INTEVAC

Engineering Advanced Solar Cells with High Throughput Ion Implantation

Intevac

Henry Hieslmair

Intevac Business Segments

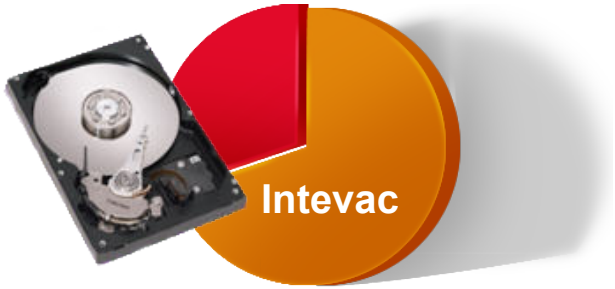
Equipment Business

High Productivity Vacuum Process Solutions Since 1991

Photovoltaic Cells

Enabling process solutions
focus on efficiency and cost

Hard Drive Media



Technology leader
1 billion disks per year

Photonics Business

Digital low-light sensor technology leader

Intevac Equipment Product Family

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200 Lean®
Hard Drive Media

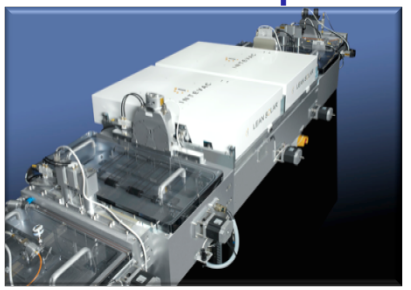
Proven Reliability and Productivity

Solar

NanoTexture™ Etch

ENERGi ™ Ion Implant

Lean Solar™ Deposition



- Higher cell efficiency
- Lower cost per watt
- Technology extendibility

Universal platform addressing multiple advanced solar technologies

Ion Implantation for Solar

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Benefits

- Tailoring of Phosphorus Profile
- Boron
- 1 sided doping
  - Process simplification
  - Improved cost, no edge iso
- Patterning of dopants
  - Selective emitter
  - Inter-digitated Back Contact Cells
- Uniformity & repeatability
  - Better binning
  - Better FF

Drawback

- Cost $/Wp
  - Low throughput
  - High capital cost
- Patterning reduces throughput

ENERGi™ Designed for Solar

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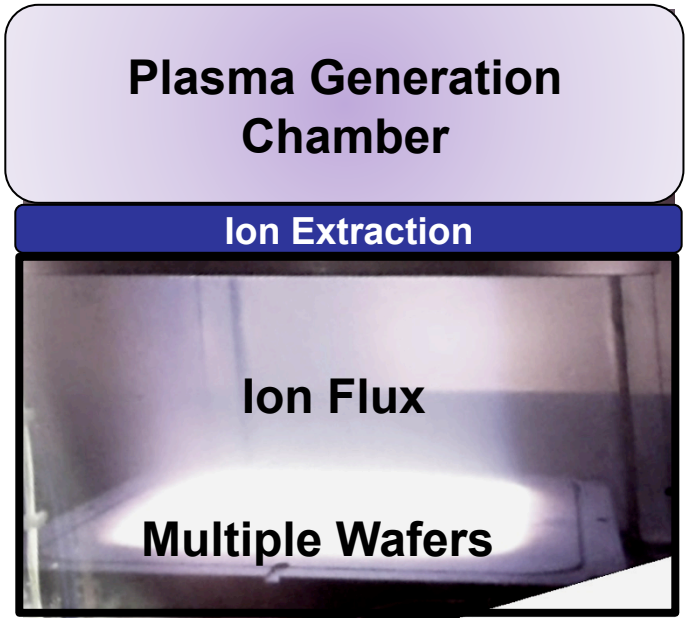
Continuous Flux Ion Beam

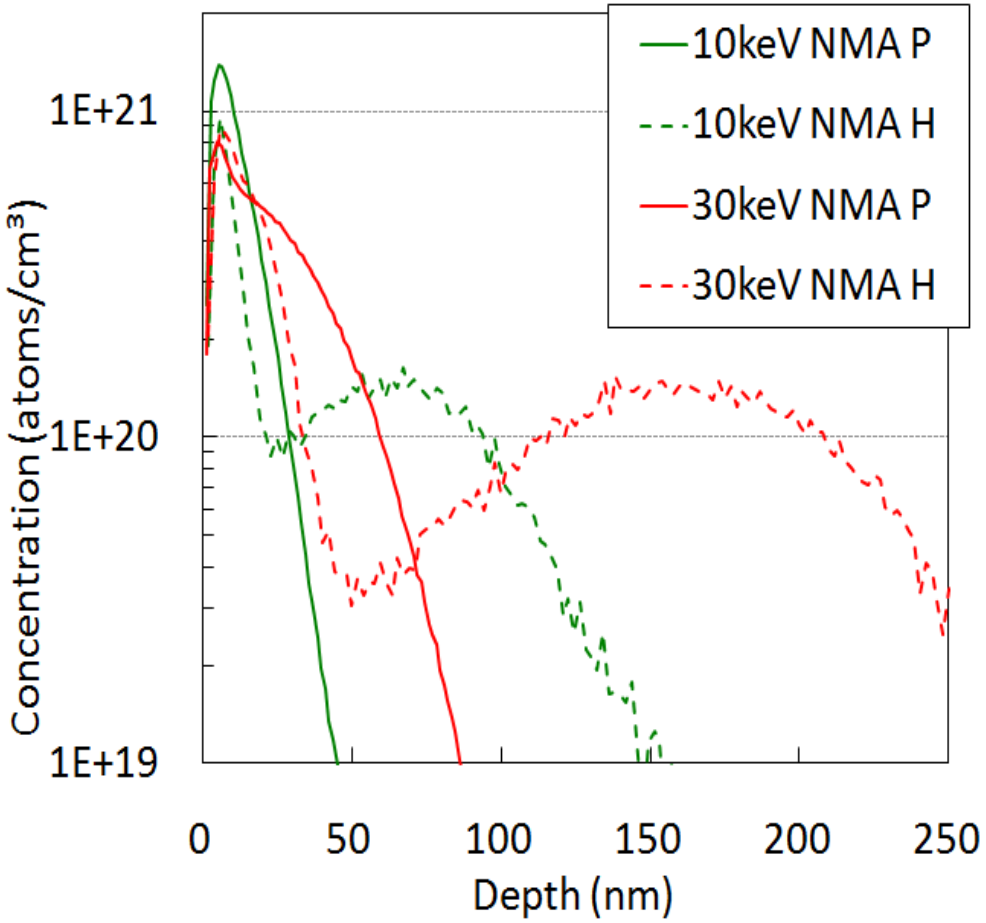


Patent Pending

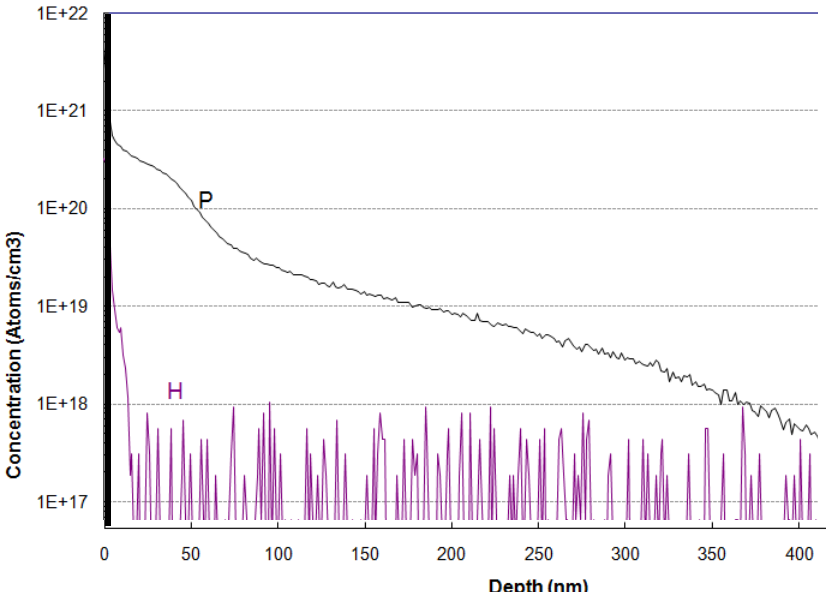
- **Lowest cost solution to ion implant**
- **2400 wph throughput (Identical for P and N type implant)**
- **Wide energy range capability for customer required junction depths**
- **Simultaneous emitter formation (homogeneous and selective)**
- **Small footprint and ease of service**

***ENERGi* enables lowest cost of ownership solution for ion implant**

Non-mass analyzed implant



- Co-implantation of H^+ from PH_3
- Dose P ≅ H
- H^+ low damage creation
  ⇒Electronic stopping
- H diffuses out after anneal



ENERGi ™ Continuous Flux System

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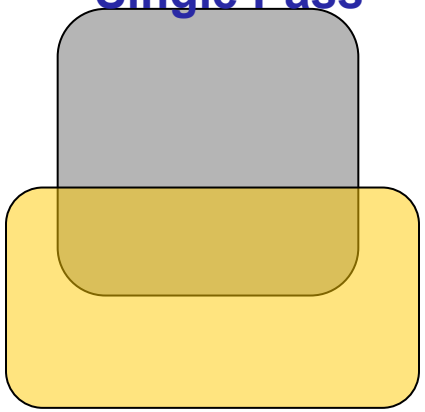
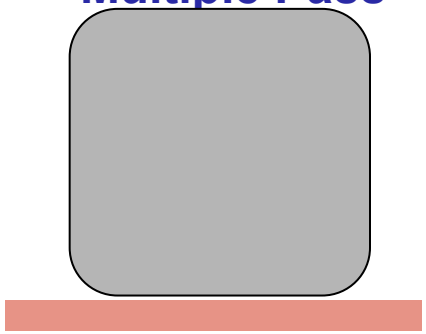
Continuous Flux
Single Pass

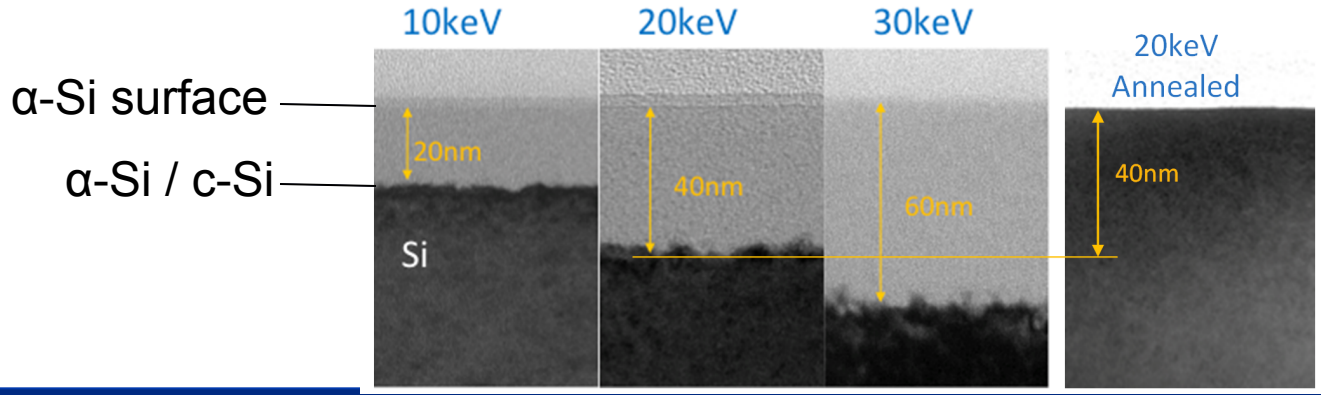


Ribbon (Beamline)
Multiple Pass



High quality amorphized layer via
- High continuous dose rate
- Single pass

Improves Solid Phase Epitaxial Re-growth (SPER)
- Low remaining defects



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TAILORING OF PHOSPHORUS PROFILE

Tailoring of Phosphorus Profile

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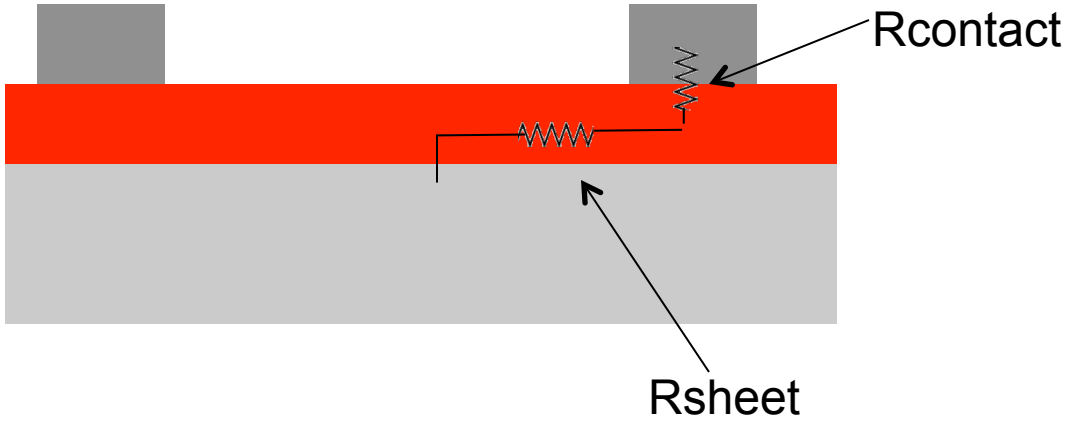
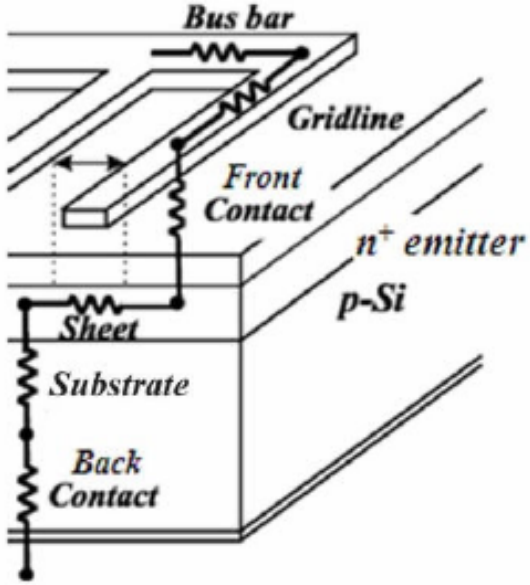
- **Sheet resistance**
- **Contact resistance**

Series resistance & FF improves with high P doping and high near surface P dose

- **Recombination**

Voc and Jsc improve with low P doping and low P surface concentration.





$POCl_3$ - Infinite P source

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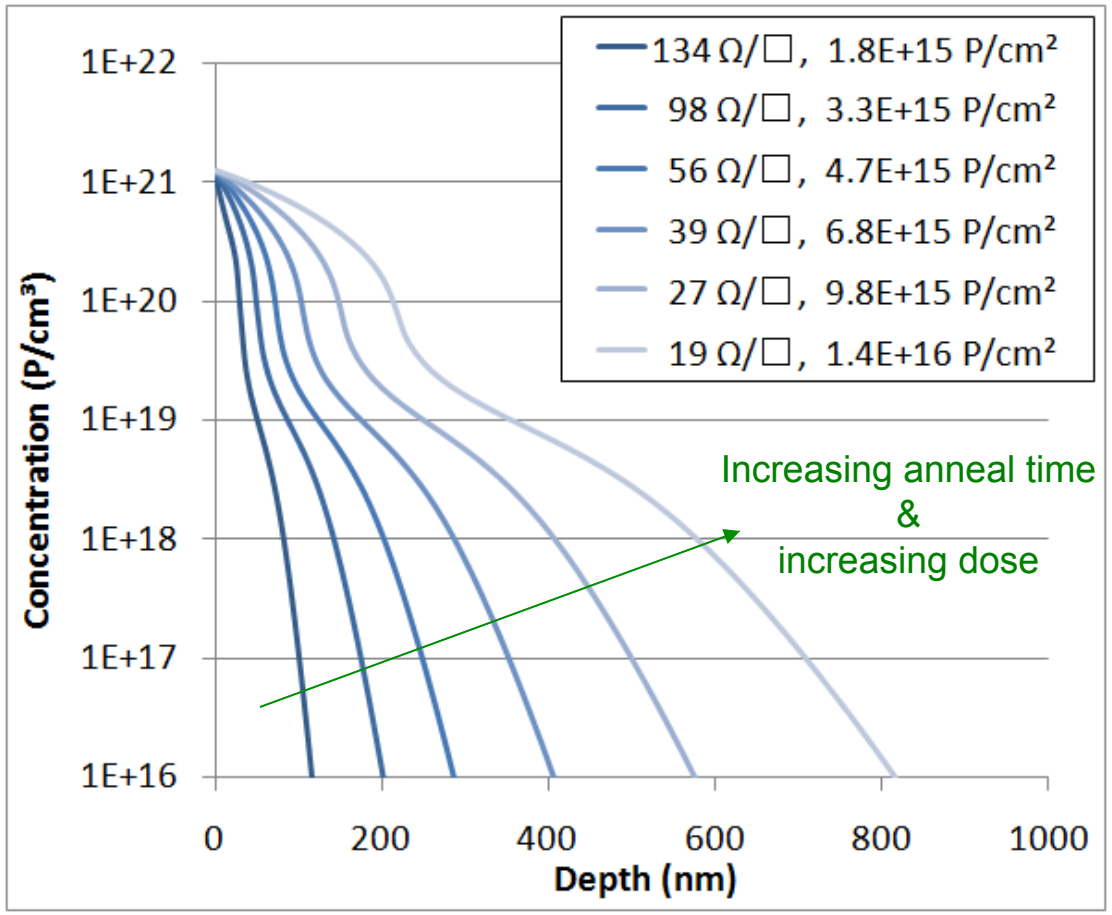


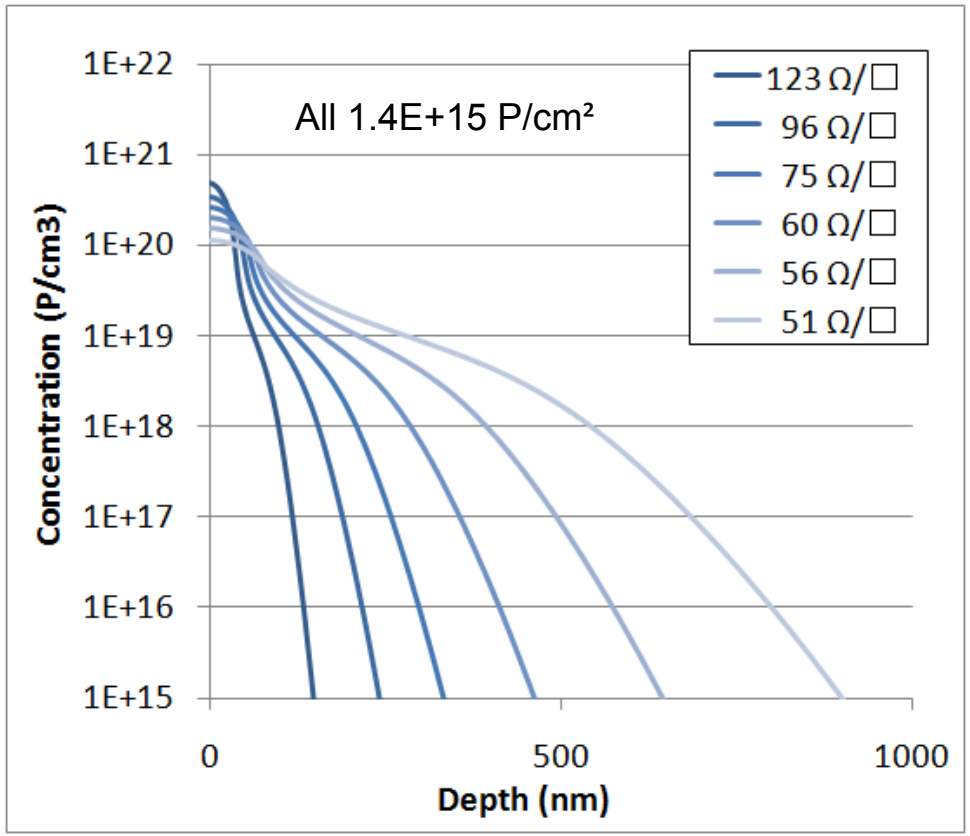
Dose increases with time

$POCl_3$ has infinite source

High surface concentration

Time and Ω/☐ tightly linked.

Fixed P dose



Profile shape changes lead to lower sheet resistance for fixed dose of P.

$$R_{sheet} = \frac{1}{q \int_0^{x_j} \mu_n(x) n(x) dx}$$

Process paths

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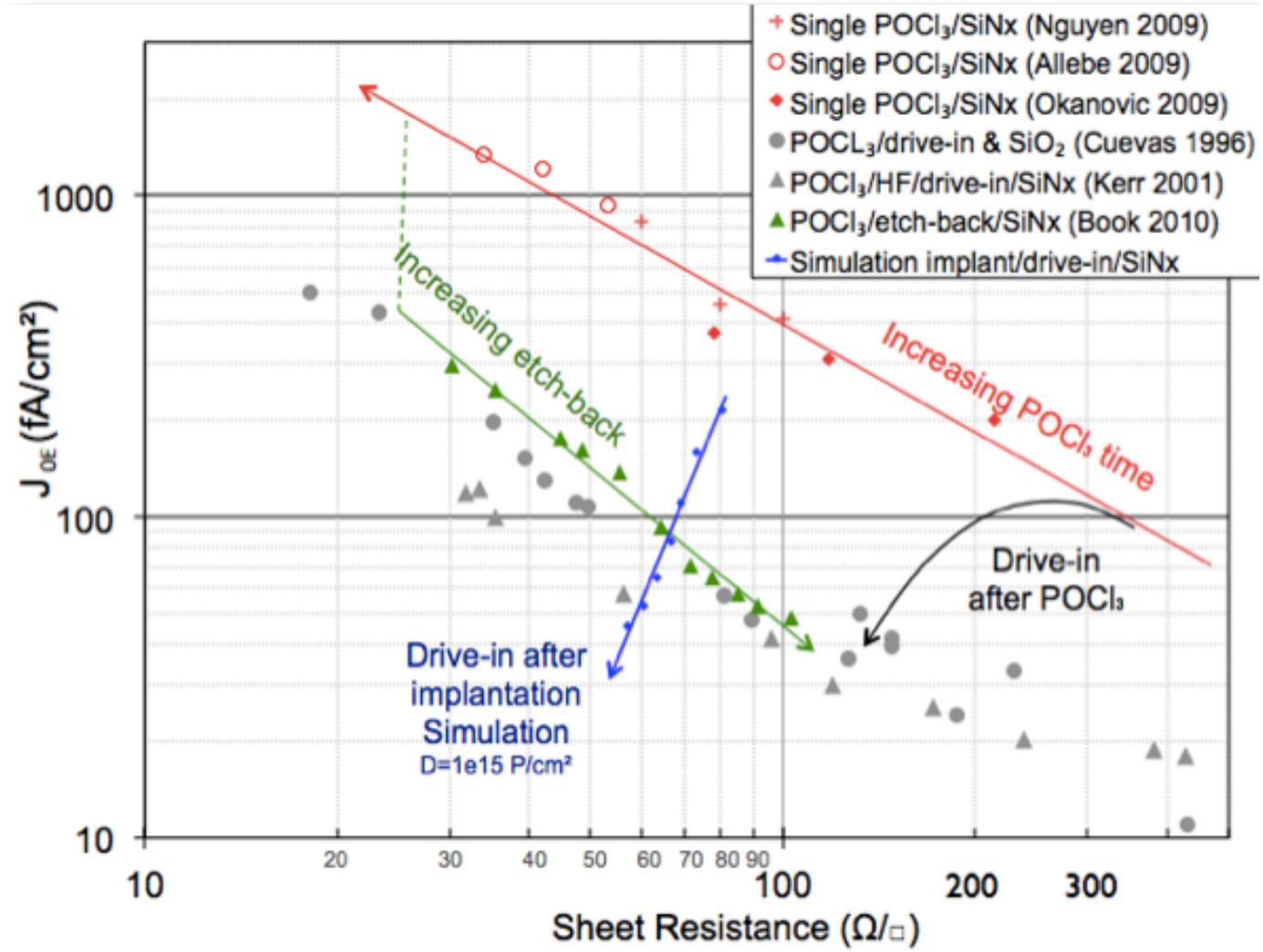

Profile tailoring implanted finite P dose

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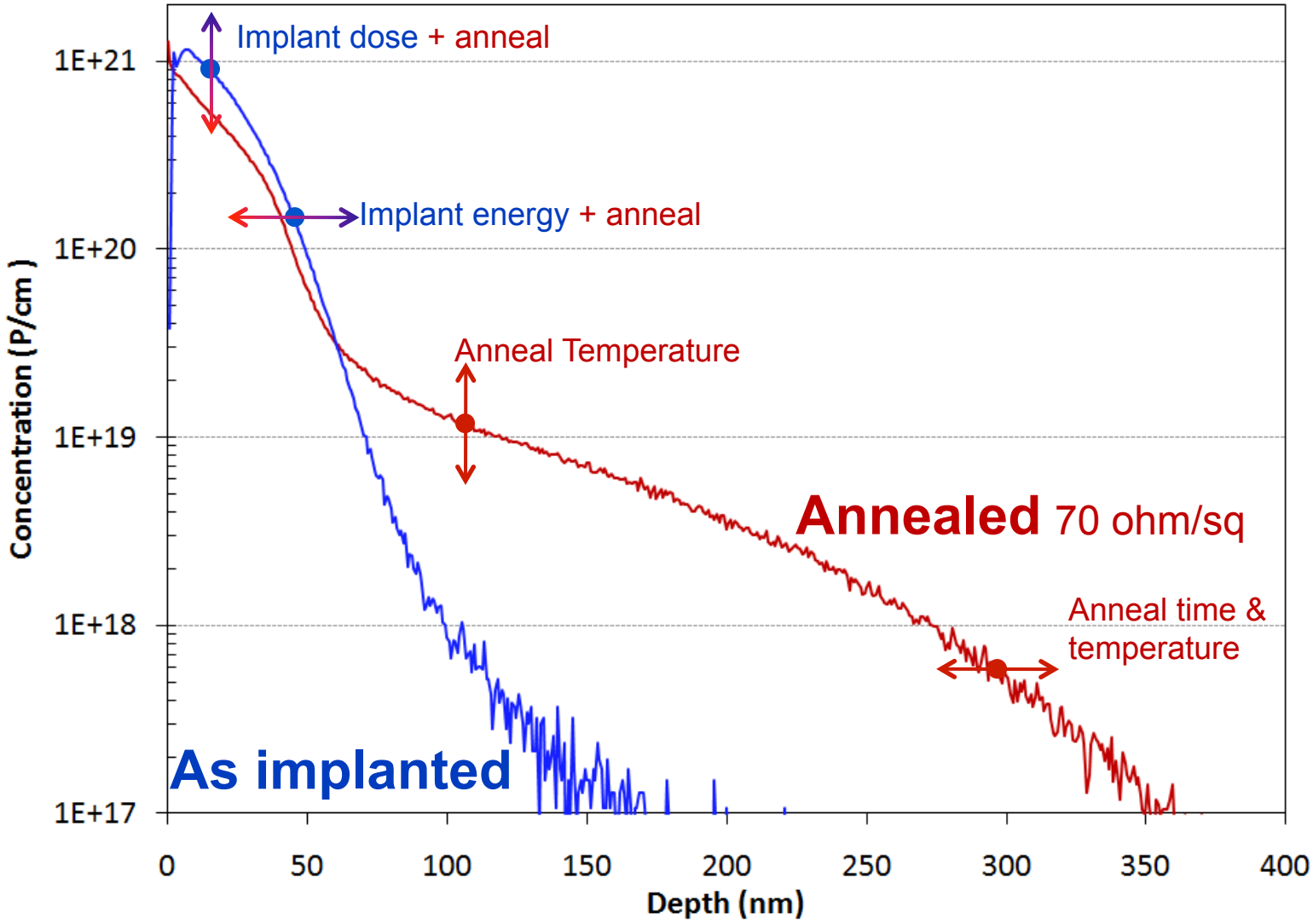
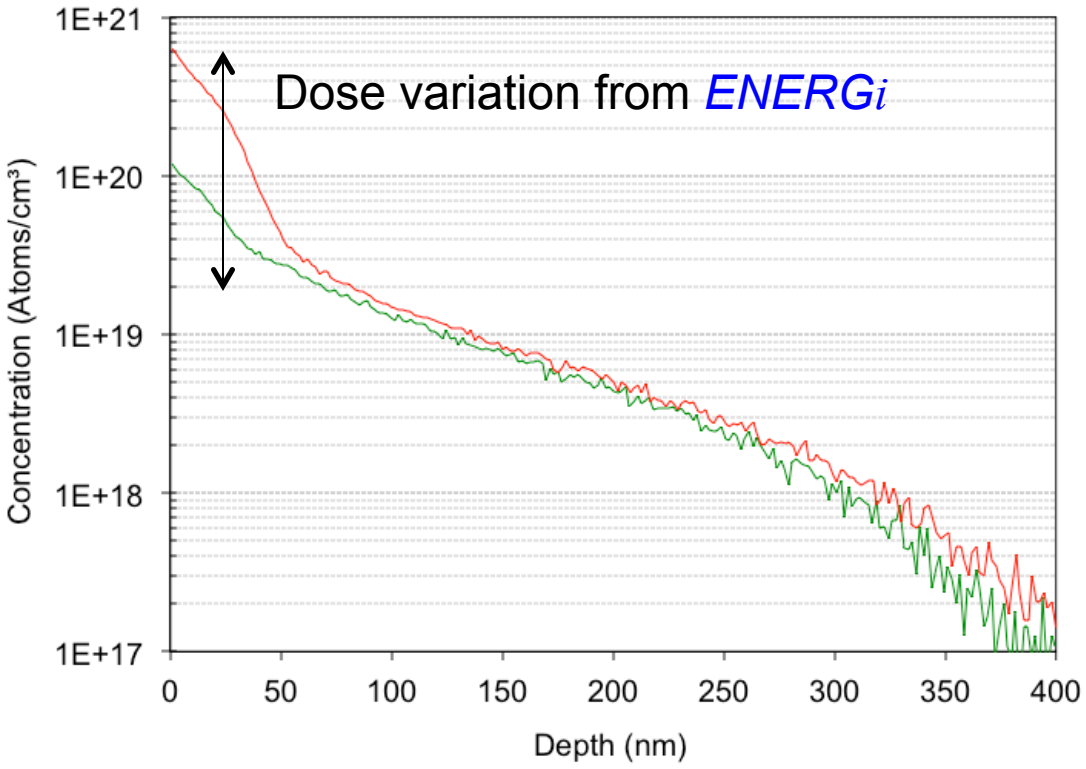


Tuning of surface P by implant dose



Near surface dose can be manipulated by varying implant dose

Selective emitters have local regions of high dose and other regions of low dose

CONTACT RESISTANCE

Commercial Ag paste contacting

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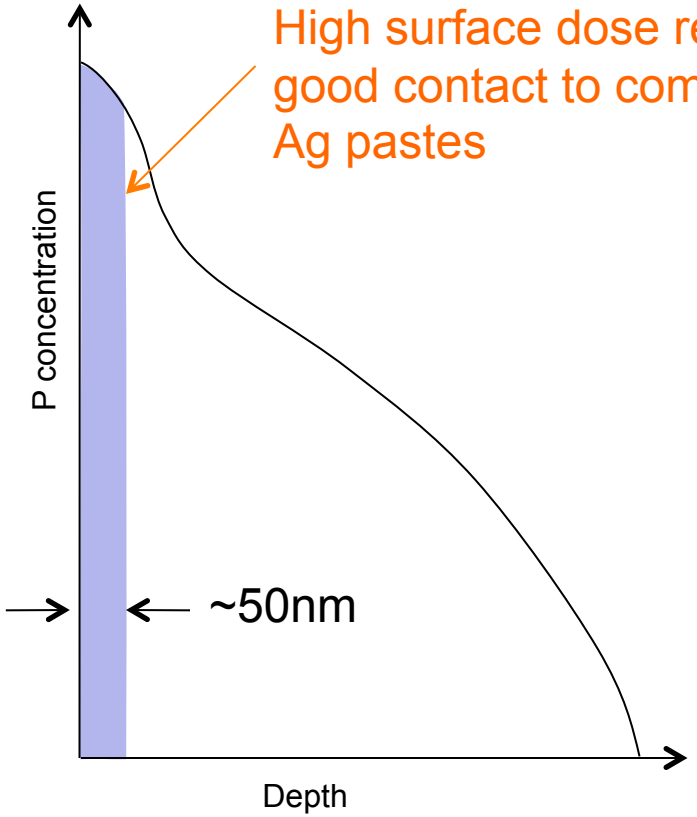

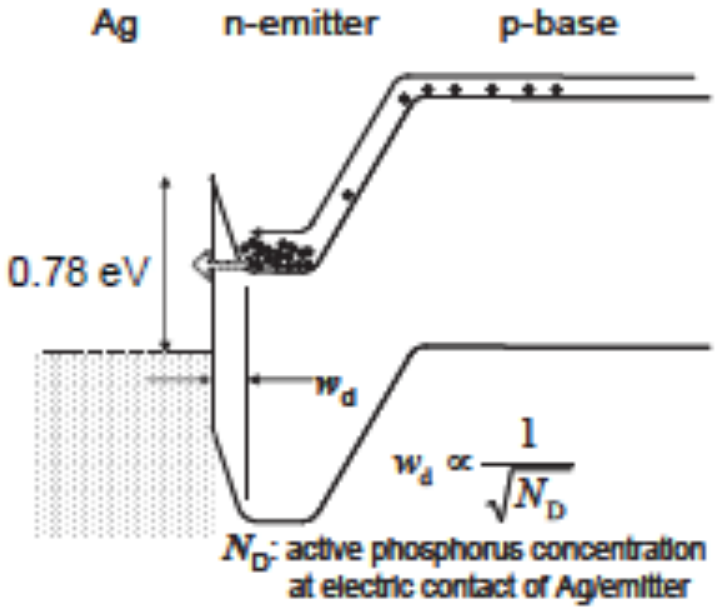

Y. Komatsu et al, "Efficiency Improvement by Deeper Emitter with Lower Sheet Resistance for Uniform Emitters"
Energy Proceedia 8 (2011) 515-520

- Ag does not form silicide. Ag-Si contact is a tunneling junction
- Good tunneling required high/degenerate doping
- Tunneling has threshold behavior – Rc increases rapidly below threshold N_{Dose}

FF and Sheet Resistance from $POCl_3$

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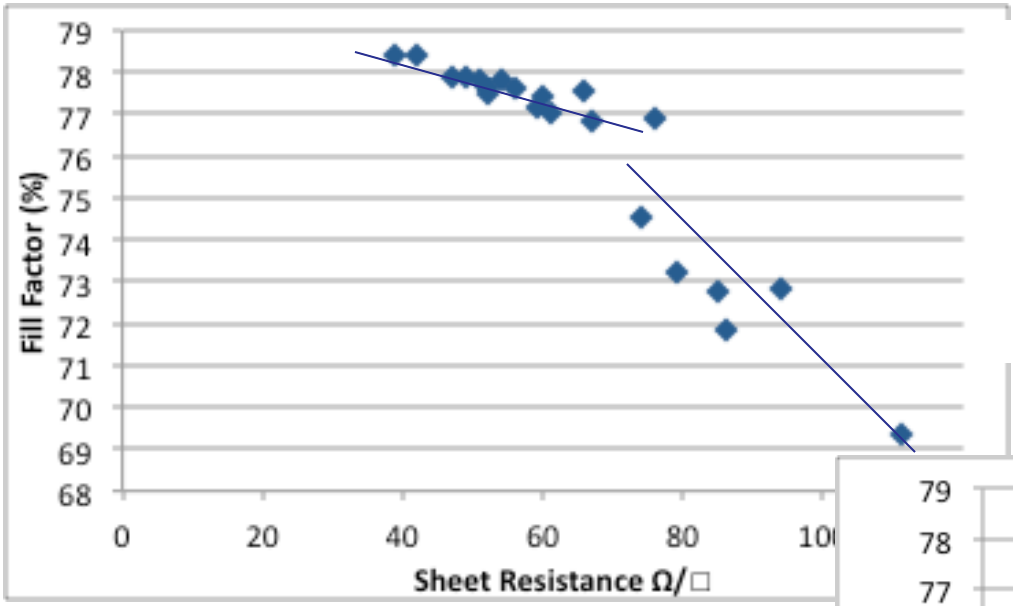
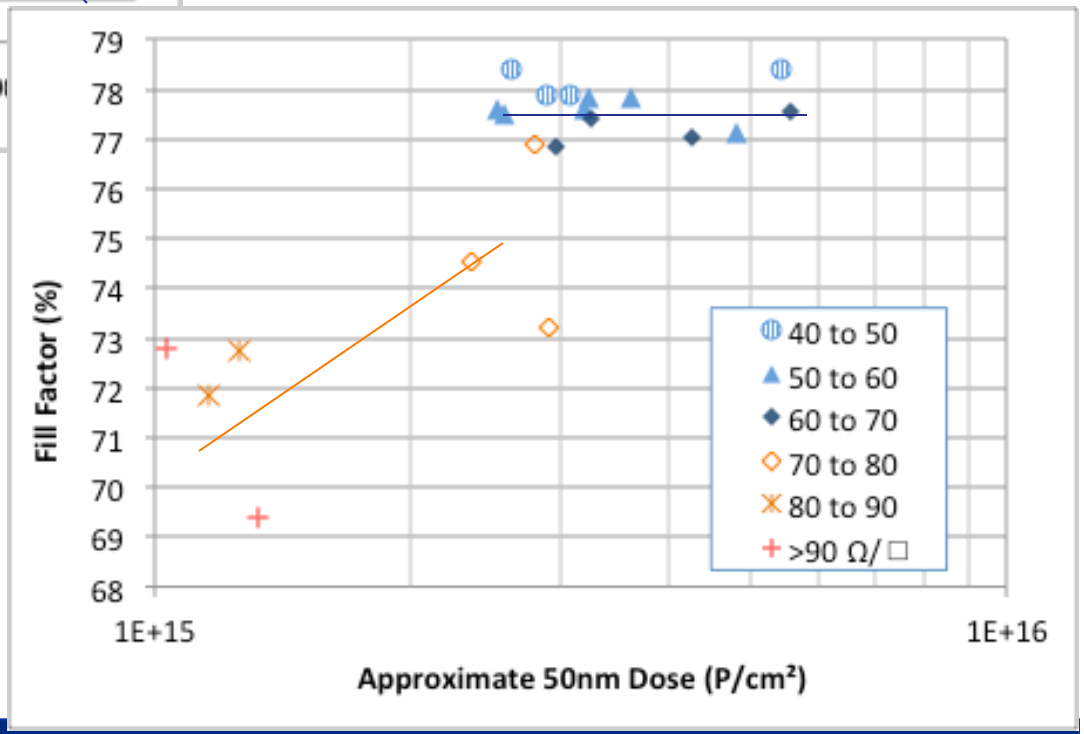


-Various $POCl_3$ anneals
-Numerical integration of author's SIMS profiles
-Below ~2.5e15 P/cm^2 in first 50nm, FF drops off



Y. Komatsu et al, "Sophistication of Doping Profile Manipulation – Emitter Performance Improvement without Additional Processing Step"
25th EuPVSEC Valencia, Spain 2010

Tailoring implanted emitters

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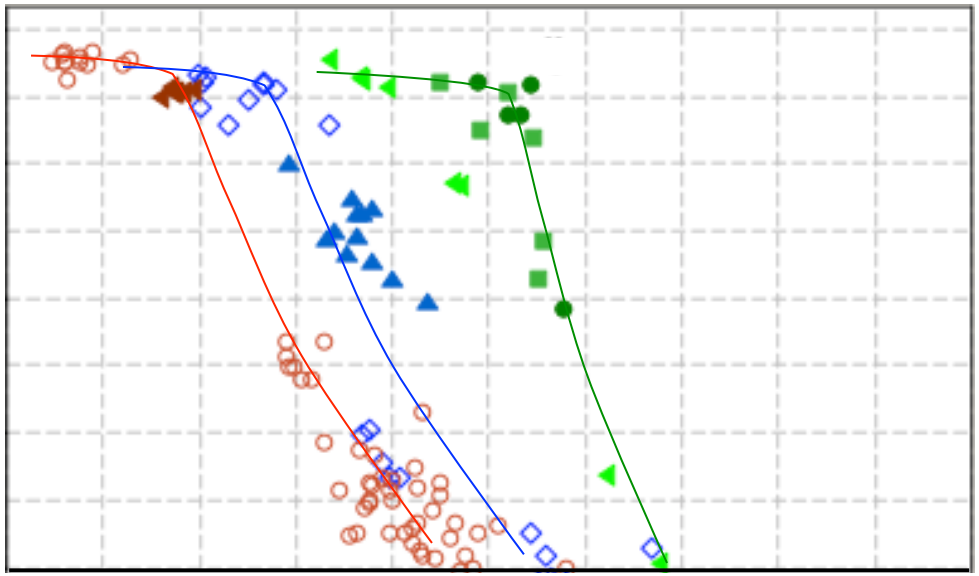
Implanted phosphorus with various annealing temperatures



Anneal temperature

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Near surface dose

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Implant provides opportunity to finely tune cell process

RECOMBINATION

Recombination mechanisms

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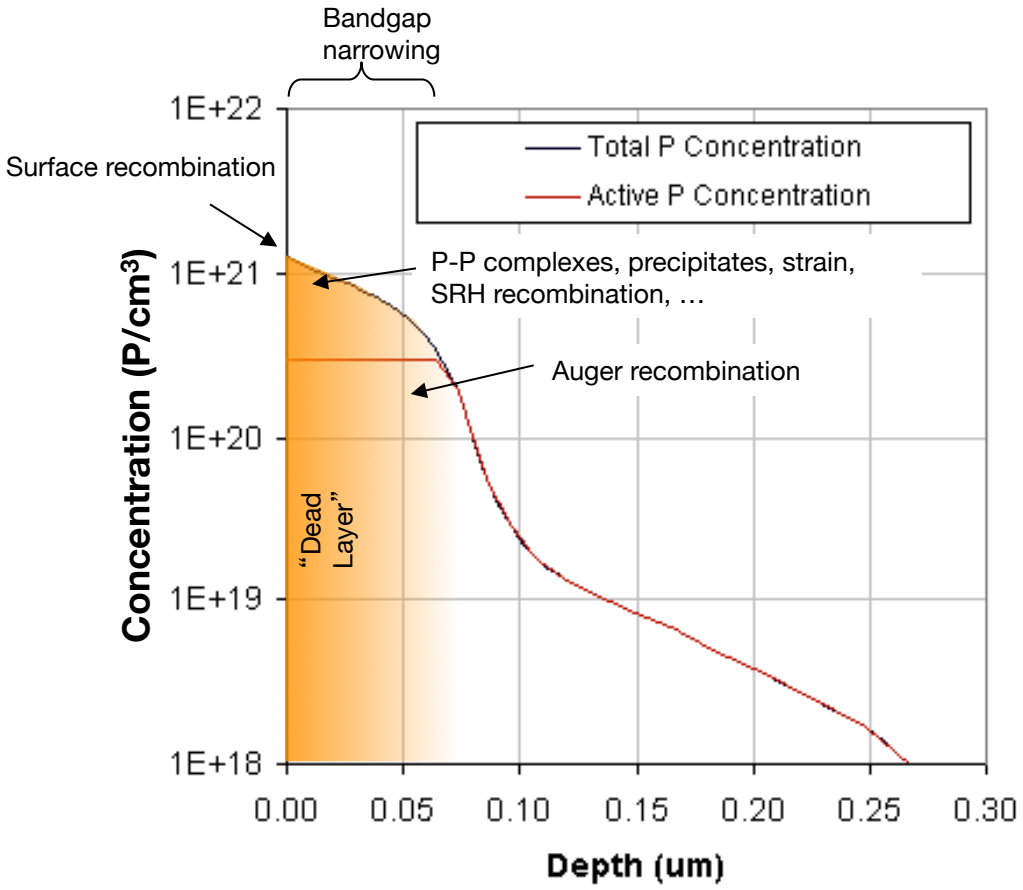
Lower recombination increases V_{oc}



Surface recombination increases with surface concentration

Auger recombination at high P concentrations

SRH at precipitate/clusters above solubility concentration

Simulations showing recombination loss in emitter

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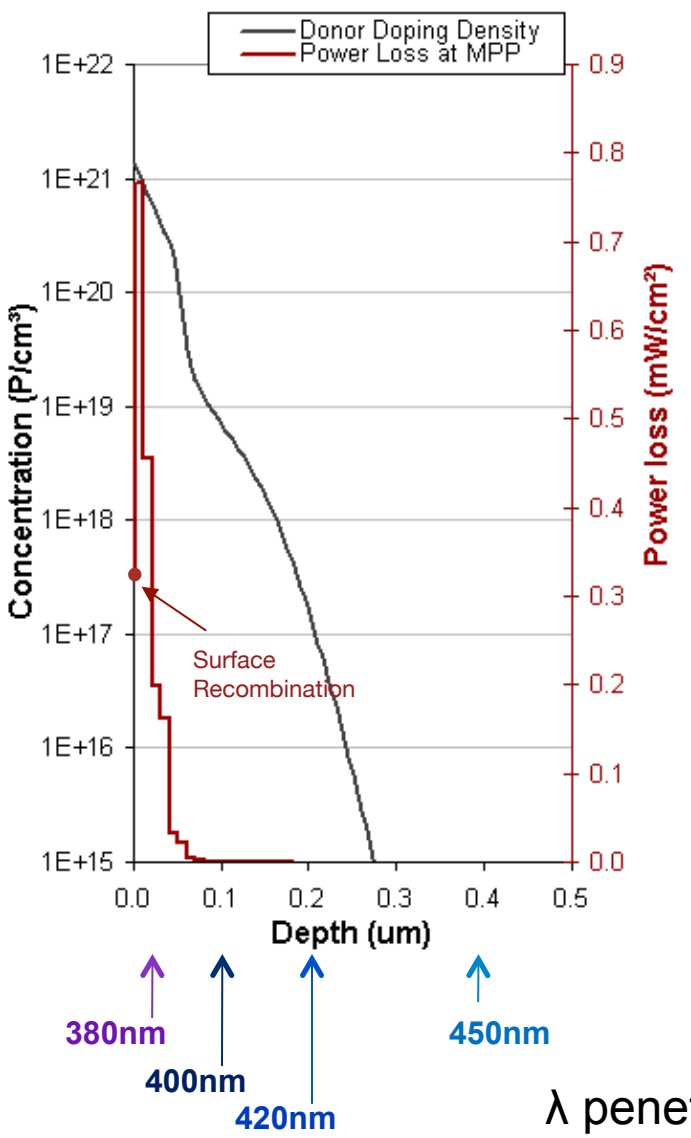
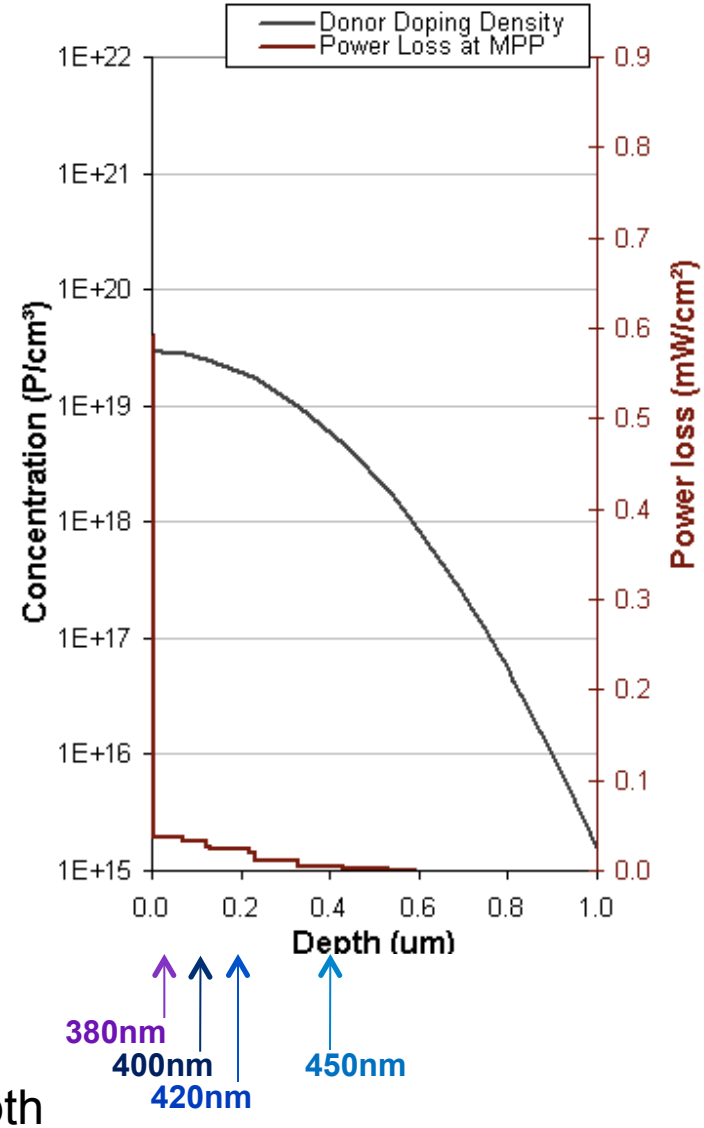
Simulations of power losses (red) in two different 70 Ω/□ emitters (x-axis scale differs)





λ penetration depth

ENERGi manipulation of profiles

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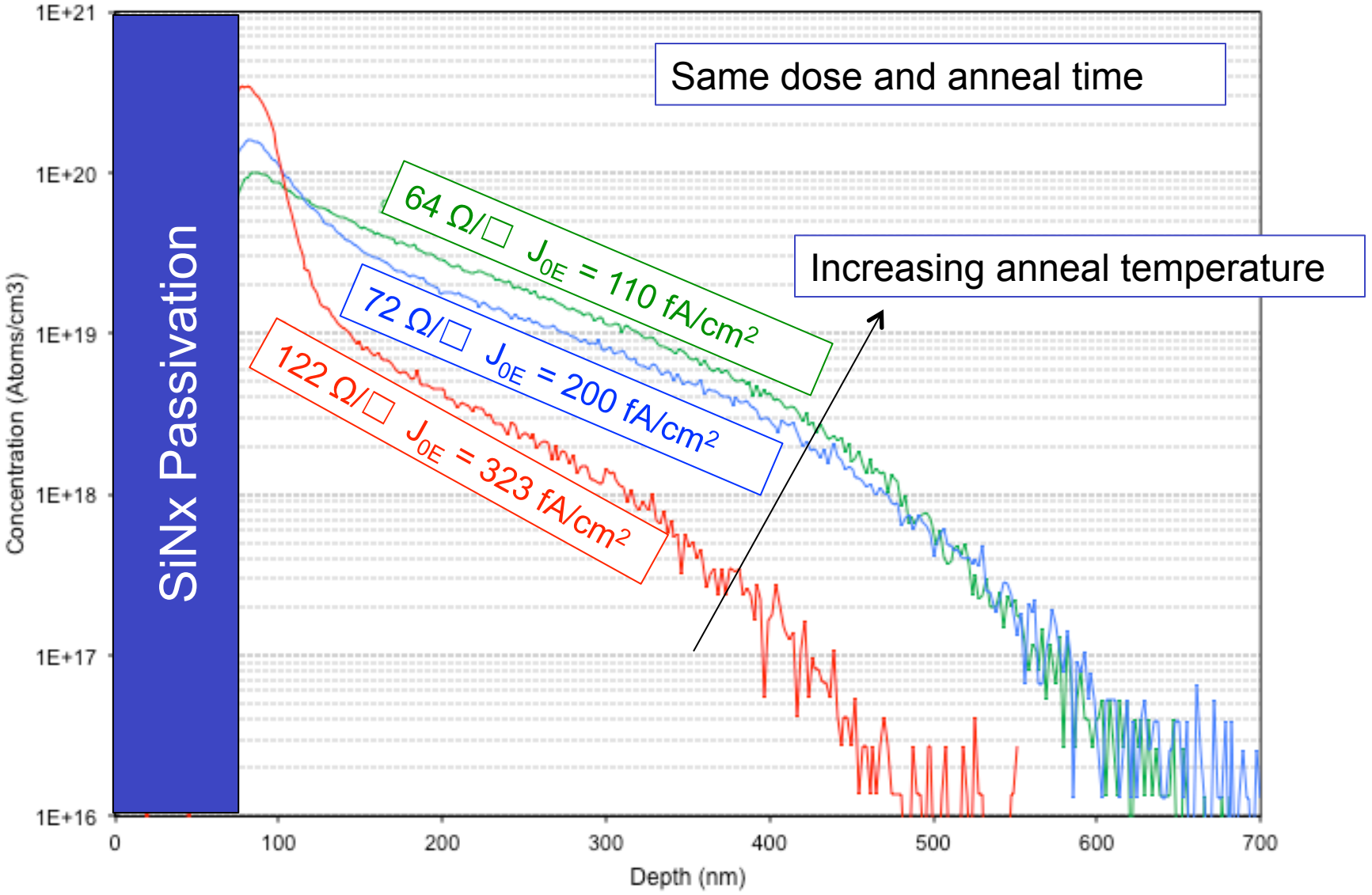

IQE Data Comparison for 60 Ω/□ Emitters

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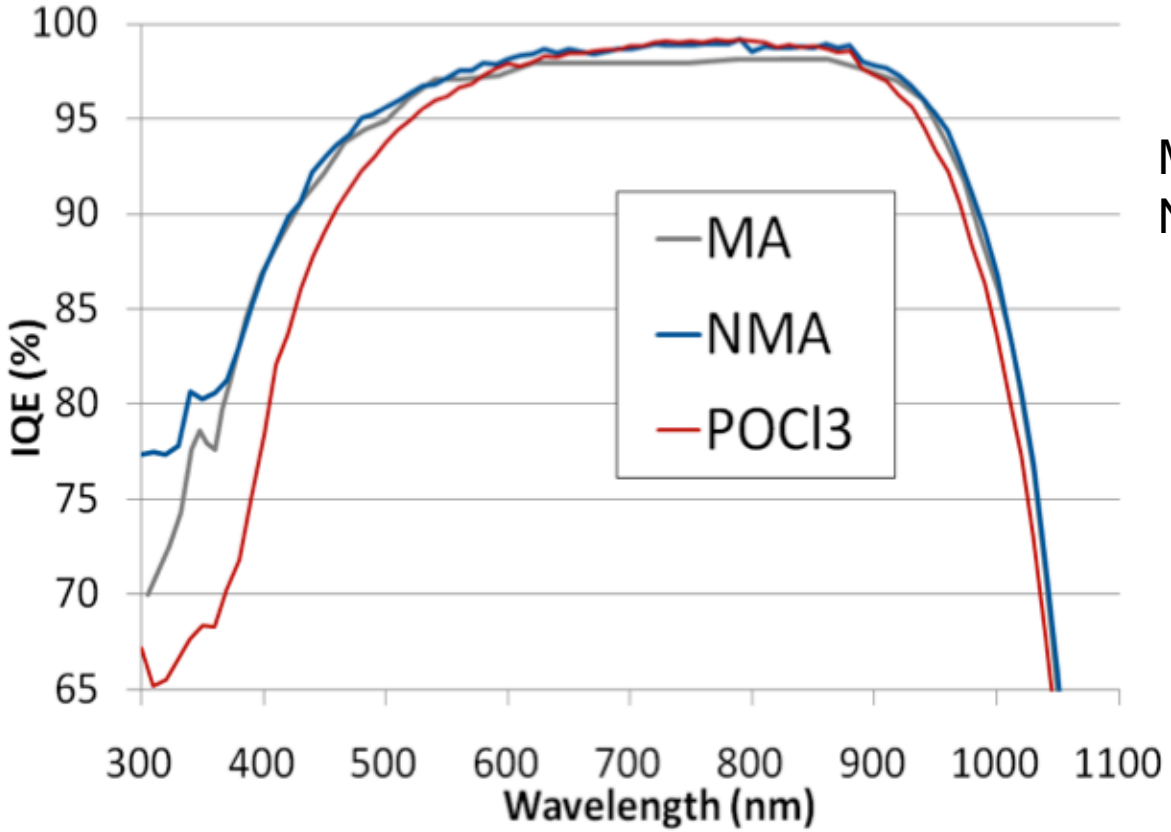

Mass Analyzed (MA)
Non-Mass Analyzed (NMA)

***ENERGi* shows**
-Improved IQE performance over traditional $POCl_3$
-Equivalent performance to mass analyzed implant

MA IQE from A. Gupta, et al., High Efficiency Selective Emitter Cells Using In-Situ Patterned Ion-Implantation, 25th EUPVSEC, Valencia Spain, 2010.

ENERGi J_{0E}

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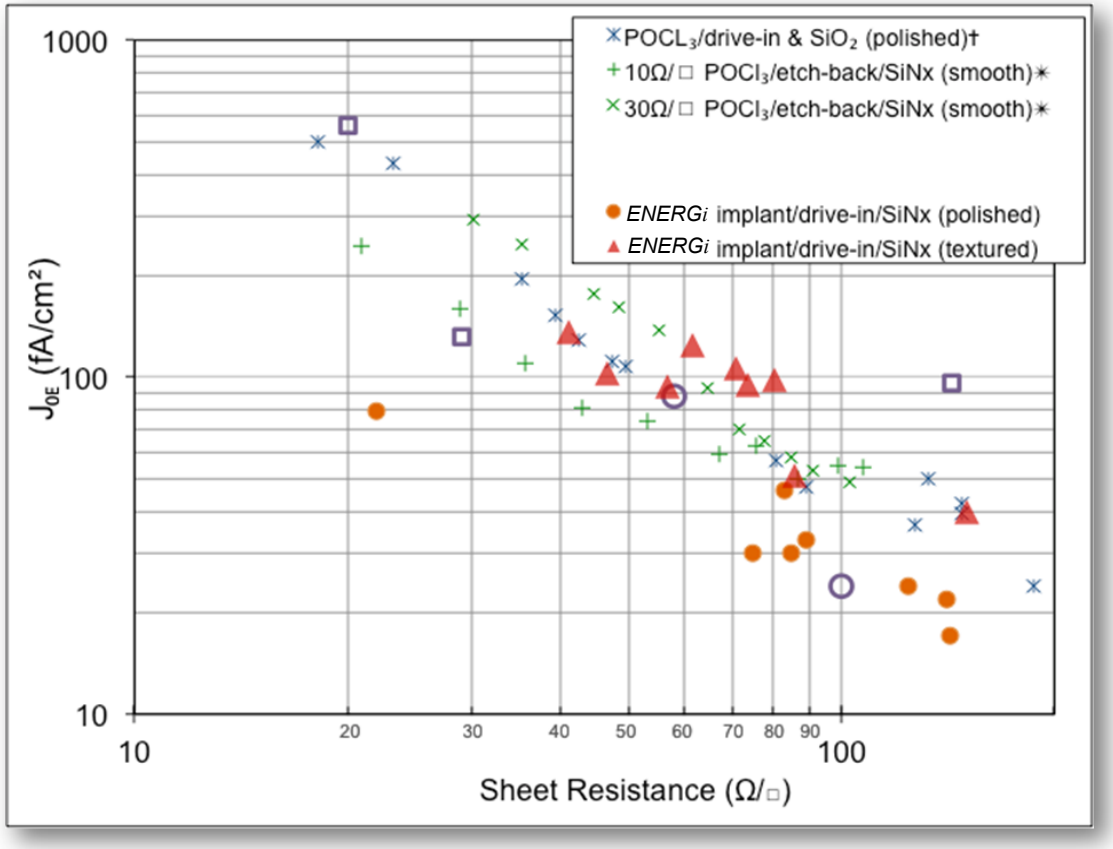

Schematic illustration of emitter optimization

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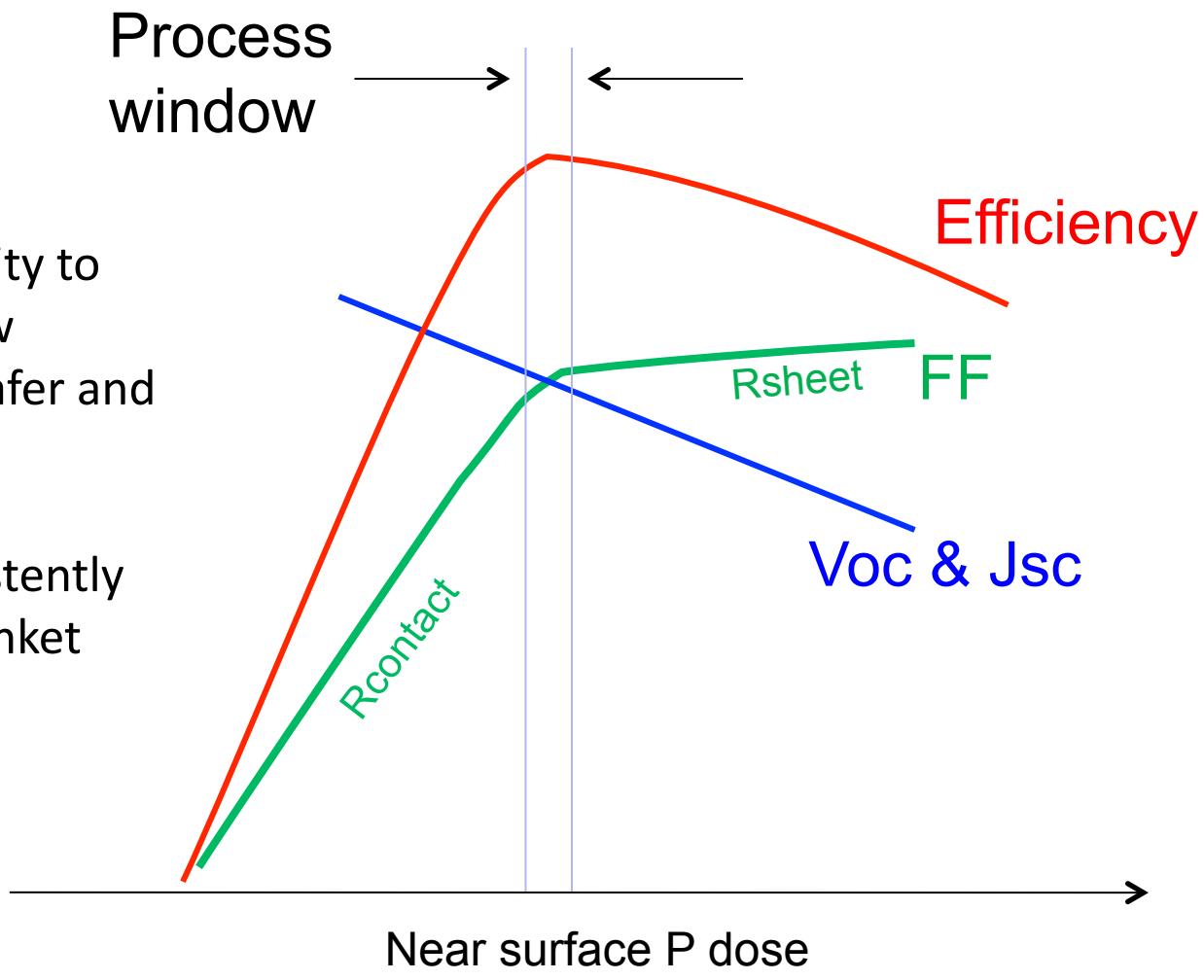
High efficiency requires ability to consitently achieve a narrow process window – within wafer and wafer to wafer.

Implantation helps to consistently achieve same P dose on blanket emitters



SELECTIVE EMITTERS with *ENERGi* implantation

Selective emitters

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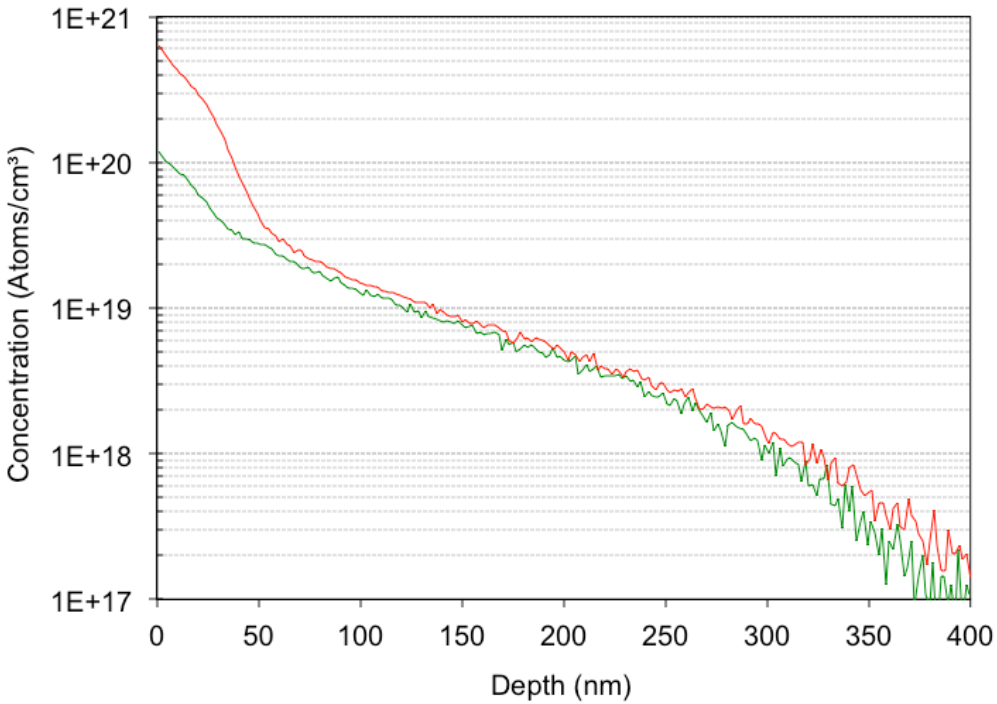
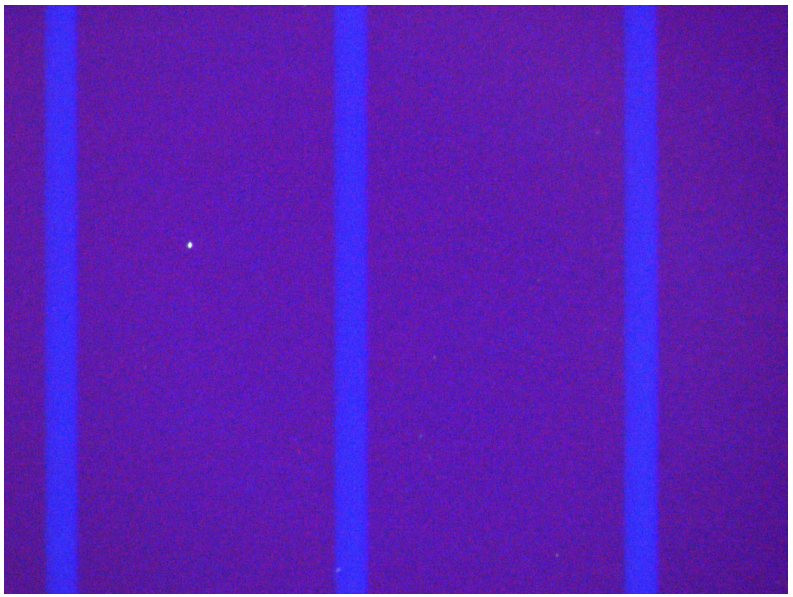
High P dose only under metallization for low Rcontact
Low P dose elsewhere for high Voc, Jsc





Optical image of *ENERGi* single pass implanted and annealed SE

One pass SE using shadow mask

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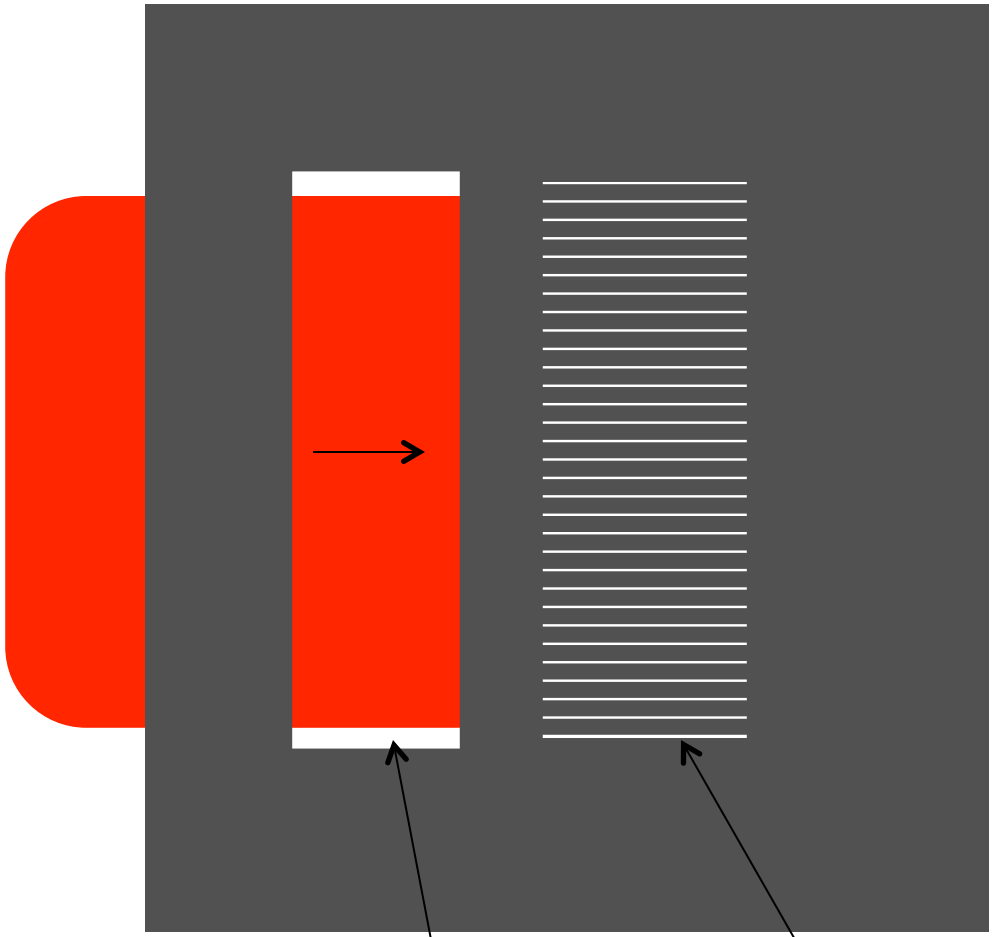


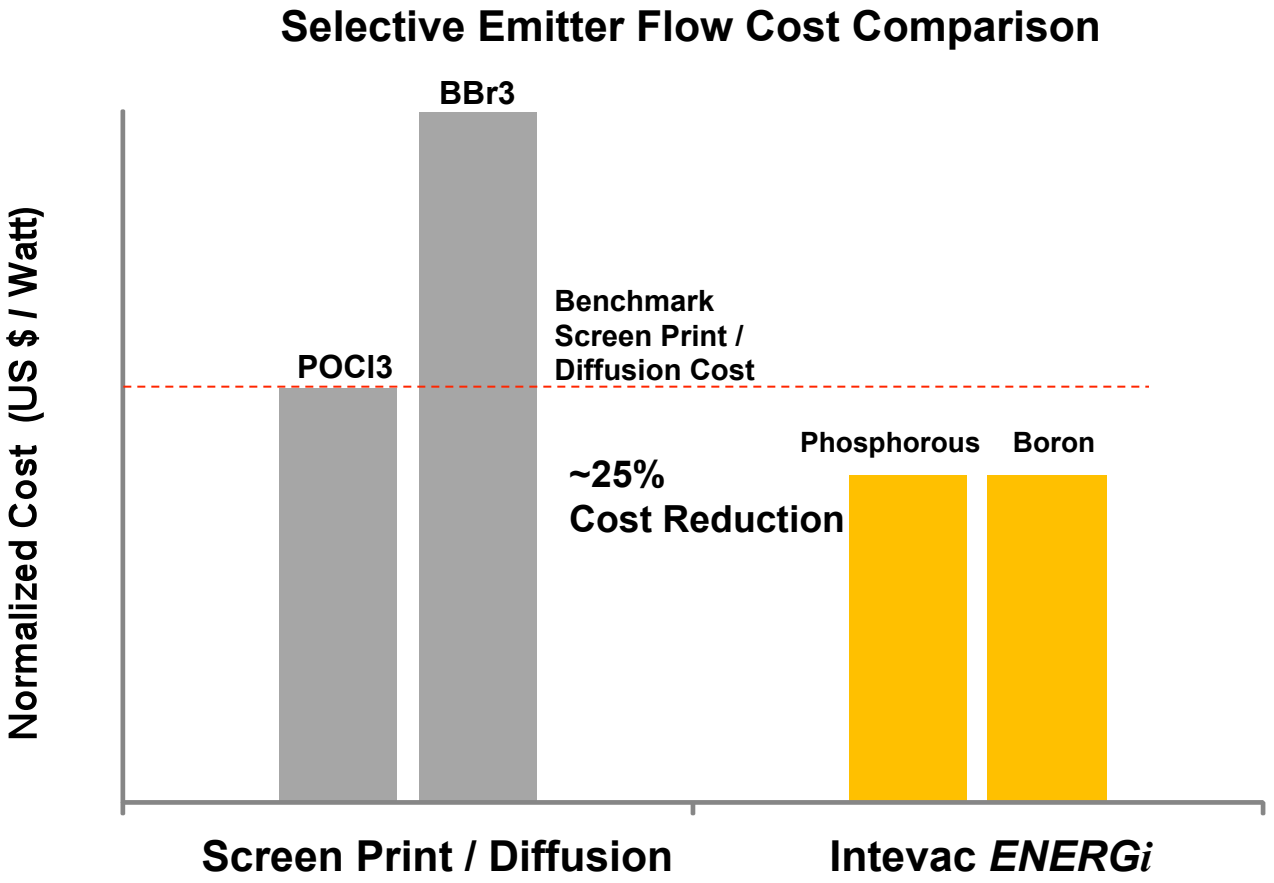
Selective emitter openings

Homogenous emitter opening

ENERGi schematic of single pass selective emitter doping.

Two zones of shadow mask create homogenous and selective doping

Cell Manufacturing CoO Reduction



ENERGi™ **enables lower cost of ownership for N and P-type cells**

Cost of ownership components: Capital, Gas, Utility, Floor space, Consumables, Labor

Enabling Ion Implant Solution

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Lean Solar *ENERGi*

- Improved emitter profiles for higher cell efficiency
- Capable of simultaneous selective and homogeneous emitter in one system
- Single sided implant enabling reduced process steps
- High productivity, lower COO than screen print / diffusion flow for selective emitter
- Enables high efficiency N-type cells

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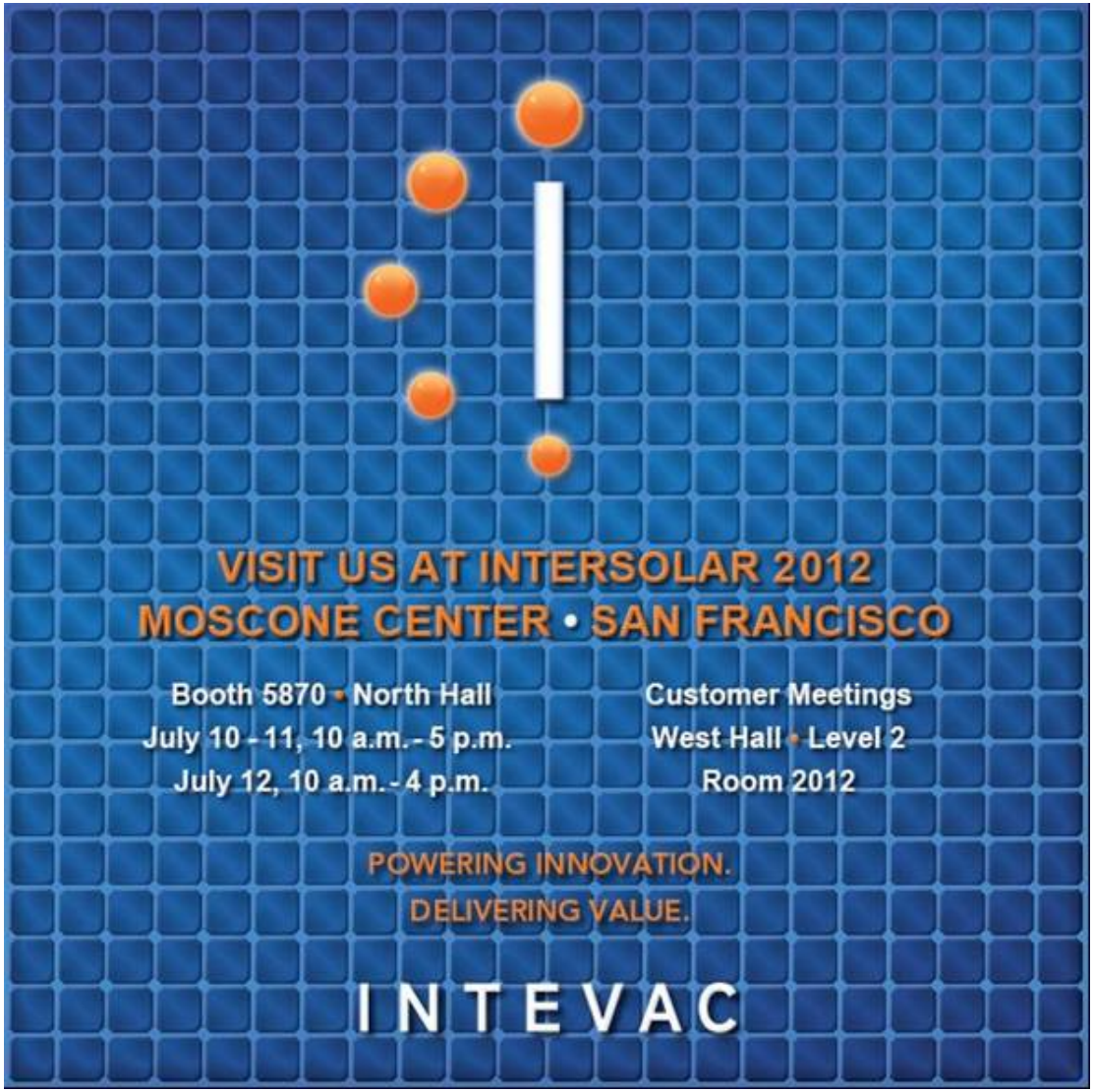

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