808nm – high power diode lasers for long term stable pump modules

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Outline

- FBH
- Design, technology and properties of single emitters
- Performance of CW laser bars
- QCW pump sources for BepiColombo
- First results for QCW pump sources with higher power and repetition rate (ATLID)
- Summary and outlook
Facts & Figures

- **Shareholders**
  - State of Berlin / Federal Republic of Germany

- **Founded in**
  - 1992

- **Member / Partner of**
  - Forschungsverbund Berlin e.V.
  - Leibniz Association
  - Technische Universität Berlin
  - Humboldt-Universität zu Berlin

- **Staff**
  - 160 (including 75 scientists & PhD students)

- **Budget / Turnover**
  - 14 M€ (including 5 M€ project revenues)
Mission of FBH

Applied research and development of microwave & optoelectronic devices, circuits and modules:

Innovations with Microwaves & Light

Market-driven & customer-oriented

- Close cooperation with partners in research and industry serving customers needs
- Part of value chain
- Demonstrators, pilot & small scale production
- Stringent quality management, DIN EN ISO 9001:2000
Research Topics

- Microwave components
- Power diode lasers
- UV emitters
- III/V-technologies

Programs

- Research and Development on microwave & optoelectronic devices, circuits, modules
- Transfer programs
  - Spin-offs and start-ups
  - SMEs
  - Global players
- Services
value chain
808nm diode lasers - basic technology of FBH

- **design:**
  - GaAsP – QW,
  - AlGaAs LOC structure \( (x \approx y+0.3) \)
  - low vertical divergence

- **chip-technology**
  - MOVPE multi wafer reactor
  - process line (full wafer 3"")
  - passivation after cleaving
  - coating by dielectric layers using IBS

- **mounting**
  - AuSn soldering of chips
  - use of expansion matched submounts
  - Au wire bonding
808nm diode lasers of FBH – basic data

typical data of 100µm stripe emitters

- **Threshold current density**
  \[ \approx 250 \text{A/cm}^2 \]

- **Slope efficiency**
  \[ > 1.2 \text{W/A} \]

- **Temperature stability**
  \[ > 120 \text{K} \]

- **COD level (500µs, 50Hz)**
  \[ > 10 \text{W/100µm} \]

- **TM polarisation**
808nm diode lasers of FBH – basic reliability

- Lifetime test at high facet load
  - Mounting on C-Mount ($R_{th} \approx 10\,\text{K/W}$)

- Excellent stability
  40mW / $\mu$m stripe width

- Failures at 50mW / $\mu$m stripe caused by internal defects

- QCW – bar performance determined by mounting issues and homogeneity!
  - Stability of chip material against optical load
    > 50 000h @ 2% duty cycle
  - Small chips
CW – laser diode benches for space suited 808nm pumping modules

- Projects
  - LCTSX
  - ALADIN
  - GIFTS
  - LTP
  - QSL

- Chip design
  - minibar (chip size <5mm)
  - low fill factor

- Space qualified mounting process
  - expansion matched materials
  - AuSn – solder
  - high precision, robust FAC fixing
  - external spectral stabilization
Reliability of space suited CW- laser diode benches

- Long term test ⇒ reliability > 0.99  4 years at P = 1W  (≤10mW/µm)
- Tested mounting scheme
  - temperature cycling
  - mechanical issues

4W, 10 000h, 60°C  LCTSX

4A, 10 000h, 25°C  ALADIN

- Status: Jan. 2006, test finished
  - Aging at constant current
    I = 4.0 A, T = 25°C  \( t = 10000 \) h
    (after 1500 h at const. power \( P = 3.33 \) W / \( T = 60°C \))

- 10 LDB at 60°C / 4W aging time: 10 000 h
  - test finished April 2005

- device hours (se): 600 000 h
  \( \Rightarrow \text{MTTF}_{0.6} = 11 \) Mh @ 0.325W / 45°C
808nm – QCW pump sources for Bepi Colombo

Requirements

- 700 W usable power (fibre coupled)
- 200µs pulse width, ≤10Hz rep. rate
- Long term stability
  - 300 Mio shots
  - about 10 year storage
- $T_{op} = (22 \pm 10)$ °C
- Environmental conditions (-45°C ... 65°C)
- small size and low weight
808nm – QCW pump sources for Bepi Colombo: chip - design

- design for 70W power / bar (derated power level)
- GaAsP QW
- LOC -structure
- small chip size
  - facet load 20mW/μm
  - 4.5 mm emitting aperture (half of standard bar!)
  - 1.5 mm resonator length
  - 35 emitter, filling factor 70%
- conversion efficiency of chip ≈ 60%
- wavelength (807 ± 2)nm
808nm – QCW pump sources for Bepi Colombo: mounting issues

- no dense vertical stacks
- Single devices
  on 10x10mm² footprint
- Expansion matched materials
- AuSn soldering
  (chip, n-contact plate)
- Wire bonding
- Approved FAC fixing
808nm – QCW pump sources for Bepi Colombo: L-U-I curves

- $I_{\text{th}} \approx 15$ A
- $I_{\text{op}} \approx 70$ A @ 70W
- Slope $\eta_d \geq 1.25$W/A
- Conversion efficiency $\eta_c \approx 50\%$ @ 70 W
- Series resistance $R_s \approx 9$ mΩ
- COD level $P_{\text{max}} > 250$W! ($>80$ mW/µm)
808nm – QCW pump sources for Bepi Colombo: spectral

- spectral peak 806nm
- spectral width (95% power) < 4nm
- additional modulation by FAC
- wavelength shift determined by temperature

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<th>Power</th>
<th>Wavelength</th>
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<tr>
<td>70W</td>
<td>805.6nm</td>
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<tr>
<td>100W</td>
<td>806.5nm</td>
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<tr>
<td>150W</td>
<td>808.7nm</td>
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</table>

Bar 09a12 from F0694-4; t=22°C
808nm – QCW pump sources for Bepi Colombo: beam profile

- Fast axis with collimation \( \theta_\perp < 5 \text{mrad} \ (>95\% \text{ power}) 
- slow axis \( \theta_\parallel < 120 \text{mrad} \ (>95\% \text{ power}) 

Pixel vertical

Pixel lateral
Preliminary life test for bars Bepi Colombo

- **Purpose**
  - demonstration of feasibility
  - determination of screening parameters

- **Conditions**
  - 10 devices (348 emitters) (selected by L-I curve + 300h burn in at 100A / 10Hz)
  - constant current $I_{op} = 142A$ ($P > 150$ W)
  - 20 Hz
  - 1300 h ≈ 93.6 Mshots
Results of life test

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<th>Parameter</th>
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<th>4</th>
<th>5</th>
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<td>2</td>
<td>1*</td>
<td>6</td>
<td>0</td>
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- no bar failed (EOL – current limit $I_{op} < 110A @100W$)
- Long term stable spectral behaviour $\Delta \lambda < 1\text{nm}$
- Reliability > 0.999 per bar for $P_{op} = 70W, 3.15 \times 10^8$ shots (10Hz, 1 year)
  - calculation based on random single emitter failures,
  - acceleration by power $(P/P_{op})^{2.3}$
  (2.3 standard value of 808nm devices)
808nm - QCW – pump sources for higher average power (ATLAS)

- **Requirements**
  - 808nm
  - space qualification issues similar to Bepi Colombo
  - output power ≥ 100W per bar
  - repetition rate ≈ 100Hz
  - reliability 10 Gshot

⇒

- improved chip design for slightly higher peak power
- Improved mounting scheme designed for 10x-higher average power
808nm - QCW – pump sources for higher average power (ATLAS) first results I

100W power / bar

- GaAsP QW
- improved layer - structure
- chip size
  - facet load 30mW/µm
  - 4.5 mm emitting aperture
  - 1.5 mm resonator length
  - 35 emitter, filling factor 70%
- conversion efficiency of chip ≈ 65%
- wavelength (807 ± 2)nm
808nm - QCW – pump sources for higher average power (ATLAS) first results II

- spectral peak at 804.5nm
- enabling λ - tuning by CW bias current
- spectral width < 4nm (95% power)
- wavelength shift determined by temperature
Summary – 808nm QCW pump lasers

- electro – optical performance
  - \( I_{op} < 100A @ 100W \) (\( \approx 70A @ 70W \))
  - \( P_{cod} > 3x P_{op}(70W) \)
  - \( \lambda \approx (805...806)nm, \Delta \lambda (95\%) \leq 5nm @ P_{op} \)
  - far field \( \Theta_{\perp} < 5\text{mrad}, \Theta_{\parallel} \approx 120\text{mrad} @ 95\% \)
  - \( U_{op} \approx 2.4 \text{ V at 100A} \)

- mounting scheme
  - proved design for 10Hz
  - thermal cycling between – 45°C and 65°C

- reliability > 0.999 (70W, 1 year, 10Hz) expected
outlook

- To do - short range
  - screening procedure
  - verification of reliability
  - extended life time tests (acceleration!?)
  - reducing series resistance

- Improvement opportunities chip - longer range
  - optimised design (pumping scheme)
  - wavelength stabilisation by internal gratings (DFB / DBR)