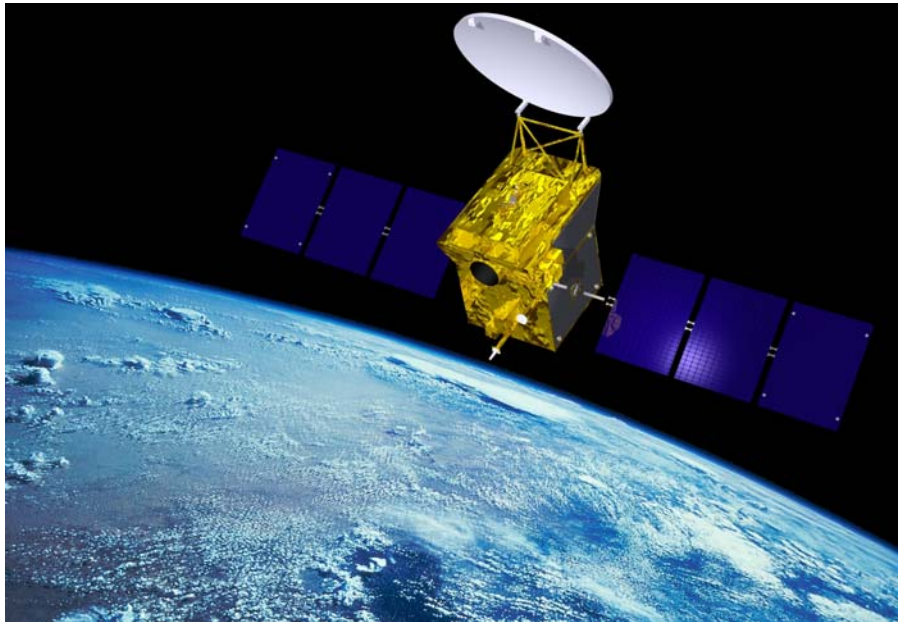
Assessment Test Programme for the ALADIN Pump Laser Diodes

Selected Earth Explorers mission with Lidar



2nd Core: ADM-Aeolus - 2008

3rd Core: EarthCARE - 2012

In the second call for Core Explorer mission: 4 lidars proposed

The Pre-Development Programme

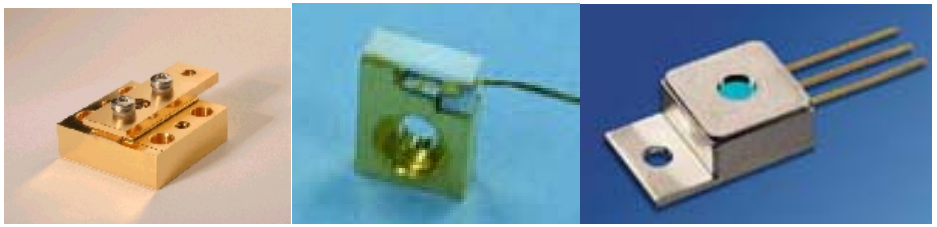
- **Goal: risk reduction before committing to full development of instruments approved for flight**
- **How?**
  - **Design, manufacture and test critical subsystems**
  - **Space-representative build standards**
  - **Demonstrate instrument performances**
  - **Realisation of ground/airborne instrument**
- **Atmospheric LAser Doppler INstrument (ALADIN) Pre-Development Programme (start 2000):**
  - **Pre-Development Model of receiver**
  - **2 parallel contracts on laser transmitter**
  - **4 parallel contracts on pump laser diodes assessment: CW & QCW**
  - **Studies of specific technology improvement**

Pump Laser Diodes Assessment

- **Aim: Identifying most suited components and key parameters relevant to the Pump Laser Diodes Qualification Programme for Aeolus**

- **Tools**
  - **Lifetime: 10000 h**
  - **Proton Irradiation tests up to $2e^{+10}$ p/cm^2**
  - **Failure Analysis**

- **Laser diodes**
  - **Thales Laser Diodes (QCW)**
  - **Dilas (QCW)**
  - **Ferdinand Braun Institute (CW)**
  - **InnoLight: Infineon & Thales Laser Diodes (CW)**



Endurance Test specifications

Endurance Test conditions:

- **10000 hours @ constant current in air**
- **4 groups of laser diodes**

	Power	Current	Temperature	Wavelength
Nominal	P_{nom}	I_o for P_{nom}	25 °C	λ_o for I_o
High current		1.4 I_o	T for λ_o	λ_o
High temperature		I_o	45 °C	
Burst (9s ON, 10 s OFF)	P_{nom}	I_o for P_{nom}	25 °C	λ_o for I_o

Electro-optical characterisation

Electro-optical characterisation:

- @ **0**, 48, 168, **500**, 1000, **2000**, 3500, **5000** and **10000** hours

	Complete	Reduced
Optical output power		
Forward voltage		
Center wavelength		
Threshold current		
Optical efficiency		
Divergence		
Characteristic temperature		
Thermal resistance		

- **In addition, near-field pictures were taken**

Radiation Test specifications

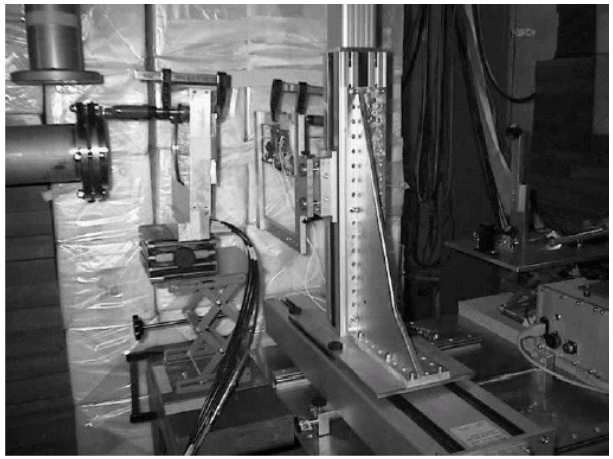
Proton radiation:

Orbit at 400 km during 4 years operation (launch in year 2009, solar maximum)

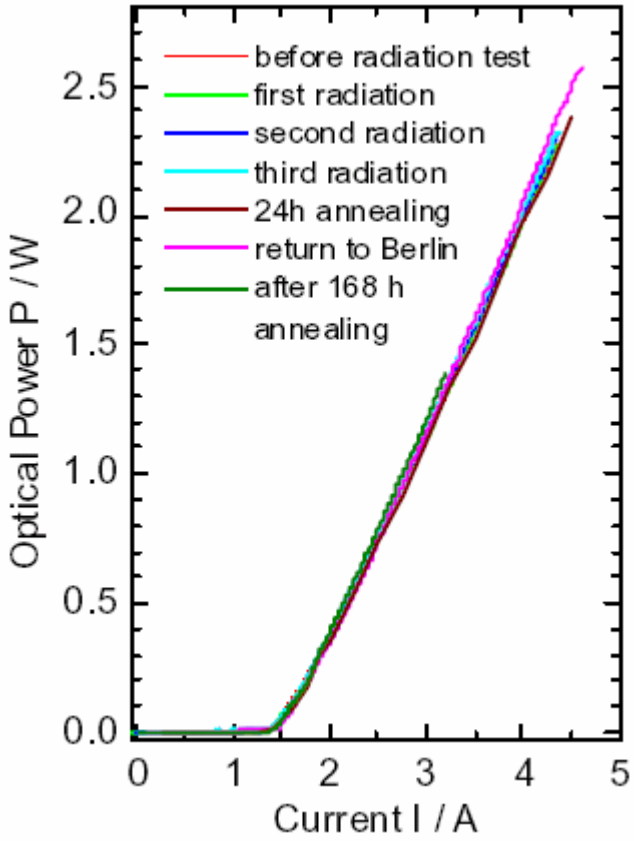
Assumption: in-flight equivalent shielding: 16mm Al

Radiation Test: 1, 2 and 10 E+9 p/cm^2 @60MeV

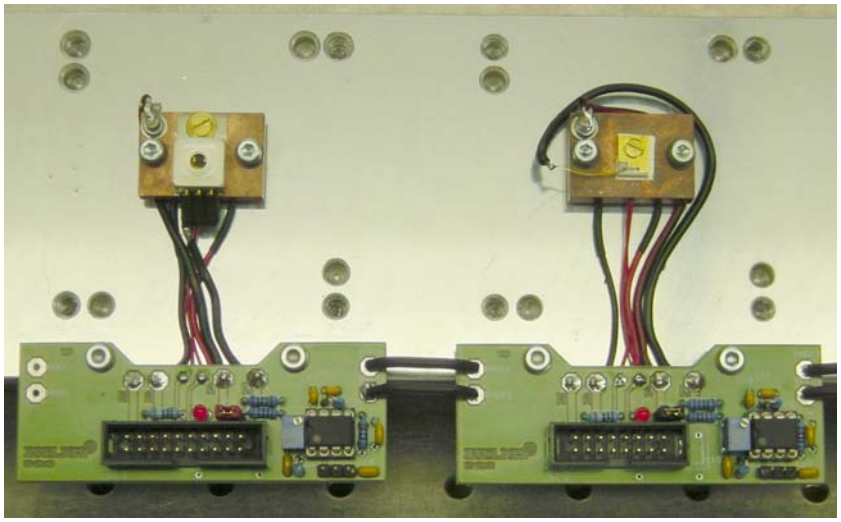
- **-Irradiation with sample ON**
- **-Irradiation with sample OFF**

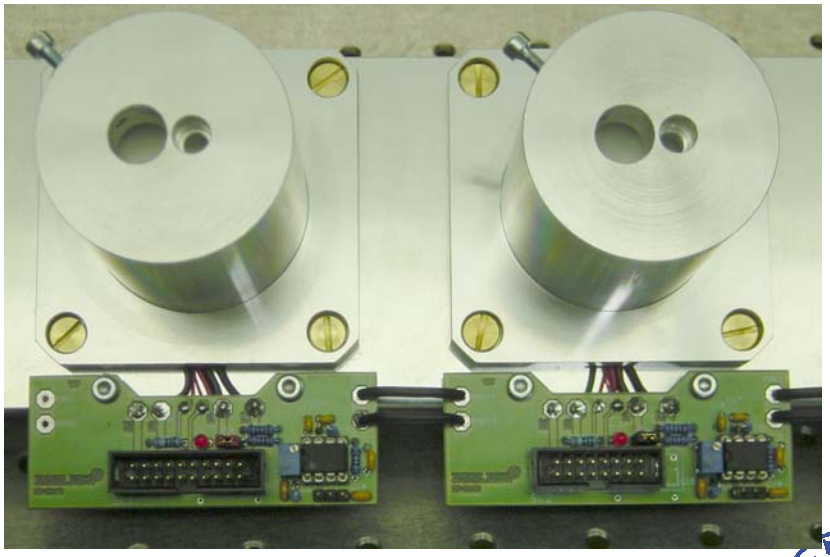


Ionisation chamber at the Paul Scherrer Institute (Switzerland)



Assessment of CW Laser Diodes at InnoLight

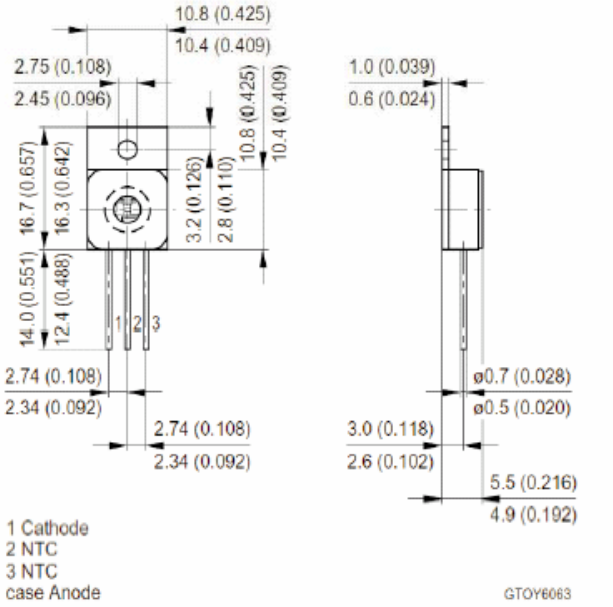




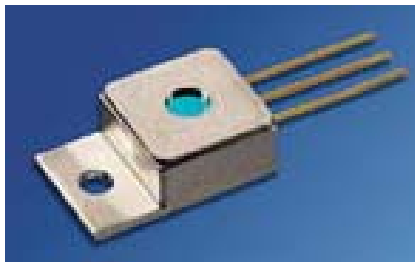
Endurance test bench setup under a class 100-1000 laminar flow box. Laser diode holder with protecting tube.

Assessment of CW Laser Diodes at InnoLight

Parameter	Typical Values	Units
Peak wavelength	808 ± 3	nm
Spectral width (FWHM)	3	nm
Output power	2	W
Differential efficiency	1.1	W/A
Threshold current	0.65	A
Operating current	2.5	A
Operating Voltage	2.0	V
Reverse voltage	3	V
Beam divergence (FWHM)	1.5 X 8	deg.
Thermal resistance (junction →heat sink)	6.5	K/W
Heat-sink temperature	25	°C
Storage temperature	-40 to +85	°C

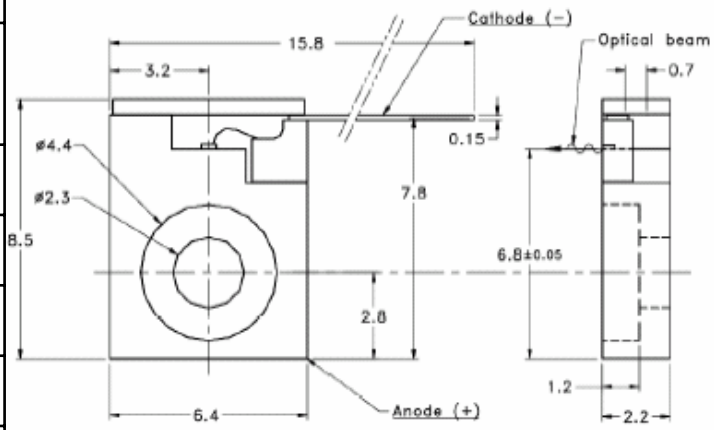


- *Infineon* SPL 2Y81
- Class IV Laser Product (IEC 60825-1)
- TO-220 package (copper base)
- InGa(Al)As strained layer qw structure
- Laser aperture 200 µm
- Cylindrical correction
- Mechanical tolerances: ± 0.2 mm

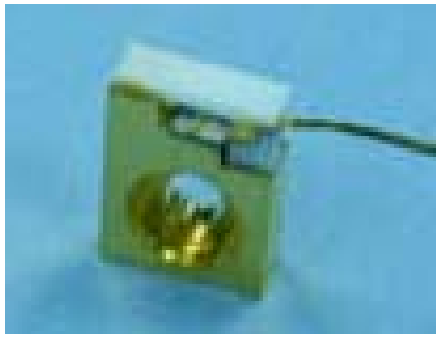


Assessment of CW Laser Diodes at InnoLight

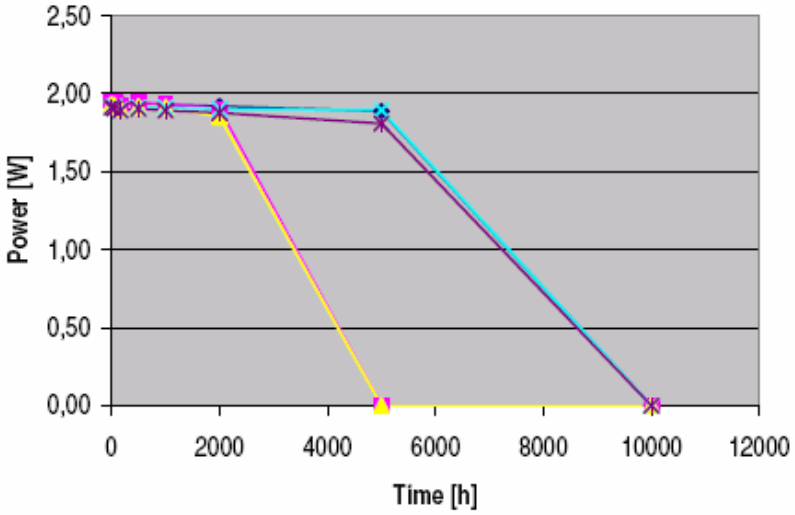
Parameter	Typical Values	Units
Peak wavelength	808 ± 3	nm
Spectral width (FWHM)	3	nm
Output power	1	W
Slope efficiency	1.0	W/A
Threshold current	0.4	A
Operating current	1.4	A
Operating Voltage	1.9	V
Reverse voltage	3	V
Beam divergence (FWHM)	12 X 35	deg.
Emitting area	100 x 1	μm^2
Heat-sink temperature	25	°C
Storage temperature	-40 to +85	°C



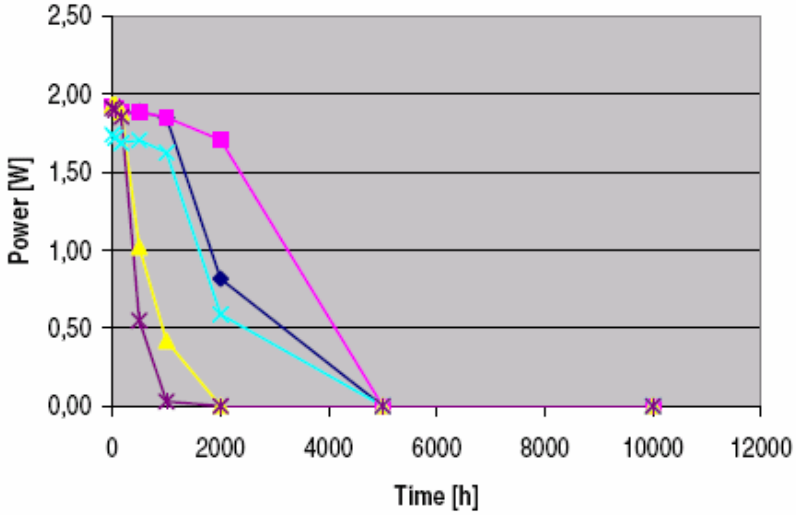
- *Thales* TH-C1301-E
- Class IV Laser Product (IEC 60825-1)
- Package "E" (c-mount)
- GaAlAs broad area single emitter
- Laser aperture 100 µm
- No cylindrical correction
- Mechanical tolerances: ± 0.2 mm



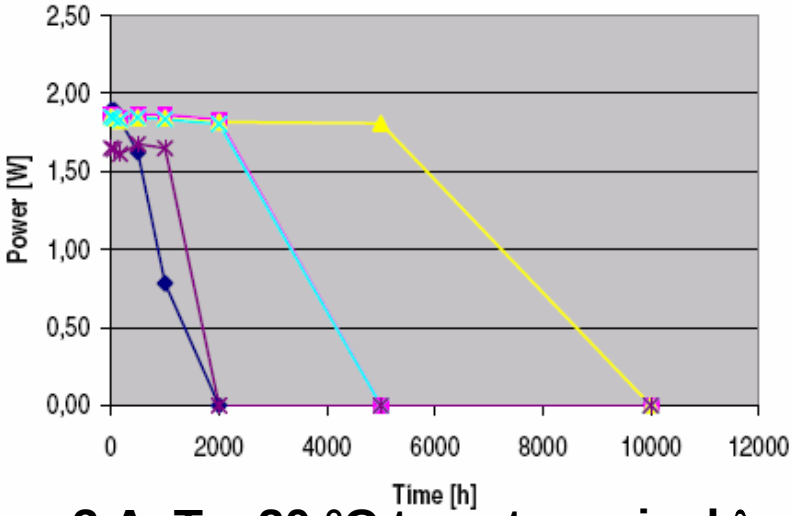
Endurance test results: Infineon



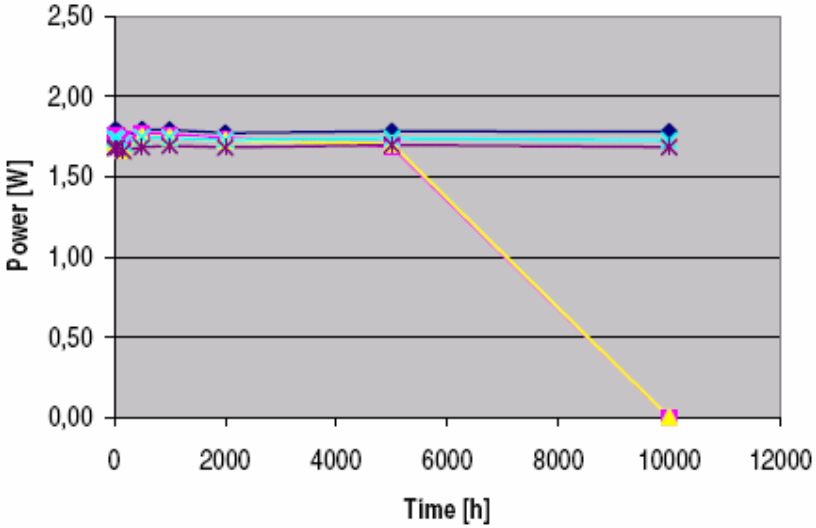
Nominal current 2.5 A, T = 25 °C



Nominal current 2.5 A, T = 45 °C

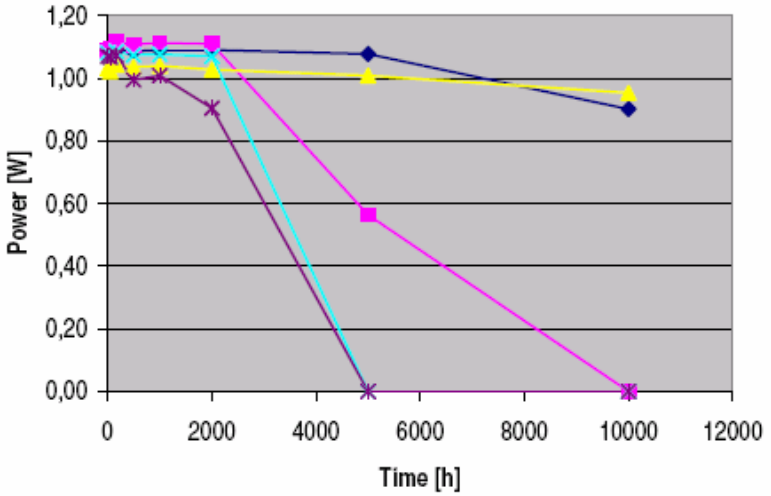


3 A, T ~ 20 °C to get nominal λ

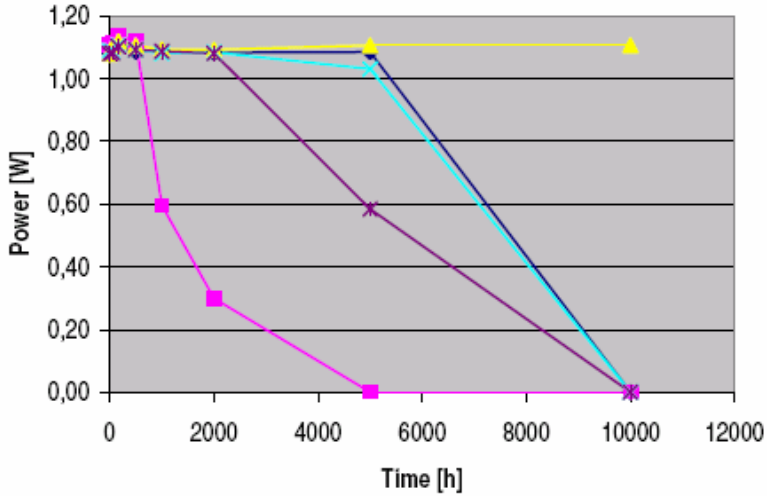


1.7 A, T = 25 °C

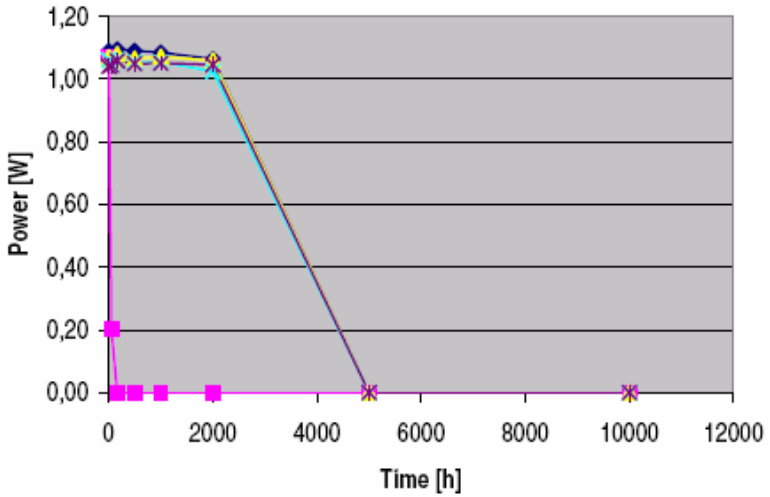
Endurance test results: Thales Laser Diodes



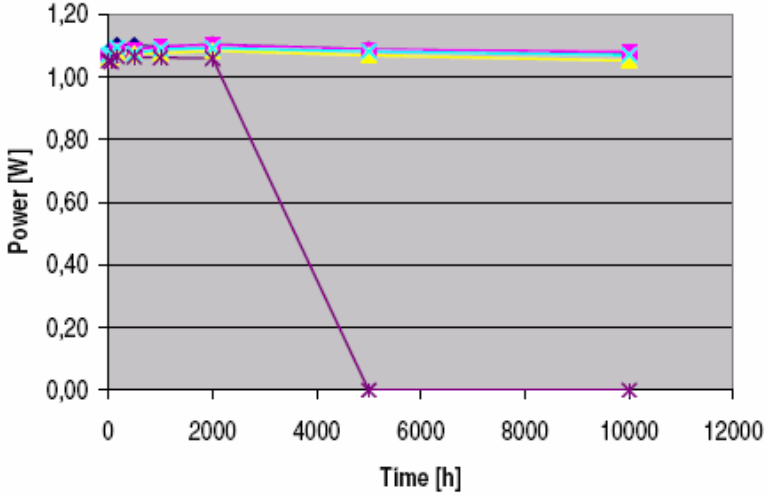
Nominal current 1.4 A, T = 25 °C



Nominal current 1.4 A, T = 45 °C

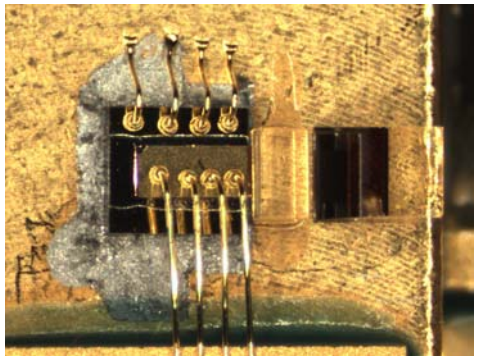
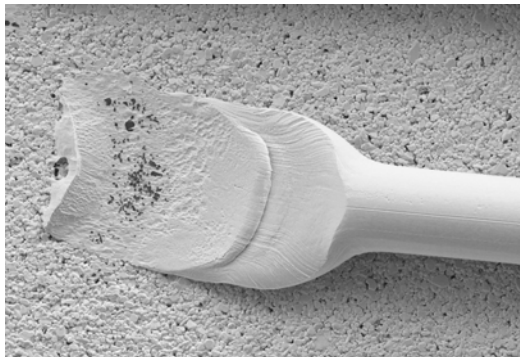
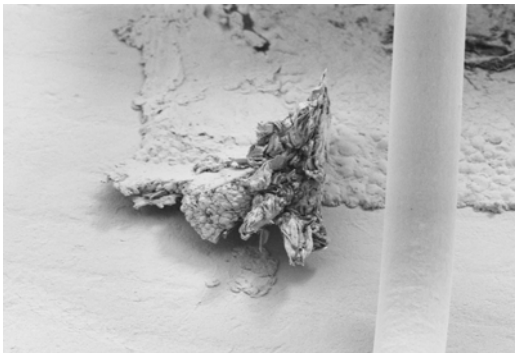
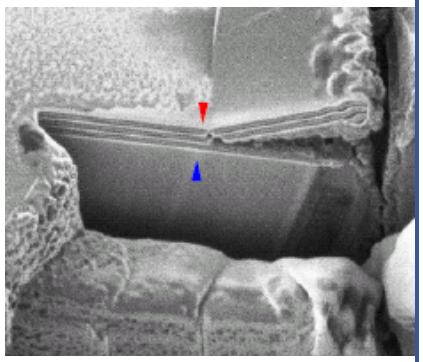


1.7 A, T ~ 22 °C to get nominal λ



0.8 A, T = 25 °C

Failure analysis results

Failure analysis performed at ESTEC:

- **Visual inspection**
- **Scanning Photon Emission Microscope**
- **LEO 1530VP Scanning Electron Microscope,**
- **INCA EDX system installed on the SEM**
- **Radiographic inspection**
- **Bond strength test**
- **Microsection with a FEI STRATA FIB 205 Focused Ion Beam System**

In conclusion these analyses revealed some scratches, some minor chip-outs along laser diode edges, some fractures along the same edges and peeling/crack of the backside mirror, not acceptable soldering.

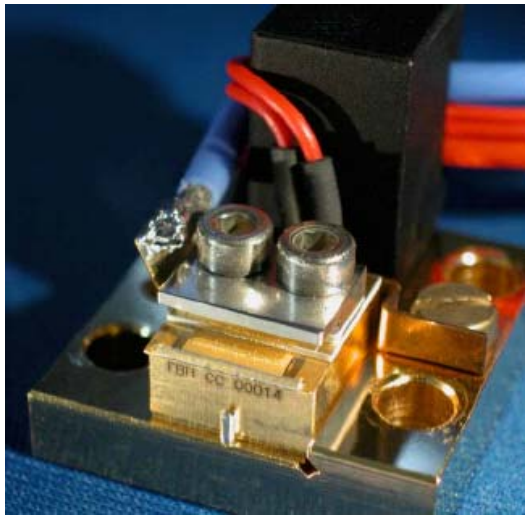
Assessment at Ferdinand Braun Institut

Electro-optical characterisation setup

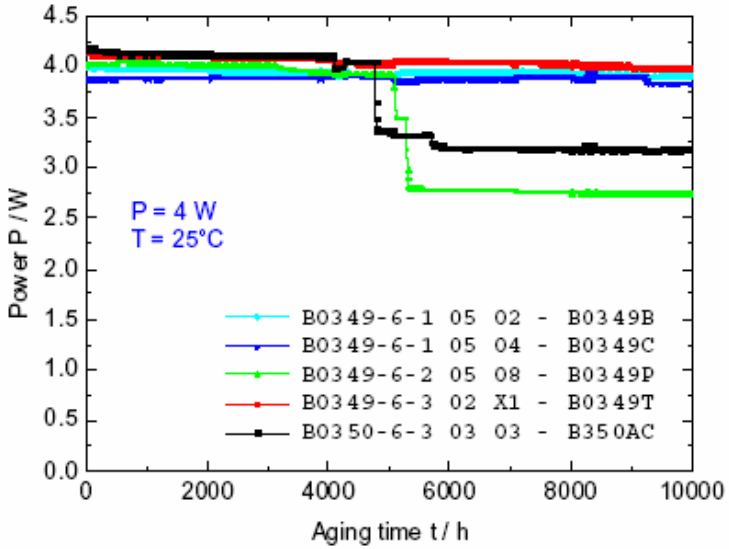
Endurance setup : test chamber for 2 DL and test rack for the 20 DL

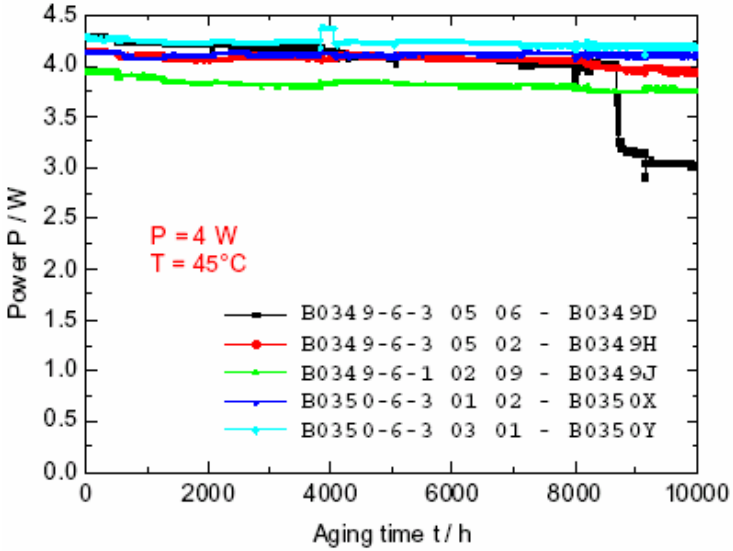
Assessment at Ferdinand Braun Institut

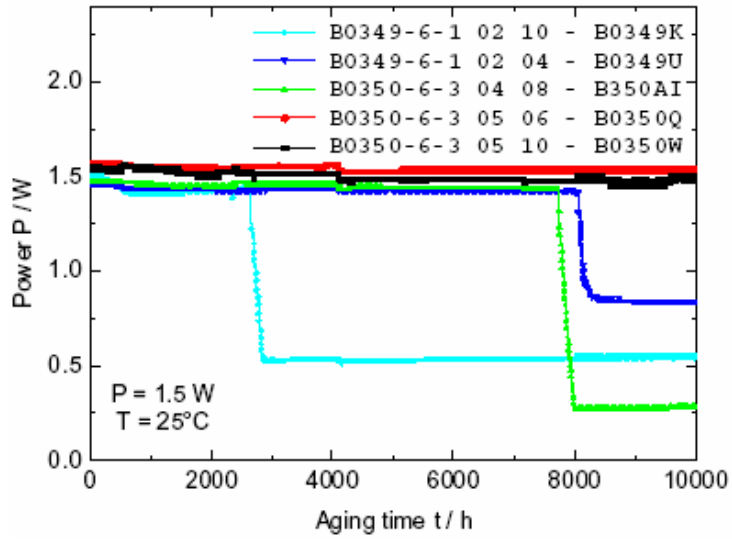
Parameter	Value
Emitting area	6 emitters, 60 µm width, 1 mm pitch
CW output power P_{op}	> 1 W
Operating current I	< 3.1 A
Threshold current I_{th}	< 1.8 A
Slope efficiency S	> 0.95 W/A
Operating voltage U	< 1.8 V
Life time	> 4 years
Reliability within life time	0.98
MTTF	1.73×10^6 h
Wavelength λ	(807 ± 1) nm
Spectral width $\Delta\lambda$	3 nm
Beam divergence – fast axis	< 60°
Beam divergence – slow axis	< 6°

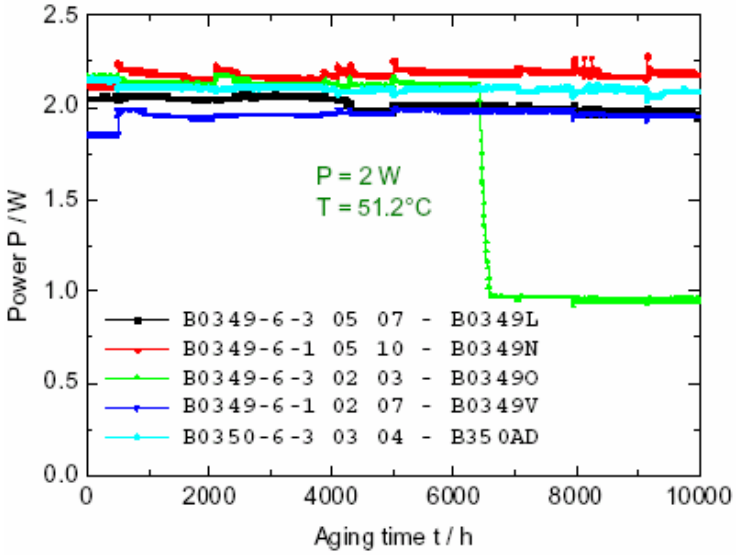


Endurance test results







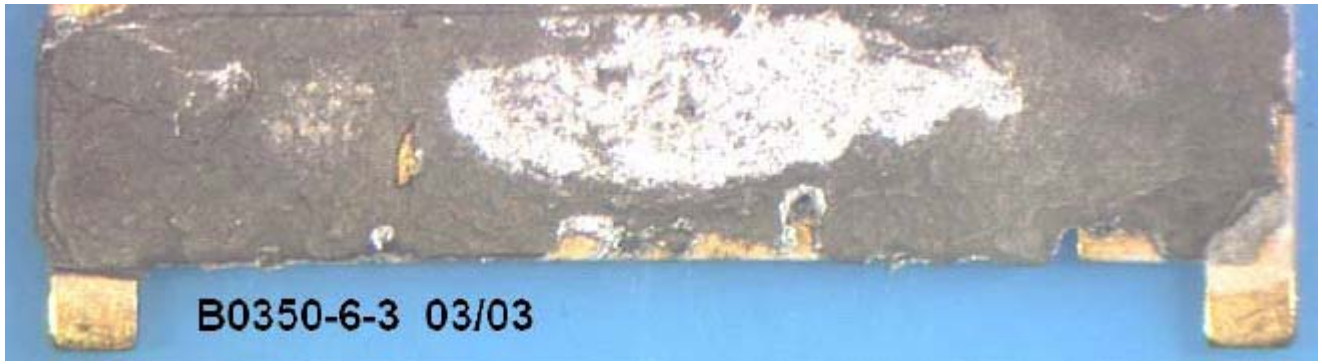


Failure analysis results

Anomalous failure behaviour:

- **More failure at lower temperature**
- **No mirror defect, but electrical shunts within the diode laser bars**

At lower temperature, the strain between the mounting layers is more important for larger differences between soldering and operating temperatures



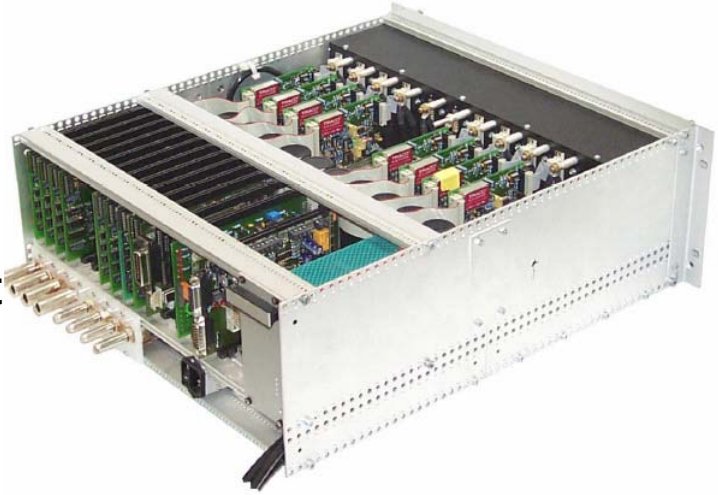
Solder between heat sink and Cu mount: intermetallic compound

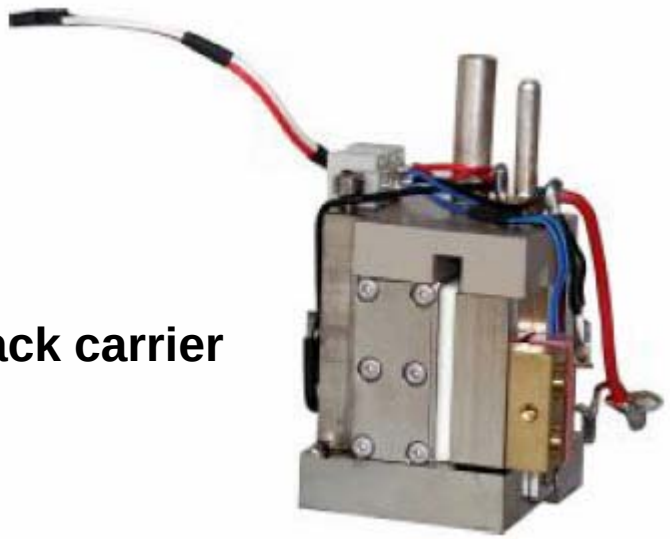
Soldering process optimised, Cu mount supplier changed
Overall strain reduced by smaller resonator length

Assessment of QCW Laser Diodes at Dilas

Mobile electro-optical charaterisation setup

Rack for endurance test of 8 stacks

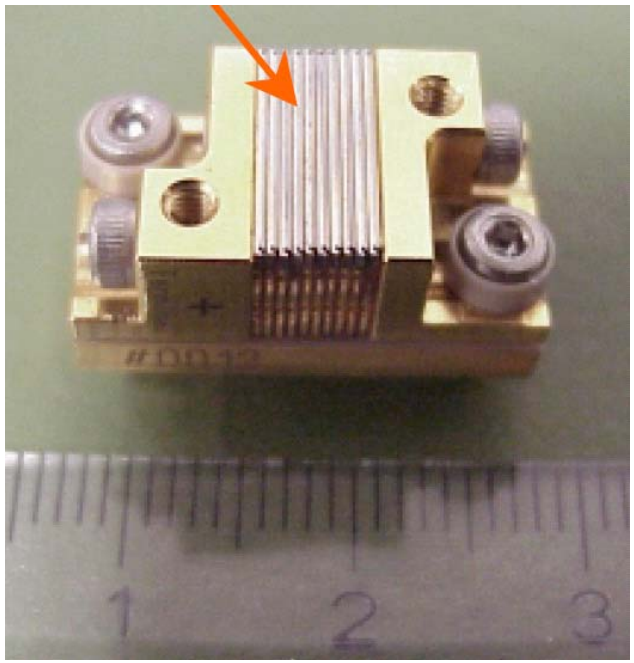




Stack carrier

Assessment of QCW Laser Diodes at Dilas

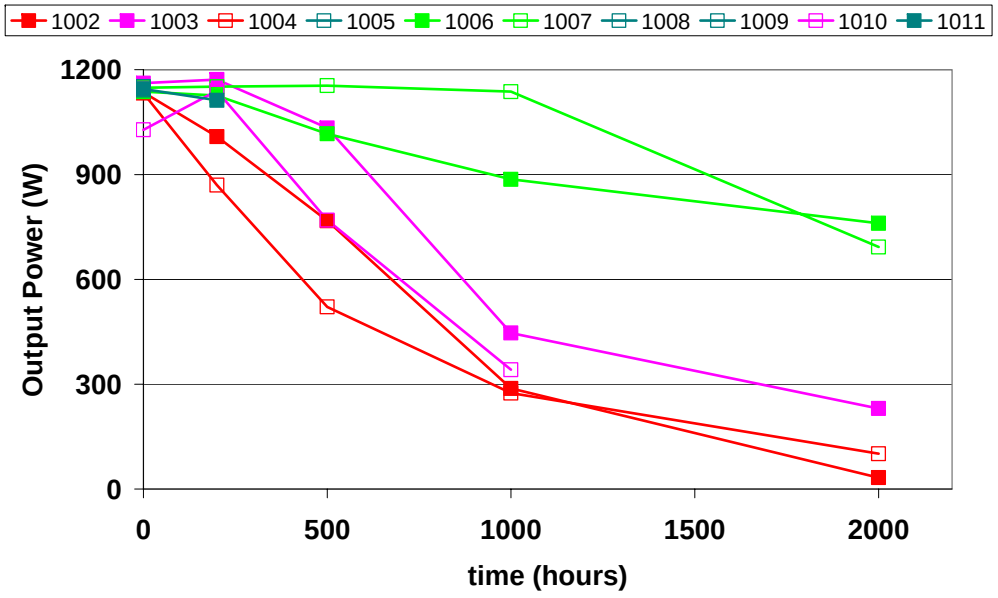
Parameter	OSRAM	TUTCO RE	Units
Peak wavelength	808 ± 3		nm
Spectral width (FWHM)	3		nm
Number of bars	10		
Pitch	0.5		mm
Duty cycle	1.5		%
Output power	1000		W
Slope efficiency	1.1	1.2	W/A
Threshold current	22	16	A
Operating current	120	105	A
Operating Voltage	18		V
Overall efficiency	40		%
Beam divergence (FWHM)	12 X 35		deg.
Emitting area	4.5 x 10		mm^2
Heat-sink temperature	25		°C

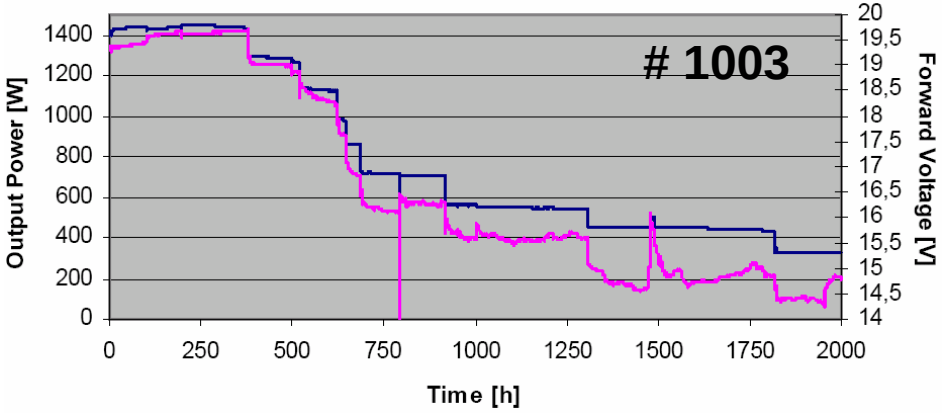


Endurance test results

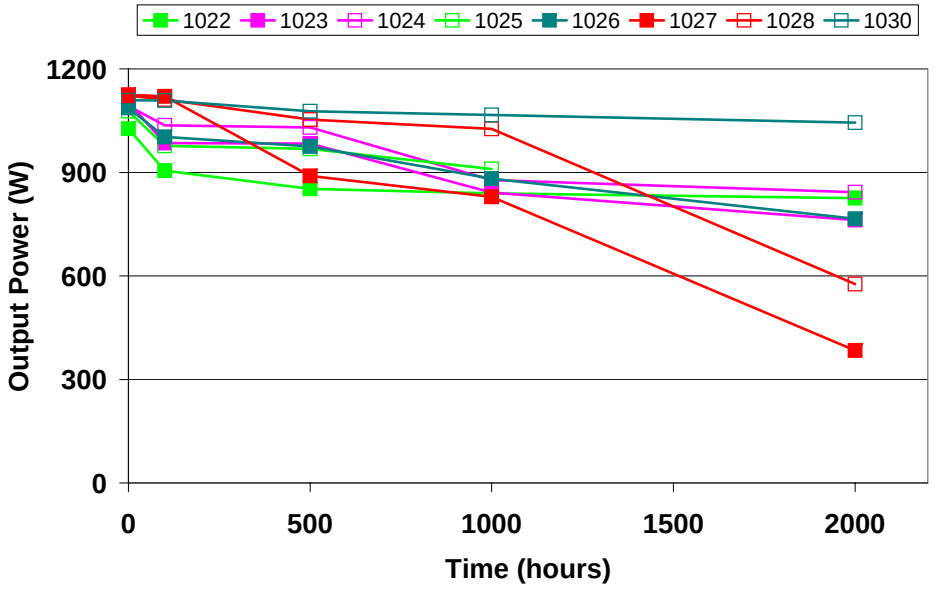
Output power at nominal current

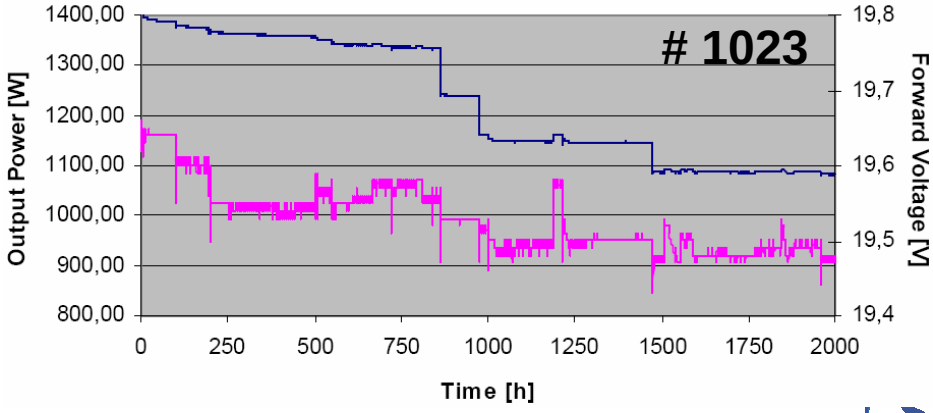
Osram (I = 120 A)





Tutcore (I = 105A)

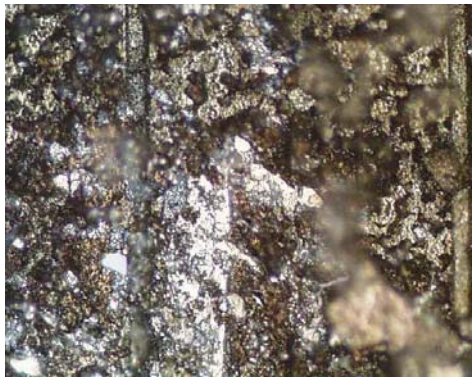




Failure analysis results

Anomalous failure behaviour:

- **Emitter breakdown as the typical failure mode**
- **No significant difference between OSRAM and TUTCORE**
- **Delamination of some bars running in burst mode**
- **Mainly spontaneous failures at bar level**

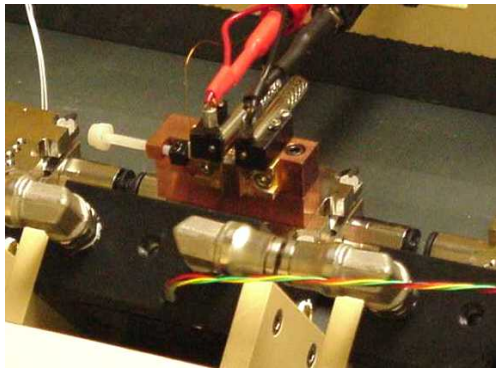


Shear test: porous interface between heat sink and laser bar and intermetallic compound

→ **Heat sink contaminated: Additional process steps implemented**

Assessment of QCW Laser Diodes at N.E.

Rack for endurance test of 2*8 stacks instaled in clean room class 10000



Stack carrier

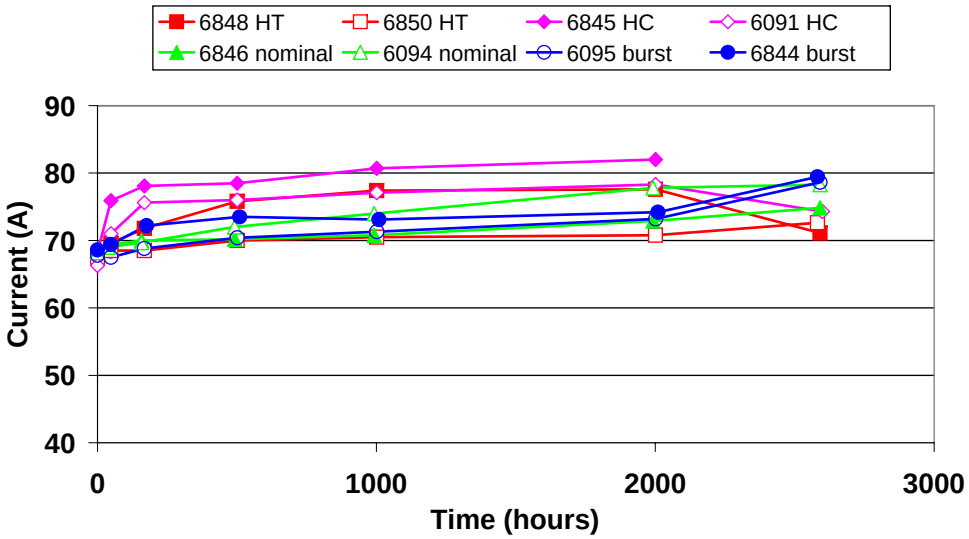
Assessment of QCW Laser Diodes at N.E.

Parameter	Stacks	Auto stacks	Units
Peak wavelength	**808 ± 3**		**nm**
Spectral width (FWHM)	**3.5**	**5**	**nm**
Number of bars	**12**	**8**	
Pitch	**0.4**		**mm**
Duty cycle	**1.5**		**%**
Output power	**1000**	**500**	**W**
Slope efficiency	**0.9**	**1**	**W/A**
Threshold current	**15**		**A**
Operating current	**105**	**80**	**A**
Operating Voltage	**24**	**16**	**V**
Overall efficiency	**40**		**%**
Beam divergence (FWHM)	**10 X 40**		**deg.**
Emitting area	**4.4x10**	**0.9x10**	**mm^2**
Heat-sink temperature	**25**		**°C**

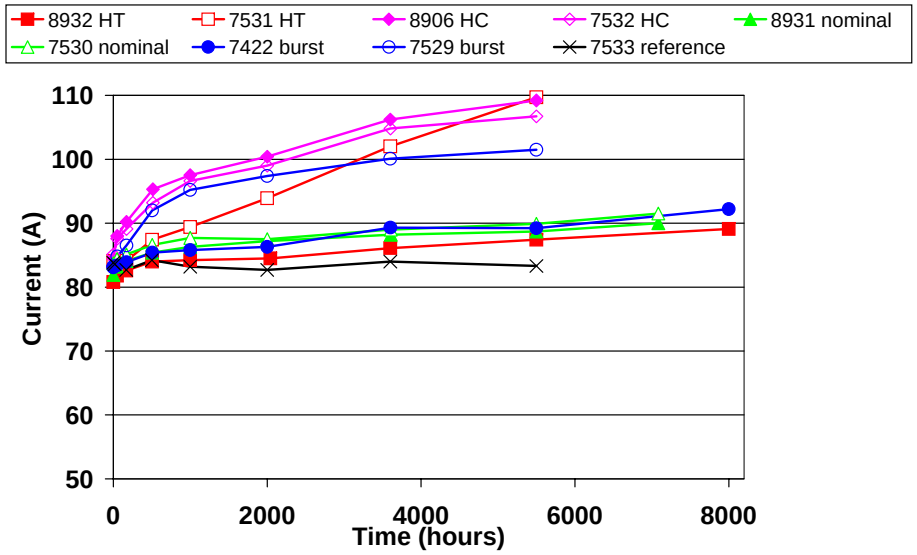
Endurance test results

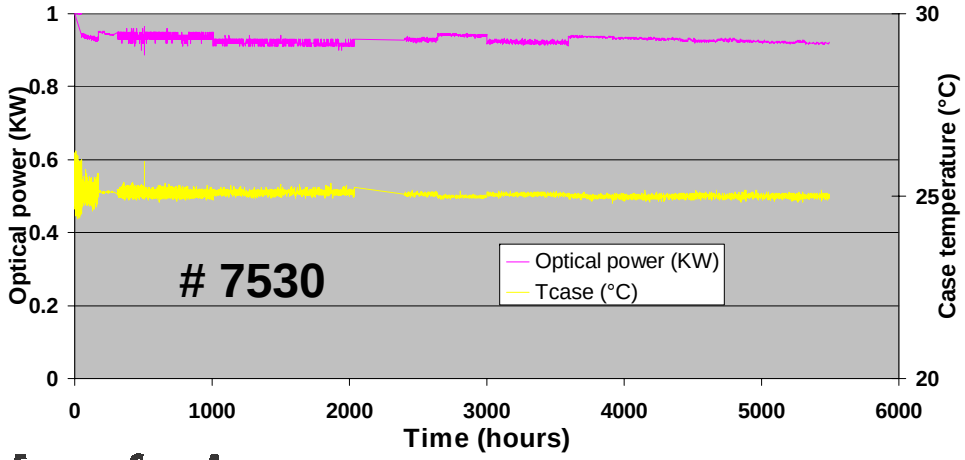
Output power at nominal current

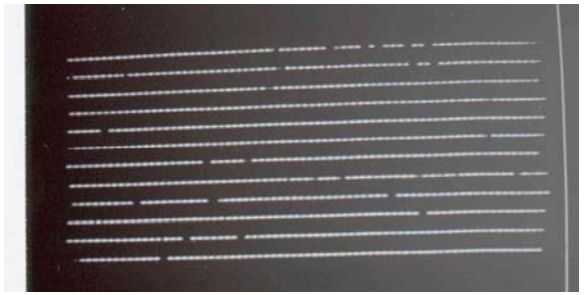
Autostack



Stacks





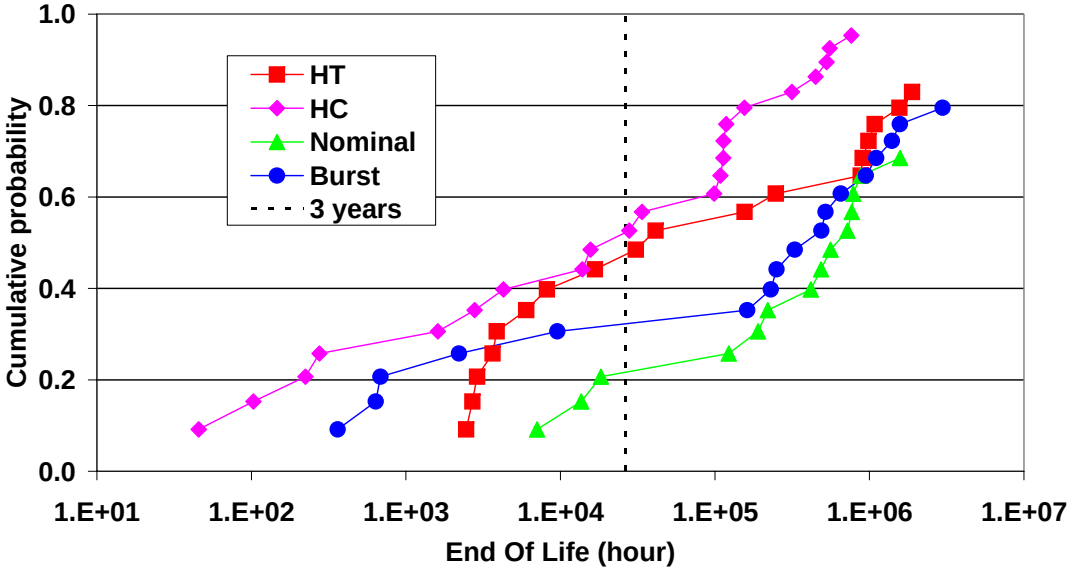


Near field picture of # 7422 @ 1000 h

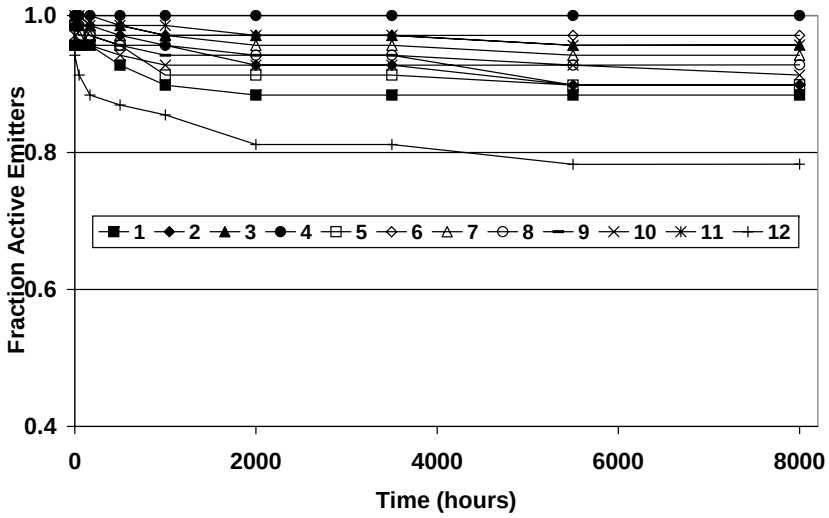
Failure analysis results

Failure behaviour:

- **Degradation is faster in the first hundreds hours (infant mortality regime)**
- **Correlation between near-field data and electro-optical degradation**
- **No correlation between position of bar and rate of death emitters**



Lognormal distribution of the EOL of bars



Evolution of the fraction of active emitter within one stack

In a stack the degradation is induced mainly by few bars

Conclusion

Radiation tests: successful for all laser diodes under the given environment (typical for LEO and 3 years lifetime)

Endurance tests: useful

- **CW Thales Laser Diodes: lifetime reached when derated**
- **CW Osram: lifetime not met**
- **CW FBH customised laser diodes: chip technology is reliable**
- **QCW Nuvonyx Europe: lifetime reachable for some bars in burst mode**
- **QCW Dilas: lifetime not met**

Failure analysis: useful
Many areas in the mounting processes to be improved (soldering, bonding, gluing)
Some part of design to be optimised

Conclusions of the Assessment Test Programme:

- **Laser diodes from FBH and Nuvonyx Europe selected for the ALADIN transmitter.**
- **COTS laser diodes are less suitable for space applications than custom-designed.**

Way forward

ALADIN:

- **CW FBH Laser diodes have passed qualification**
- **QCW NE laser diodes are ongoing qualification**
- **Additional tests of QCW Dilas and CEO laser diodes**

EarthCARE:

2 activities started to develop and assess long lifetime high-power laser diodes arrays

- **NE**
- **Jenoptik Germany**

Emphasis on improving the design and the mounting processes to improve the lifetime up to 10 Gshots and to secure the reproducibility of the manufacturing chain.