Assessment Test Programme on the ALADIN CW Pump Laser Diodes

European Space Agency
Agence spatiale européenne

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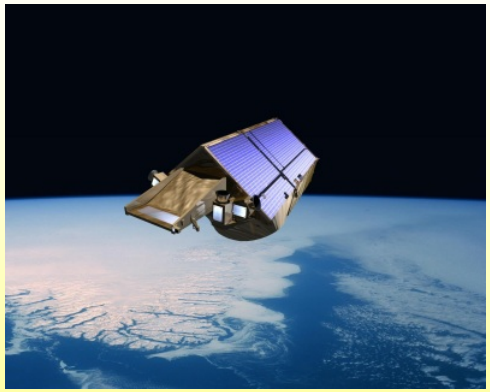
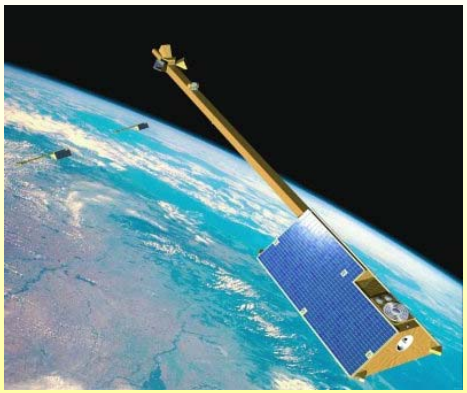
the Living Planet

Selected Earth Explorers



CRYOSAT - 2005

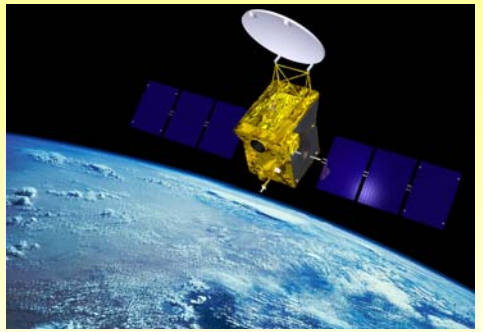
SMOS - 2007



SWARM - 2009

GOCE - 2006

ADM-Aeolus - 2008



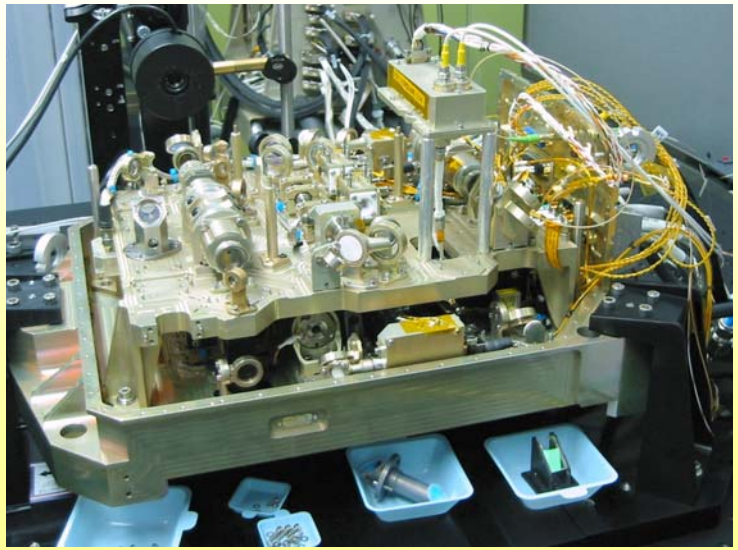
EarthCARE - 2012

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

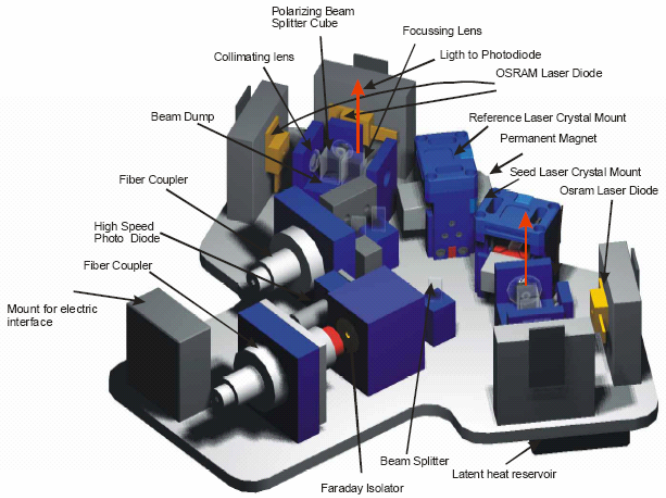
Laser Transmitter Programme

- **Tripled-frequency Nd:YAG, 150 mJ at 100 Hz, operating in burst mode (7s ON 21s OFF)**
- **Seeded by a reference laser**
- **RLH Breadboard activities run by**
  - **Innolight**
  - **Tesat**

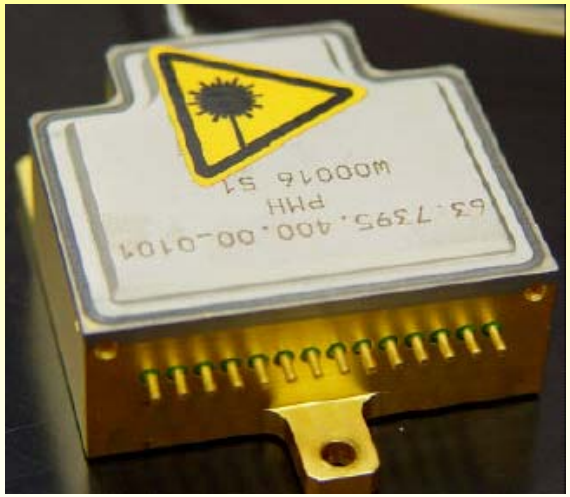


EQM of the ALADIN transmitter

Innolight RLH BB



TESAT RLH

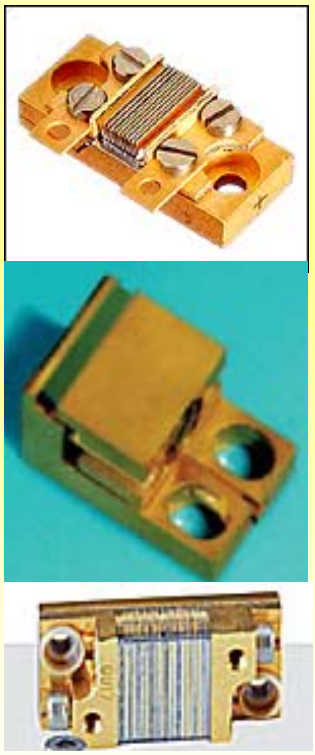


Pump Laser Diodes Assessment

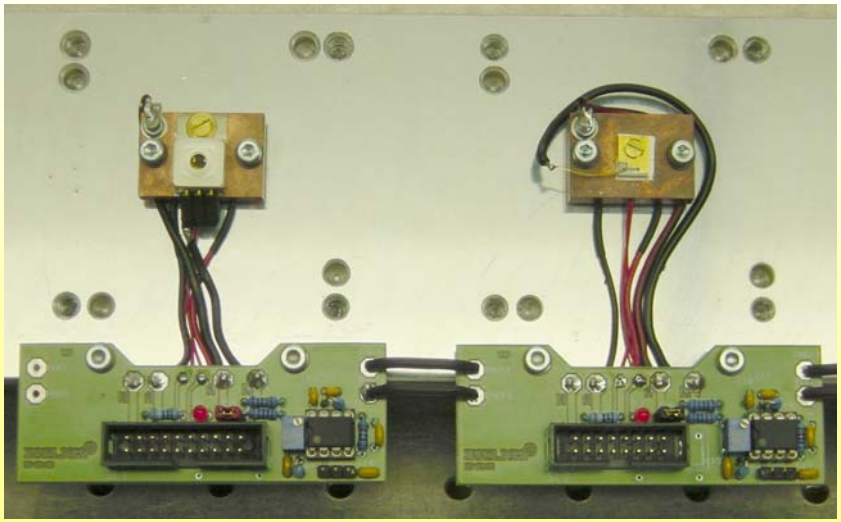
- **Aim: Identifying key parameters relevant to the Pump Laser Diodes Qualification Programme for Aeolus**

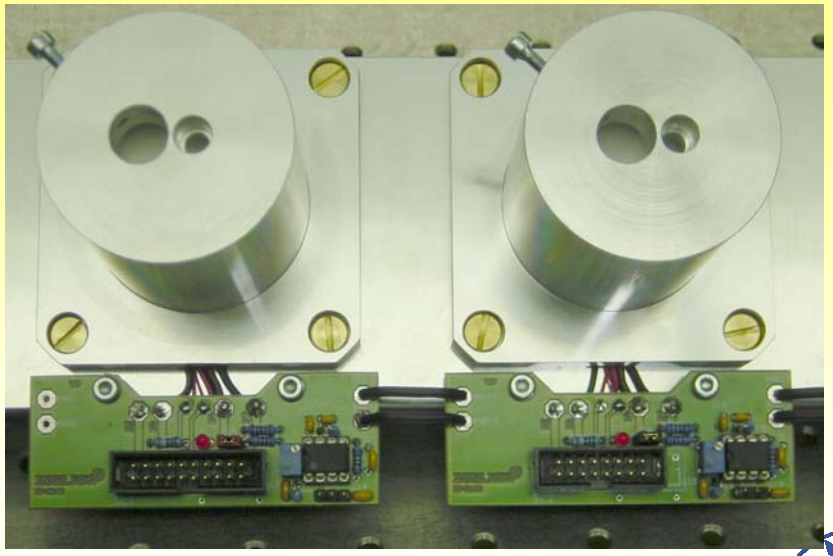
- **Tools**
  - Lifetime: 10000 h
  - Proton Irradiation tests up to $2e^{+10}$ p/cm^2
  - Failure Analysis

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



Assessment at InnoLight

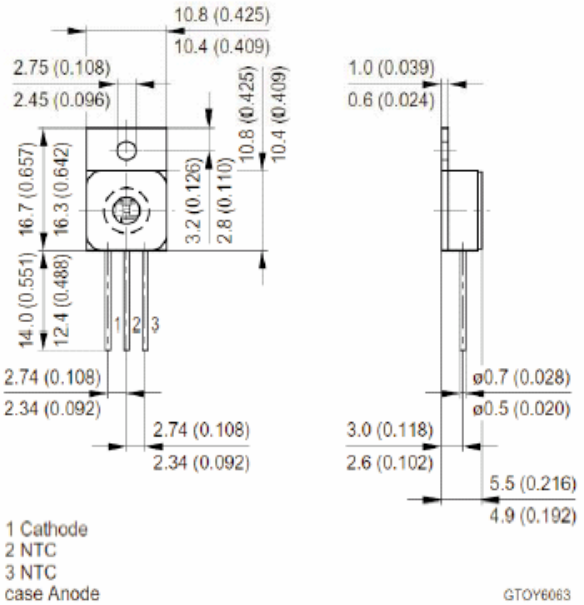




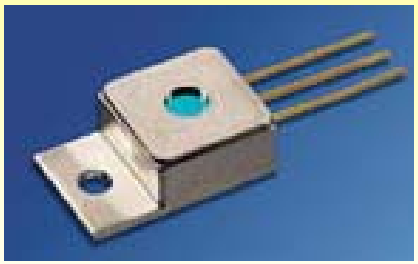
Endurance test bench setup under a class 100-1000 laminar flow box. Laser diode holder with protecting tube.

Assessment 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

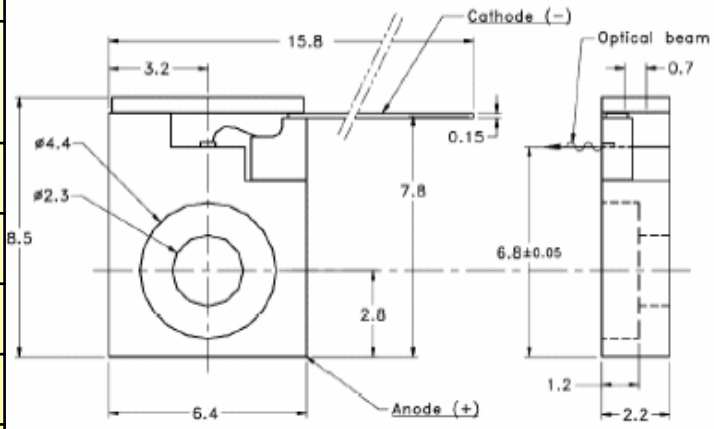


- *Infineon* SPL 2Y81
- Class IV Laser Product (IEC 60825-1)
- TO-220 package (copper base)
- InGa(Al)As strained layer qw structure
- Laser aperture 200 µm
- Cylindrical correction
- Mechanical tolerances: ± 0.2 mm



Assessment 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

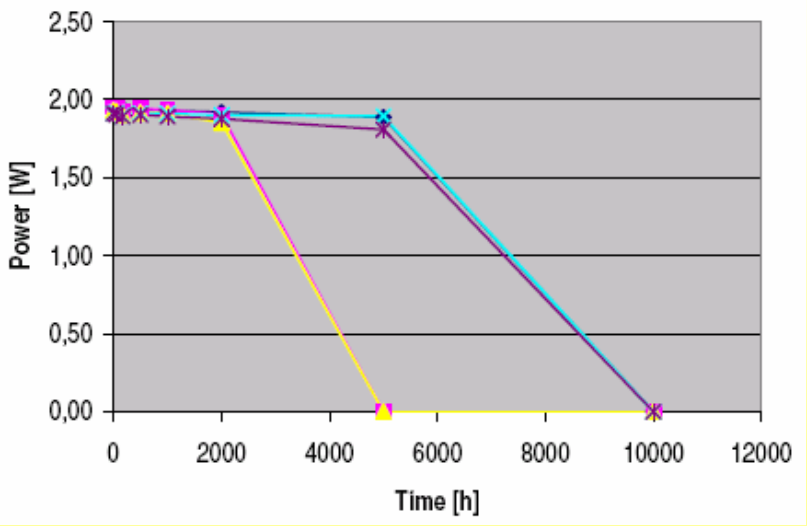
Endurance test conditions

2 * 20 DL constant current for 10000 hours:

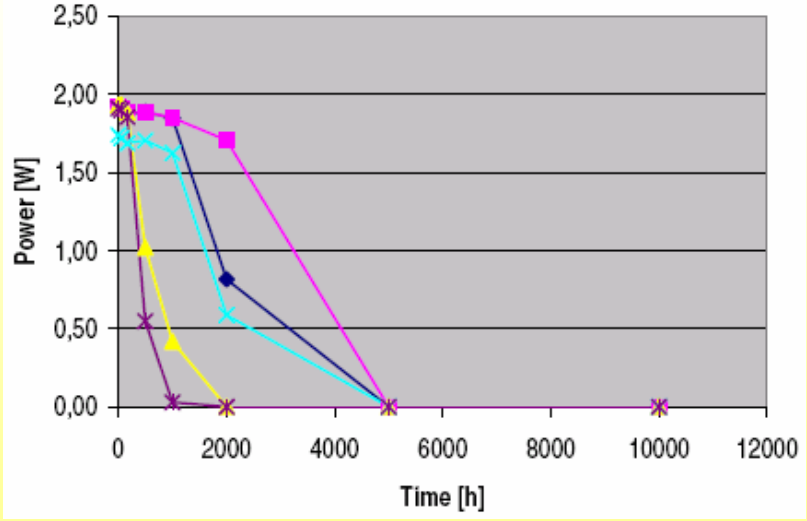
- 2 * 5: nominal current, 25 °C ± 0.5 °C case temperature
- 2 * 5: nominal current, 45 °C ± 0.5 °C case temperature
- 2 * 5: current to obtain 120% of nominal optical output power at beginning of life, temperature needed to obtain the nominal wavelength as obtained when the case temperature is 25 °C and output power is nominal.
- 2 * 5: 50 % of the nominal output power, 25 °C ± 0.5 °C case temperature

Parameter	0h	48h	168h	500h	1000h	2000h	5000h	10000h
Optical Output Power	X	X	X	X	X	X	X	X
Forward Voltage	X	X	X	X	X	X	X	X
Center Wavelength	X	X	X	X	X	X	X	X
Threshold Current	X	X	X	X	X	X	X	X
Optical Efficiency	X	X	X	X	X	X	X	X
Divergence	X			X		X	X	X
Characteristic Temperature	X			X		X	X	X
Thermal Resistance	X			X		X	X	X

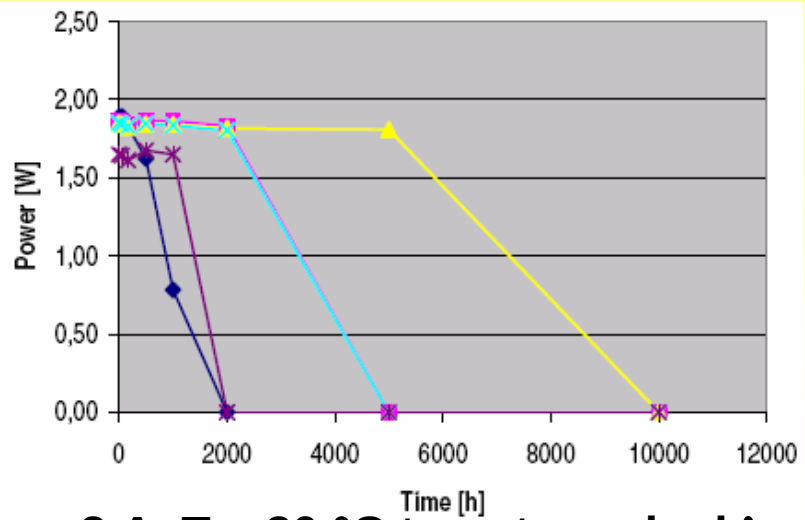
Endurance test results: Infineon



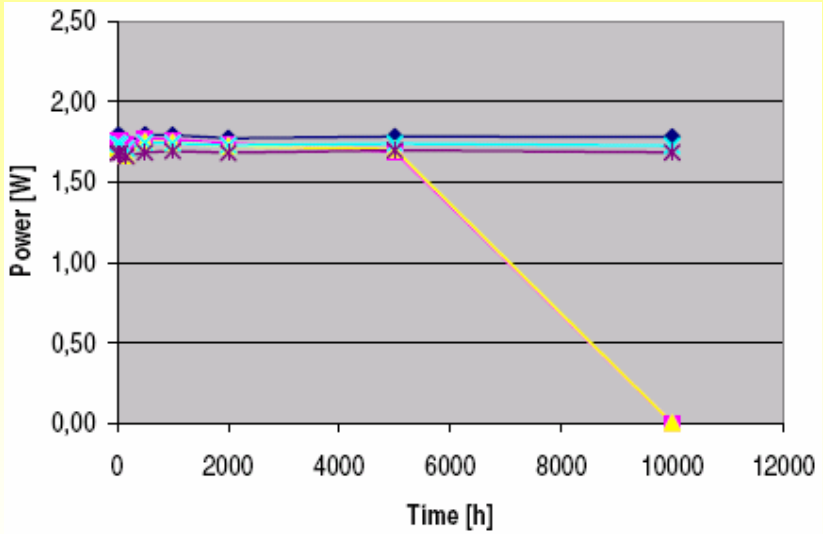
Nominal current 2.5 A, T = 25 °C



Nominal current 2.5 A, T = 45 °C

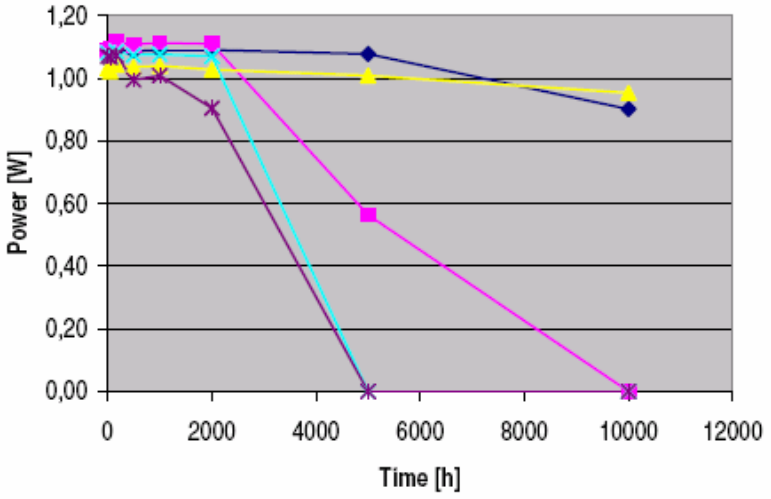


3 A, T ~ 20 °C to get nominal λ

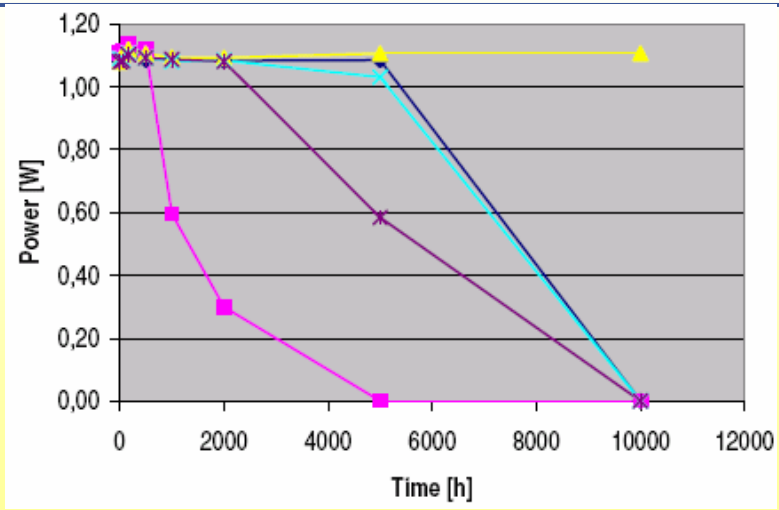


1.7 A, T = 25 °C

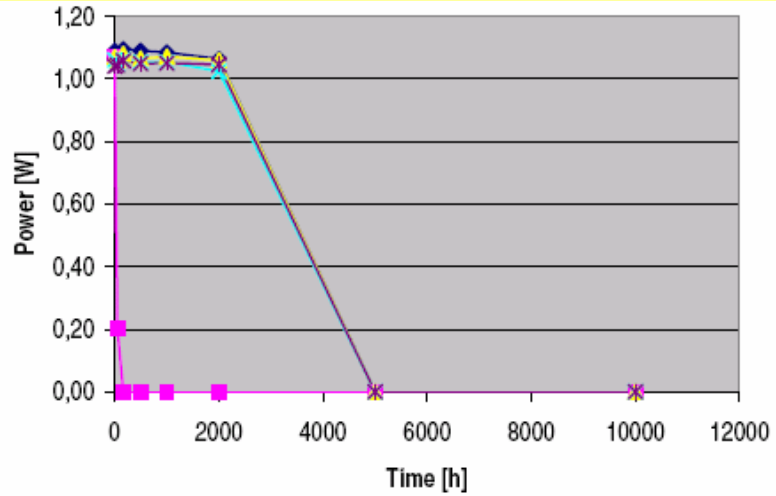
Endurance test results: Thales Laser Diodes



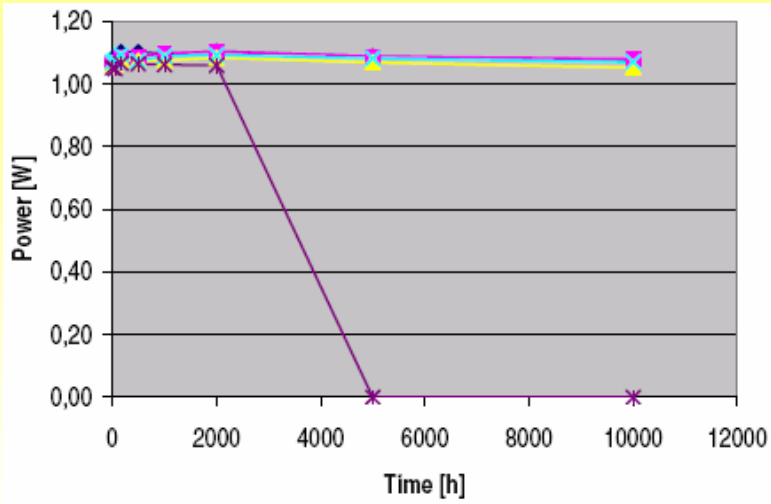
Nominal current 1.4 A, T = 25 °C



Nominal current 1.4 A, T = 45 °C



1.7 A, T ~ 22 °C to get nominal λ



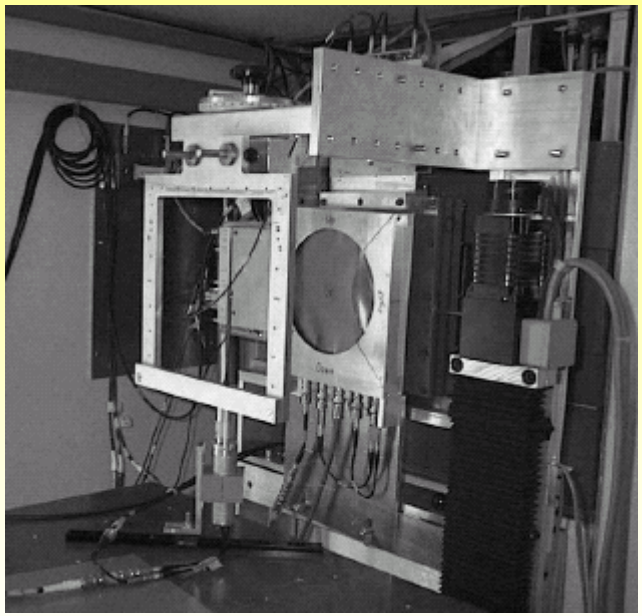
0.8 A, T = 25 °C

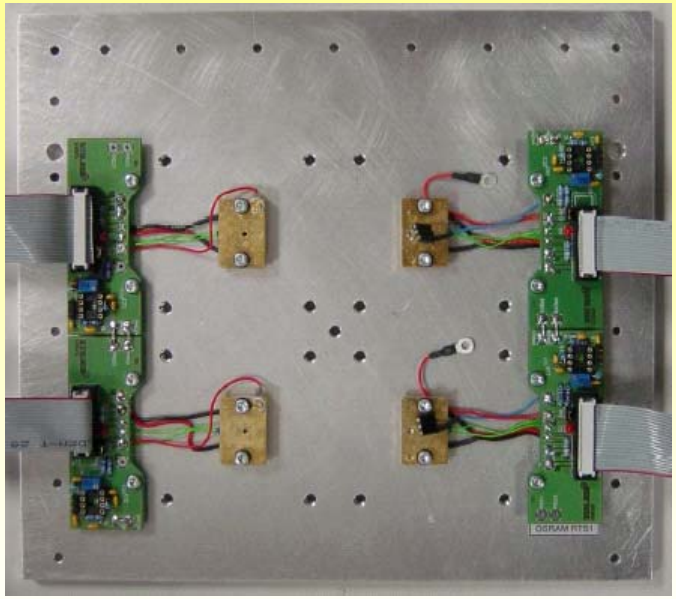
Radiation test conditions

2 * 2 DL at 2*10^9 p/cm^2, 4*10^9 p/cm^2 and 2*10^10 p/cm^2; 60MeV protons

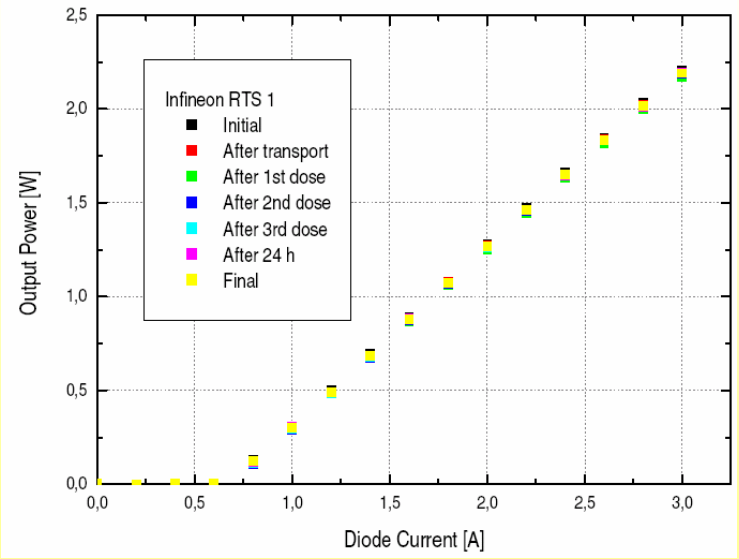
- 2 * 1: nominal operating condition
- 2 * 1: non operating condition

- Limited set of electro-optical measurement performed after each exposure level
- Full set of electro-optical measurements performed
  - 24h after last exposure level
  - after 168h annealing at 80 °C

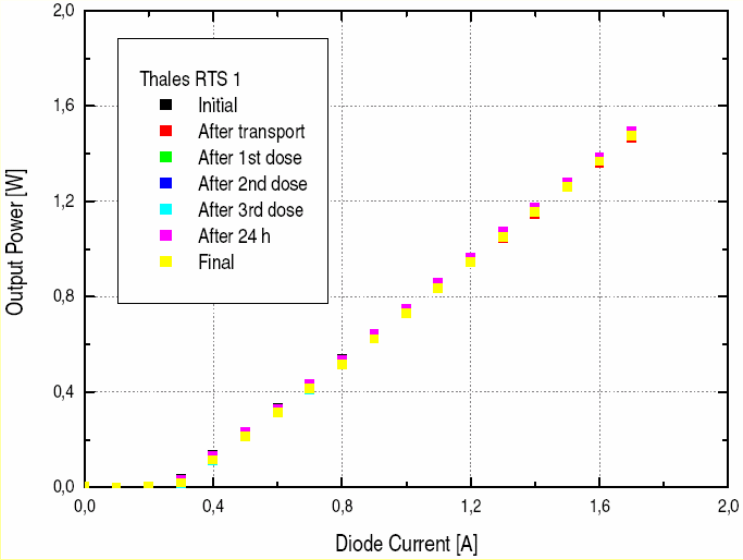


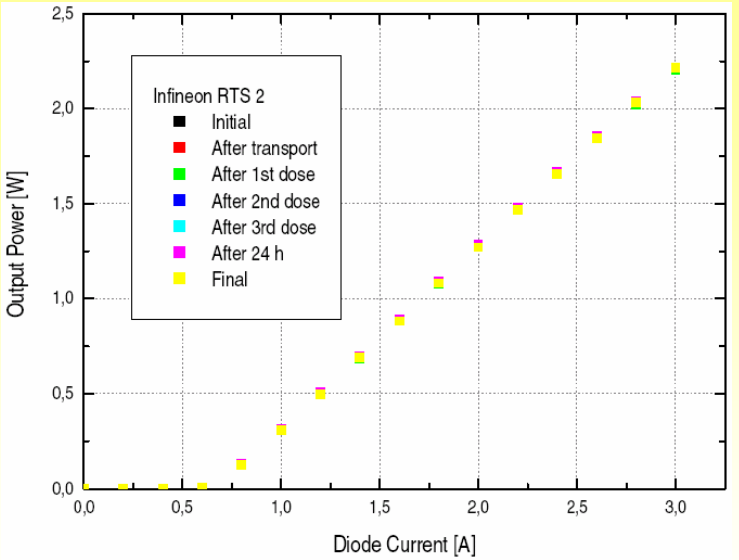


Radiation test results

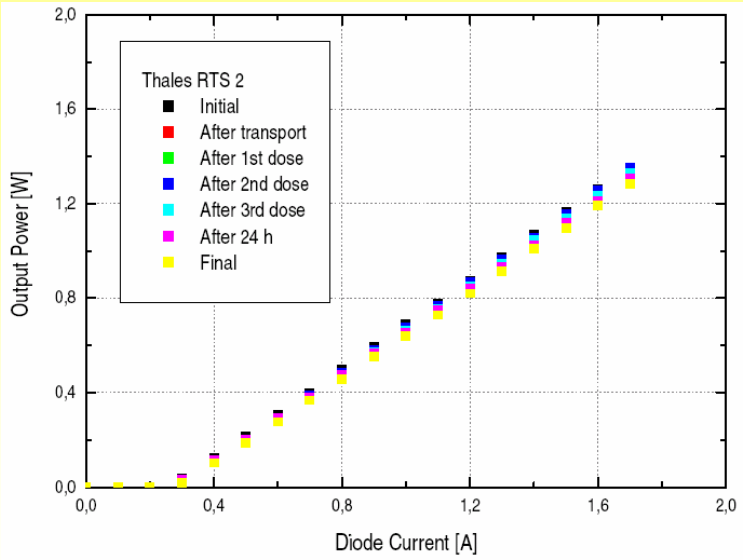


Operating

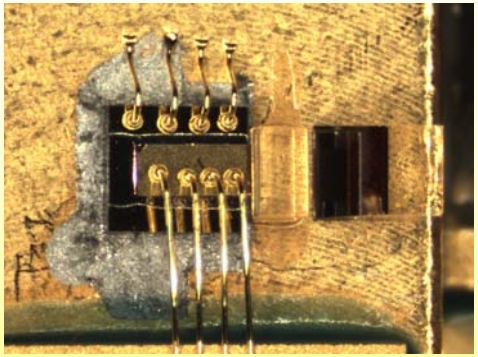
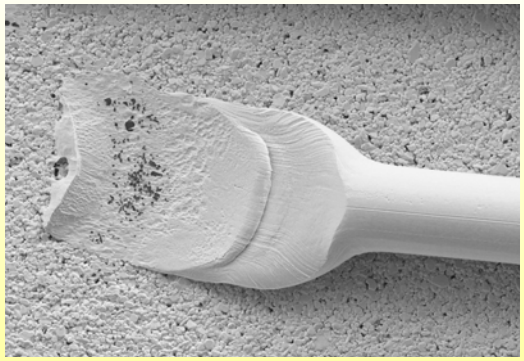
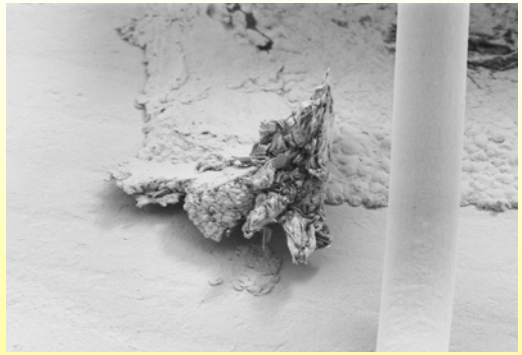
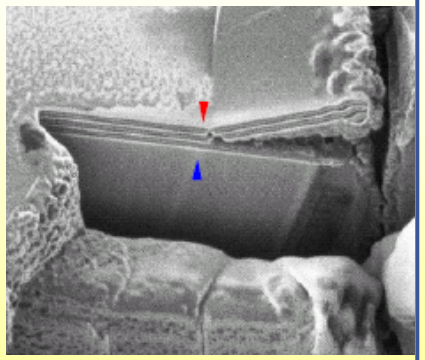




Non operating



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

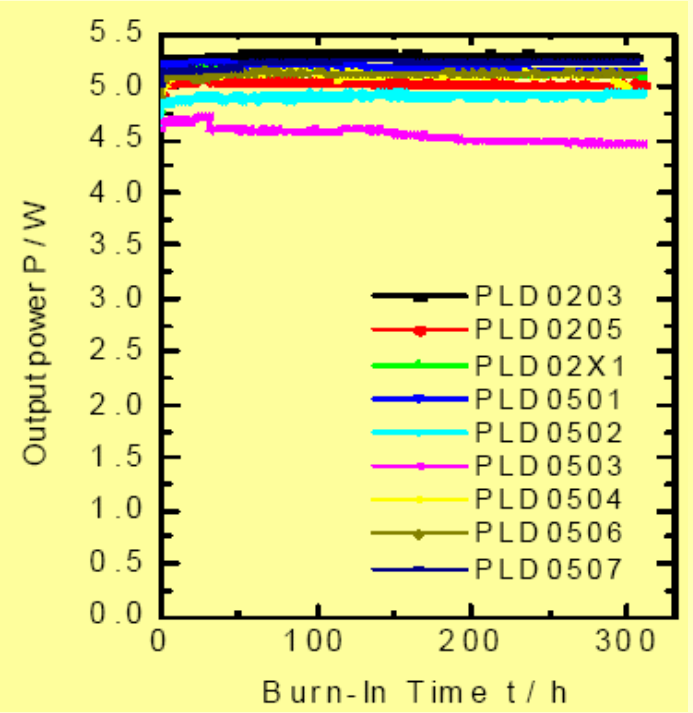
Parameter	Value	
Emitting area	6 emitters, 60 µm width, 1 mm pitch	
CW output power P_{op}	> 1 W	All values for T = 25°C and from begin of life to end of life
Operating current I	< 3.1 A	
Threshold current I_{th}	< 1.8 A	
Slope efficiency S	> 0.95 W/A	
Operating voltage U	< 1.8 V	
Life time	> 4 years	EOL: 20% power drop at constant current operation respect to BOL
Reliability within life time	0.98	
MTTF	1.73×10^5 h	
Wavelength λ	(807 ± 1) nm	
Spectral width Δλ	3 nm	
Beam divergence – fast axis	< 60°	
Beam divergence – slow axis	< 6°	

Fabrication of laser bars

Layer structure was established and grown on a 2 “ wafer
Back end process
Facet coating

Mounting on Cu carrier
Burn-in: 300 h, 5W, 70 °C
Acceptance: DP/P < 0.01 last 100 h → 38 bars passed

24 LD selected
- 20 endurance
- 2 radiation
- 2 reference



Endurance test conditions

20 DL constant current for 10000 hours:

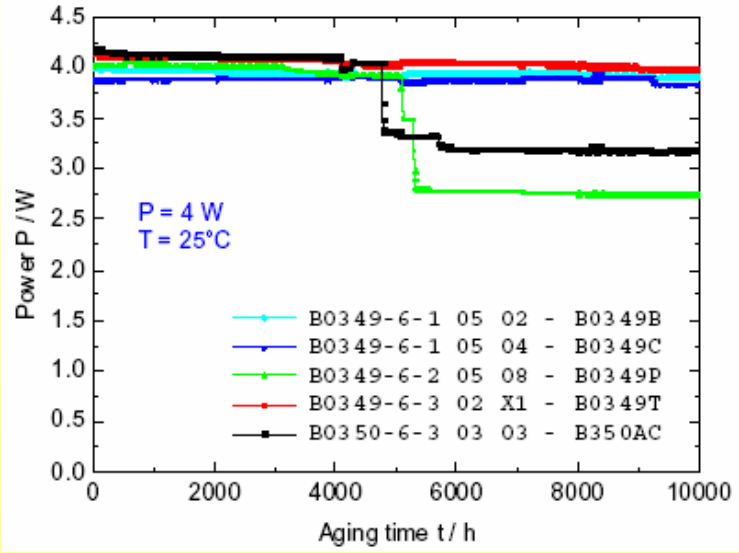
- 5: 4W, 25 °C ± 0.5 °C case temperature
- 5: 4W, 45 °C ± 0.5 °C case temperature
- 5: 2W, 51 °C ± 0.5 °C case temperature
- 5: 1.5W (nominal output power), 25 °C ± 0.5 °C case temperature

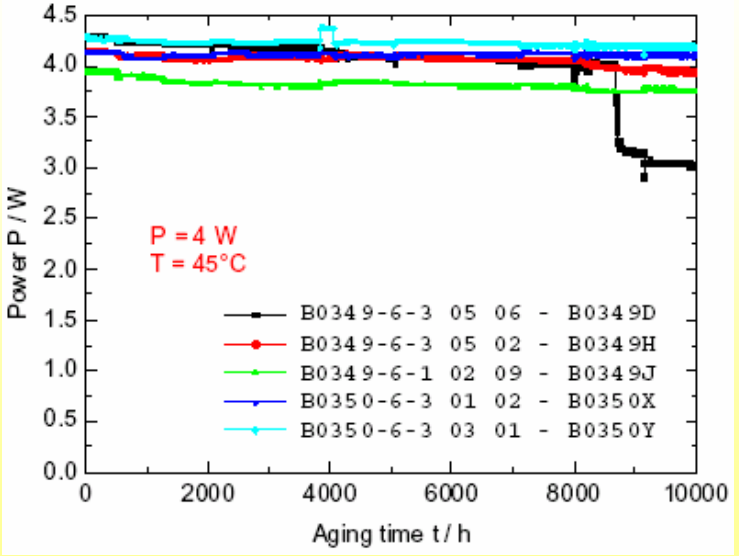
Electro-optical characterisation at 500h, 2000h and 5000h

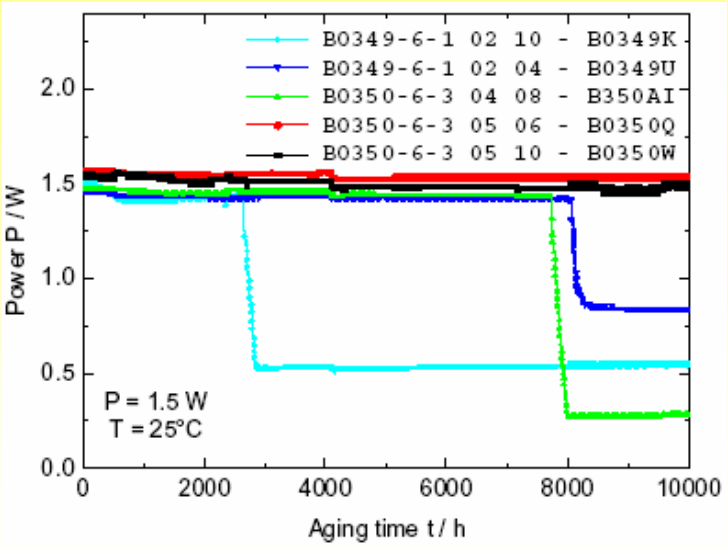
From a reliability of 0.98 for 4 years, the MTTF value is 1.73*10^6, at 1W and 25 °C .
Assumption: activation energy Ea = 0.5 eV and power law exponent n = 2.3

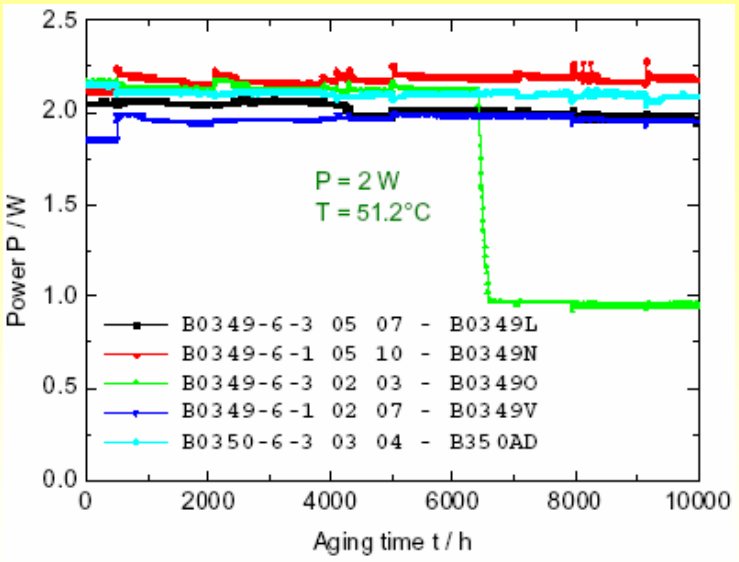
P/W	*T/°C*	Allowed Number of Failures to Proof the MTTF
4.0	25.0	0
4.0	45.0	2
1.5	25.0	-*
2.0	51.2	0

Endurance test results







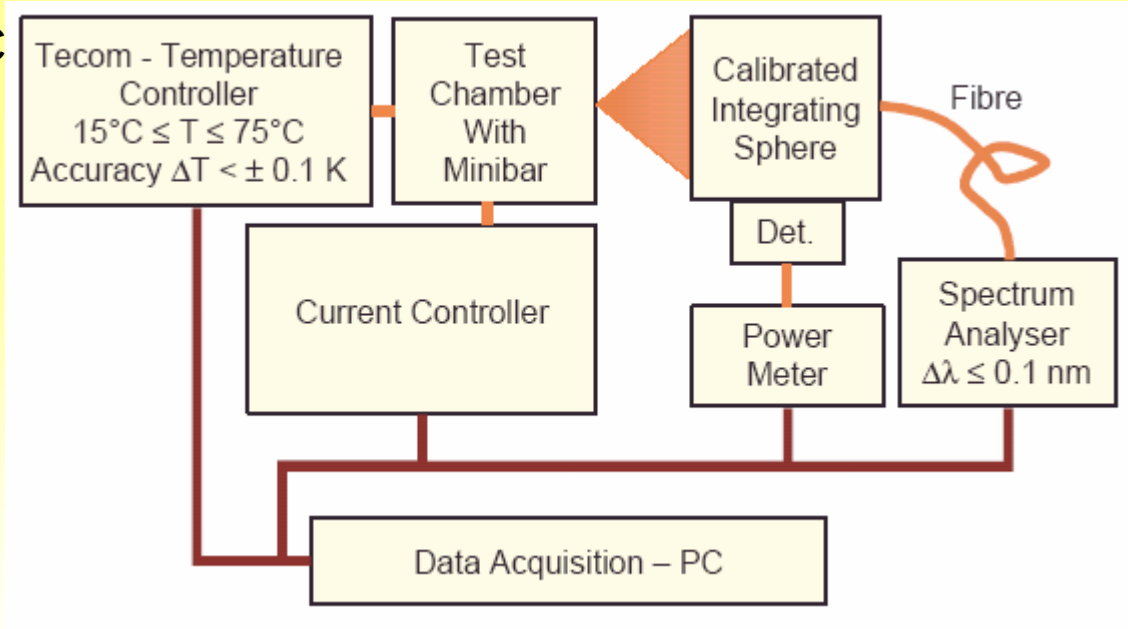


Radiation test conditions

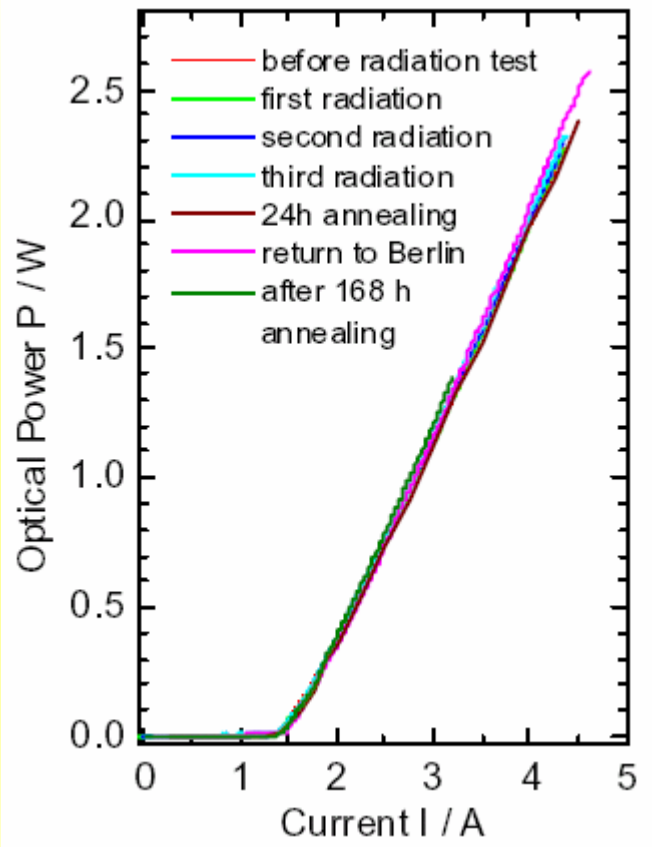
2 DL at 2*10^9 p/cm^2, 4*10^9 p/cm^2 and 2*10^10 p/cm^2;
60MeV protons 60% of rad time; 25 MeV protons 40 % of rad. time

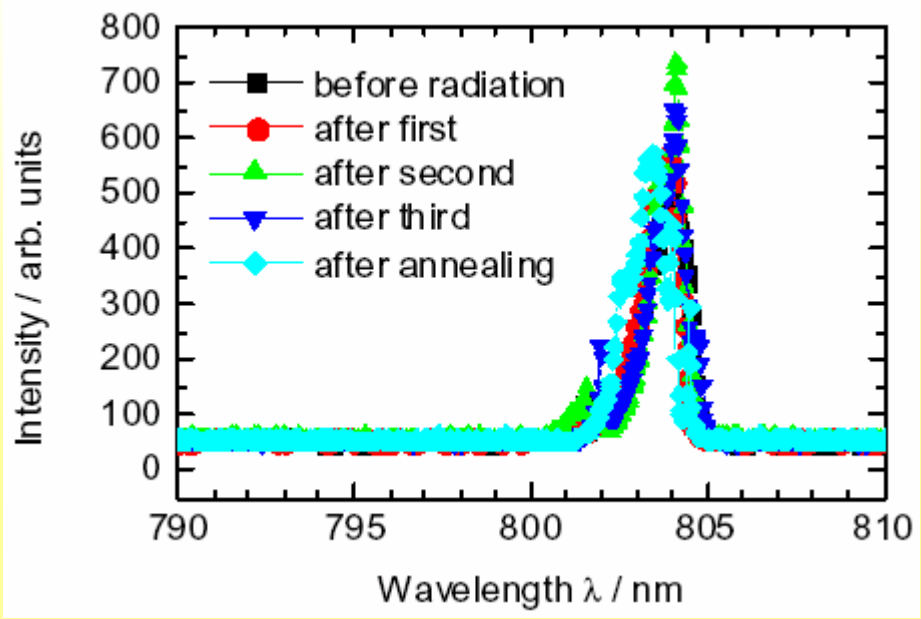
- 1: nominal operating condition
- 1: non operating condition

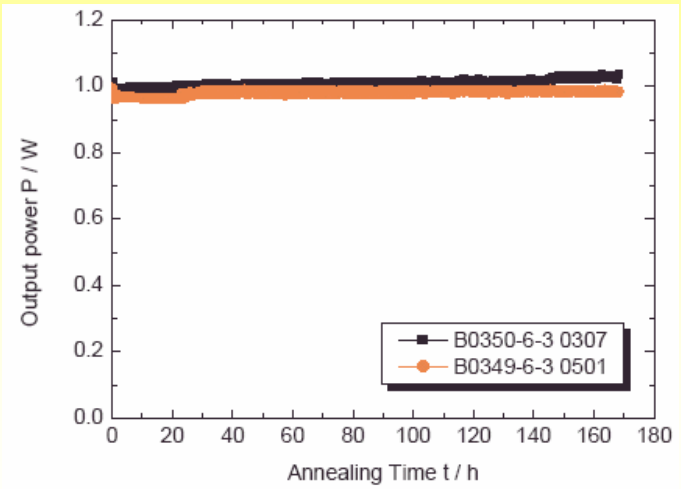
- Limited set of electro-optical measurements performed after each exposure level
- Full set of electro-optical measurements performed
  - 24h after last exposure level
  - after 168h annealing at 70 °C
- Accelerating ageing test



Radiation 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

Conclusion

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

Endurance tests: not successful, but useful:
Thales Laser Diodes: lifetime reached when derated
Osram: lifetime not met
FBH customised laser diodes: chip technology is reliable

Failure analysis:
Thales Laser Diodes-Osram: many areas to be improved (soldering, bonding, gluing…)
FBH: mounting to be improved, design to be optimised

Useful assessment test programme:
Laser diodes from FBH selected in the reference laser for ALADIN and have passed the qualification.
COTS laser diodes are less suitable for space applications than custom-designed .