Generation of a Line Focus for Material Processing from an Array of High Power Diode Laser Bars

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Overview

- **This slidepack discusses packaging of a linear arrays of laser bars**
  - Application: Laser Solid Phase Epitaxy (SPE) of photovoltaic cells
  - Based on the use of next generation 808nm laser bars

- **Sponsoring**
  - This work was sponsored by EU project **HIGH-EF**
    - 7th technological framework program under contract 213303
Laser-SPE

- **Starting material**
  - Amorphous silicon [a-Si] film deposited on glass substrate

- **Growth of multi-crystalline silicon film**
  1. Scanning of the a-Si film by **line focus laser**
     - Formation of 100µm wide seed crystallites (mc-Si) from the melt
  2. Deposition of a-Si onto the seed layer of mc-Si
  3. Furnace anneal
    - Epitaxial growth from the solid phase of deposited a-Si
    - Starting from the seed layer formed by laser treatment
Solution based on Diode Laser Bars

• **Requirements for the annealing laser source**
  
  – Short emission wavelength  
    • Absorption in silicon decreases towards higher wavelengths
  
  – High output power concentrated in a narrow (spatial) line  
    • Fast melting and cooling rates necessary in the silicon film
  
  – Scalable concept
    
    • L=5cm, 10cm,…, 100cm
Solution based on diode laser bar

- **Laser bars** are an ideal source to meet the requirements

\[ \theta_F = 30^\circ \text{ FWHM} \]
\[ \theta_S = 10^\circ \text{ FWHM} \]

- Technology available at short wavelengths **800nm-810nm**

- High efficiency and power levels can be realized
  - State of the art: 100W / bar at 800nm-810nm
  - Demonstrated advancement in this project: **125W-140W CW / bar**
    - E2 facet passivation to avoid COMD
    - Hard soldering of bars onto Micro-Channel Coolers

- Low bow assembly **< 1\mu m** achievable
  1. Soft soldering: Disadvantage insufficient long term stability
  2. Soldering onto stress buffer (CuW or CuMoCu) + hard solder (AuSn)
  3. Use of expansion matched Micro Channel Coolers + hard solder (AuSn)
Bar Performance

Hard-solder die attach with minimum smile onto Micro Channel Cooler

180W / 200A CW at 808nm, 600W / 500A quasi-CW (500µs)

<1µm bow
From the Laser Bar to the Line Focus

• **Combine the output of 7x 808nm laser bars**
  - Hard soldered onto expansion matched Micro Channel Coolers
  - Arranged in a linear geometry
  - Up to 1.3kW of input power available

• **Independently transform Slow and Fast Axis angle spectra**
  - Fast axis transformation defines the width $2w$ of the line focus
  - Slow axis transformation defines the length $L$ of the line focus
From Bar to Line Focus: Optical Concept

- **Fast Axis transformation** *(define width 2w of line focus)*:
  1. Aspheric Fast Axis Collimation *(FAC)* lenses
    
    - **High vertical divergence of bars** ➔ **Vertically collimated beam**

    ![FAC diagram](image)

  2. Concentration via cylindrical Fast Axis Focusing *(FAF)* Lens
    
    - **Collimated beam** ➔ **Focus**

    ![FAF diagram](image)
From Bar to Line Focus: Optical Concept

- **Slow Axis transformation** *(define length L of line focus):*
  1. Homogenizer
     
     Slow Axis angular spectrum of laser \(\rightarrow\) “Top Hat” angular distribution
  
  2. Transform (Fourier) lens
     
     “Top Hat” angular distribution (after homogenizer) \(\rightarrow\) "Top Hat" intensity profile

\[ L = 2\beta f_{TL} \]
Implementation: FAC attachment

- Bar on Micro Channel Cooler
- Glue point
- FAC Lens
- Laser Bars
Implementation: Homogenizer

Transform optics

Homogenizer

Fast Axis Focusing Lens
Scaling of Line Length

- Industrial scale applications require annealing of 1m-panels
- Scale-up of the present approach
  - Via joining of lines from multiple sources
  - Angled stitching of 5 cm lines
Electro-Optic Performance of Line Source

- **920W at 140A**
  - Throughput of optics = **87%**

- **<9nm spectral shift threshold to 130A**
  - Thermal resistance = **0.35K/W**

![Graphs showing Electro-optic Characteristics and Spectral Shift](image)
Parameters of Line Focus

- **Peak irradiance, 140A** = 10kWcm\(^{-2}\)
- **Length of line** = 45mm
- **Homogeneity** = ±3% rms
  - Variation of peak intensity
Achieved Performance in Laser-ESP

- **Successful application of developed line source demonstrated**
  - Collaboration with Institute for Photonic Technology HT Jena
- **Seed crystals formed from the melt of a-Si film evaporated on glass**
  - Generation of domains > 100μm achieved
  - Peak irradiance during processing 6kWcm⁻²
  - Scan speed 1 cm sec⁻¹
Conclusion

• **Line source based on newly developed 808nm laser bars presented**
  – Field of application:
    Annealing of a-Si films in Laser-ESP growth of mc-Si for solar panels

• **Presented line source combines the output of 7 bars on MCC**
  – Demonstrated peak irradiance 10kWcm⁻²
  – Length-scalable concept

• **Successful application demonstrated in Laser-SPE process**
  – Length scaling via stitching presently under investigation
  – Evaluation in the solar cell process scheduled as next step