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

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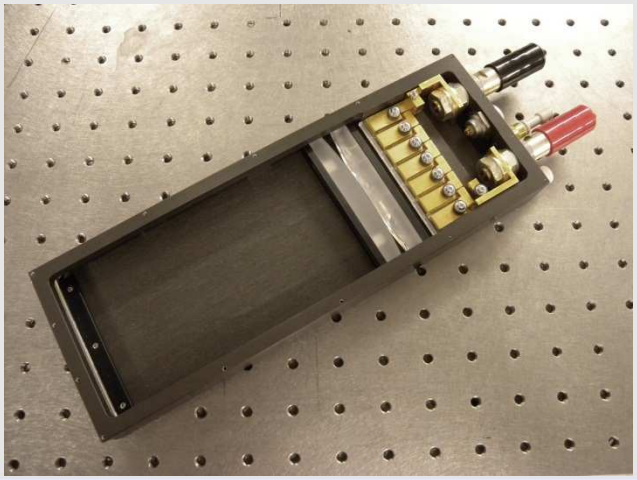


# Overview

- **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

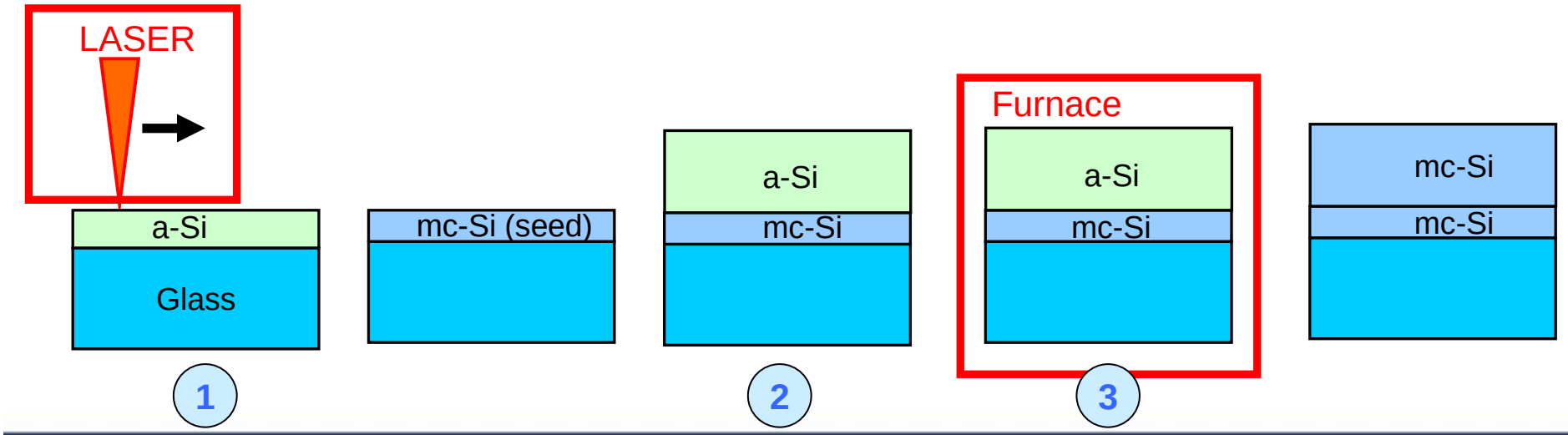
# Laser-SPE

- **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

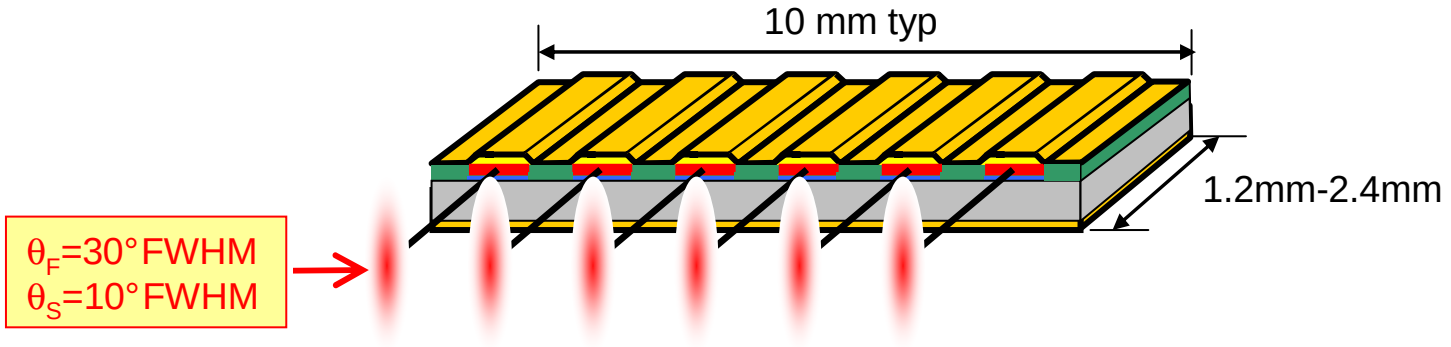


# Solution based on Diode Laser Bars

- **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**

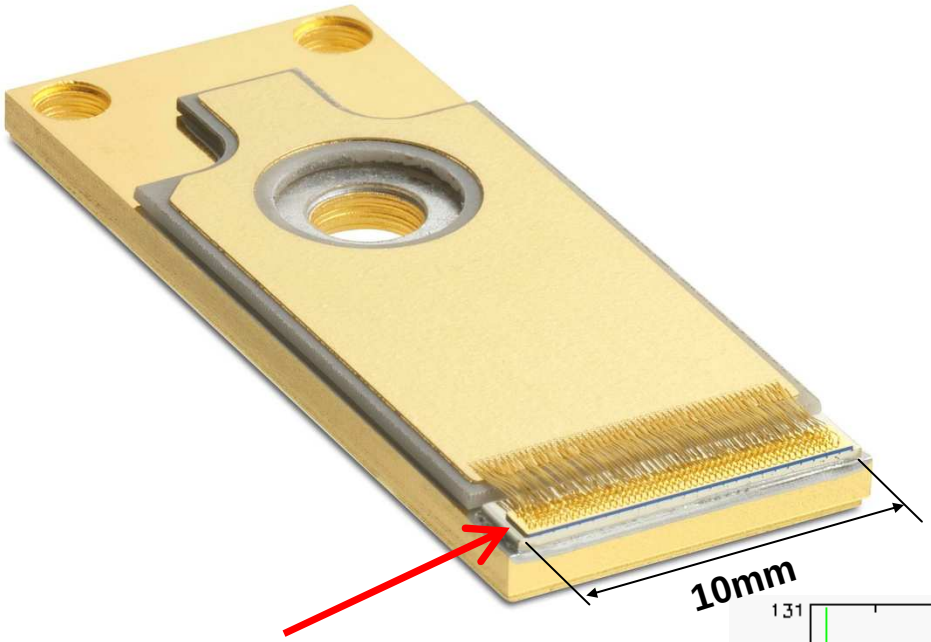



- **Technology available at short wavelengths 800nm-810nm**

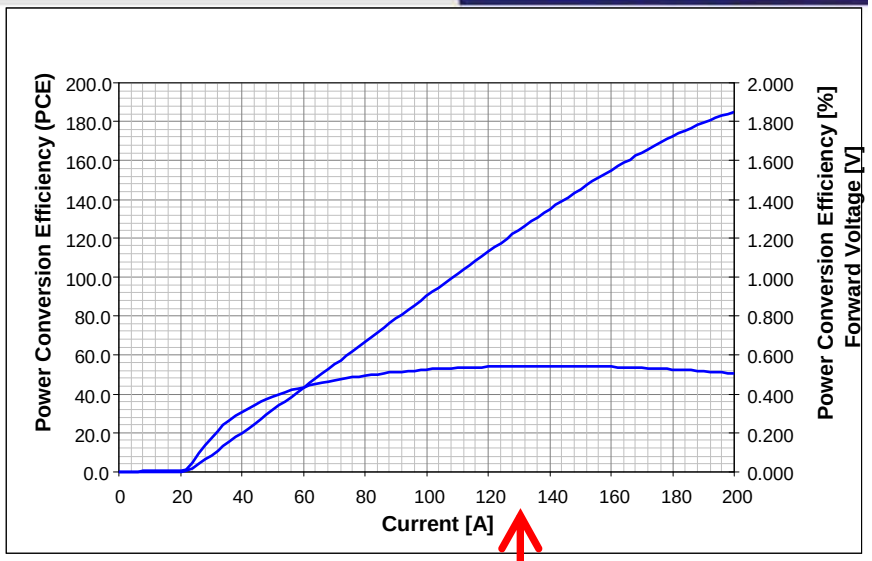
- **High efficiency and power levels can be realized**
  - State of the art : 100W / bar at 800nm-810nm
  - Demonstrated advancement in this project: **125W-140W CW / bar**
    - E2 facet passivation to avoid COMD
    - Hard soldering of bars onto Micro-Channel Coolers

- **Low bow assembly < 1μm 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)

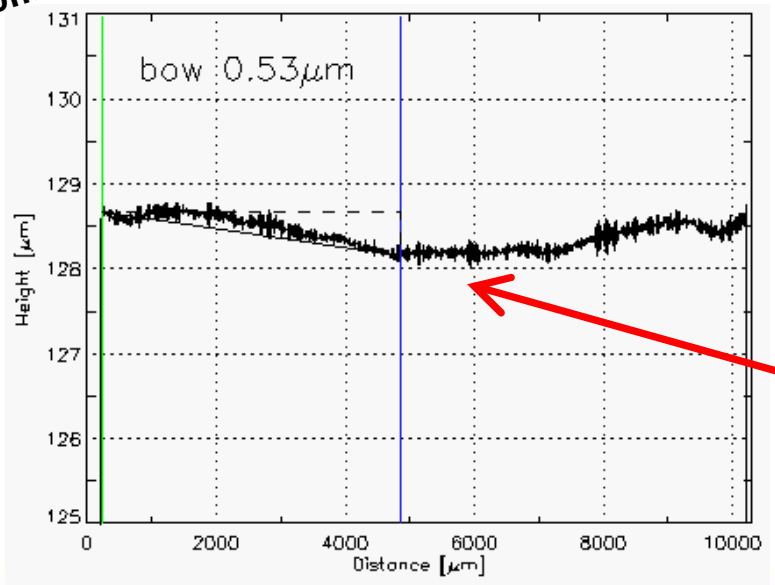
# Bar Performance




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

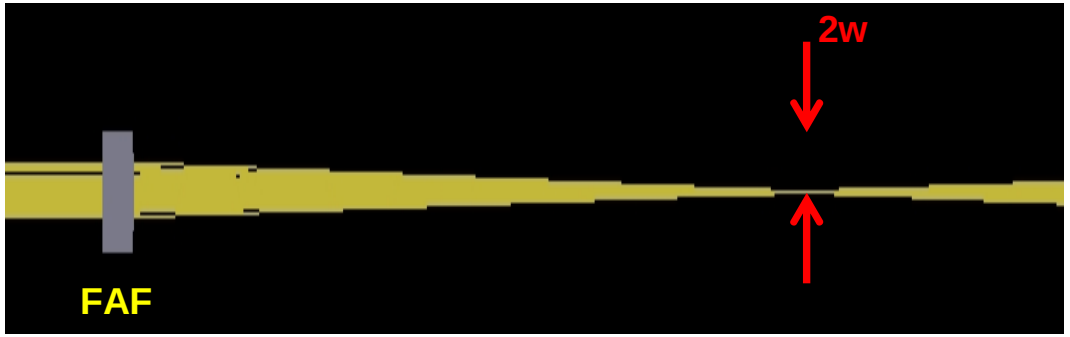
- **Fast Axis transformation (define width 2w of line focus):**

1. Aspheric Fast Axis Collimation (**FAC**) lenses

**High vertical divergence of bars** → **Vertically collimated beam**


2. Concentration via cylindrical Fast Axis Focusing (**FAF**) Lens

**Collimated beam** → **Focus**



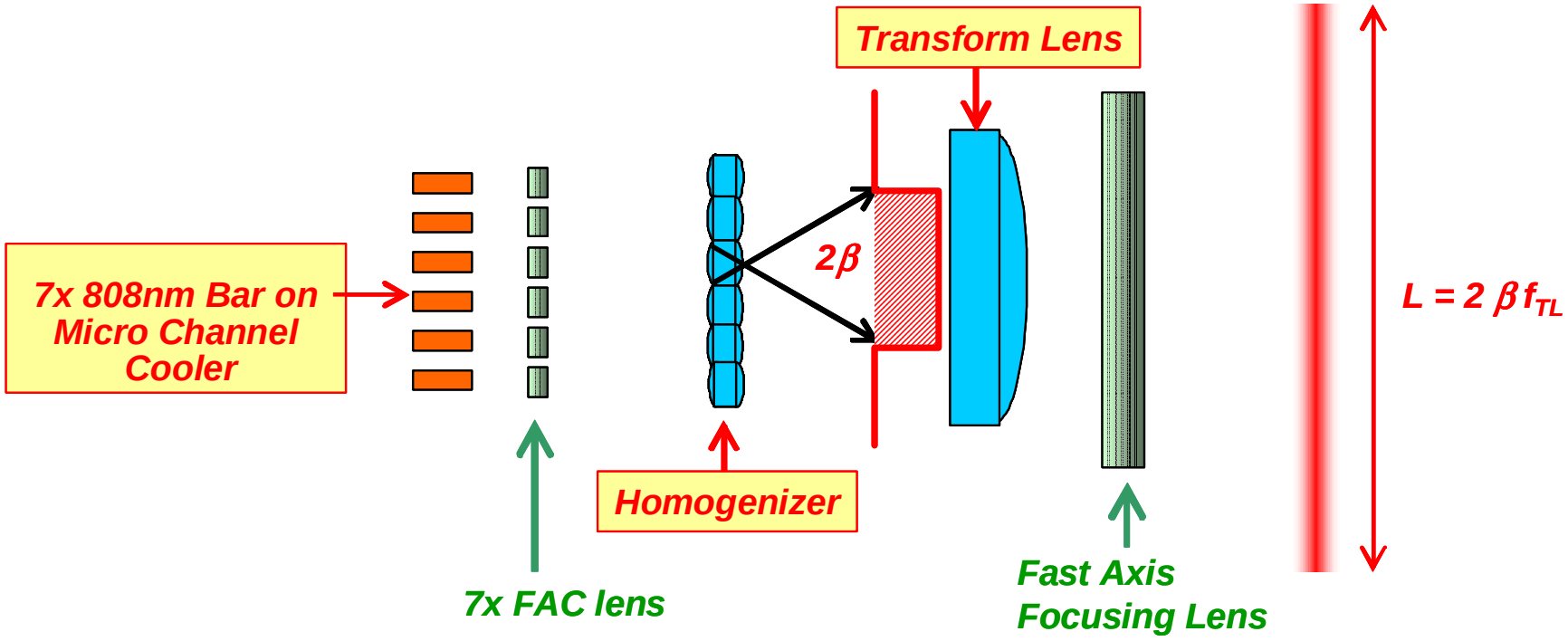
# From Bar to Line Focus : Optical Concept

- **Slow Axis transformation (define length L of line focus):**
  1. Homogenizer

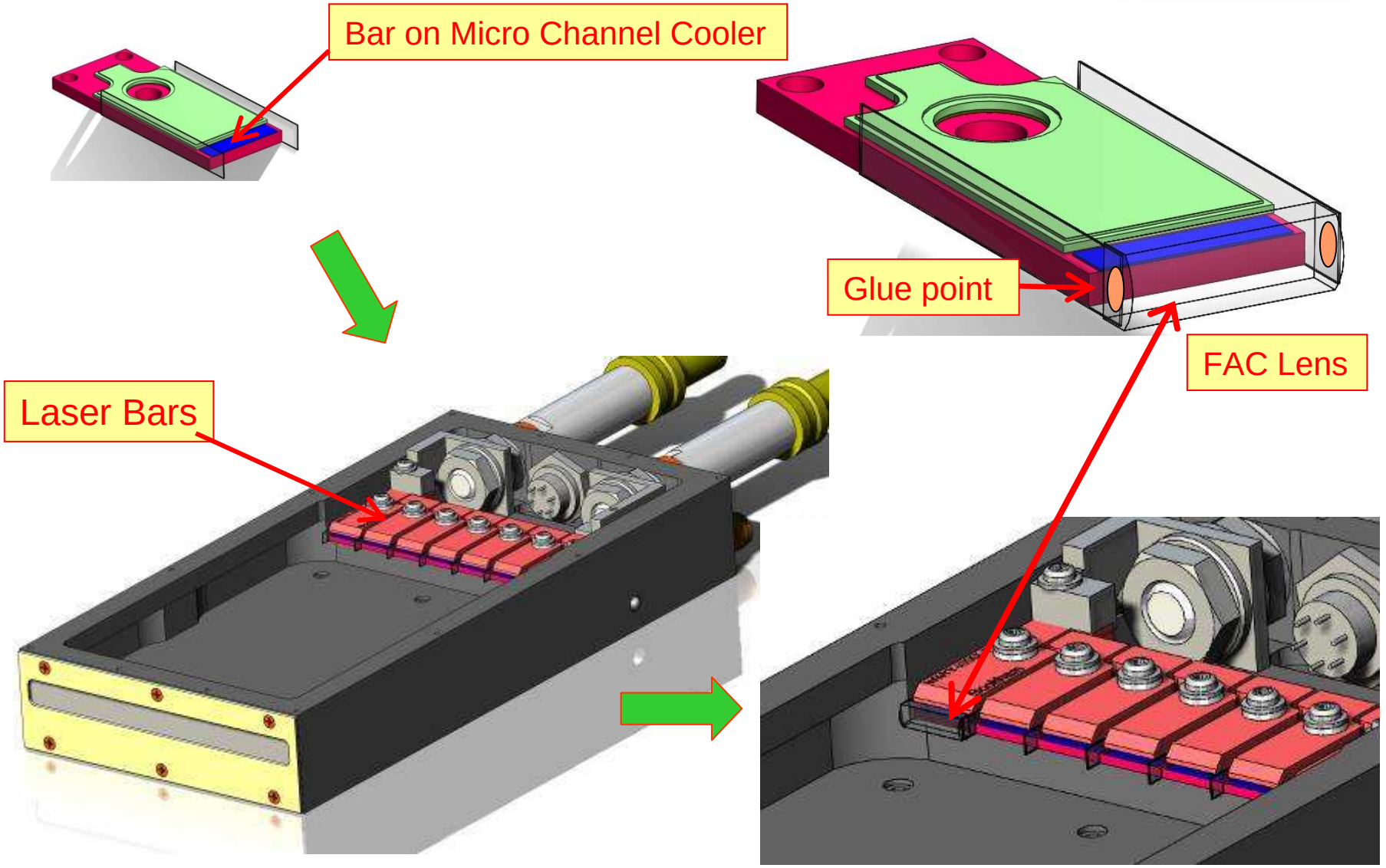
     **Slow Axis angular spectrum of laser** → **"Top Hat" angular distribution**

  2. Transform (Fourier) lens

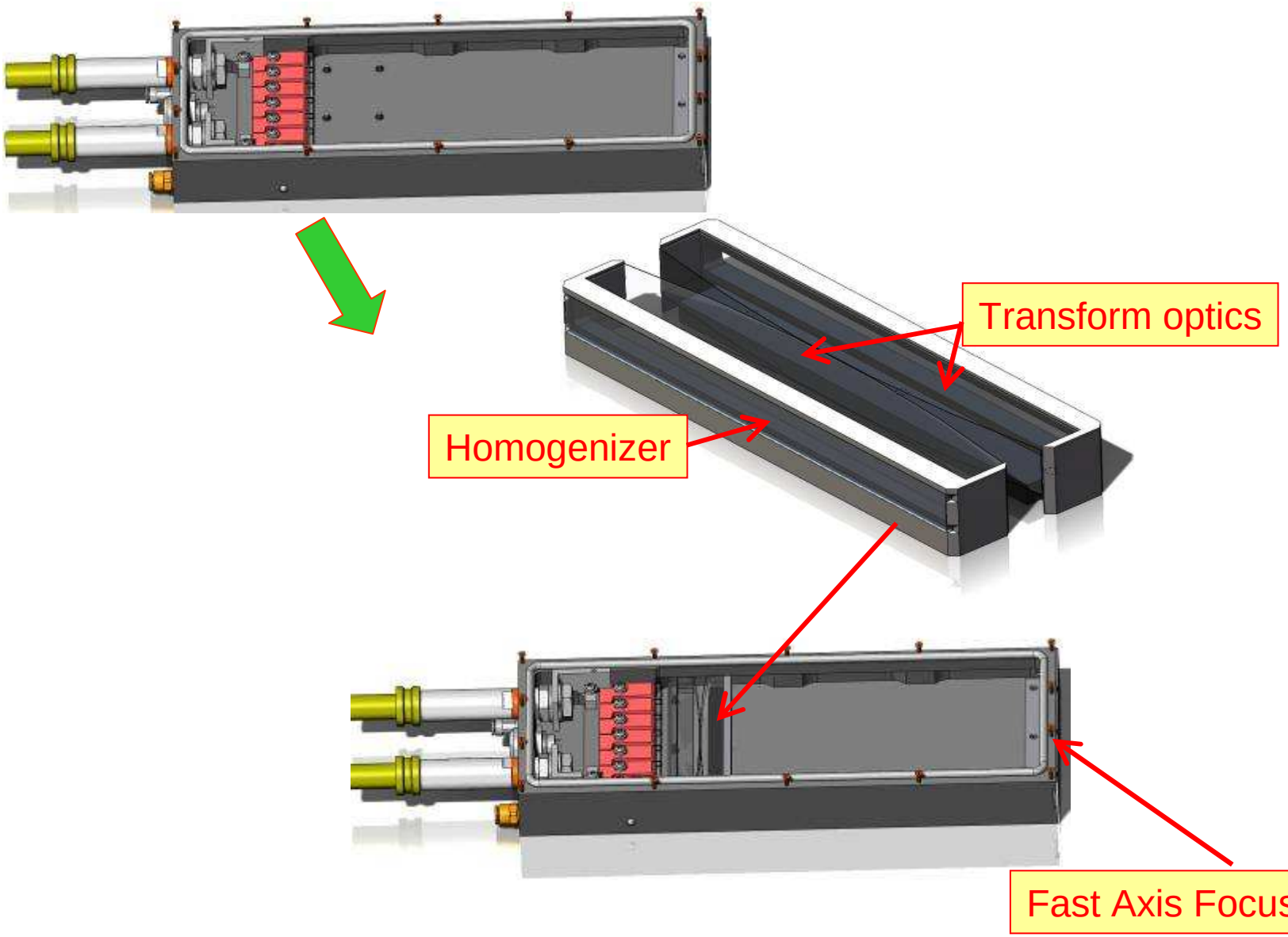
     **"Top Hat" angular distribution (after homogenizer)** → **"Top Hat" intensity profile**



# Implementation : FAC attachment

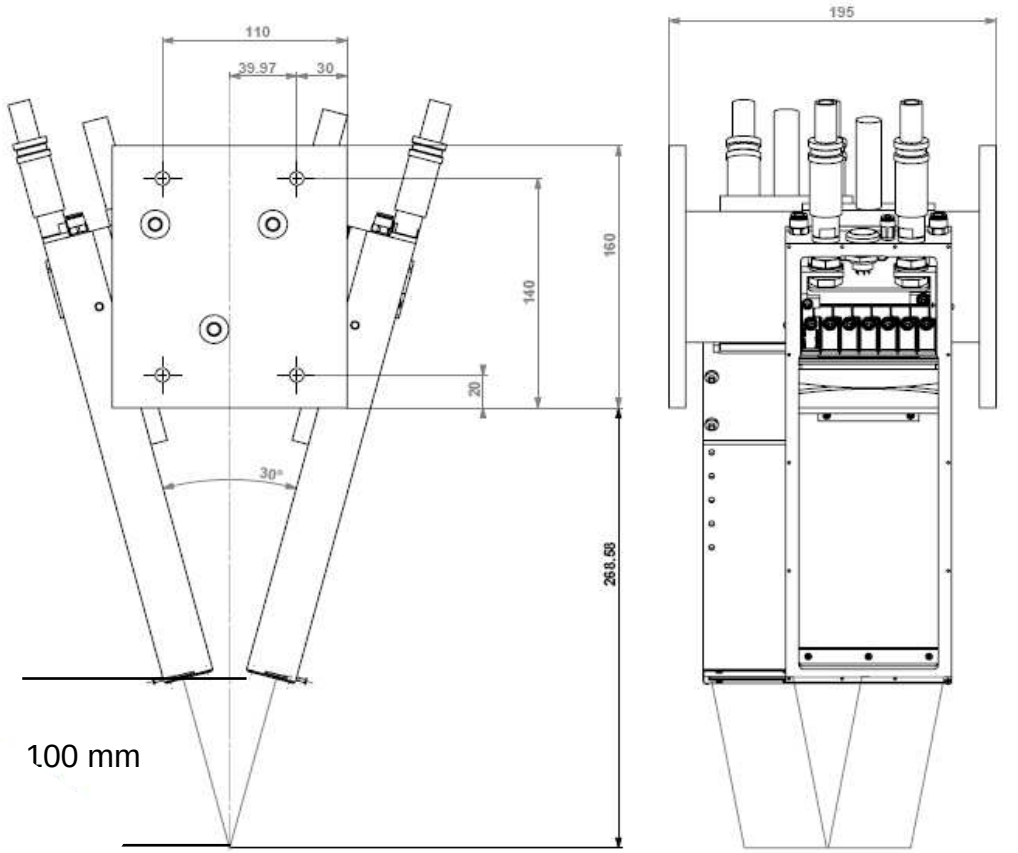


# Implementation : Homogenizer



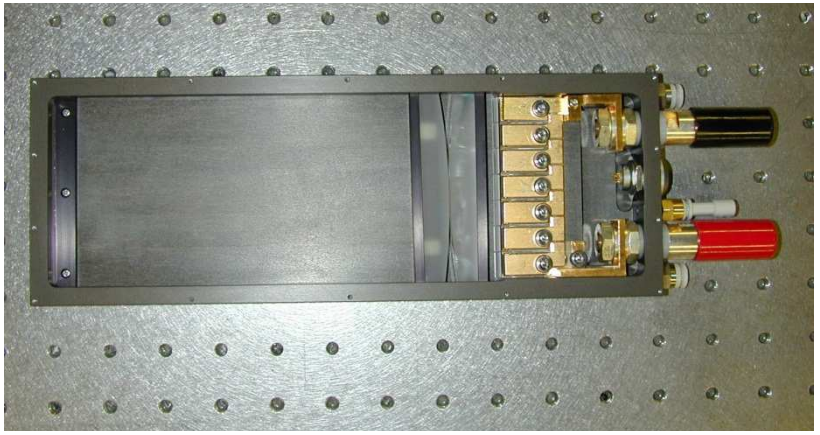
# Scaling of Line Length

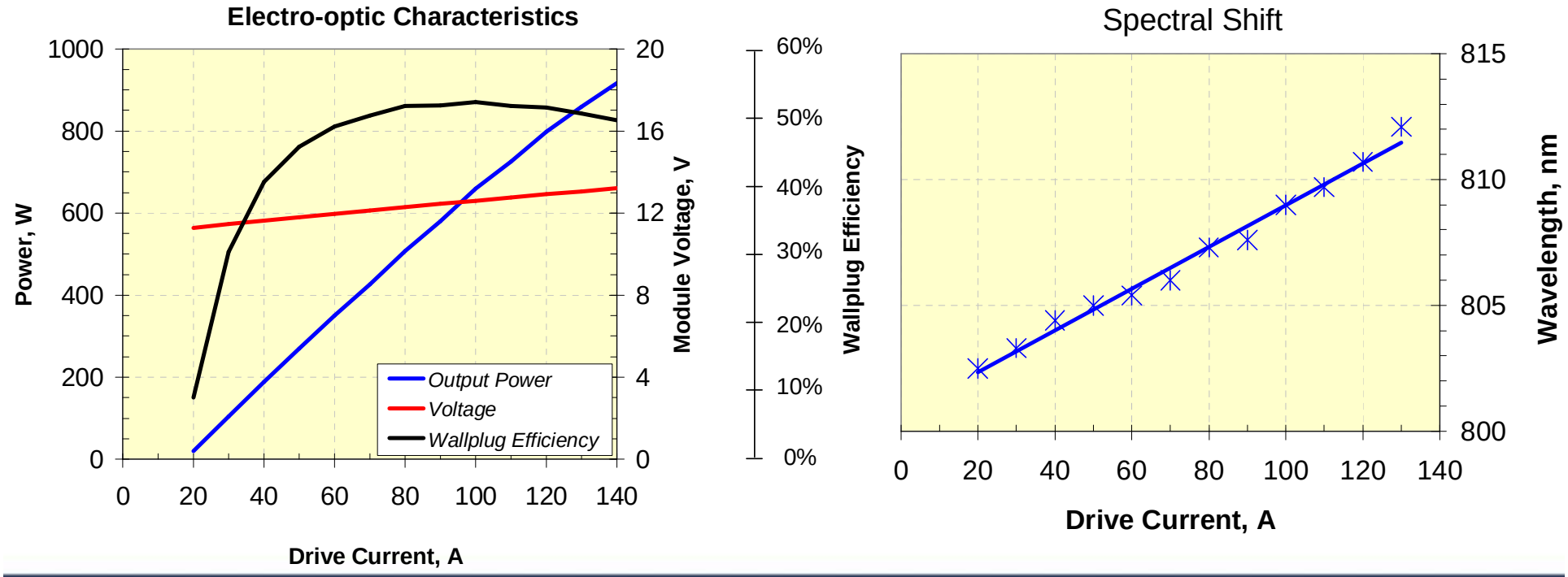
- **Industrial scale applications require annealing of 1m-panels**
- **Scale-up of the present approach**
  - Via joining of lines from multiple sources
  - Angled stitching of 5 cm lines



# Electro-Optic Performance of Line Source

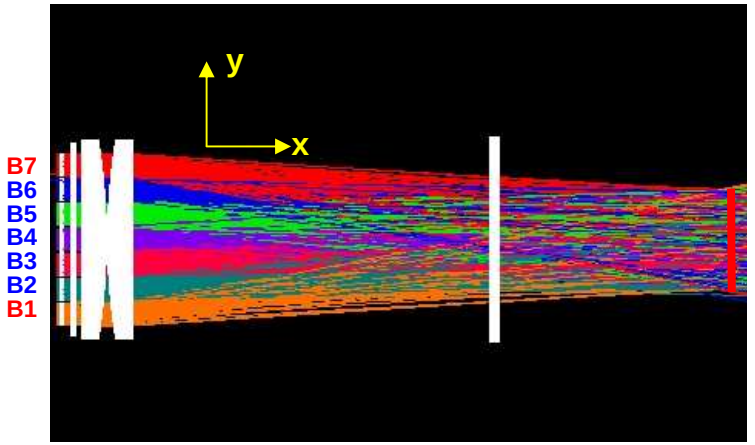
- **920W at 140A**
  - Throughput of optics = **87%**
- **<9nm spectral shift threshold to 130A**
  - Thermal resistance = **0.35K/W**

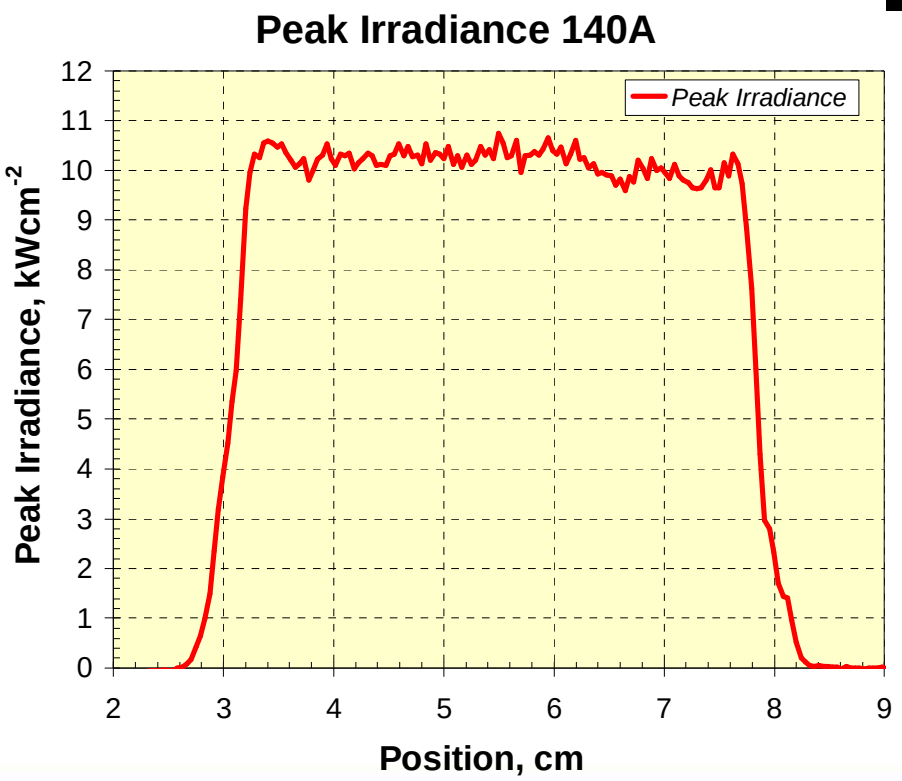




# Parameters of Line Focus

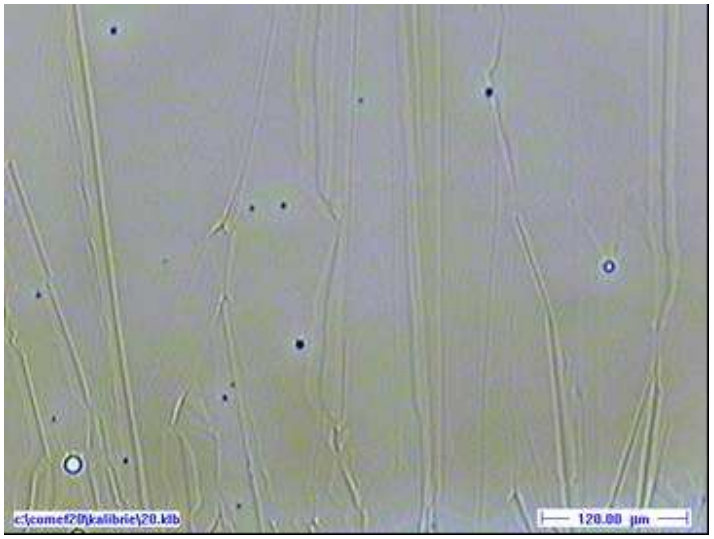
- **Peak irradiance, 140A = 10kWcm$^{-2}$**
- **Length of line = 45mm**
- **Homogeneity = ±3% rms**
  - Variation of peak intensity



# 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 1cm sec$^{-1}$




mc-Si film formed by laser annealing IPHT Jena

Setup realized at IPHT Jena

# 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