GaInP/GaAs/Si Triple-Junction Solar Cell Formed by Wafer Bonding

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Outline

- Triple-junction solar cells
- The GaInP/GaAs/Si solar cell
  - Why these semiconductors?
  - Challenge of the fabrication process
  - Wafer bonding process
- Results of the GaInP/GaAs/Si solar cell characterisation

Triple-Junction Solar Cells
Concentrator Technology

Single-junction Si solar cell:

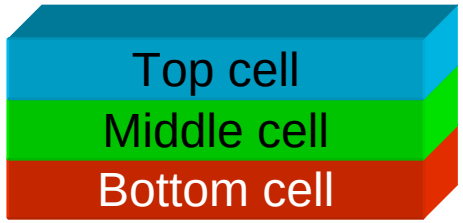
η = 25.5 %

Spectrum: AM 1.5g [1]

GaInP/GaInAs/Ge triple-junction solar cell:

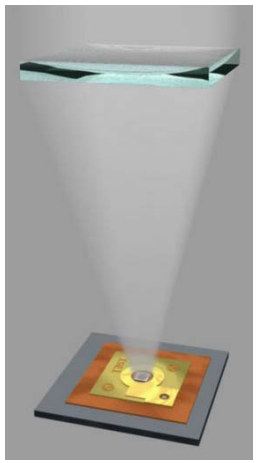
η = 41.6 % at 364 suns

Spectrum: AM 1.5d [1]



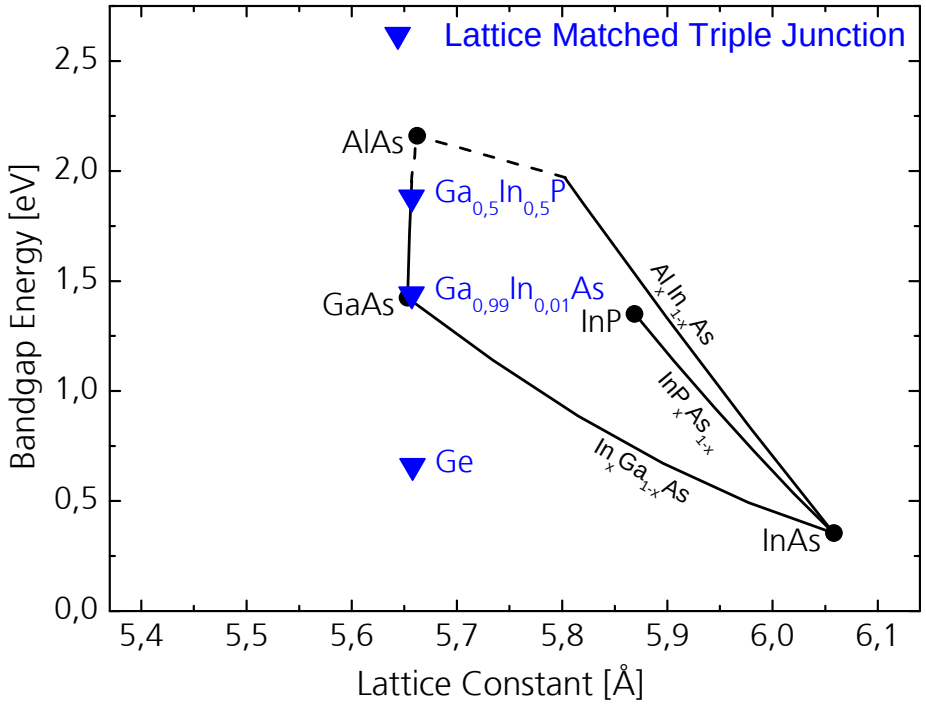
Advantages of concentrator cells:

- Efficiency enhancement under concentrated light
- Cost reduction by decreasing solar cell size to a few mm²



[1] Green et al., Progress in Photovoltaics: Research and Applications 18 (5), 2010

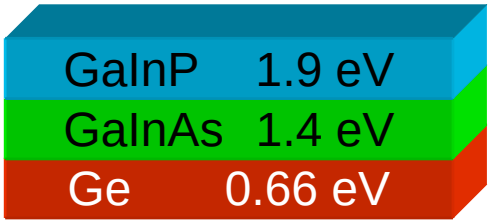
Triple-Junction Solar Cells
III-V Semiconductors



- Wide range of possible bandgap energies
- Epitaxy: high crystal quality for lattice matched semiconductors

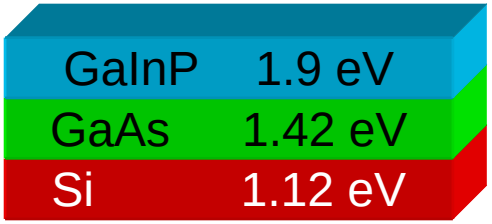
Triple-Junction Solar Cells
Solar Cell Designs

Conventional lattice matched triple-junction solar cell



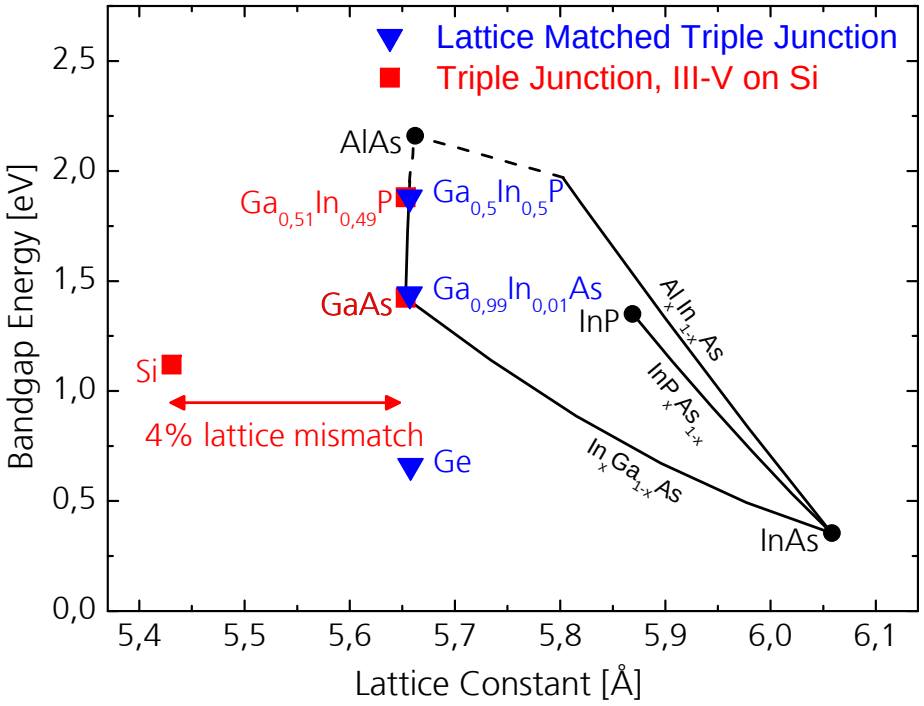
- Ge bottom cell produces high excess current
  - → Cannot be used due to serial connection

III-V on Silicon



- Higher bandgap
  - → Higher voltage
- Cheaper substrate material

Triple-Junction Solar Cells
III-V on Silicon



4% lattice mismatch between III-V dual-junction and silicon solar cell

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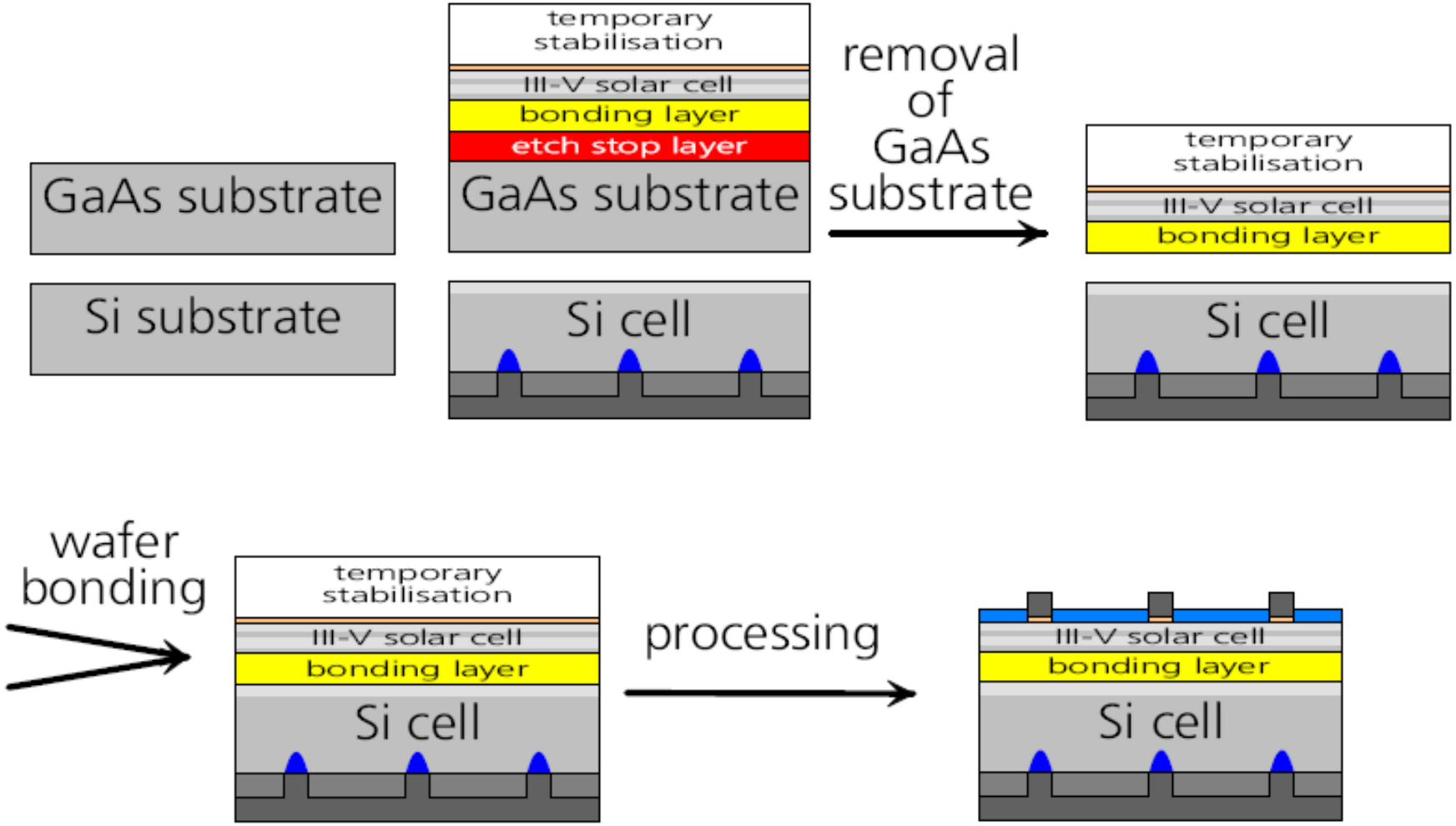
III-V on Silicon

Process of Fabrication



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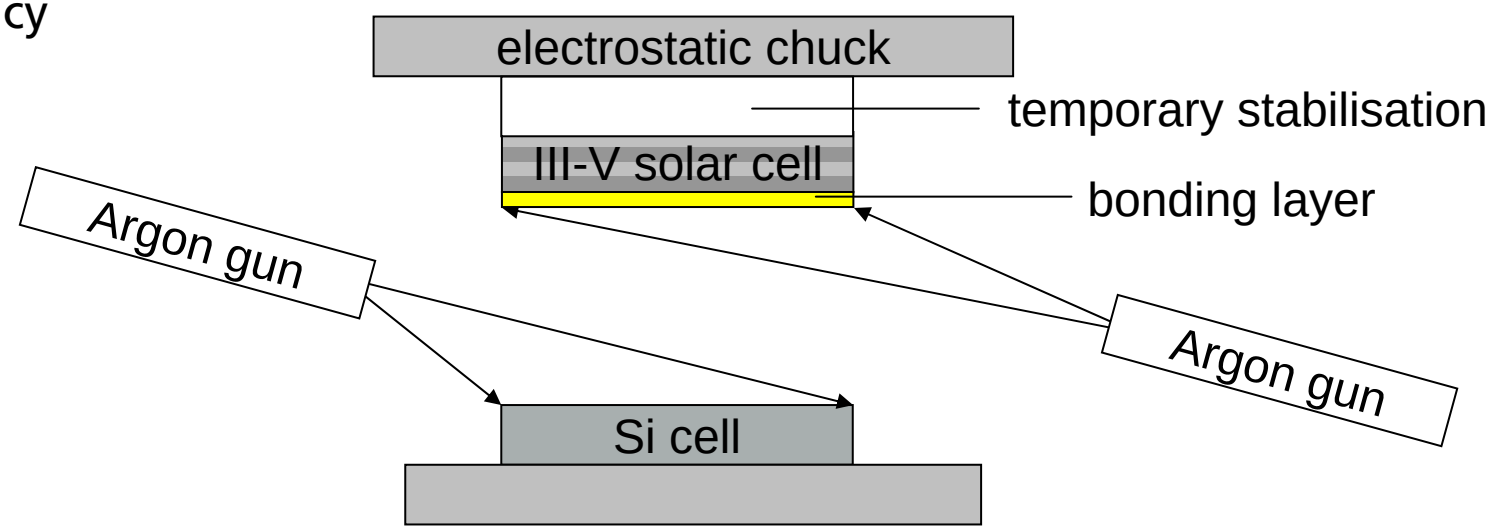
III-V on Silicon

Direct Wafer Bonding: Surface Cleaning and Activation

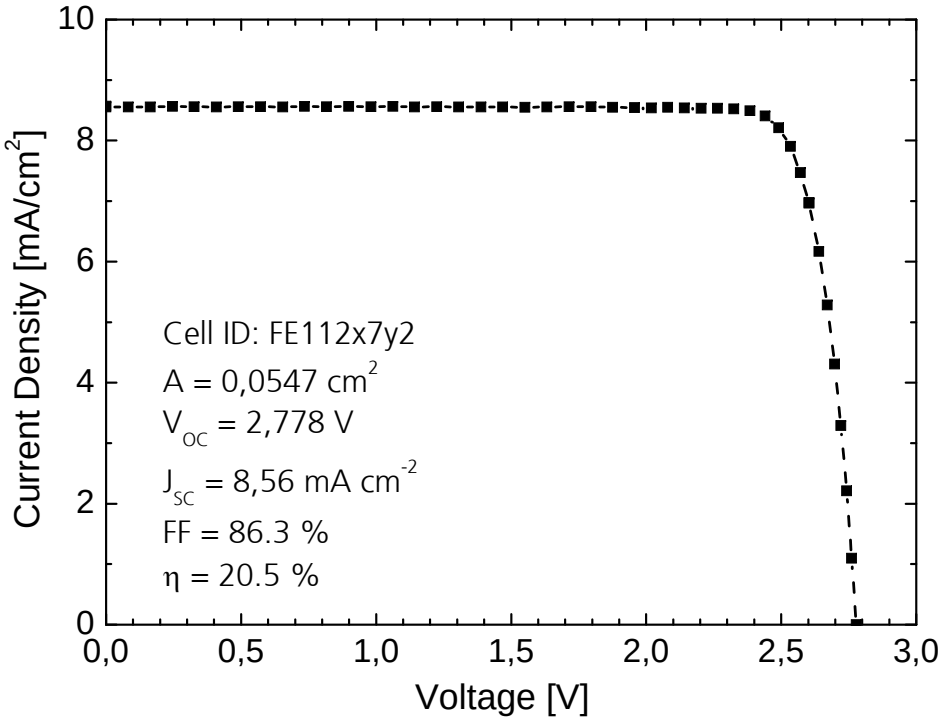
Demands on bond interface:

- High electrical conductivity
- Transparency



- Surface cleaning and activation by Ar-beam
- Bonding in vacuum chamber at room temperature

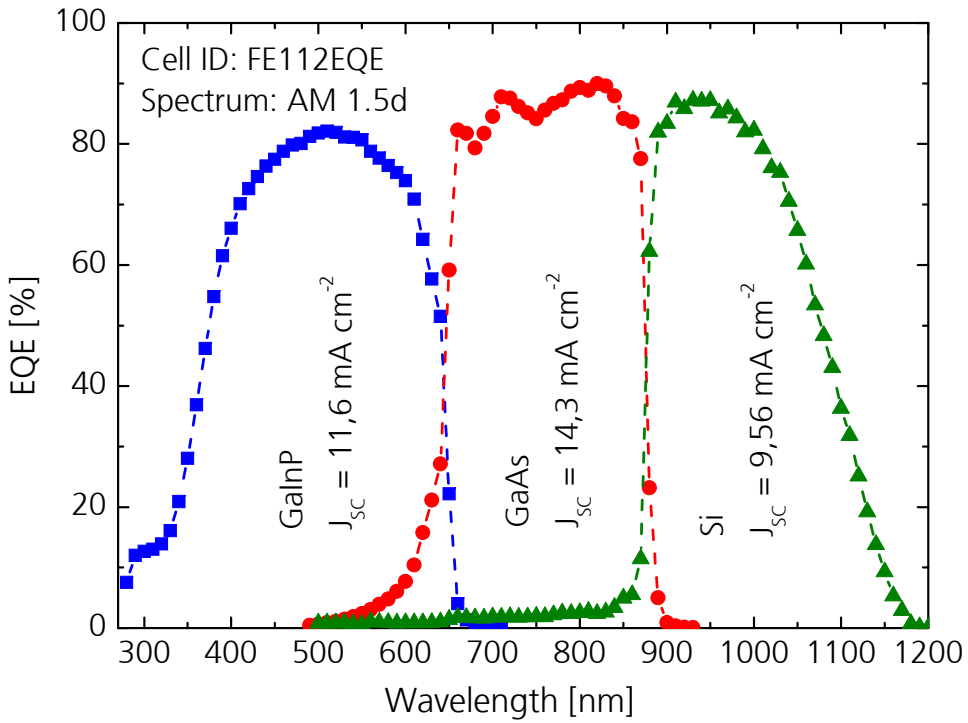
GaInP/GaAs/Si Solar Cell
IV-Characteristic



Remarkable cell efficiency for the first GaInP/GaAs/Si solar cell fabricated by wafer bonding:

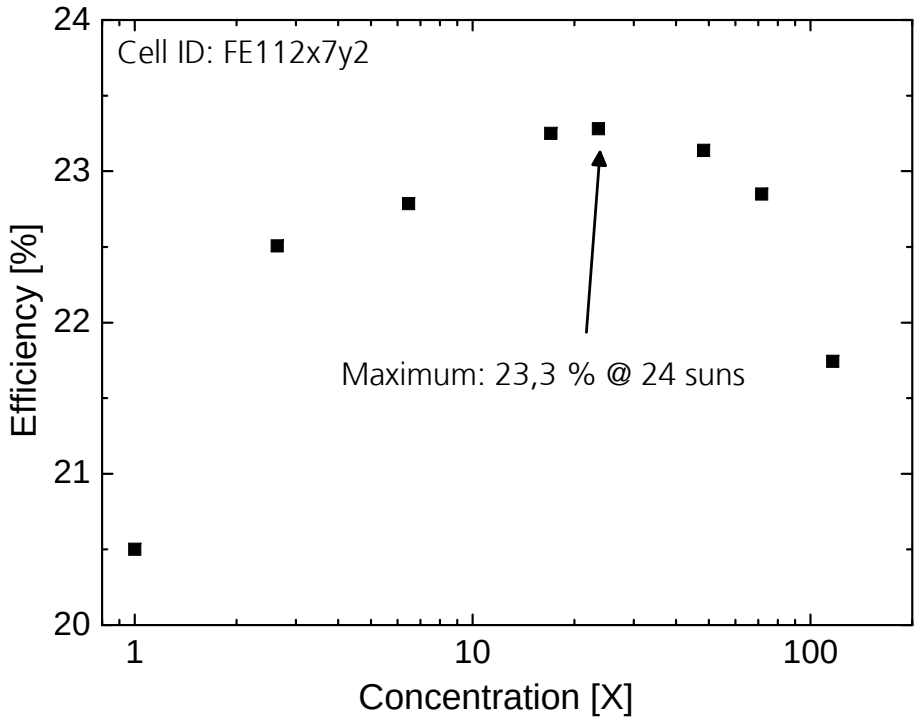
20.5 % under AM 1.5d spectrum

GaInP/GaAs/Si Solar Cell
External Quantum Efficiency



- Si subcell has lowest current density
  - → limits the total current density
- Energy conversion in Si has to be increased
- Thickness of upper subcells should be reduced

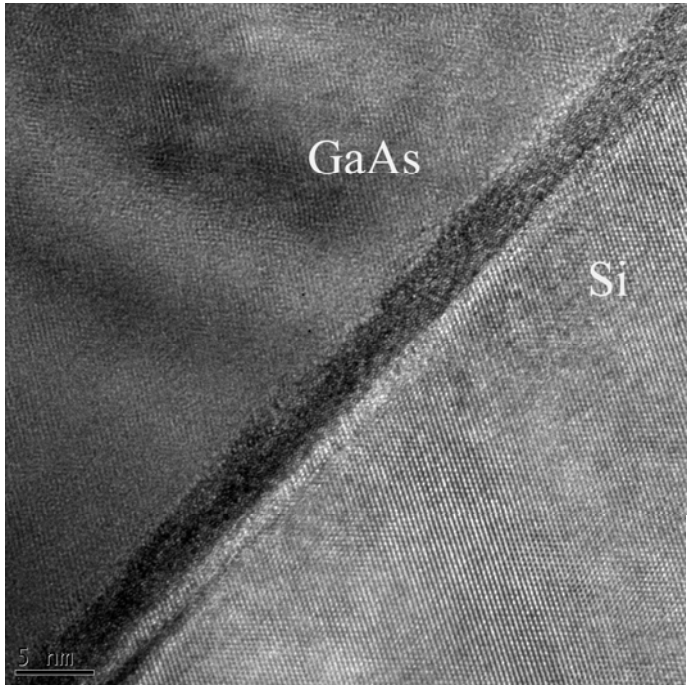
GaInP/GaAs/Si Solar Cell
Efficiency under Concentrated Illumination



Efficiency starts decreasing at 24 suns

→ Series resistance in cell structure

GaInP/GaAs/Si Solar Cell
TEM Analysis of Bond Interface



High Resolution TEM Image,
Bright Field, Zone Axis Si

Universität Kiel, Institut für Materialwissenschaft, Gruppe Prof. Dr. Jäger, 2010

- TEM: amorphous layer between GaAs and Si of 3-4 nm thickness
  - → Reason for series resistance?

Summary

- Successful fabrication of first GaInP/GaAs/Si by wafer bonding
- Remarkable cell efficiency of 23.3 % at 24 suns
- Si subcell limits the current density
- Efficiency decreases strongly under high concentration
- Amorphous layer at the bond interface probably reduces current density under high concentration

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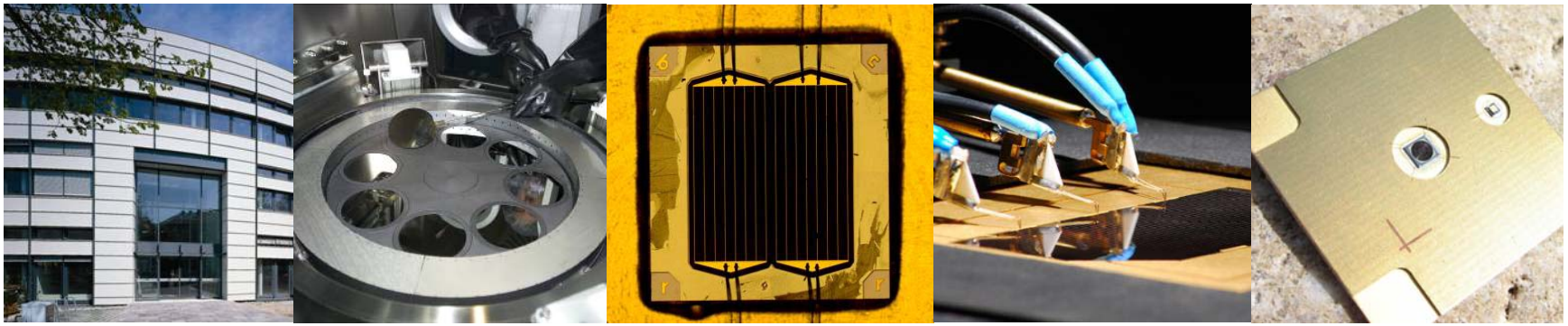
Thank You Very Much for Your Attention!



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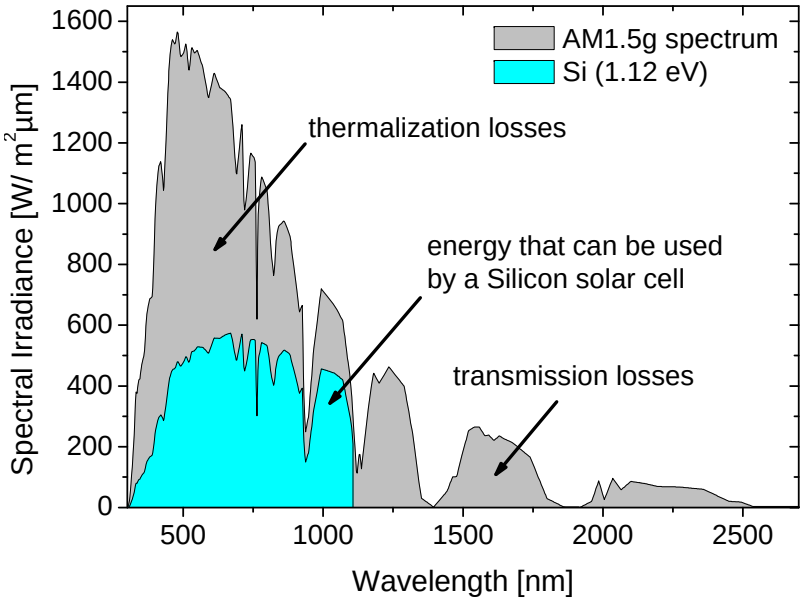
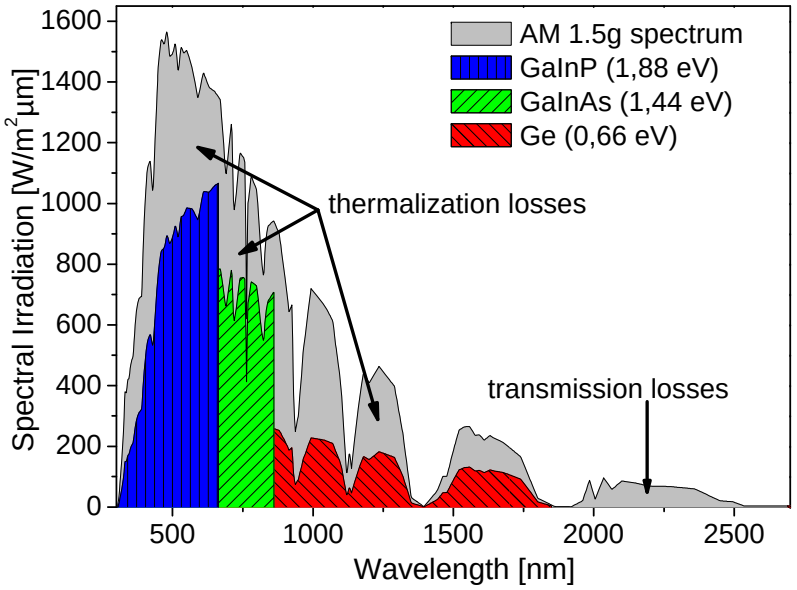
III-V on Si
Process of Production: Lift-Off

Triple-Junction Solar Cells
Theoretical Conversion Efficiency



$\eta_{theoretical,\ AM\ 1.5g} = 33{,}3\ \%$



$\eta_{theoretical,\ AM\ 1.5g} = 50\ \%$