Australian National University

# Understanding Laser Doping: Investigations using 532nm Nanosecond Lasers

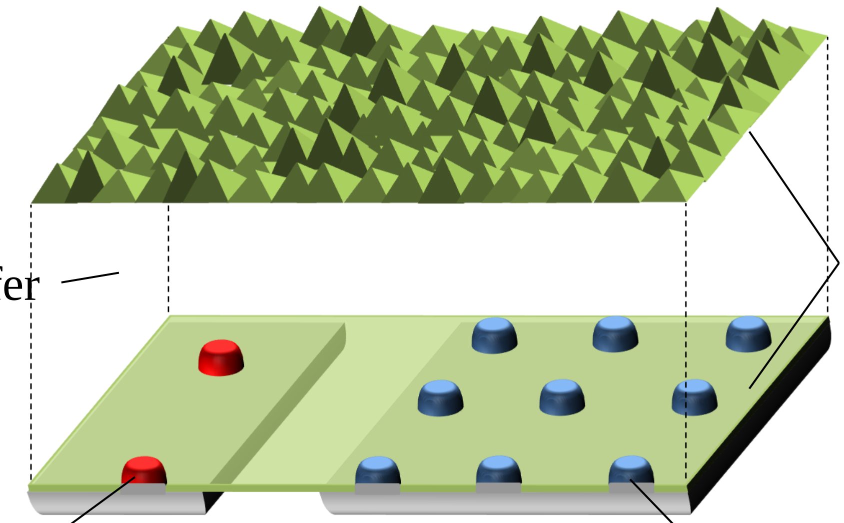
Lujia Xu, Klaus Weber, Andreas Fell, Evan Franklin, Ziv Hameiri

# Outline

- Motivation
- Dopant measurement by Scanning Electron Microscopy
- Characterisation of dielectric window edge regions
- Impact of laser parameters / dielectrics on recombination in laser doped regions

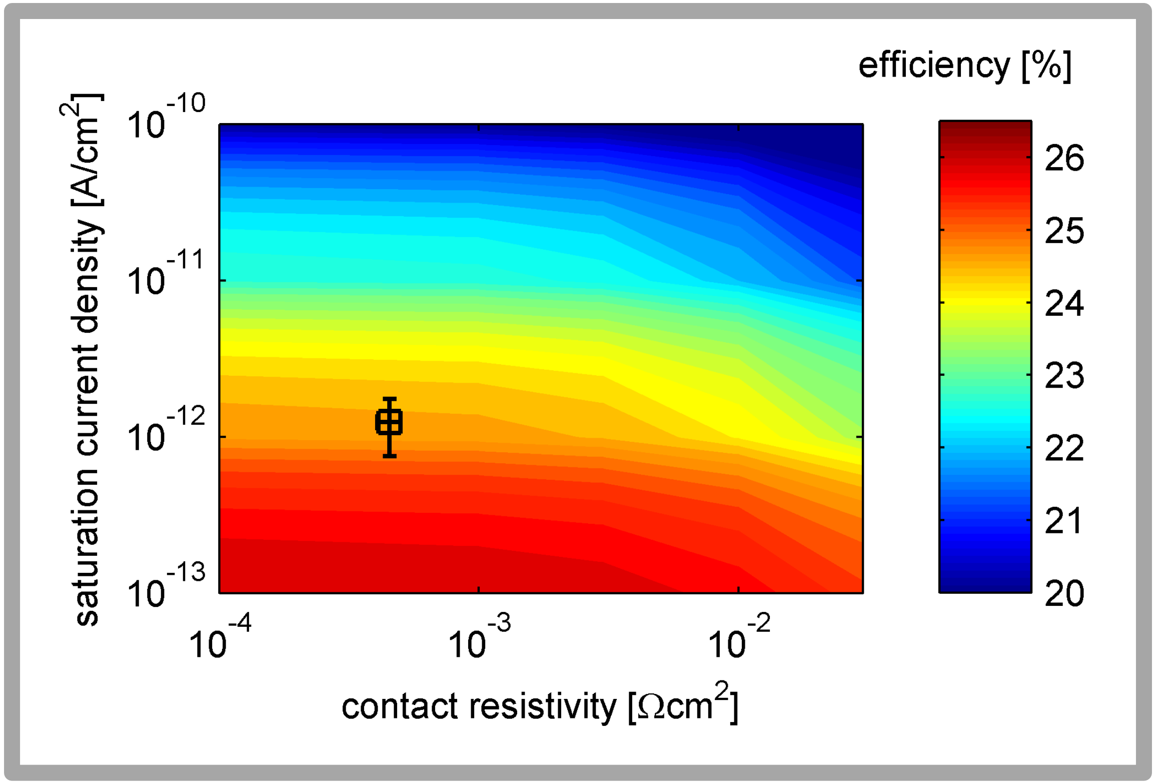
# Motivation

## All laser doped IBC cell concept

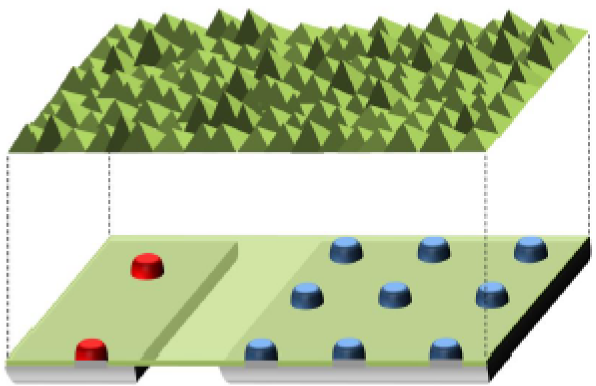


# Motivation

## Simulated efficiency potential (Quokka)

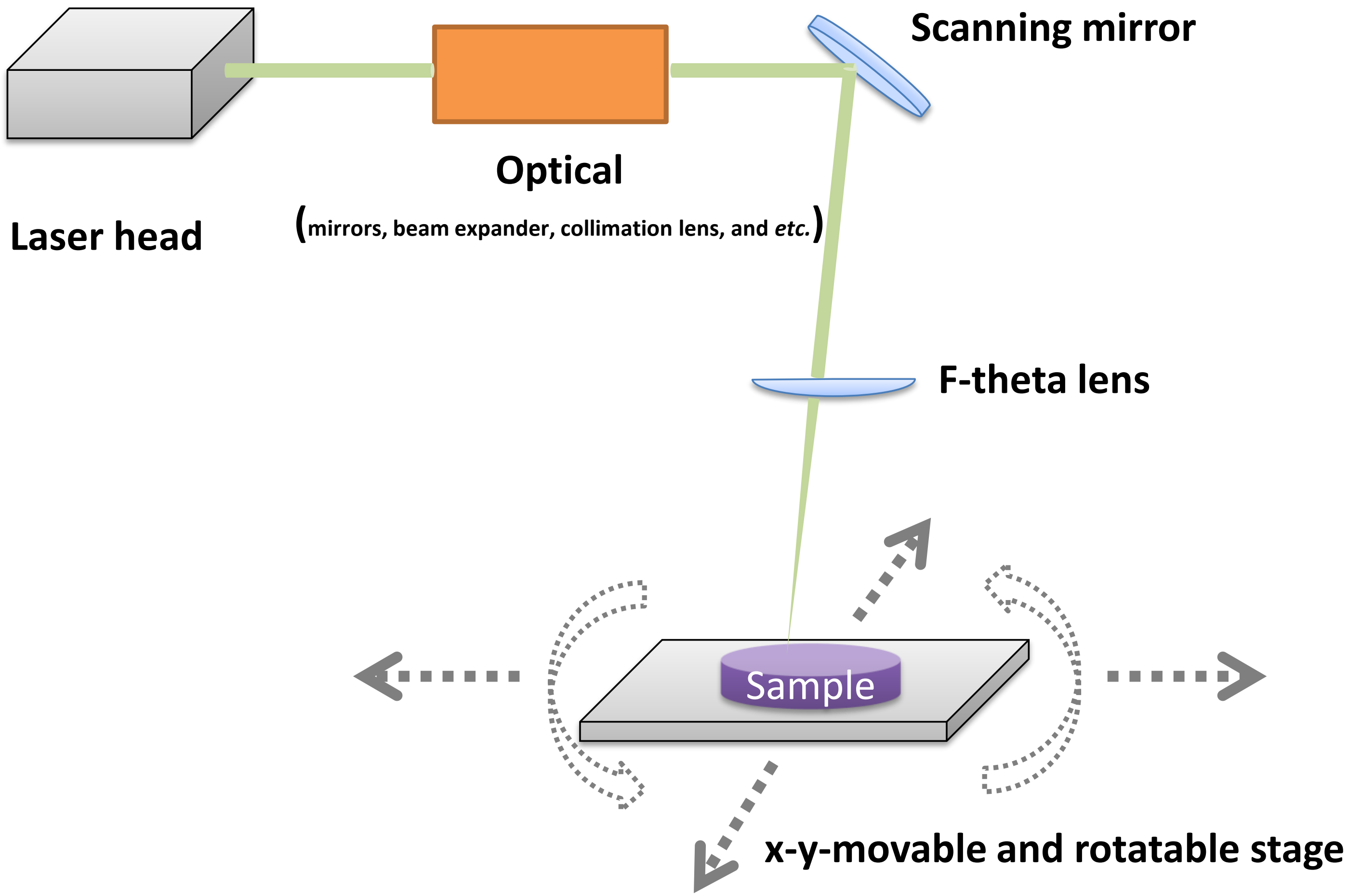


# First all-laser processed cell batch



- rear n-type laser doping (P-SOD)
- rear p-type laser doping (B-SOD)
- front + rear $SiO_2$ / $Si_3N_4$
- front + rear $SiO_2$ / $Si_3N_4$
- front strip + texture
- front passivation + AR + resist
- rear laser contact opening
- HF etch
- Al evaporation + photolit. pattern
- sinter + measure

# Laser processing (532nm DPSS)

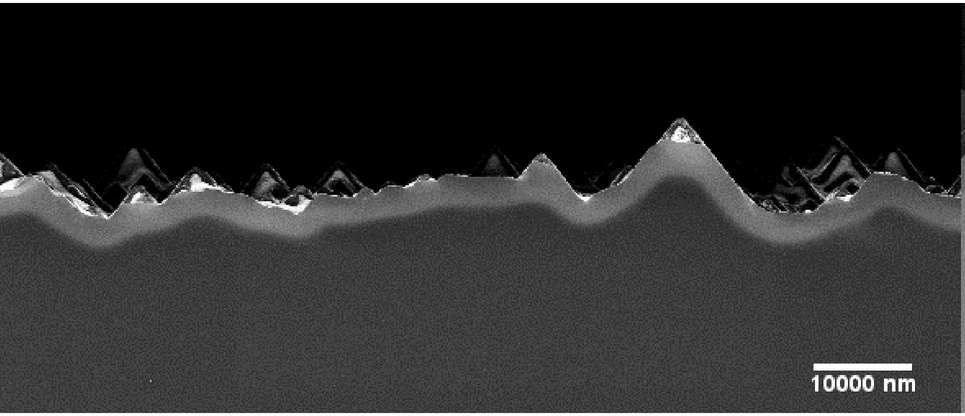


# Laser doping

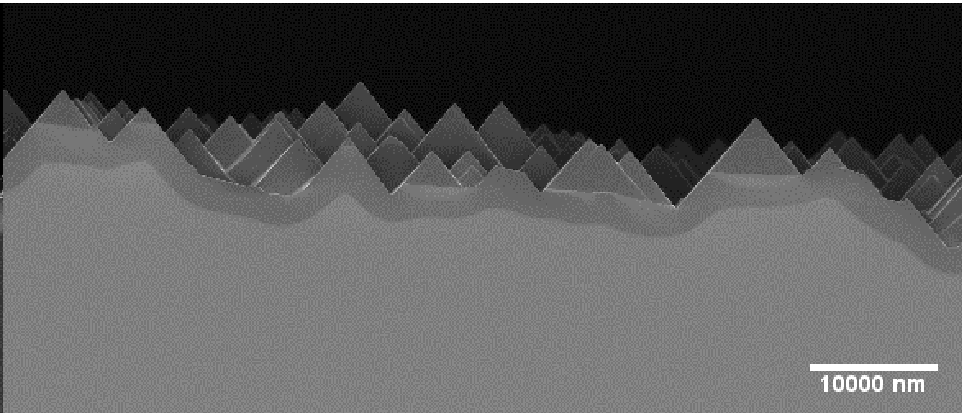
- Small, inhomogeneously doped areas
- Rough surfaces
- How to characterise?

- EBIC / SIMS?
- SEM can be used to image dopant density under certain conditions

**p diffusion / n substrate**

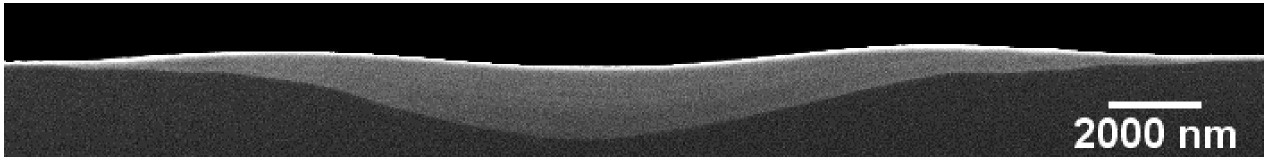



**n diffusion / p substrate**

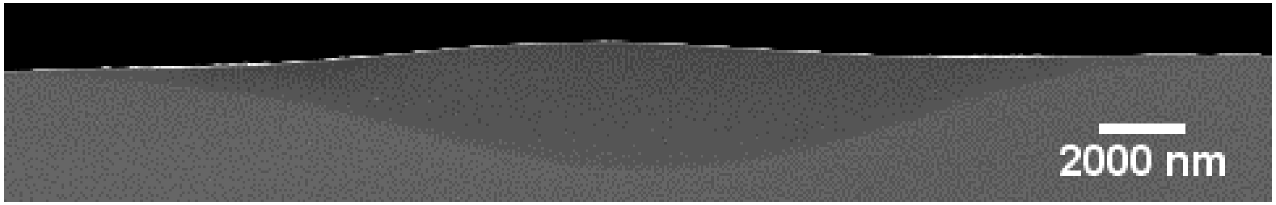


# SEM Doping Contrast – Laser doped regions

**p doping / n substrate**

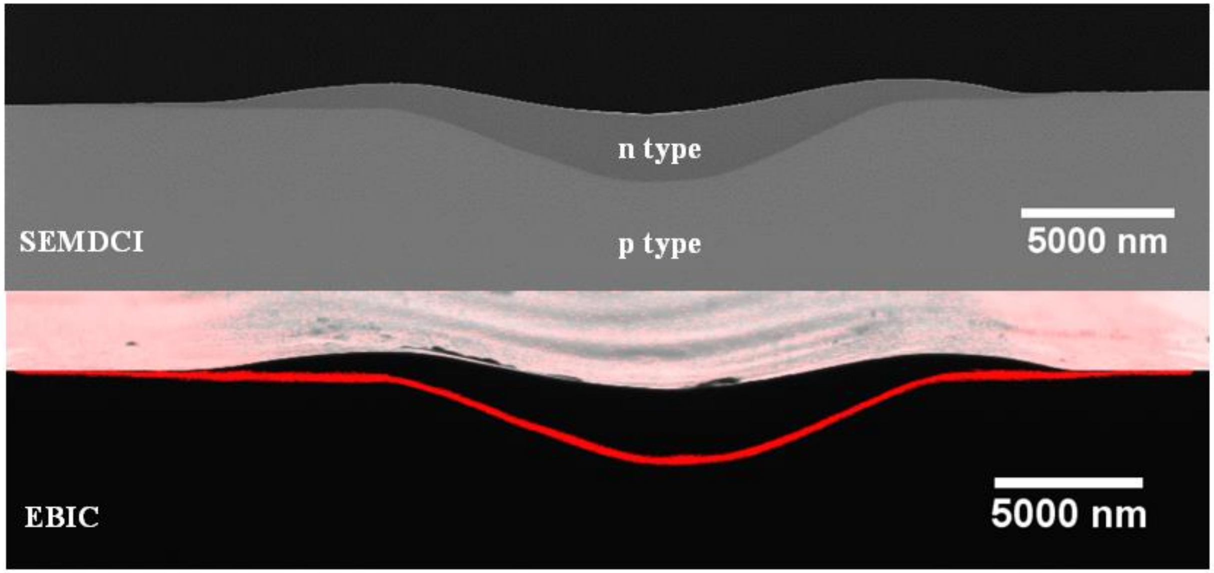



**n doping / p substrate**



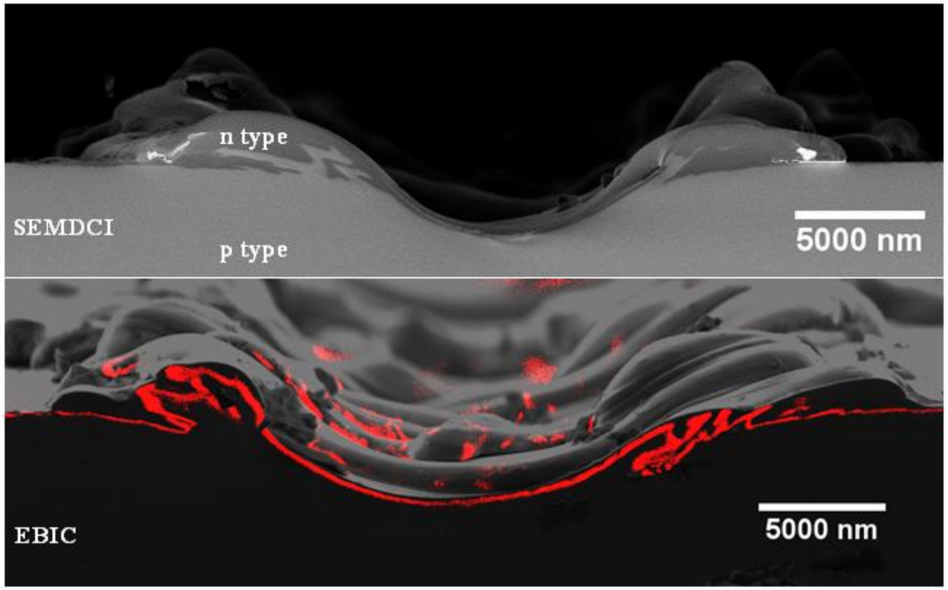

L. Xu, et al., "Secondary electron microscopy dopant contrast imaging (SEMDCI) for laser doping" *IEEE Journal of Photovoltaics*, vol. 3, pp. 762-768, 2013.

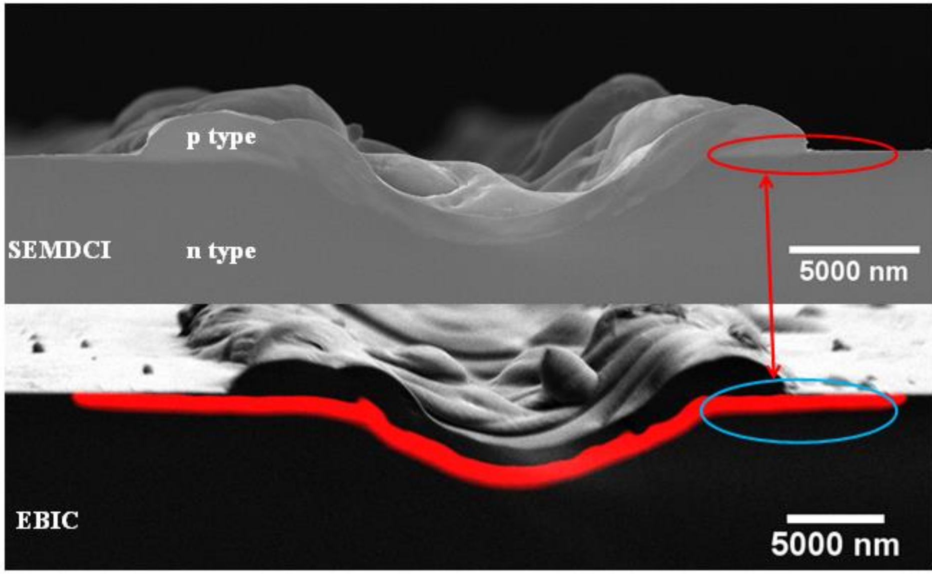
# Comparison – SEM DCI / EBIC



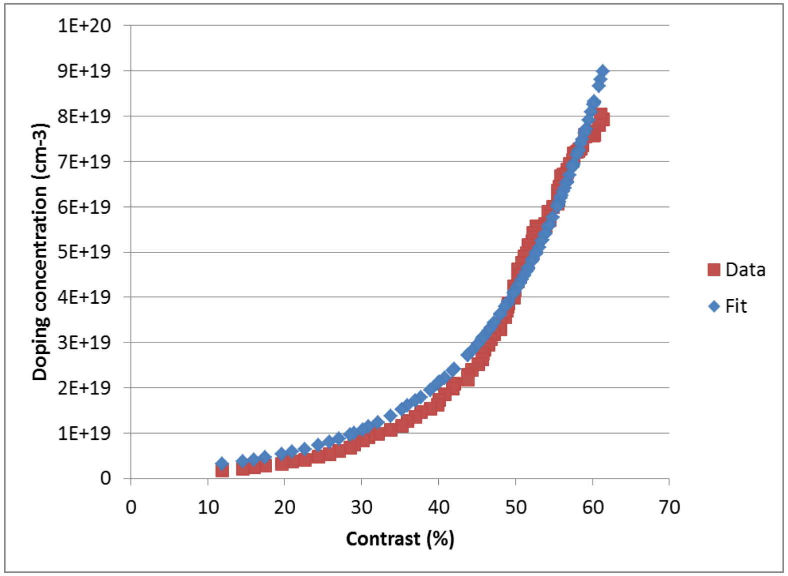

L. Xu, et al, "Comparison between SEMDCI and EBIC for Laser Doping of Crystalline Silicon"
*SiliconPV 2014*, 's-Hertogenbosch, The Netherlands, 2014.

# Comparison – SEM DCI / EBIC

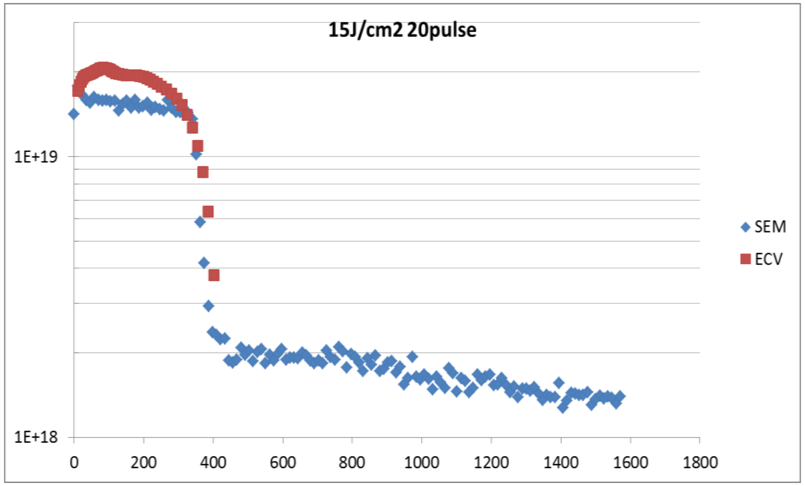


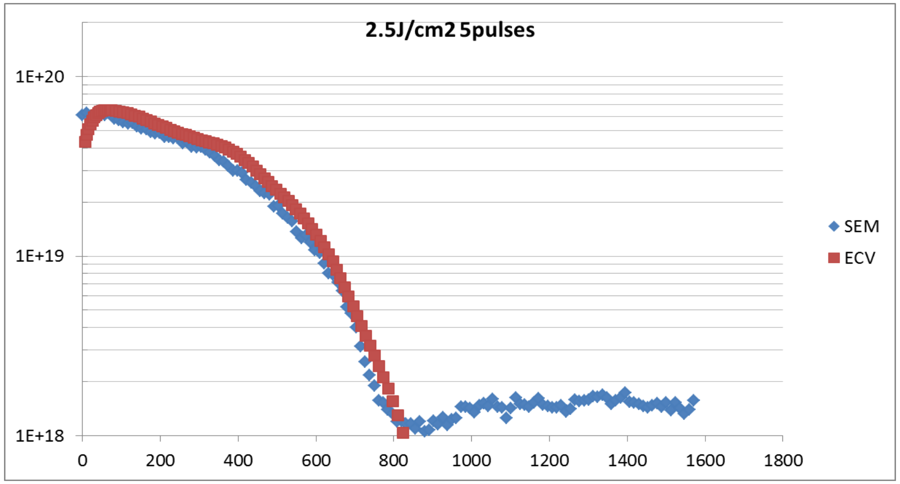



# Can SEM DCI give doping concentration?

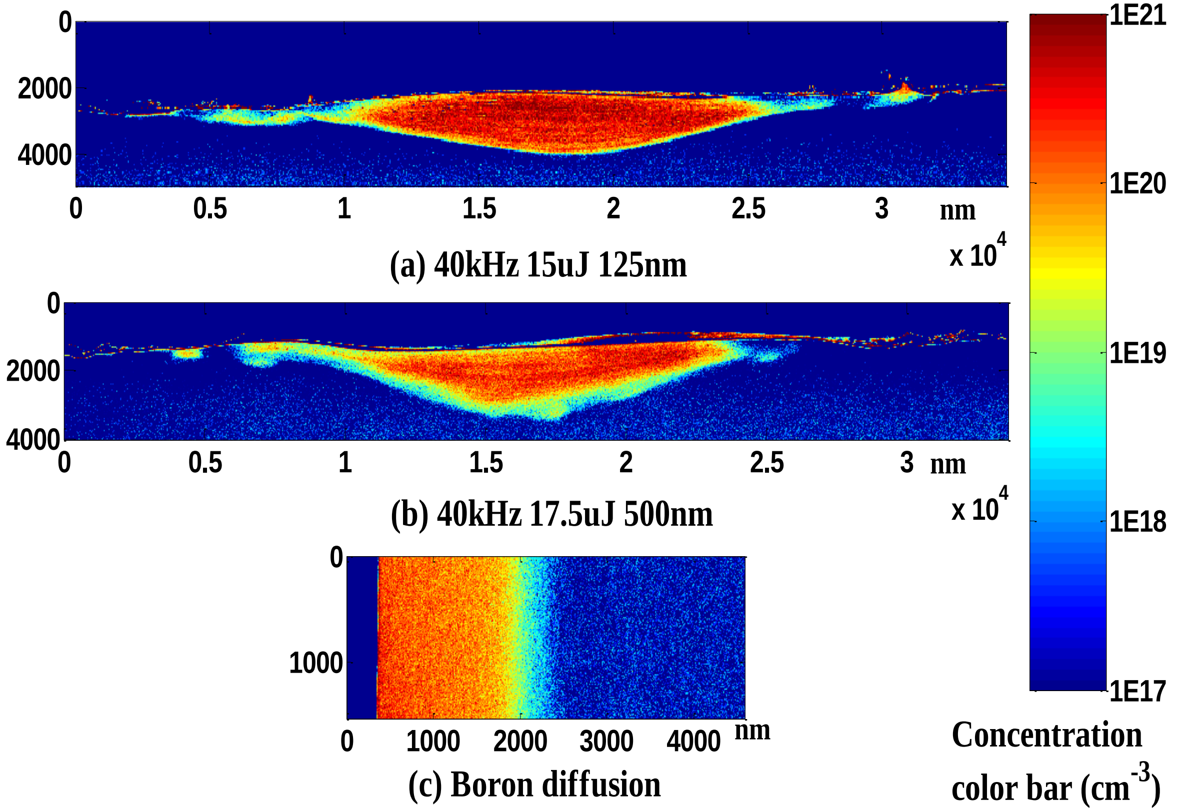



- Establish empirical relationship (diffused samples)
- Apply to laser (excimer) doped samples
- Compare with ECV profiles

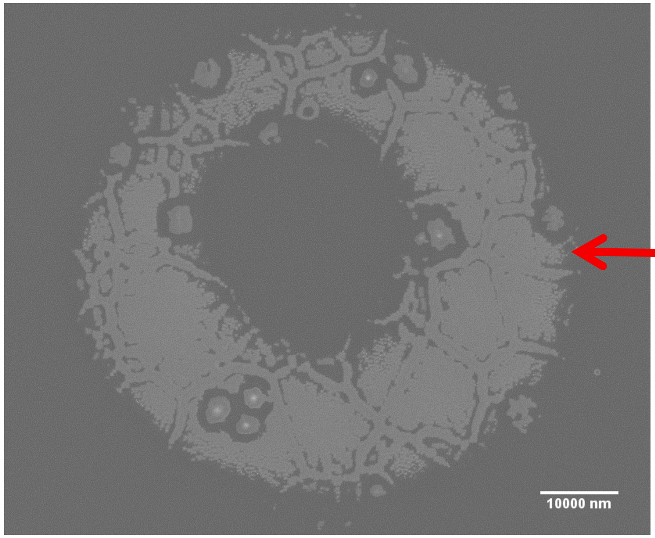


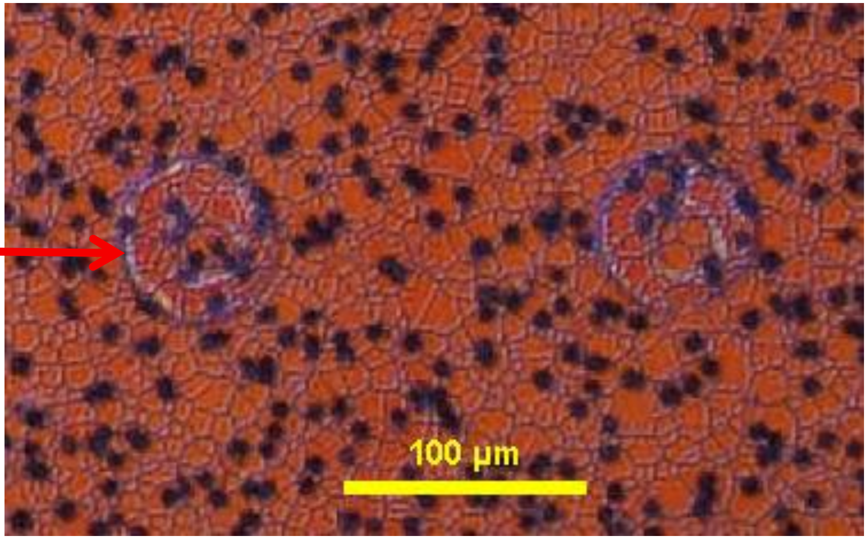
# Laser doping – (active) doping density maps



# SEM DCI – Surface profile characterisation



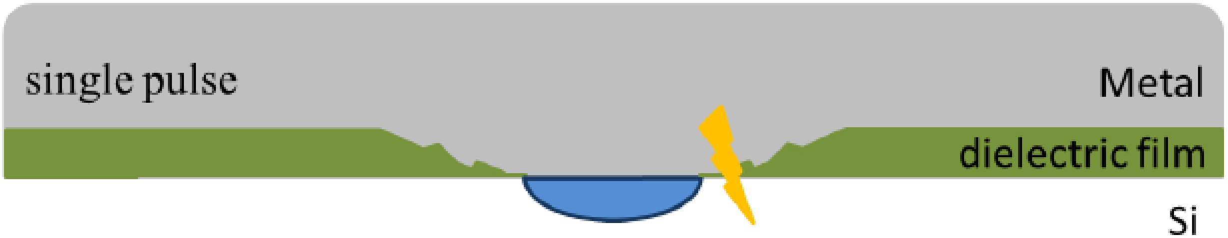

SEM DCI




Optical microscope image

# Application of SEM DCI

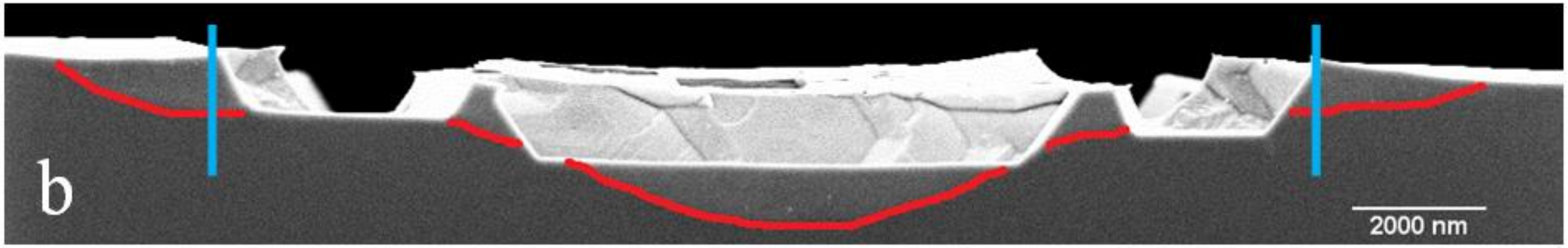
Single step doping process – what happens at the dielectric edges?

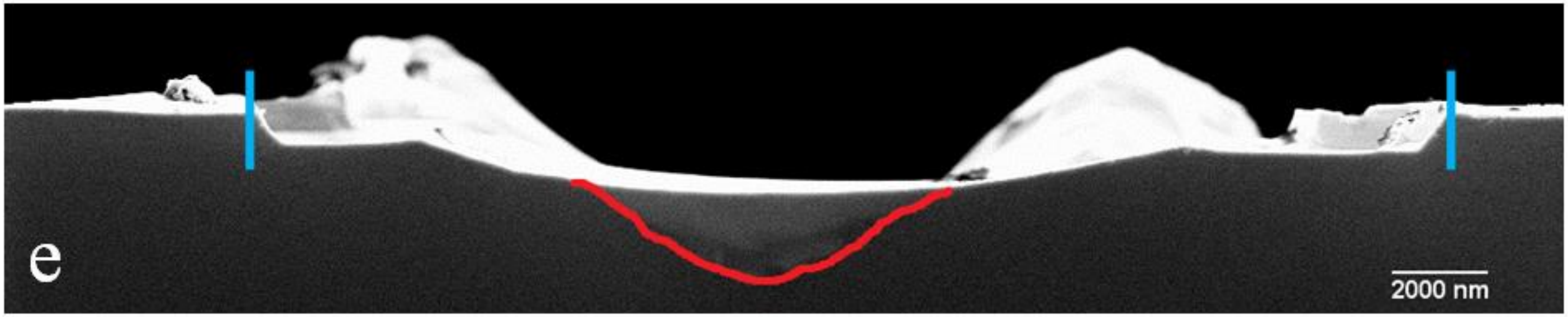



How to check the edge region?

# Application of SEM DCI

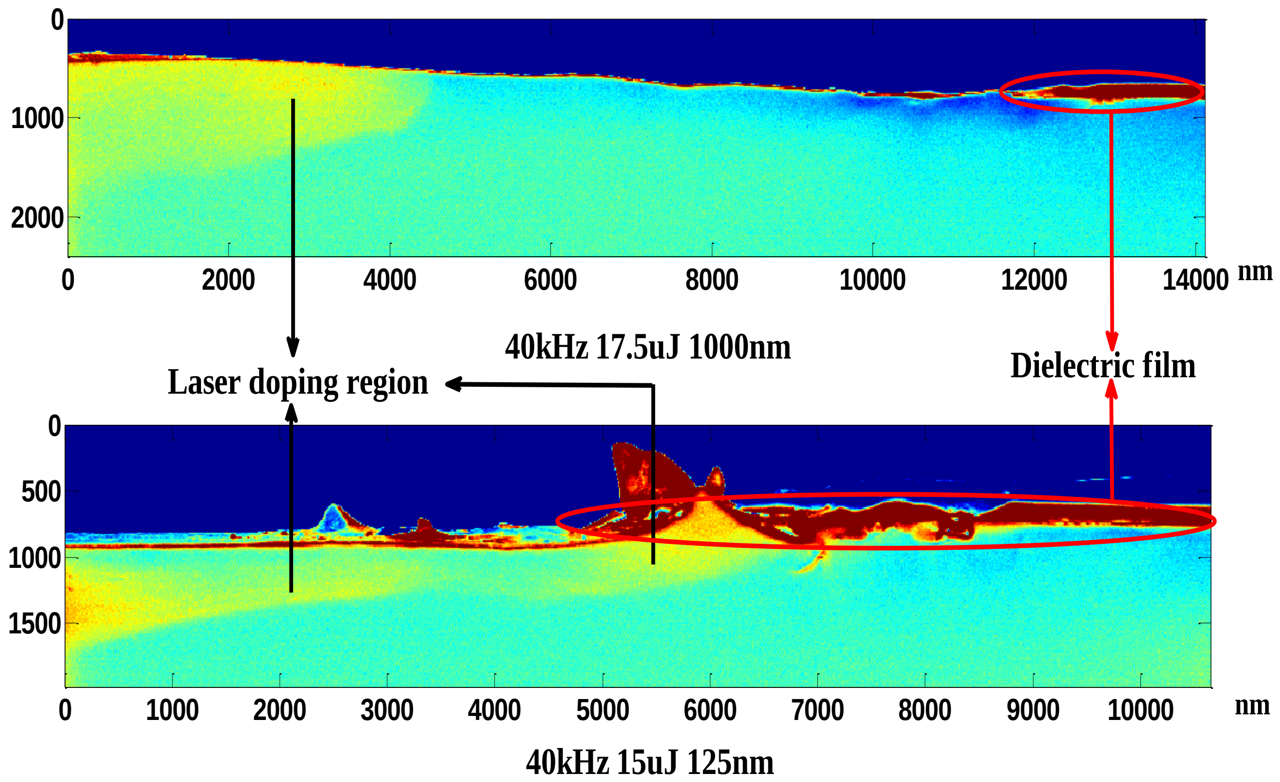
1. Use dielectric as etch mask, then use SEM



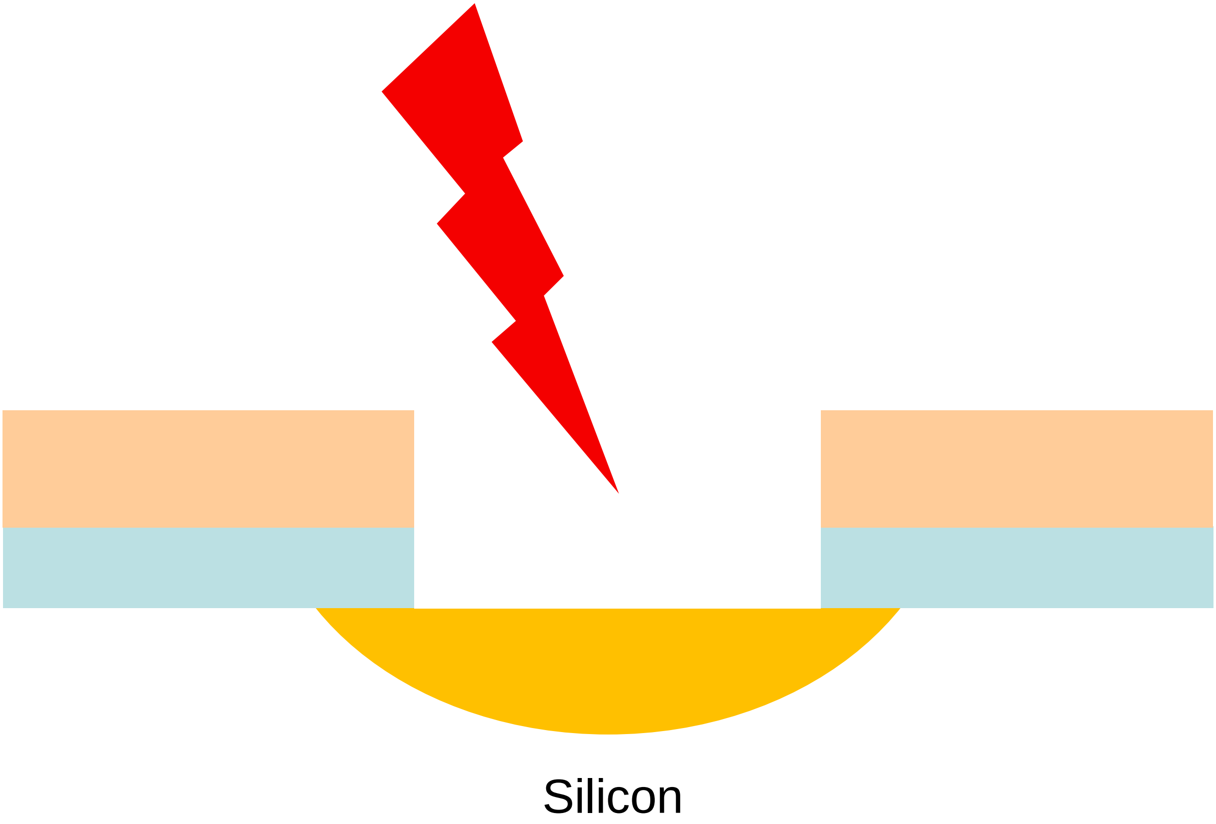



# Application of SEM DCI

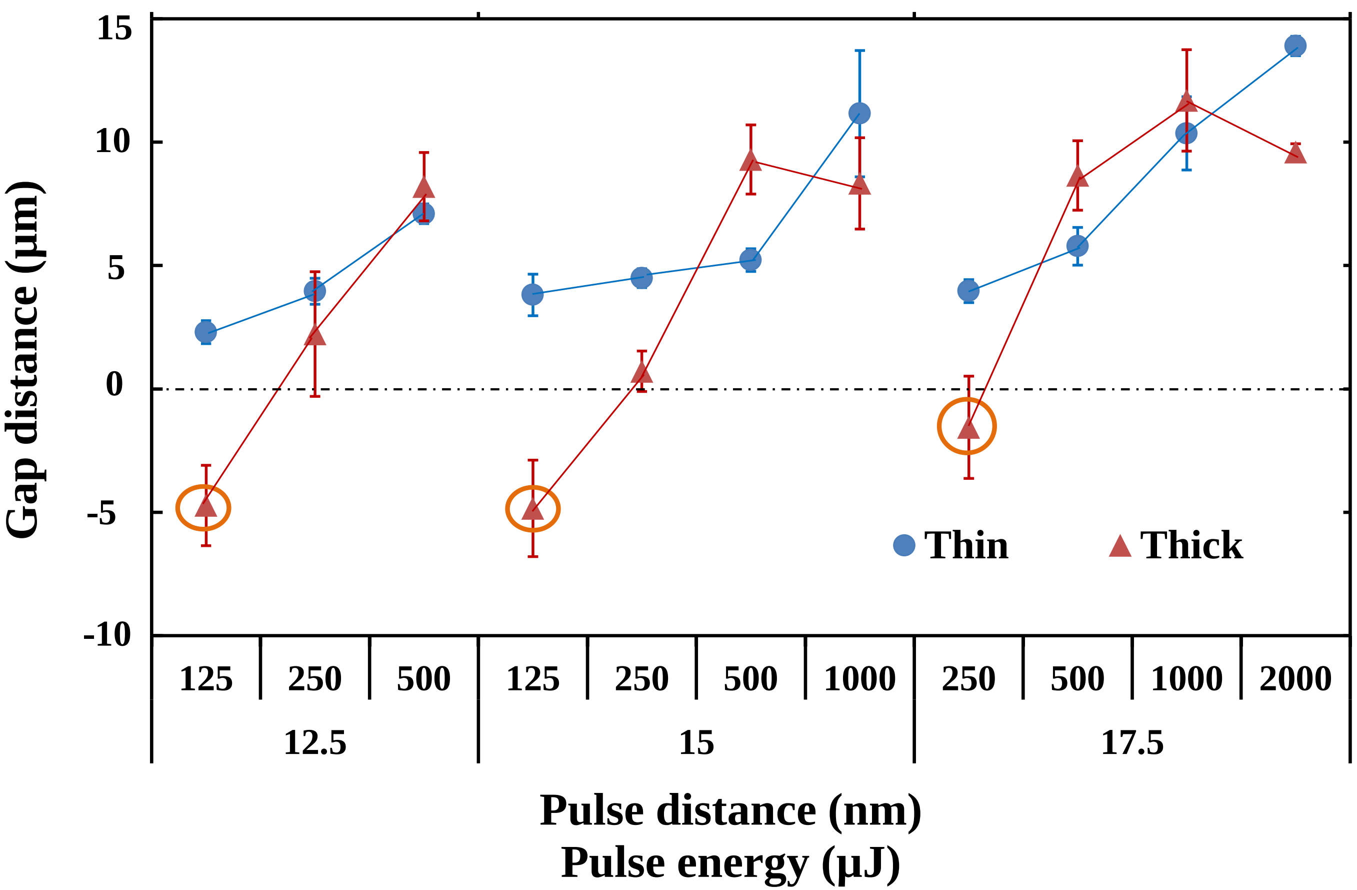
2. Direct imaging with dielectric film still present

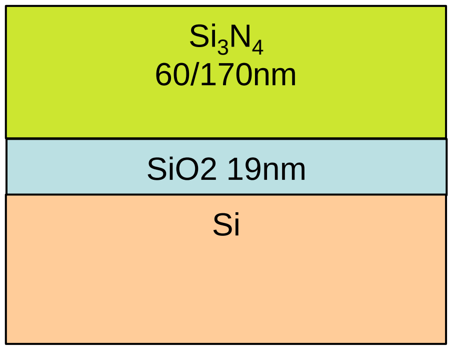


# Experiment: laser doping process



# Application of SEM DCI

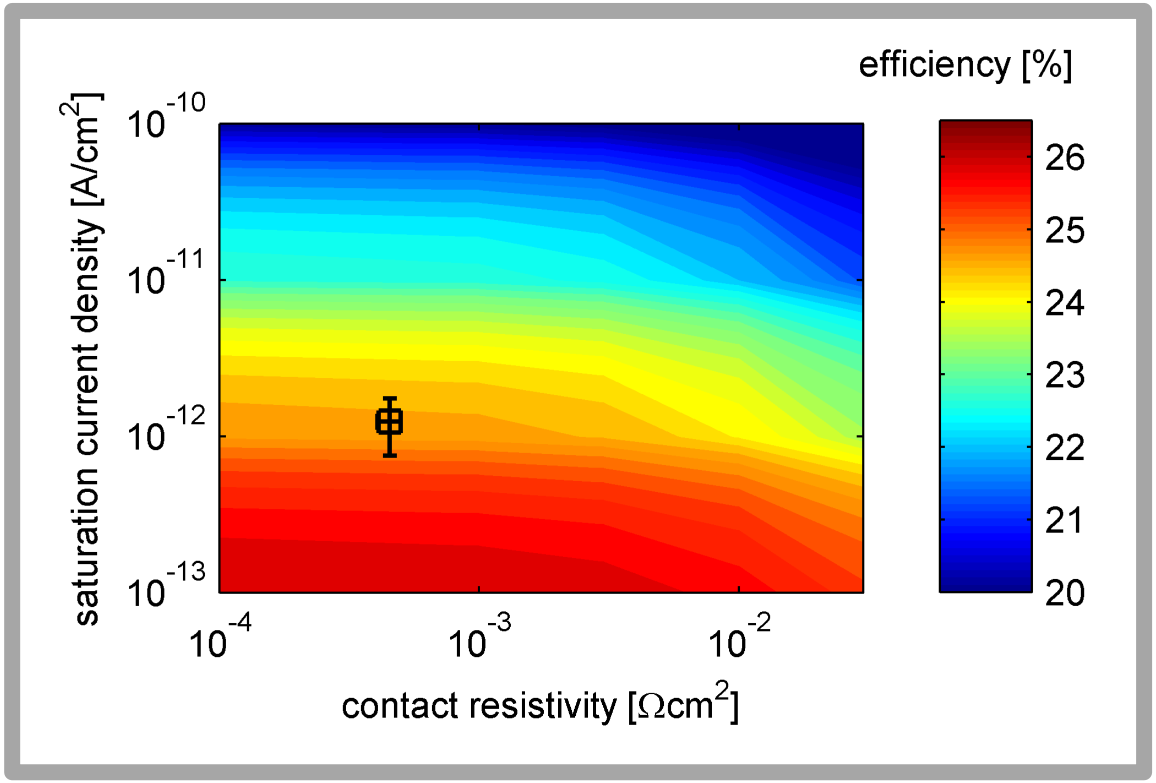



L. Xu at el., "The impact of $SiO_2/SiN_x$ stack thickness on laser doping of silicon solar cell" *IEEE Journal of Photovoltaics*, vol. 4, pp. 594-600, 2014.

# Assessing damage from laser doping

What really matters in the end?

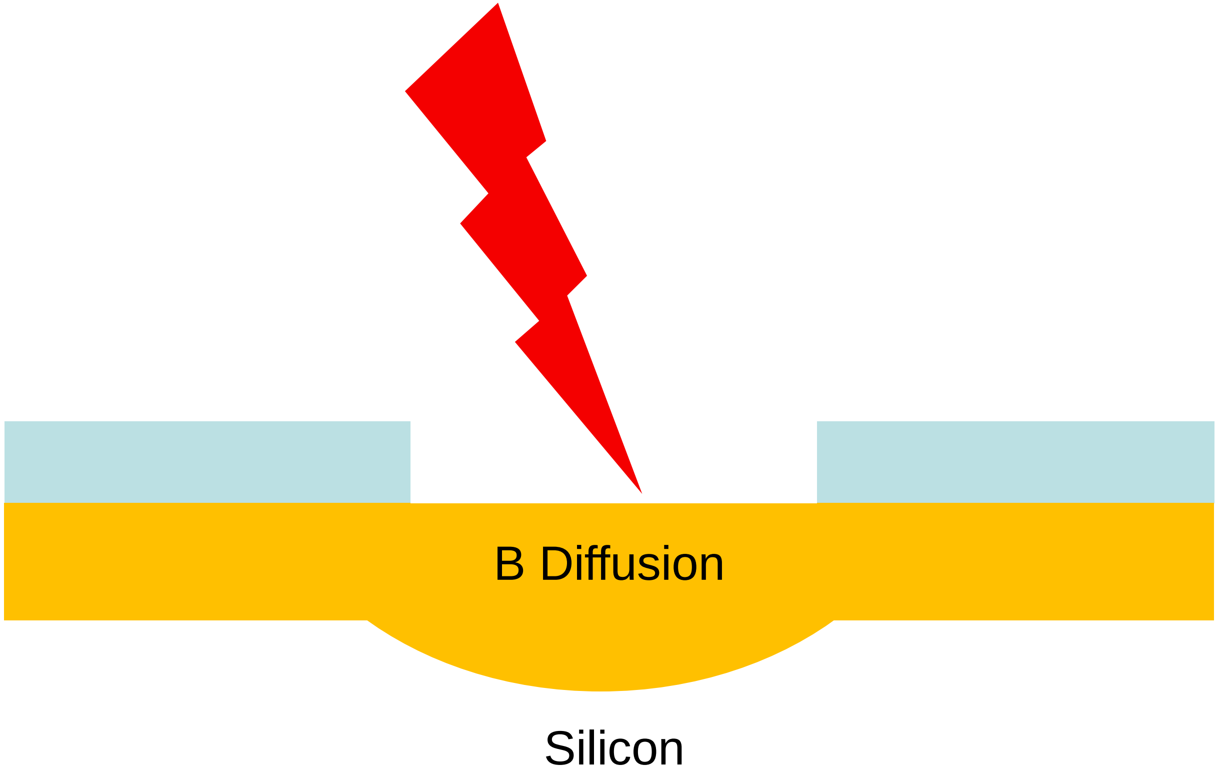



J0 depends on

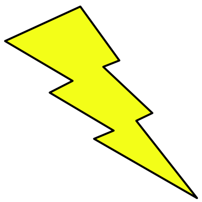
- 3-D doping profile
  - Dopant source
  - Laser properties
  - Dielectric
  - Surface roughness
  - Etc…
- Defects
  - Dopant source
  - Laser properties
  - Dielectric
  - Surface roughness
  - Etc…

# Assessing damage from laser doping

Simple experiment to focus on laser-dielectric interactions

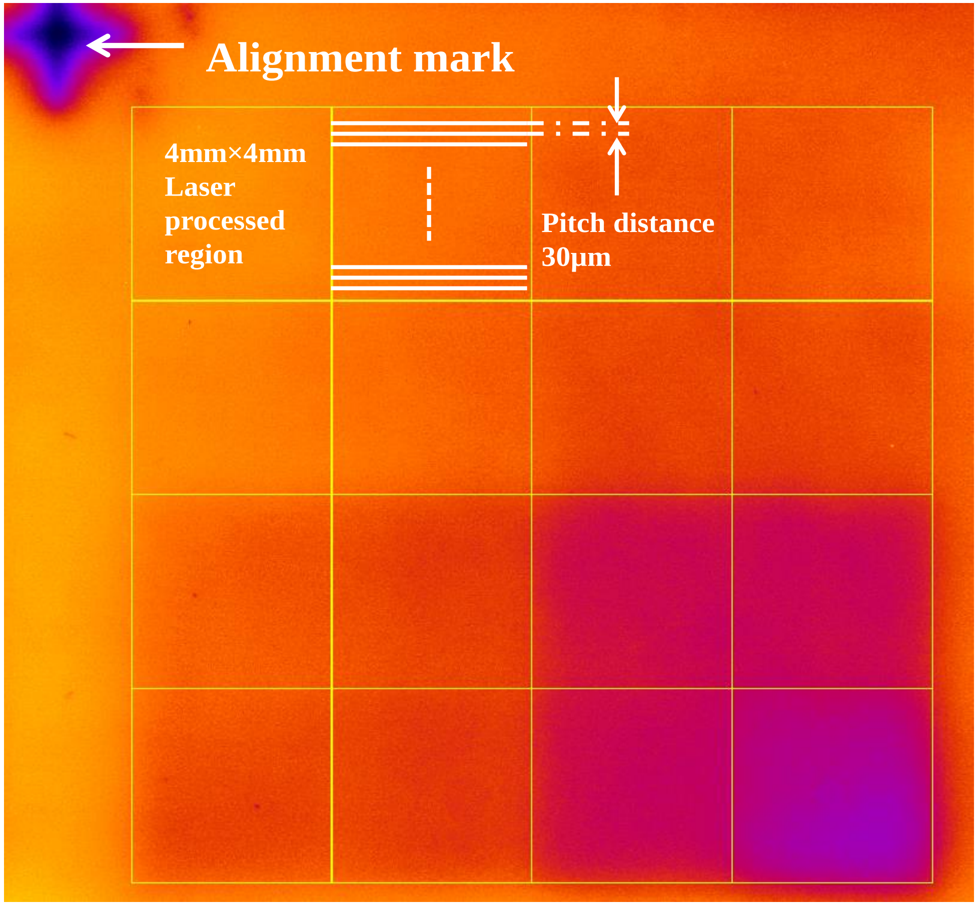


# PL Measurement test structure

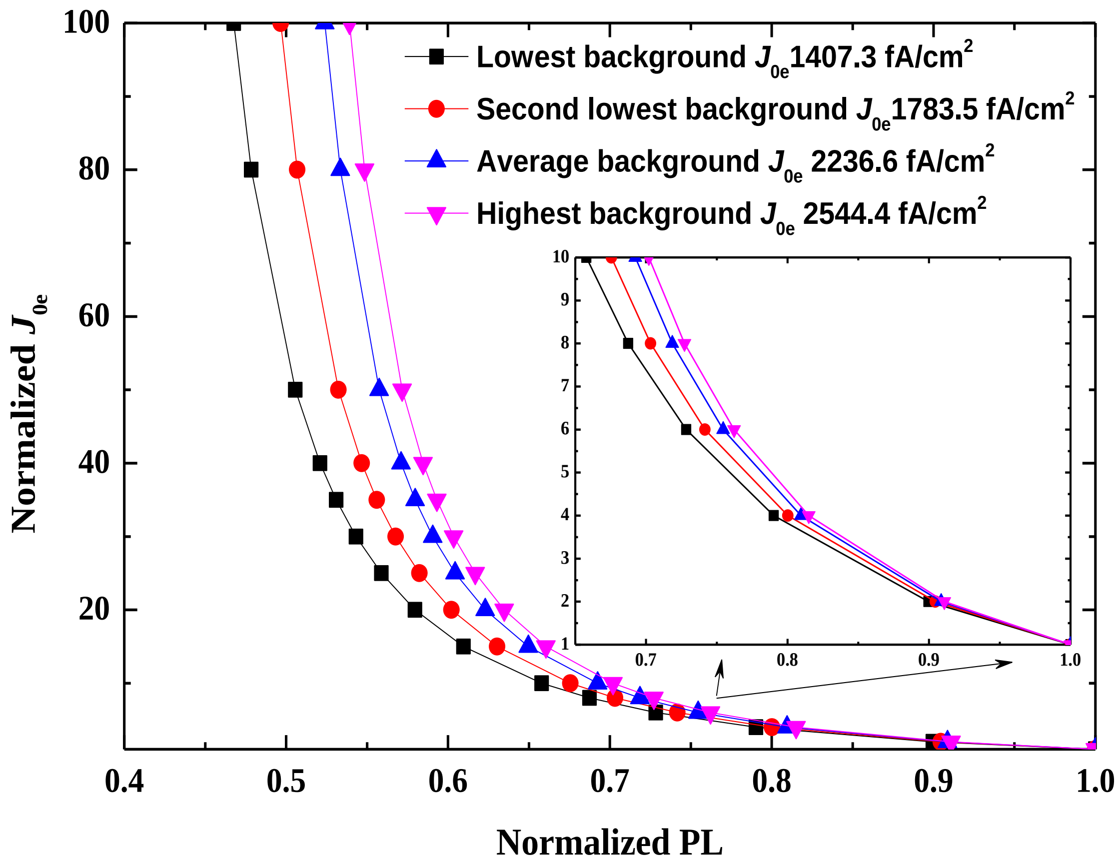


Unprocessed, B diffused, unpassivated

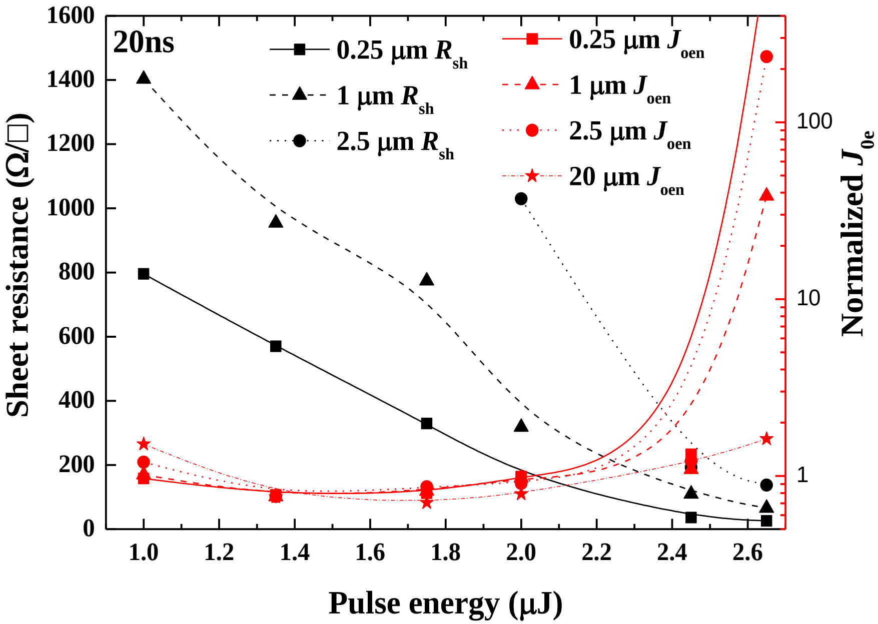
Processed, B diffused, unpassivated

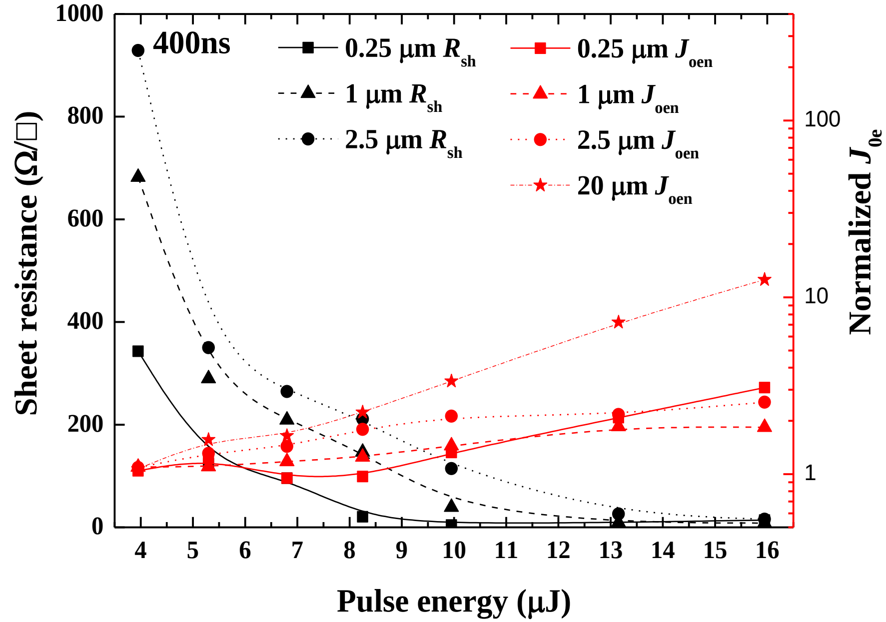


# PL Measurements - calibration



# Results – no dielectric

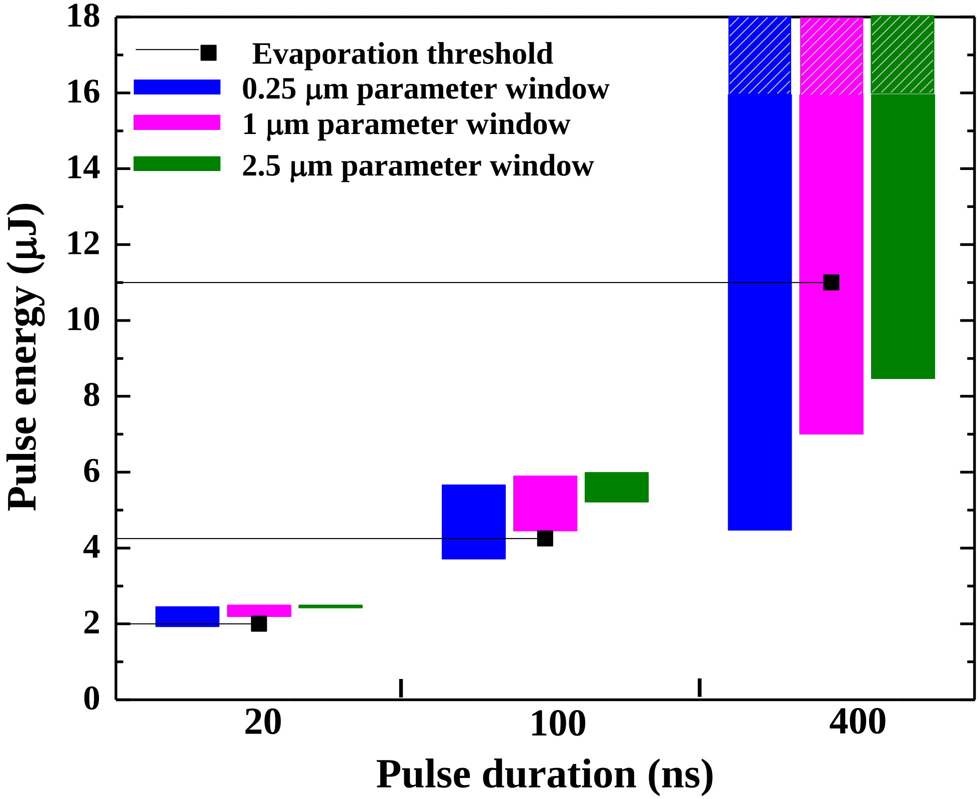


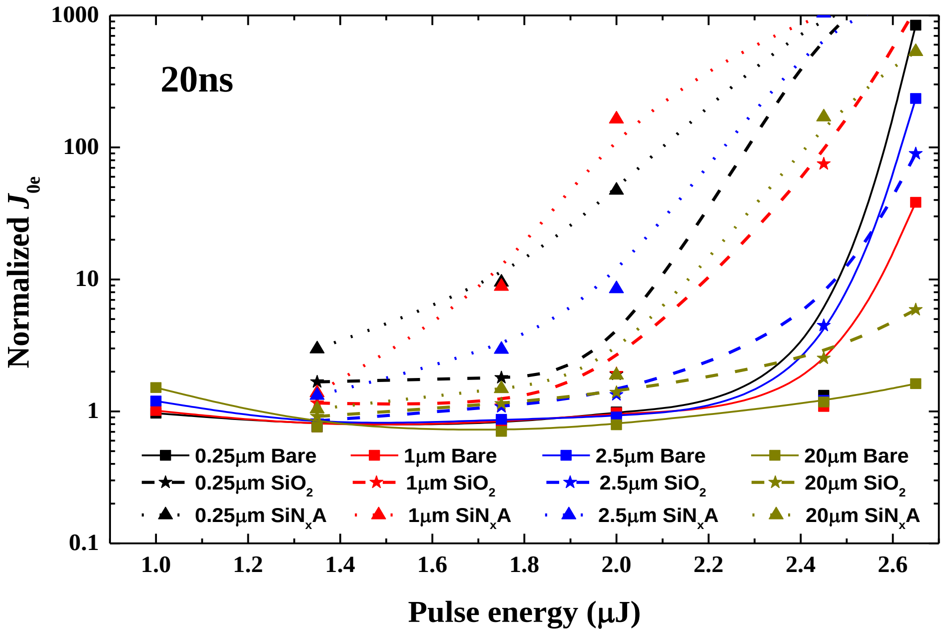

L. Xu et al., "The influence of thermal effects and dielectric films on the electronic quality of $p^+$-doped silicon processed by nanosecond laser"
*IEEE Journal of Photovoltaics*, vol. PP, pp. 1-8, 2014.

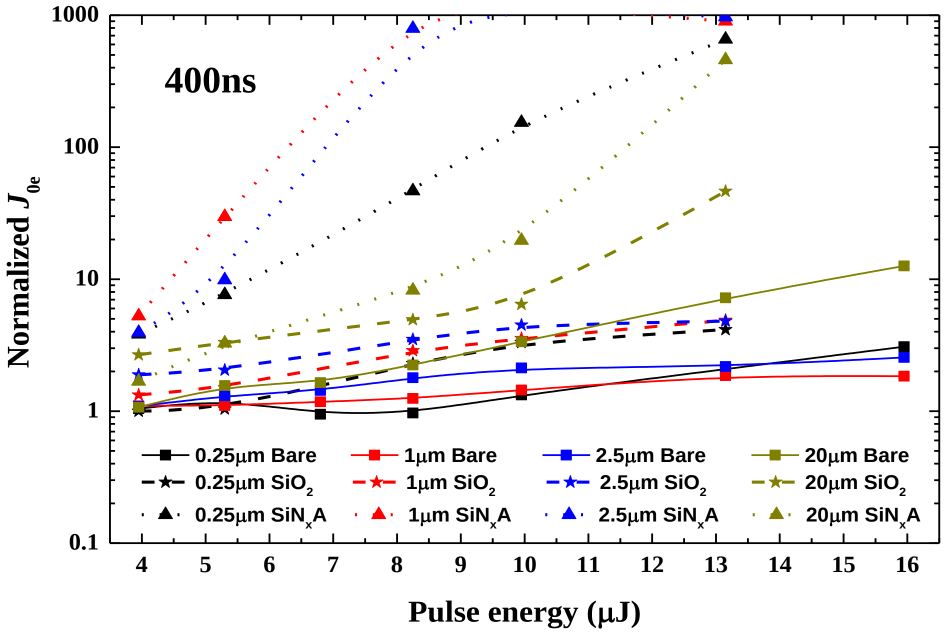
Australian National University

# Results – evaporation threshold

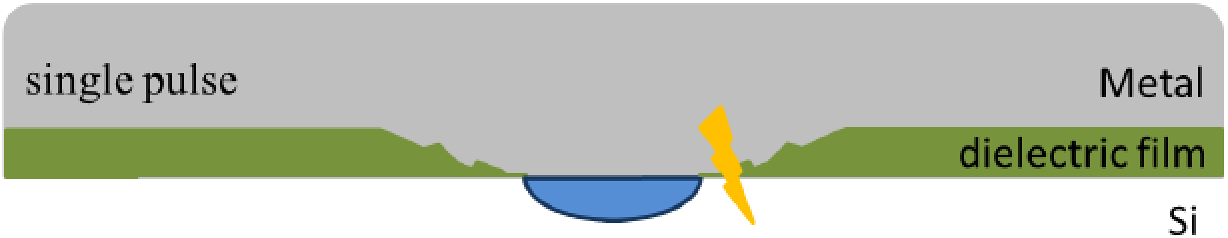


# Results – with dielectric films



# Conclusions




- Single step laser doping processes for IBC are very challenging
- SEM DCI is a convenient tool to assess laser doping near dielectric edges
- Under the right conditions, good doping is achieved under dielectric
- Laser induced damage silicon damage can be kept to acceptable levels
- More work is needed to understand dielectric edge regions / dopant precursors

Australian National University

# Acknowledgements

ANU Laser team

Colleagues at ISE and ISFH (S. Kluska, B. Fleischmann, S. Hopmann, K. Bothe, B. Lim)

Australian Renewable Energy Agency (3-GER002 “High quality laser doping for solar cells through improved characterisation techniques”)