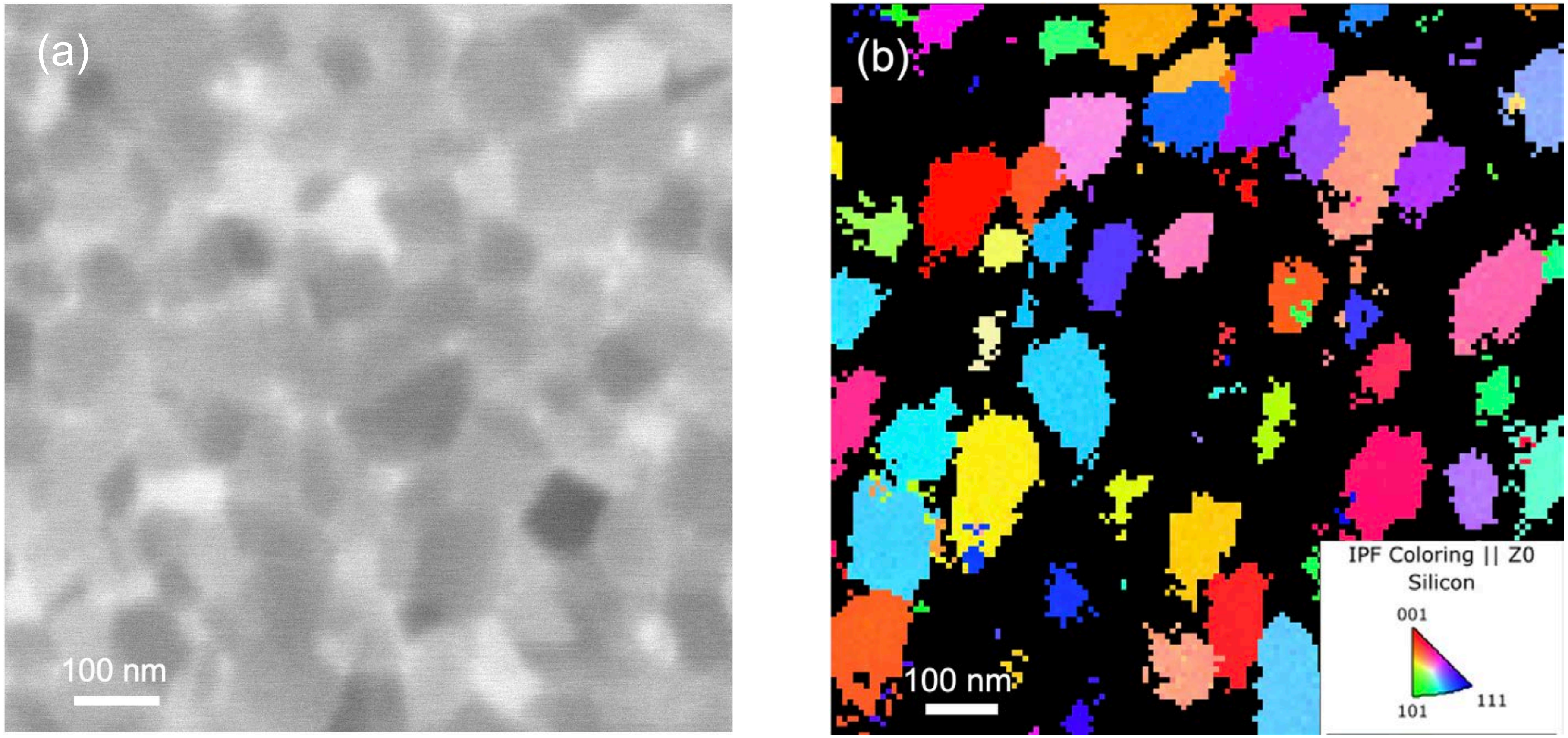
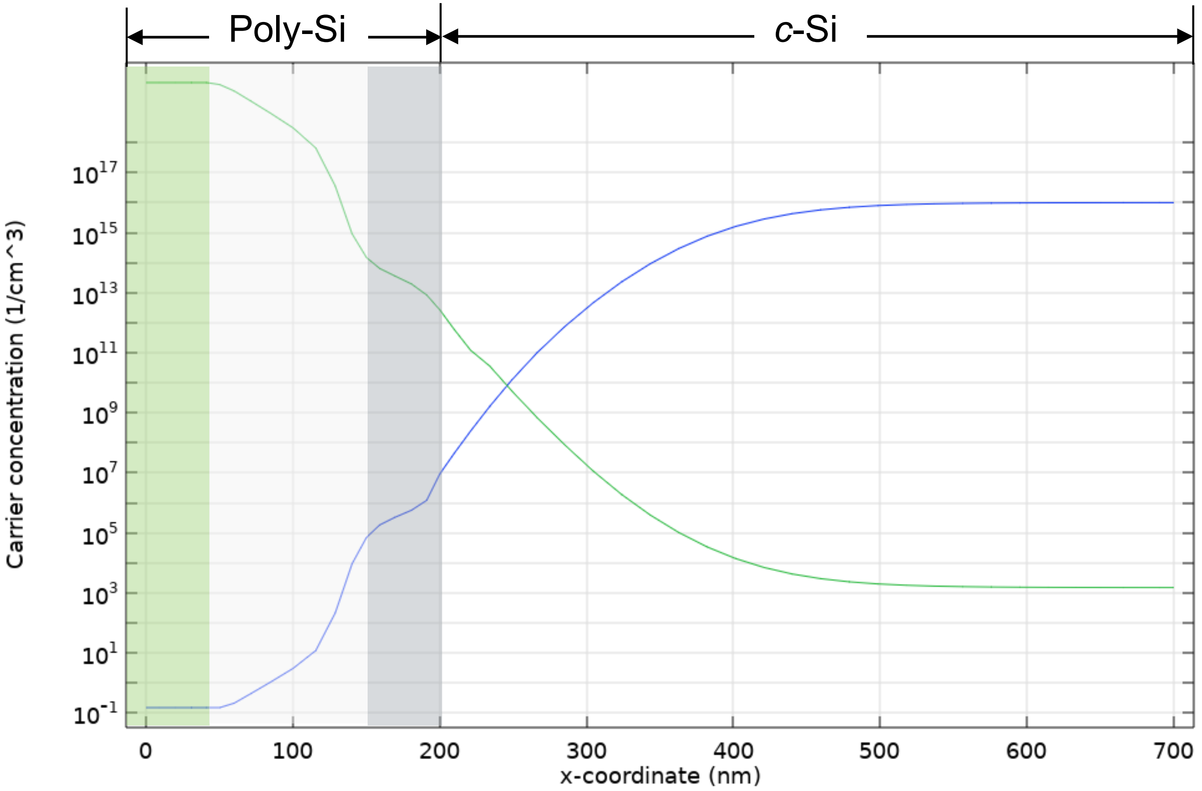


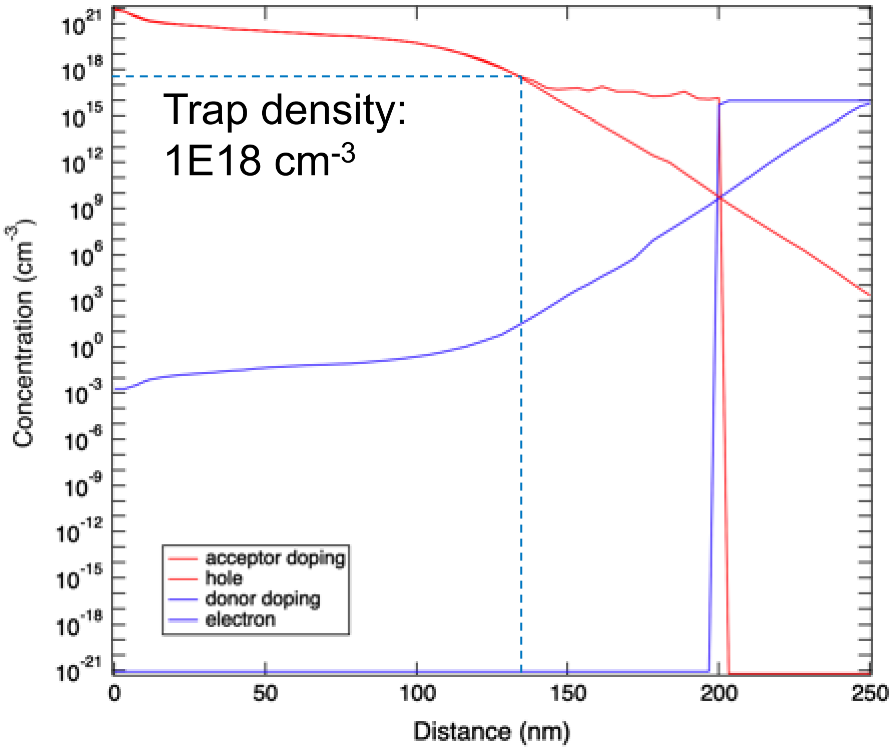
Figure 8. (a) Plan-view SEM image **(b)** EBSD inverse pole figure (IPF) map of the Ga-laser processed sample. The different colors represent different *c*-Si orientations with the IPF coloring scale at the lower bottom right. Black regions were not able to be indexed.

Simulation with 10^{18} cm^{-3} traps

Given 100 -150 nm lowly doped region, trap density should be pretty high (~10^18 cm-3)



- 50 nm heavily doped poly-Si (10^{20} cm^{-3})
- 100 nm exponential decrease to 10^{17} cm^{-3}
- 50 nm lowly doped poly-Si (10^{17} cm^{-3})



Simulated using SIMS profile

- Regarding why The Boron peak is present and not one for Gallium. There are two explanations I think
- There is a physical reason why Boron would pile up at that interface more than Gallium. An increase in signal at the oxide is difficult to interpret as it could be do the SIMS artifact of oxide enhancement, but it could also be compounded with a real increase at the interface, it is tough to say 100% one way or the other.
- It’s also possible there is a similar increase in the gallium profiles, just that the data is below the detection limit for the profiles so it just looks like background signal with no peak.