eagleyard PHOTONICS
We focus on power.

High Power Laser Diodes

WORKSHOP Laser Diodes in Space

DFB Laser Diodes at 852 nm matching Cesium absorption and their use as components for atomic clocks in space.

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May 11th, 2006

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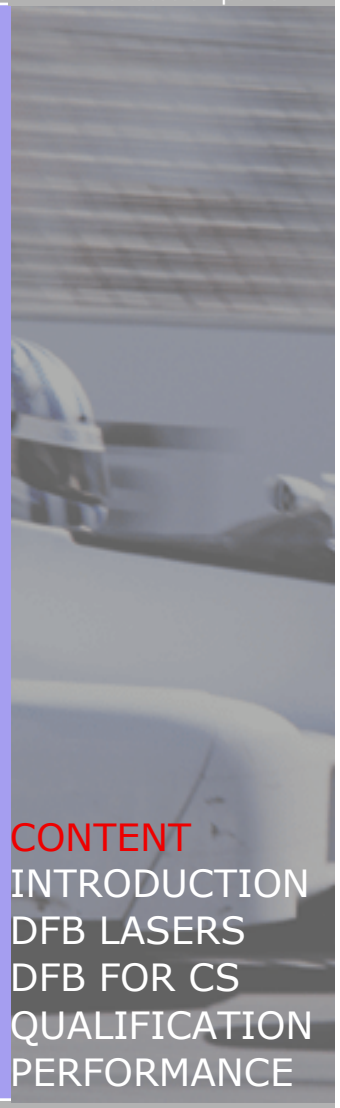


INTRODUCTION

- Company
  - Products: High Power Laser Diodes (Single Emitter)
  - Applications: Life Science, Material Processing, Spectroscopy, Metrology, Printing (CTP), Data Storage, Laser Display
  - Founded: 2002
  - Origin: *spin-off* from the Ferdinand-Braun-Institute
  - Location: Berlin-Adlershof („[eagle]-[yard]“)
  - Employees: 16
  - Sales: 50% Germany
    35% US/North America
    10% SEA

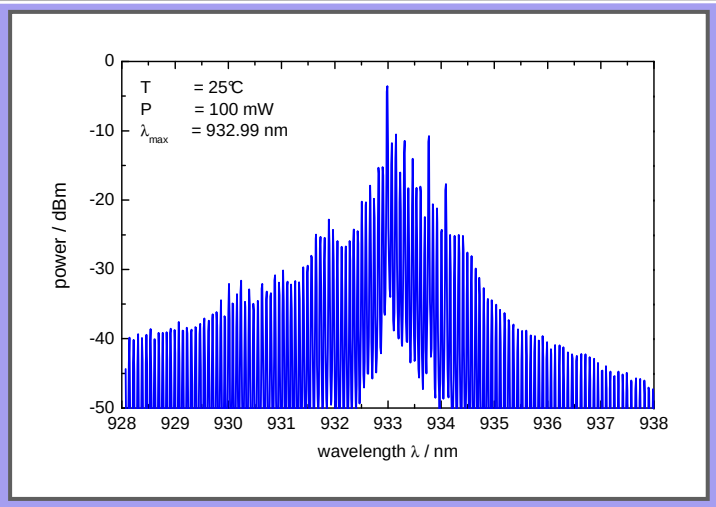
„eagleyard Photonics closes the gap between leading research results and volume production.“
(mission statement)

INTRODUCTION

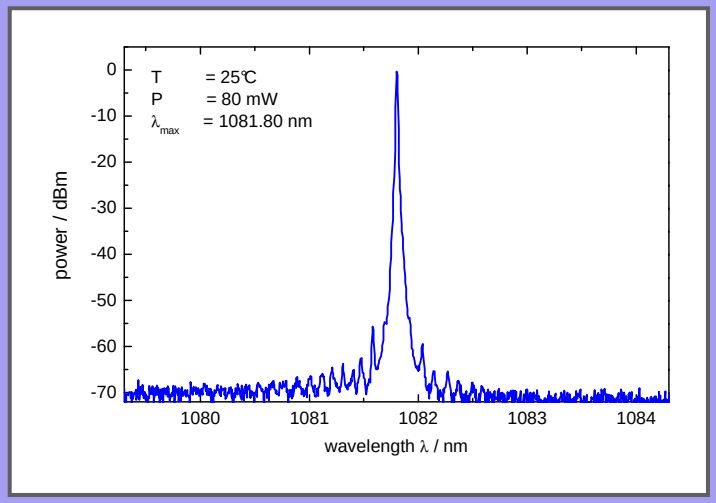
- Portfolio
  - Products: All based on GaAs semiconductor (650 to 1120 nm)
  - *Fundamental:* Ridge Waveguide Laser
    large wavelength variety
    up to 300 mW
  - *Highest Power:* Broad Area Laser
    980 nm: 12 W @ 200 µm
    808 nm: 7 W @ 200 µm
  - *Beam Quality:* Tapered Laser/Amplifier
    Best M^2 values
    up to 2 W (5 W)
  - *Precision:* DFB/DBR Laser
    unique wavelength/linewidth
    up to 400 mW @ 976 nm

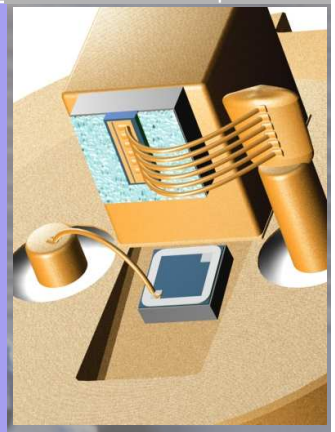
DFB LASERS

- RW Laser
  - Many Fabry-Perot modes allowed
  - Single vs. Multimode



- DFB/DBR Laser
  - Integrated grating structure acting as frequency filter
  - Purely Singlemode

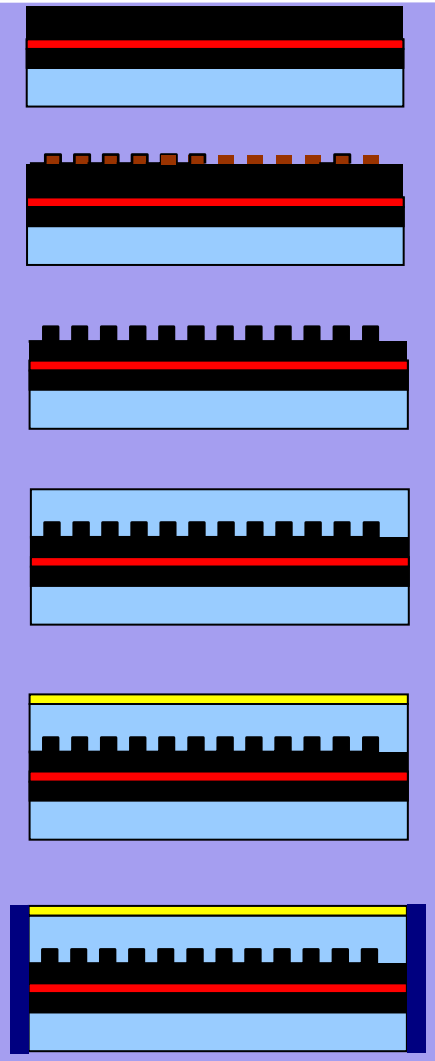




DFB LASERS - MANUFACTURING

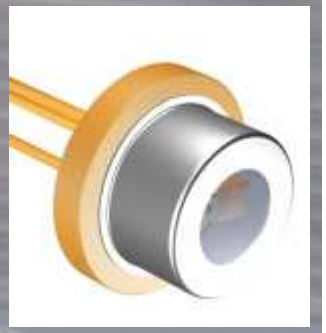
- 1st Epitaxial Run
- Mask Process
- Edging
- 2nd Epitaxial Run
- Contacts
- Facet Coating

- Patented
  - Steps 4 and 6
  - eagleyard has exclusivity



DFB LASERS

- History
  - Ferdinand-Braun-Institute
  - collaboration with scientific and industrial partners
- Current Portfolio
  - 760, 763, 780, 784, 852, 860, 923, 937, 976, 1060, 1063, 1080, 1083 nm
  - either *eagleyard* or OEM
- Roadmap
  - 785, 795, 810, 855, 894, 935, 942 …
  - More features added on chip level
  - 14 pin Butterfly Package with PM fiber



DFB LASERS FOR CESIUM ABSORPTION

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Recommended Operation Conditions

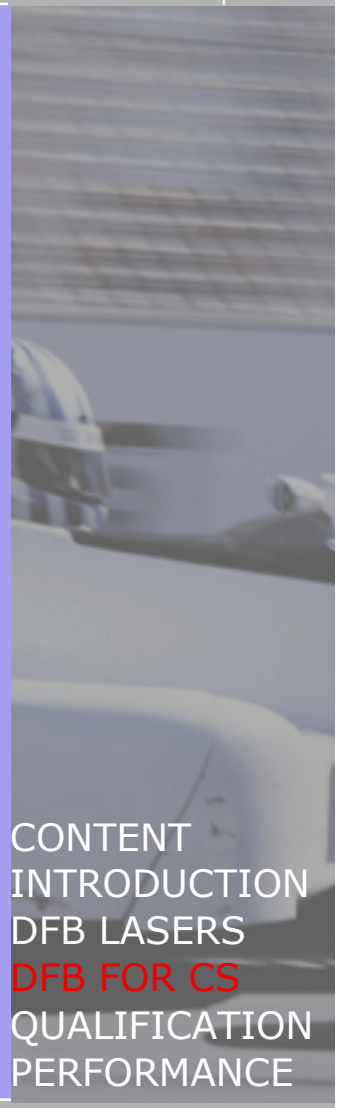
	Symbol	Unit	min	typ	max
Operational Temperature at case	T_{case}	°C	15	–	40
Forward Current	I_F	mA	–	–	230

Characteristics at T_{amb} 25°C

Parameter	Symbol	Unit	min	typ	max	Measurement Condition / Comments
Center Wavelength	λ_C	nm	850	852	854	compare images on page 3
Spectral Width (FWHM)	$\Delta\nu$	MHz		2	10	measured in homodyn-detected interferometric setup
Temperature Coefficient of Wavelength	$d\lambda/dT$	nm / K		0.06		
Output Power	P_{opt}	mW	100	150		
Slope Efficiency	η_d	W / A	0.6	0.8	1	
Threshold Current	I_{th}	mA	60	70	90	
Operational Current @ 150 mW	I_{op}	mA		230	250	
Cavity Length	L	µm		1500		
Divergence parallel (FWHM)	$\Theta_{\parallel}$	°	6	8	10	
Divergence perpendicular (FWHM)	$\Theta_{\perp}$	°	18	21	24	
Polarization				TE		Polarization in parallel plane
Spatial Mode (transversal)				TEM_{00}		Fundamental Mode
Spectral Mode (longitudinal)				Single Mode		

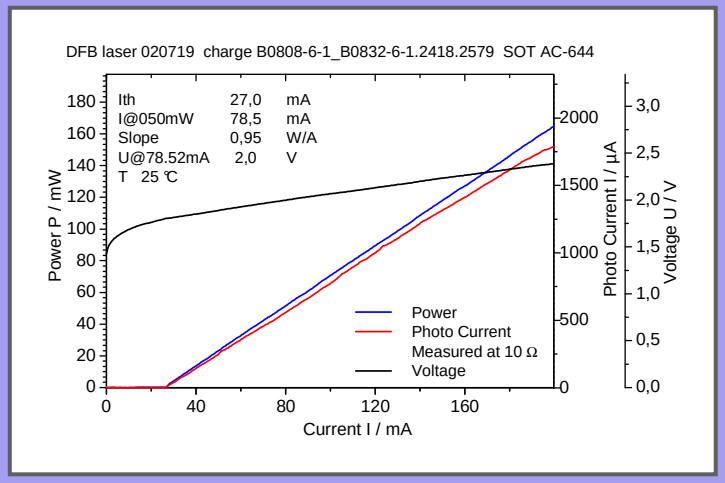
DFB LASERS FOR CESIUM ABSORPTION

- Spectral Requirements for Atomic Clocks
  - Cs D2 line at 852.014 nm vacuum (Cs D1 line at 894 nm)
  - Narrow Linewidth (~ 1 MHz)
  - Stabilized Wavelength
  - Moderate Powerlevel (~ 20 – 50 mW)
  - Long Lifetime
- Conventional optical-pumped Approach
  - Extended cavity setups
- DFB Design Approach
  - Small
  - No mechanics/alignment
  - Low weight

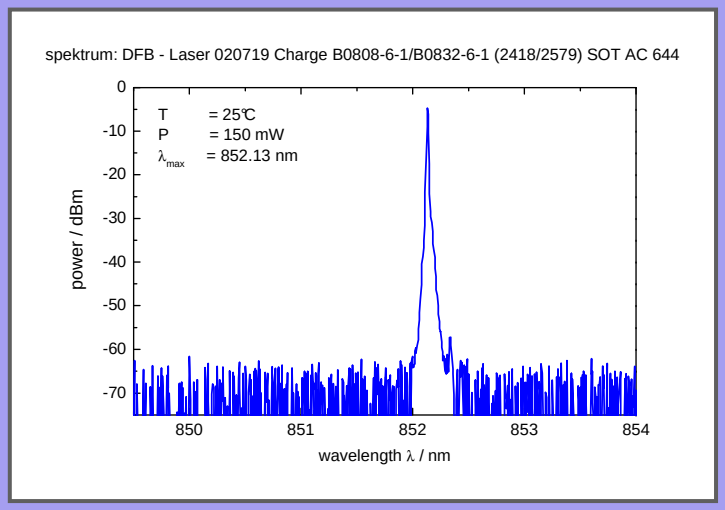


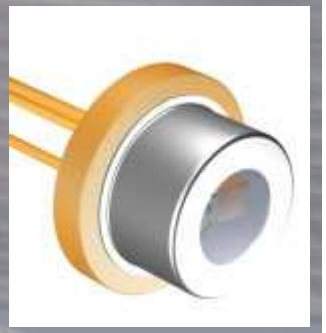
DFB LASERS FOR CESIUM ABSORPTION

- P-U-I
  - Power = 150 mW
  - Threshold = 27 mW
  - Slope = 0.9
  - T = 25 °C



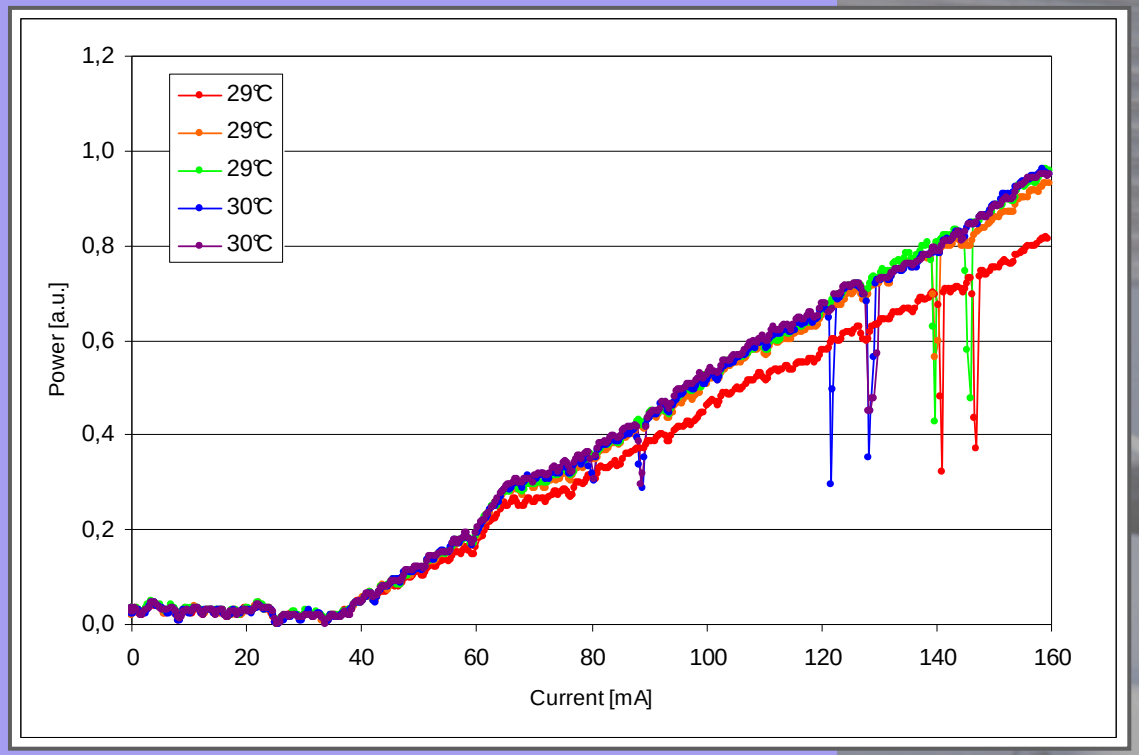
- Spectrum
  - Lambda = 852.13 nm
  - Power = 150 mW
  - T = 25 °C





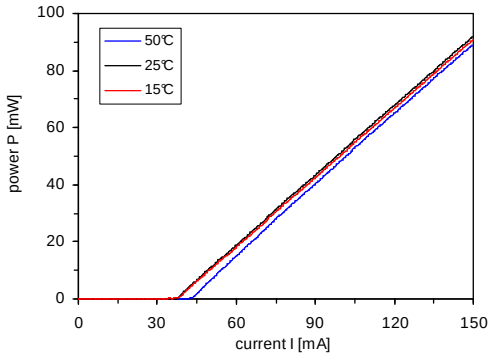
DFB LASERS FOR CESIUM ABSORPTION

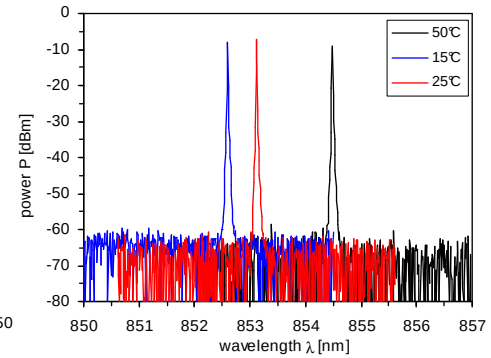
- Where is the Cs?
  - modifed test setup with double pass through Cs cell
  - *dips* of sudden power drop indicating Cs absorption
  - method is used for calibration of our equipment

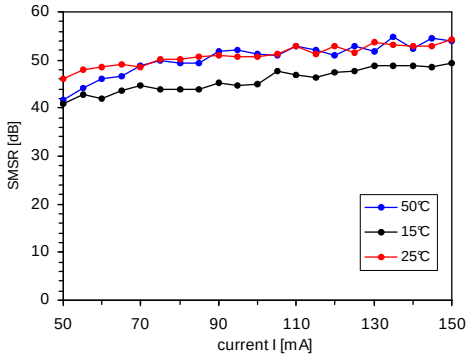


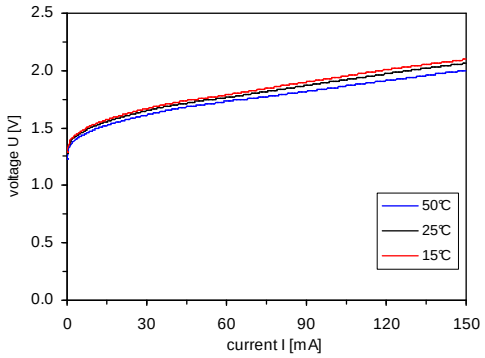
DFB LASERS FOR CESIUM ABSORPTION

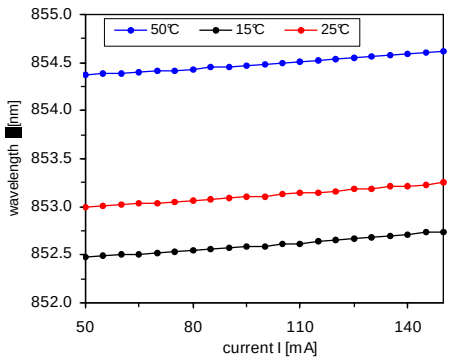
- Finding an operational window – part I
  - Temperature Coefficient: 0.06 nm/K
  - Current Coefficient: 0.003 nm/mA

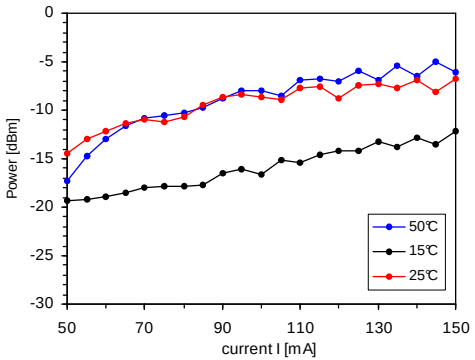






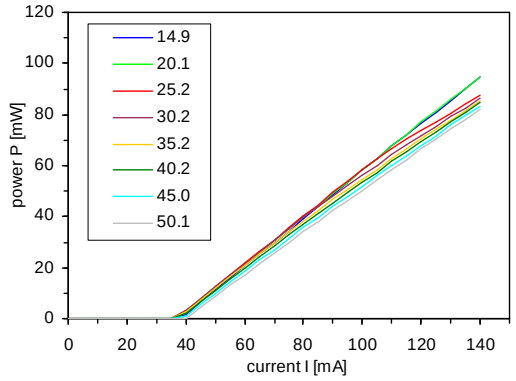


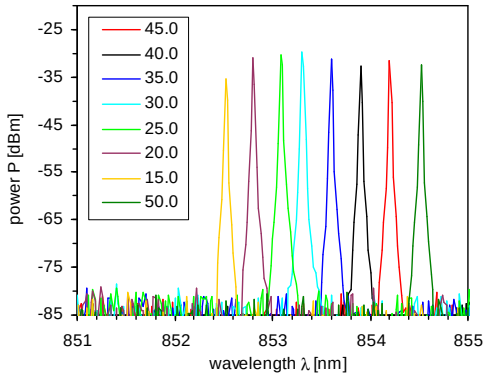


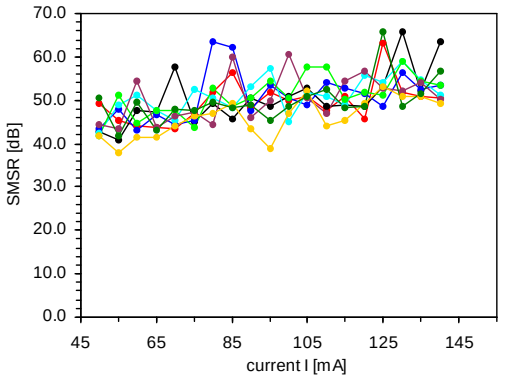


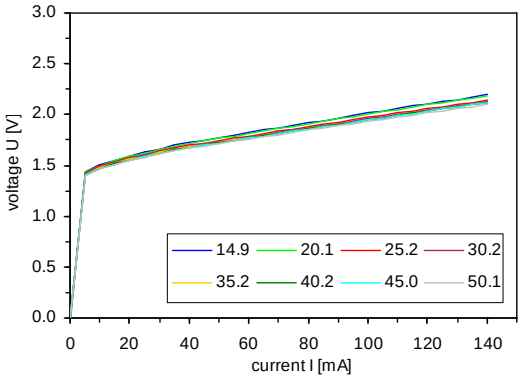
DFB LASERS FOR CESIUM ABSORPTION

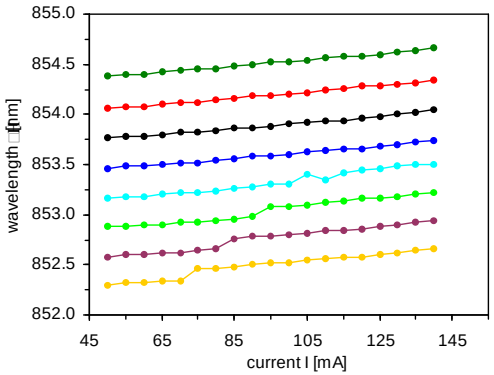
- Finding an operational window – part II

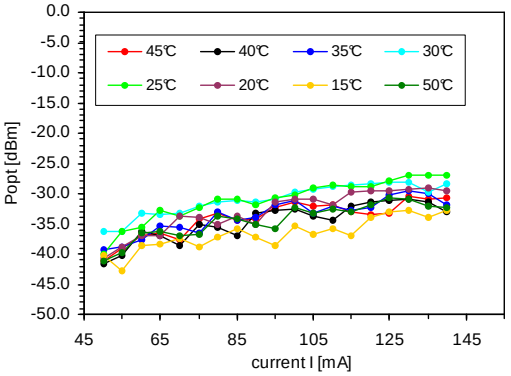








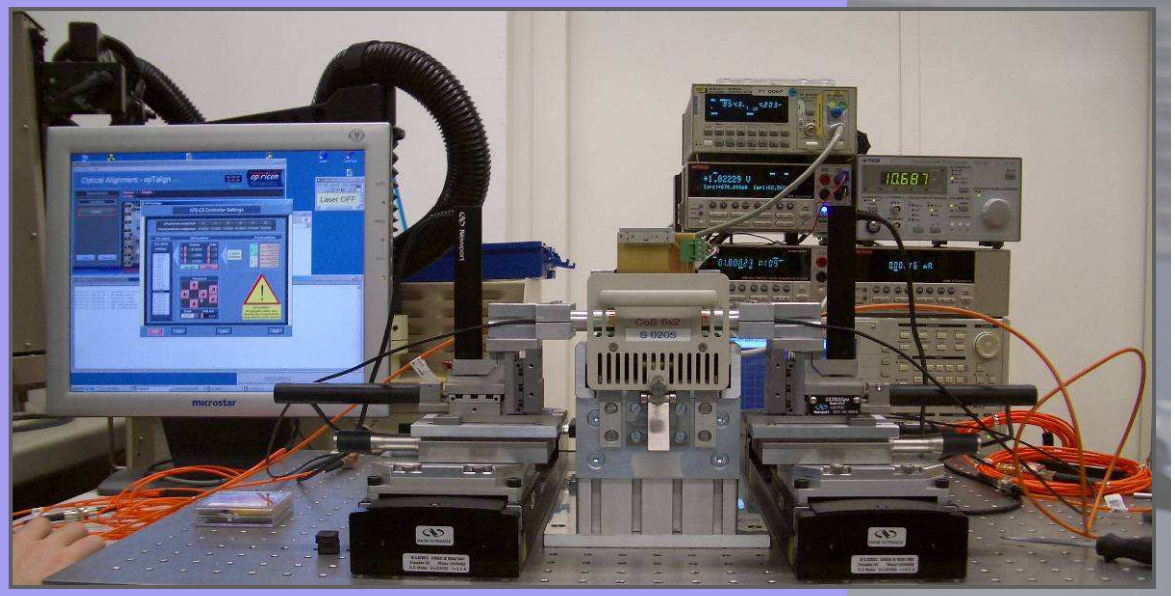




DFB LASERS FOR CESIUM ABSORPTION

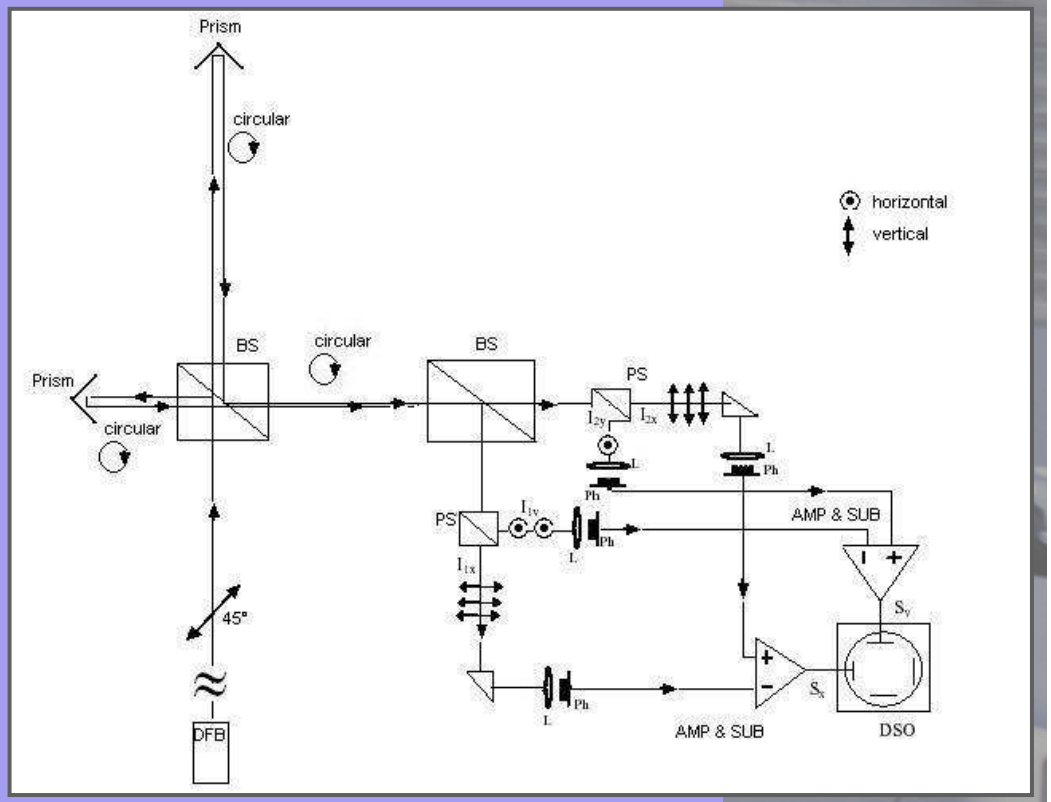
We focus on power.

- Collecting data
  - Fully automated Test-Station measures 16 DUT simultaneously
  - Compatible to Lifetime-Test/ Burn-In Stations, no additional handling needed



DFB LASERS FOR CESIUM ABSORPTION

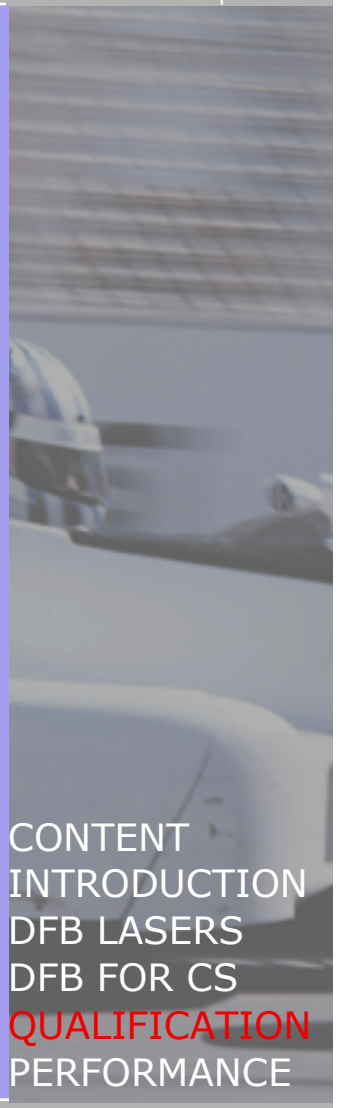
- Determination of Linewidth
  - Selfhomodyne interferometric setup*
  - Linewidth is derived from a histogram of frequeny change
  - Typical values: 2 – 4 MHz



- *) T. Kinder, K.-D. Salewski, *Characterizing tuneable external cavity semiconductor lasers using a homodyne fibre interferometer,* International Journal for Light and Electron Optics, No. 3/2000.
- *) K. Okoshi, K. Kikuchi, A. Nakayama, *Novel Method for High Resolution Measurement of Laser Output Spectrum.* Vol. 16, No. 16, P. 630-631, July 1980.

QUALIFICATION

- Spectral Requirements for Atomic Clocks
  - Cs D2 line at 852.014 nm vacuum (Cs D1 line at 894 nm)
  - Narrow Linewidth (~ 1 MHz)
  - Stabilized Wavelength
  - Moderate Powerlevel (~ 20 – 50 mW)
  - Long Lifetime
- Qualification Goal
  - Verify, that the DFB 852 satisfy these requirements with long lifetime at standard conditions
  - With more effort, they could likely meet the requirements for their use in space

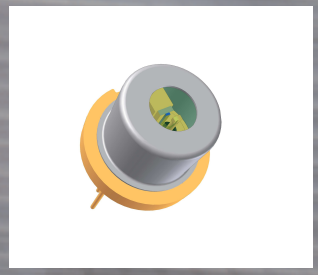


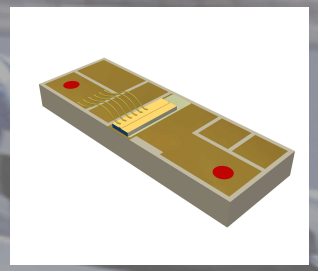
QUALIFICATION

1. Package Test
   - SOT 9 mm housing (Temperature Cycle, Temperature Humidity, Vibration, Shock, Salt Mix, Solderability)

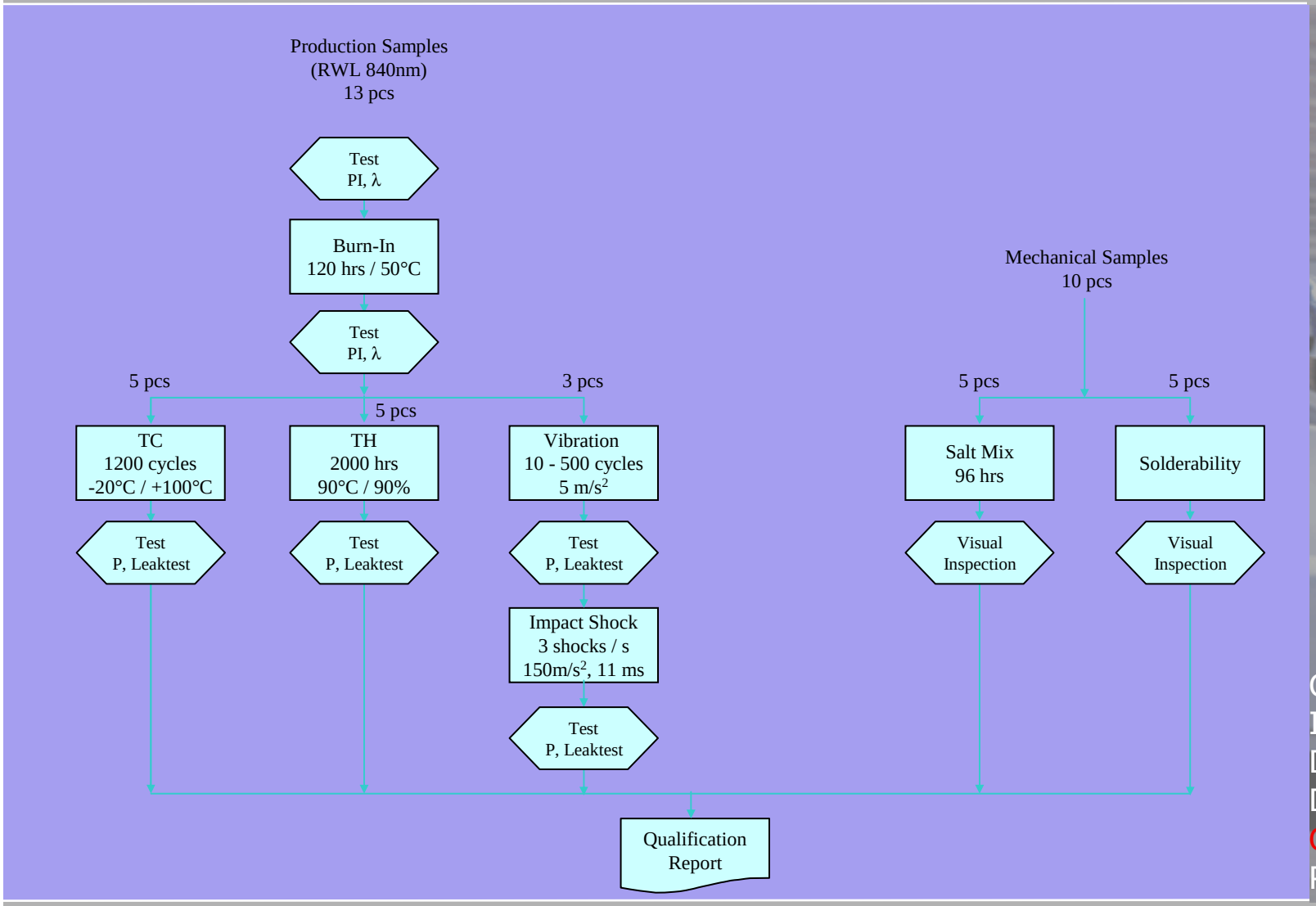
2. Accelerated Aging Test
   - HTB Tests at 50 and 60 °C
   - In SOT 9 mm and Chip-on-submount

3. Spectral properties
   - Linewidth
   - Spectral maps





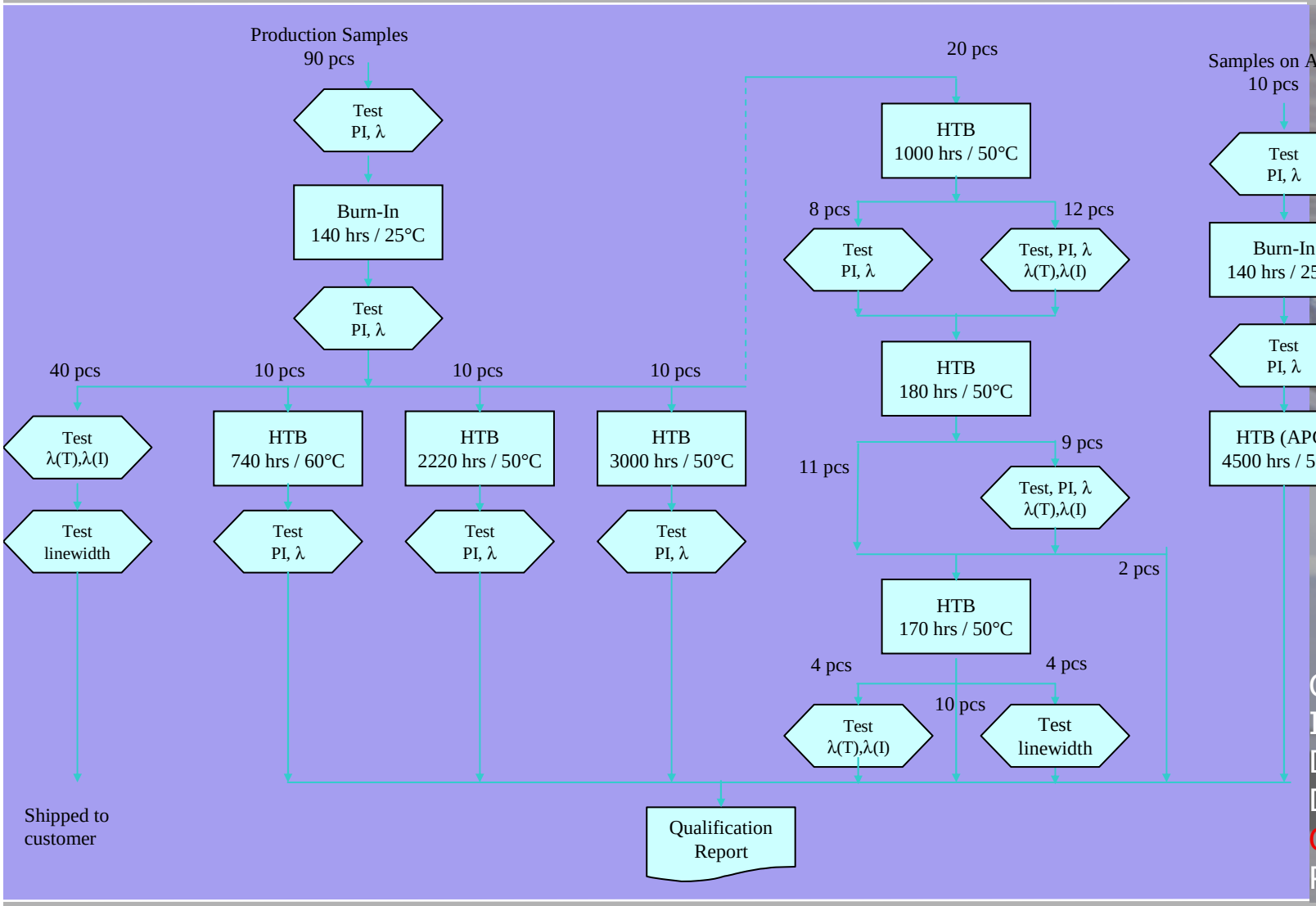
QUALIFICATION – PACKAGE

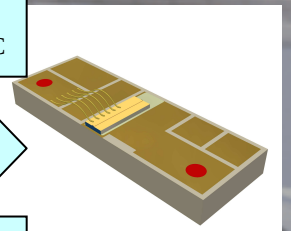


QUALIFICATION – PACKAGE

Test	Status	Result	
TC	completed	0 failures	**passed**
TH	completed	0 failures	**passed**
Vibration	completed	0 failures	**passed**
Mech. Shock	completed	0 failures	**passed**
Salt Mix	completed	0 failures	**passed**
Solder-ability	completed	0 failures	**passed**

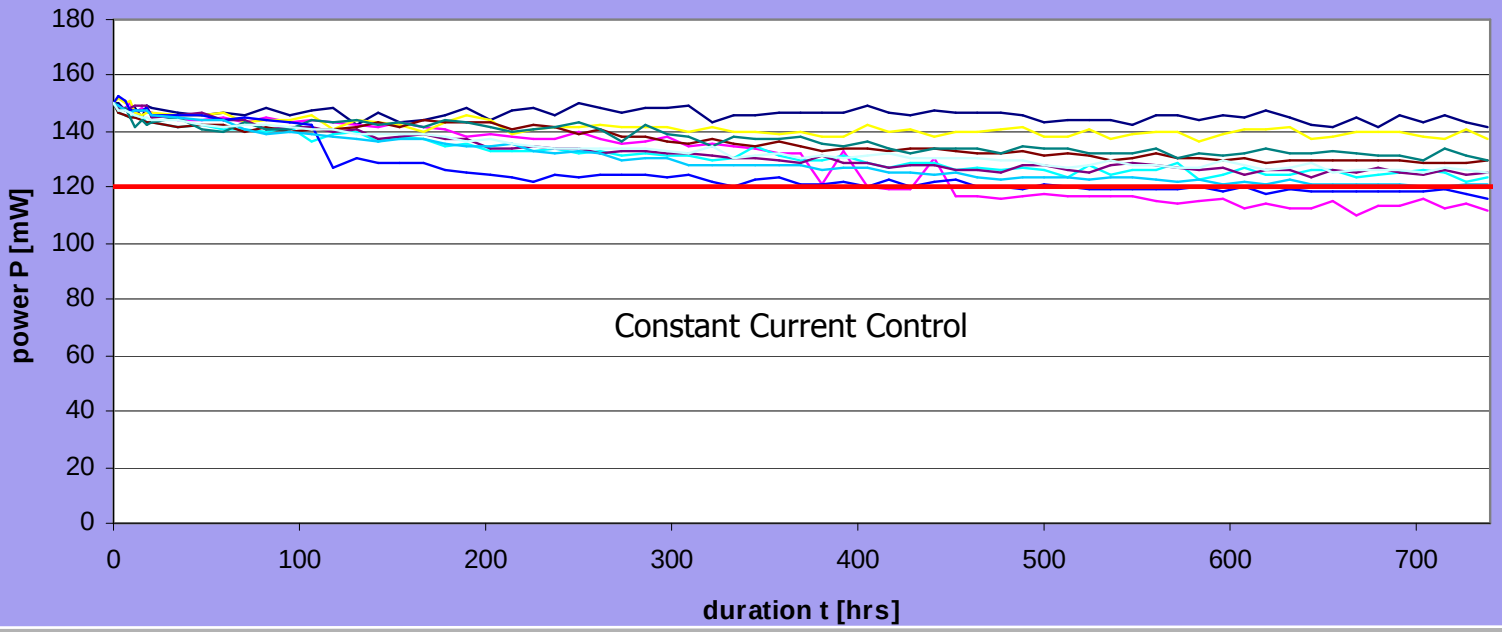
QUALIFICATION - AGING

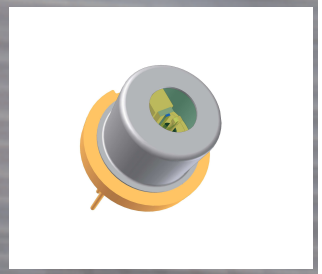




QUALIFICATION – AGING

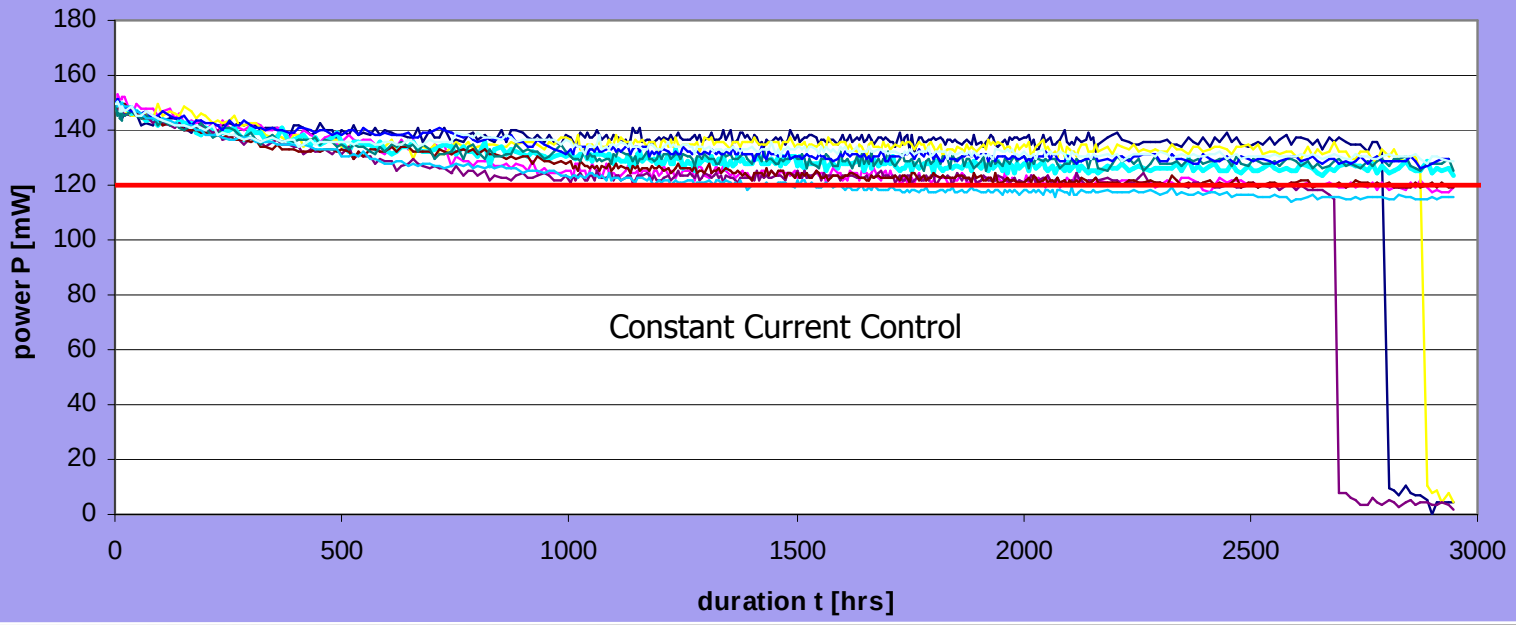
Stress conditions:	740 hrs, T_{case} = 60°C, P_{opt} = 150 mW (CW, cc)
Samples:	10 parts, SOT
Batch:	B0651-6-2/B0673-6-2
End of life criteria:	P_{opt} = 80% (120 mW)
Defects:	2 degradation defects at 420 hrs and 490 hrs
Averaged extrapolated Lifetime at 60°C:	1450 hrs
Estimated Lifetime at 30°C and 50 mW:	**107,000 hrs (Acceleration Factor: AF = 74)**





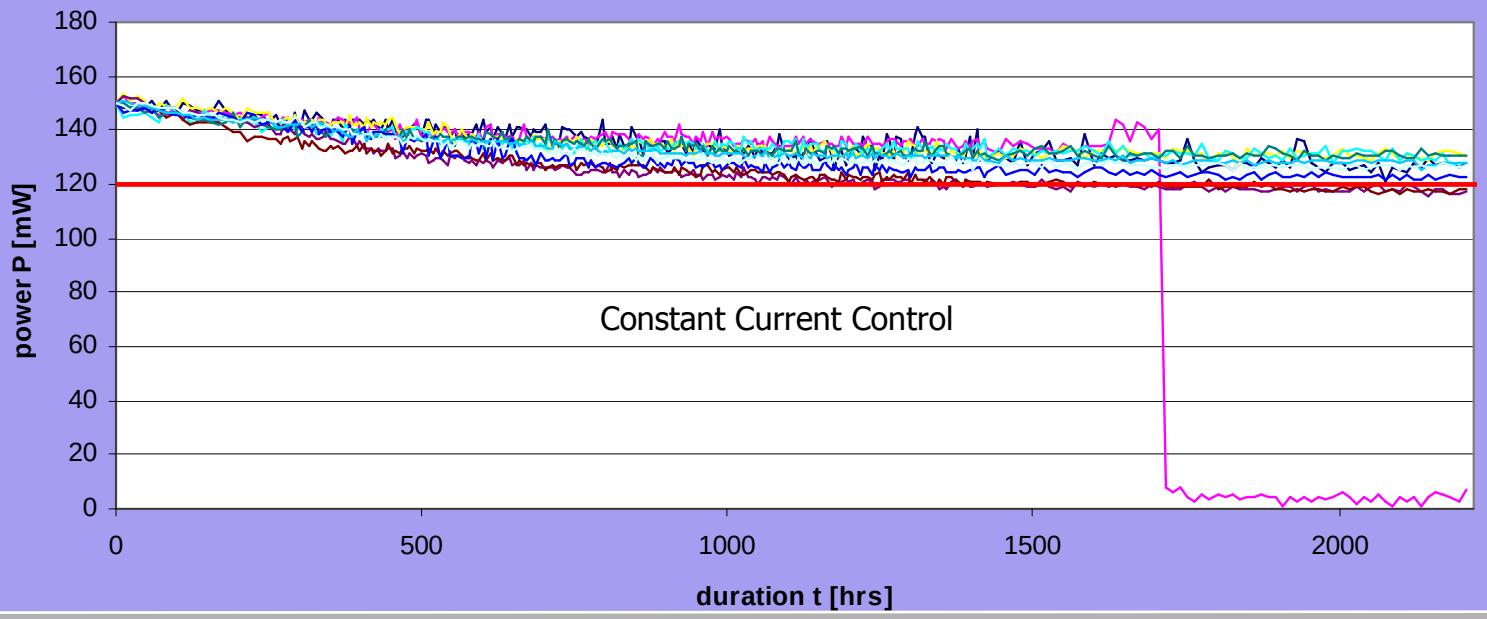
QUALIFICATION – AGING

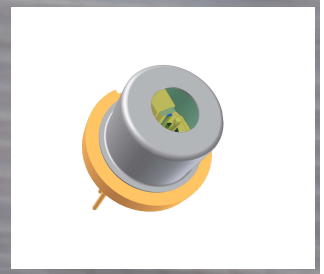
Stress conditions:	3000 hrs, T_{case} = 50°C, P_{opt} = 150 mW (CW , cc)
Samples:	10 parts, SOT
Batch:	B0651-6-2/B0673-6-2
End of life criteria:	P_{opt} = 80% (120 mW)
Defects:	4 degradation defects at 1220, 1810, 2050, 2220 hrs
	2 sudden failures at 2800, 2890 hrs
Averaged extrapolated Lifetime at 50°C:	3800 hrs
Estimated Lifetime at 30°C and 50 mW:	**173,000 hrs (AF = 46)**



QUALIFICATION – AGING

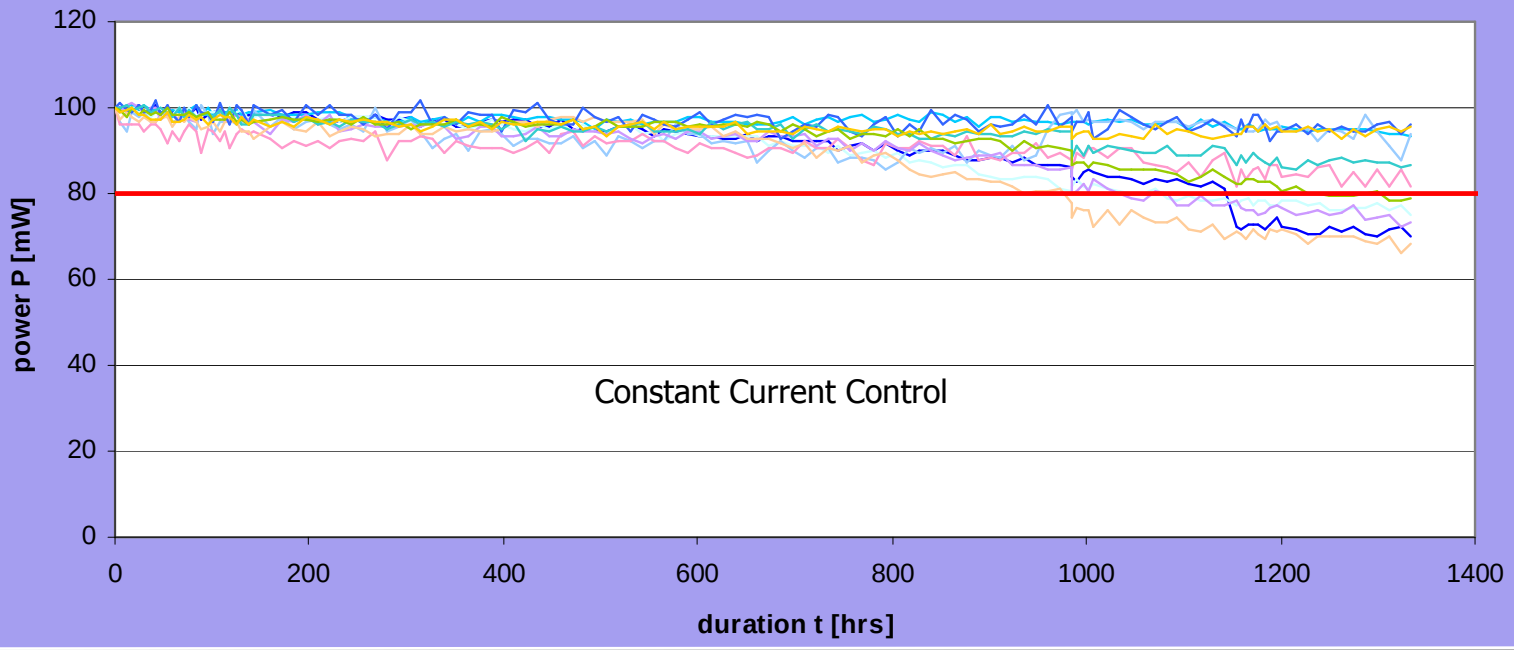
Stress conditions:	2220 hrs, T_{case} = 50°C, P_{opt} = 150 mW (CW , cc)
Samples:	10 parts, SOT
Batch:	B0651-6-2/B0673-6-2
End of life criteria:	P_{opt} = 80% (120 mW)
Defects:	2 degradation defects at 1050, 1300 hrs
	1 sudden failure at 1700 hrs
Averaged extrapolated Lifetime at 50°C:	3770 hrs
Estimated Lifetime at 30°C and 50 mW:	**163,000 hrs (AF = 44)**





QUALIFICATION – AGING

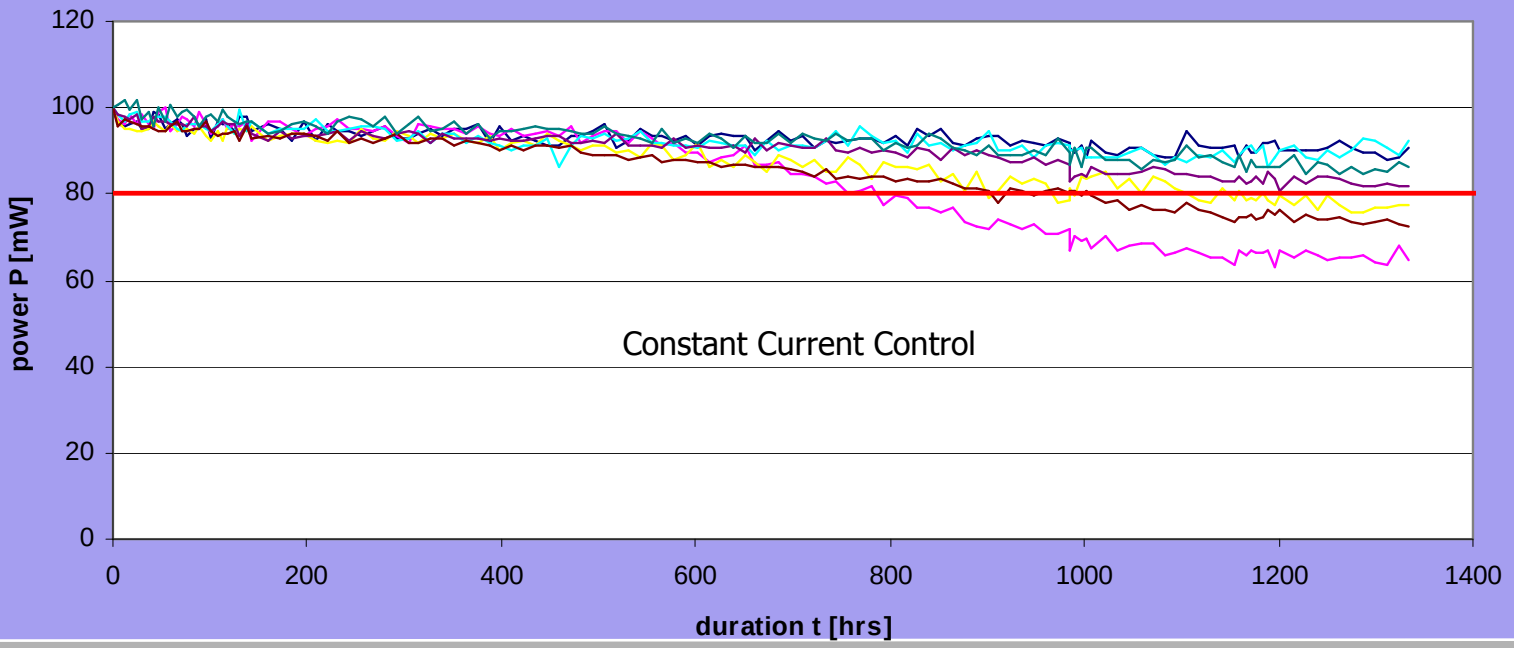
Stress conditions:	1350 hrs, T_{case} = 50°C, P_{opt} = 100 mW (CW , cc)
Samples:	11 (13) parts*), SOT
Batch:	B0808-6-1/B0832-6-1
End of life criteria:	P_{opt} = 80% (80 mW)
Defects:	5 degradation defects at 940, 980, 1080, 1150, 1230 hrs
Averaged extrapolated Lifetime at 50°C:	2450 hrs
Estimated Lifetime at 30°C and 50 mW:	**36,000 hrs (AF = 15)**

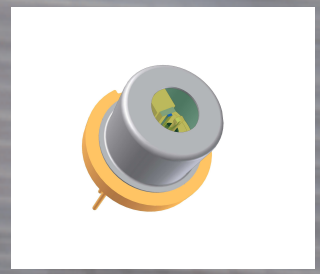


*) Two parts died accidentally during measurement (at 1180 hrs) and are therefore not used for evaluation.

QUALIFICATION – AGING

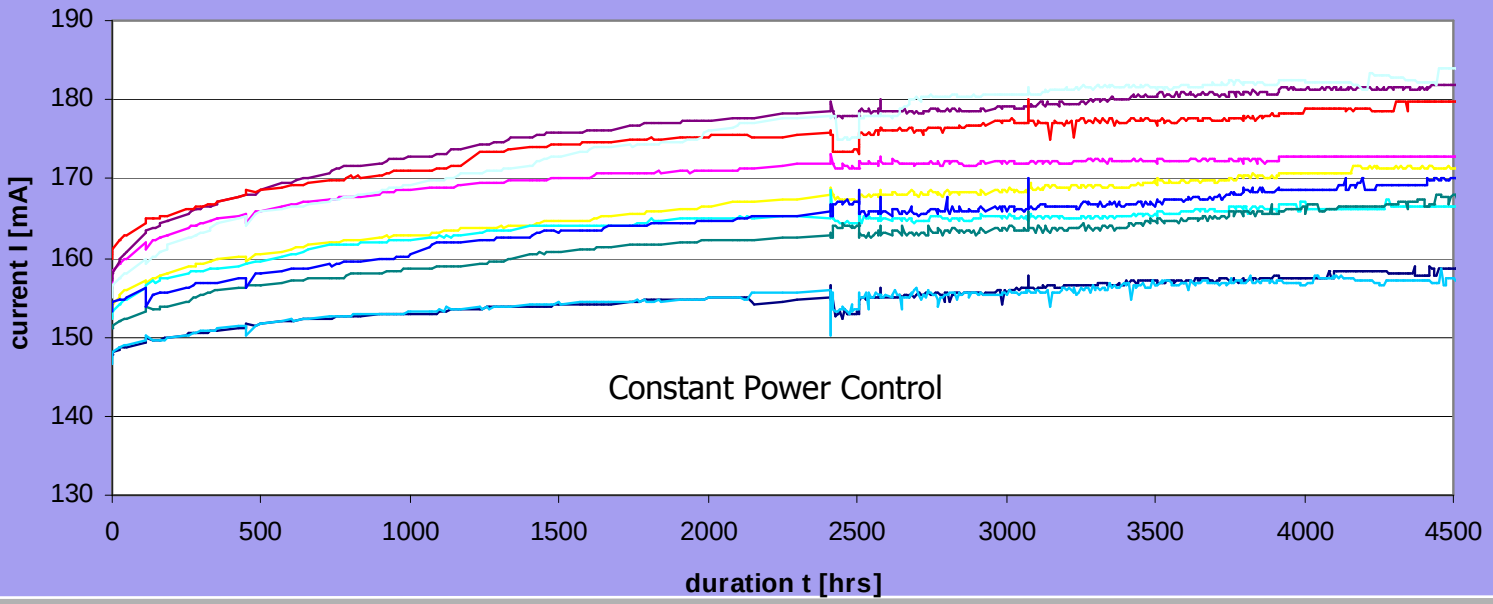
Stress conditions:	1350 hrs, T_{case} = 50°C, P_{opt} = 100 mW (CW , cc)
Samples:	7 parts, SOT
Batch:	B0651-6-3/B0673-6-3
End of life criteria:	P_{opt} = 80% (80 mW)
Defects:	3 degradation defects at 790, 900, 910 hrs
Averaged extrapolated Lifetime at 50°C:	2290 hrs
Estimated Lifetime at 30°C and 50 mW:	**36,000 hrs (AF = 16)**

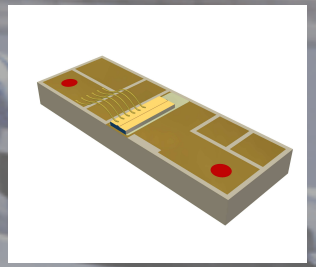




QUALIFICATION – AGING

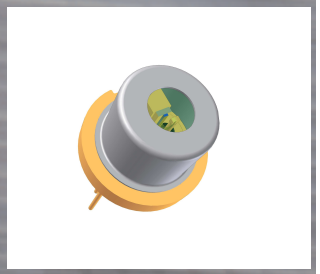
Stress conditions:	4500 hrs, T_{case} = 50°C, P_{opt} = 100 mW (CW , cp)
Samples:	10 parts, AlN
Batch:	B0808-6-1/B0832-6-1
End of Life criteria:	**I_{BOL} + 33 mA**
Defects:	0 degradation defects
Averaged extrapolated Lifetime at 50°C:	12,600 hrs
Estimated Lifetime at 30°C and 50 mW:	**179,000 hrs (AF =14)**

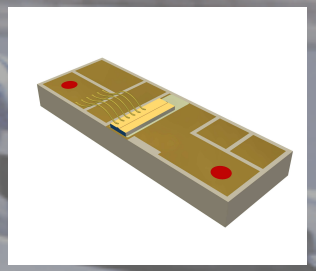




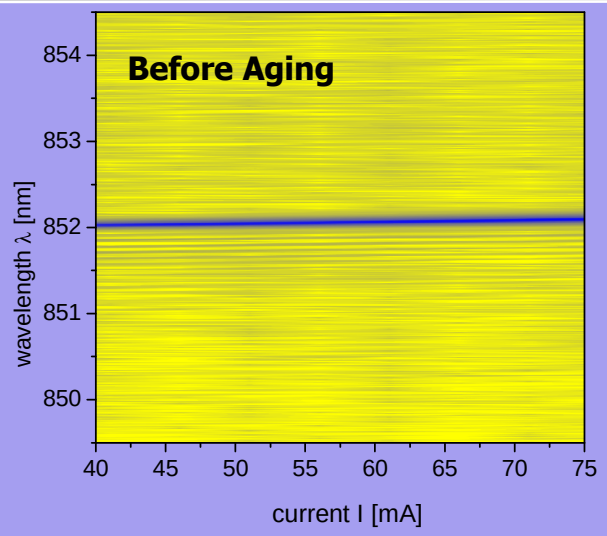
QUALIFICATION – AGING

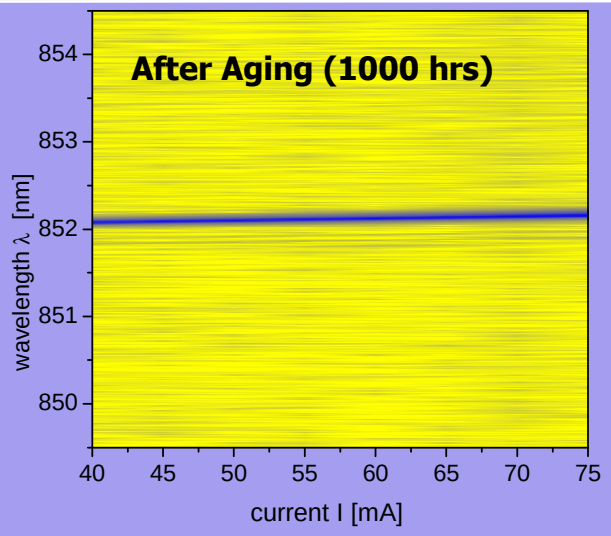
#	Batch/ Wafer	N		Stress Conditions	Failed Parts	Estimated Lifetime [hrs]
1	B0651-6-2	10	SOT	740 hrs / 60°C / 150 mW	2	107,000
2	B0651-6-2	10	SOT	3000 hrs / 50°C / 150 mW	6	173,000
3	B0651-6-2	10	SOT	2220 hrs / 50°C / 150 mW	3	163,000
4	B0808-6-1	11	SOT	1350 hrs / 50°C / 100 mW	5	36,000
5	B0651-6-3	7	SOT	1350 hrs / 50°C / 100 mW	3	36,000
6	B0808-6-1	10	AlN	4500 hrs / 50°C / 100 mW	0	179,000

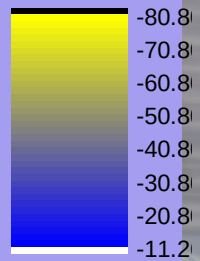


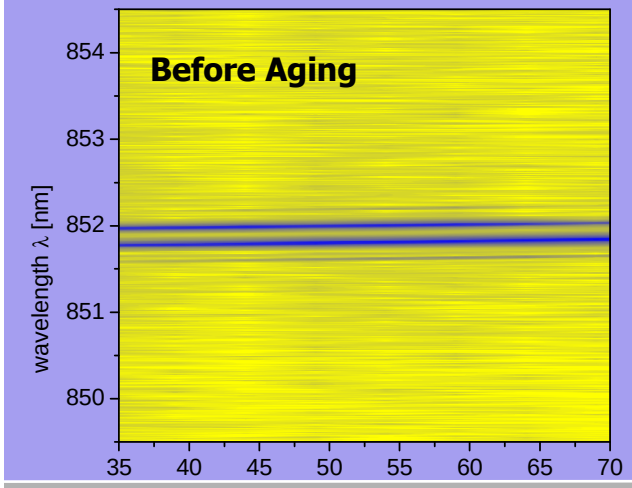


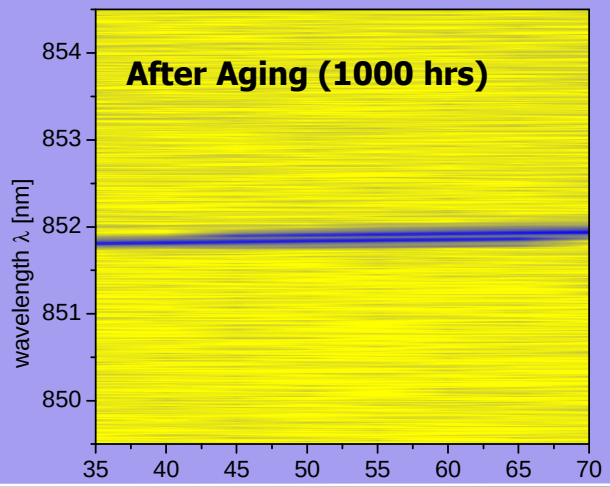
QUALIFICATION – SPECTRAL MAPS

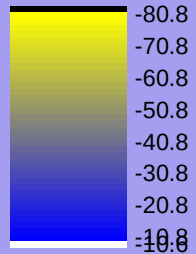




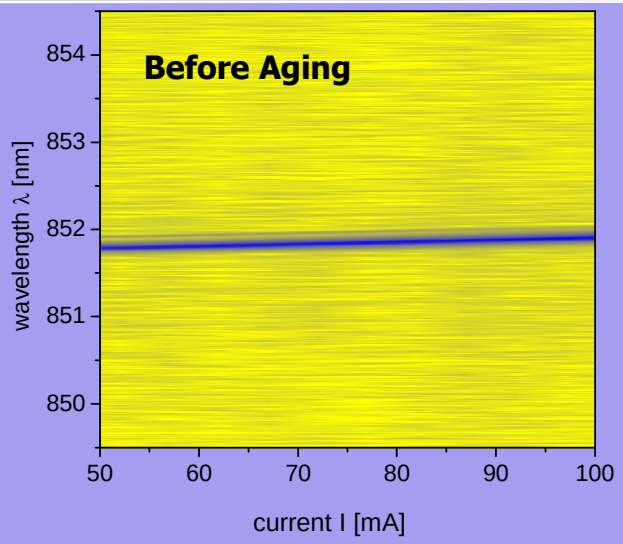


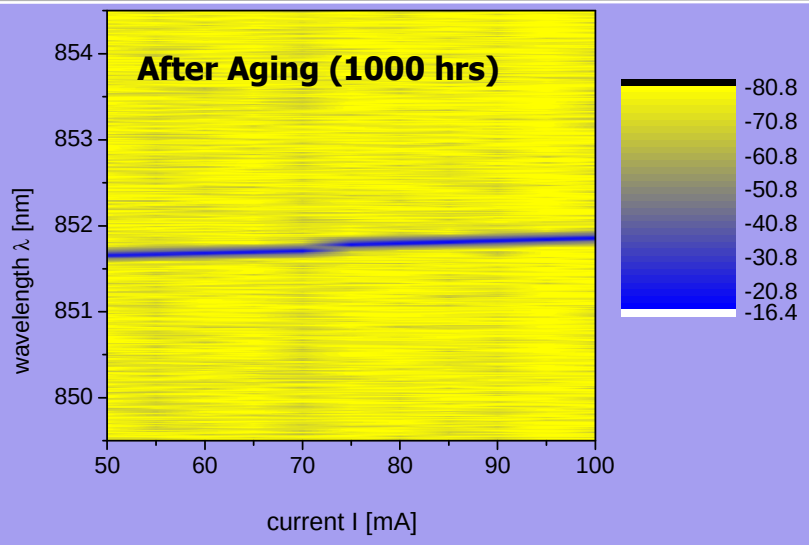


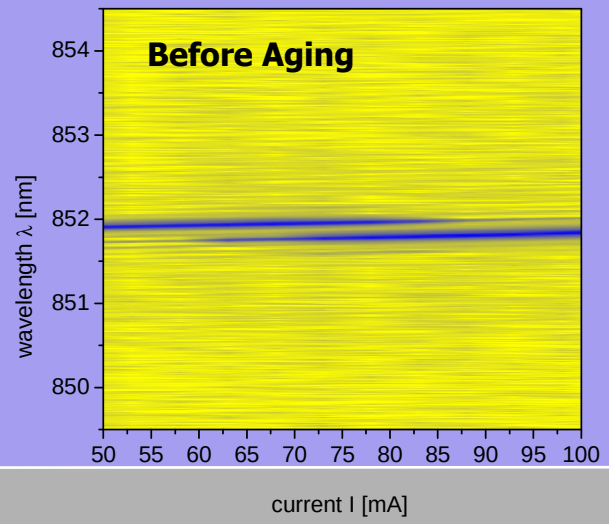


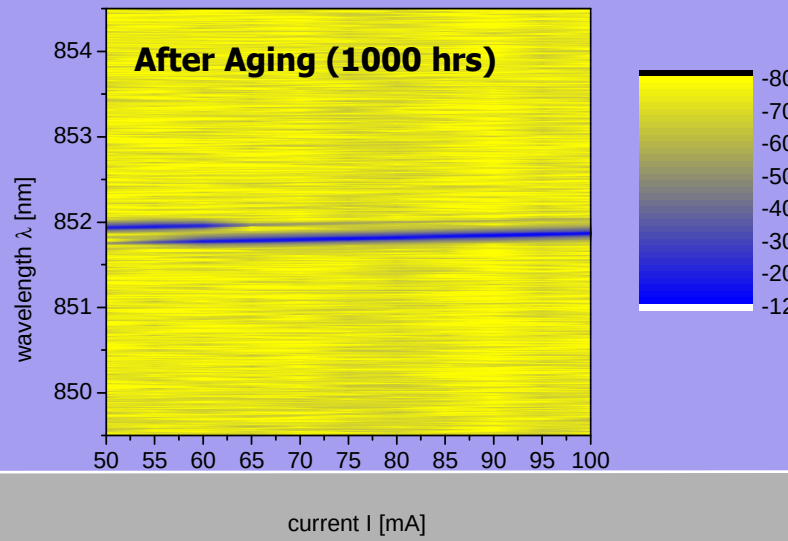


QUALIFICATION – SPECTRAL MAPS







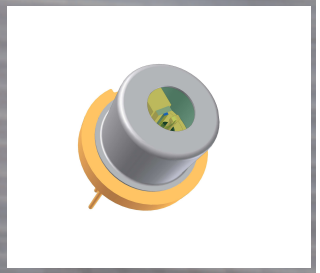


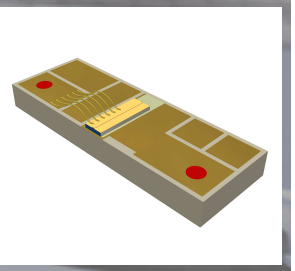
QUALIFICATION

1. Package - Test Results
   - Tests passed without defects
   - SOT package successfully qualified
   - Associated production processes are capable, frozen and qualified
   - Product is capable of being stored and operated in humid environments (w/o condensation)
   - Product is capable for manual iron solder process

2. Accelerated Aging - Test Results
   - Estimated Lifetime > 100,000 hrs.

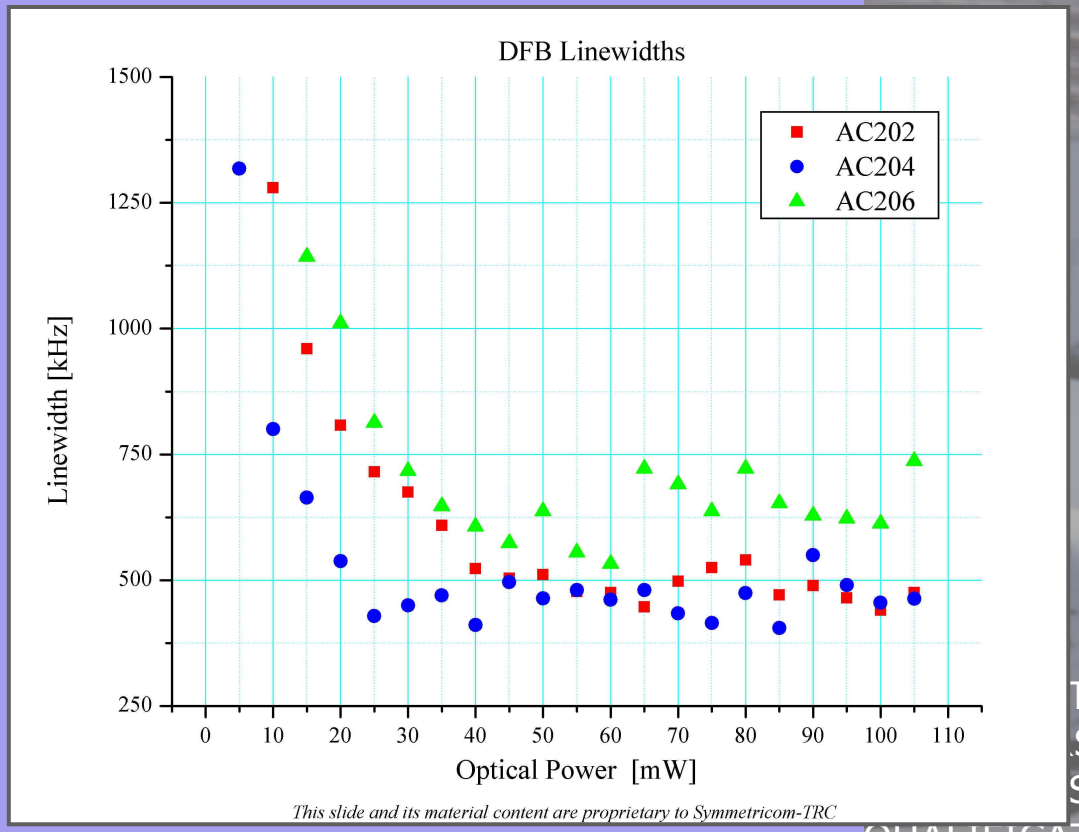
3. Spectral properties - Test Results
   - Wavelength Shift is below 0.2 nm (delta T < 3 K)
   - Linewidth < 4 MHz after aging





PERFORMANCE

- Linewidth Data
  reported by Symmetricom, Inc.
  - Derived from Beatnote Measurements
  - **< 1 MHz**



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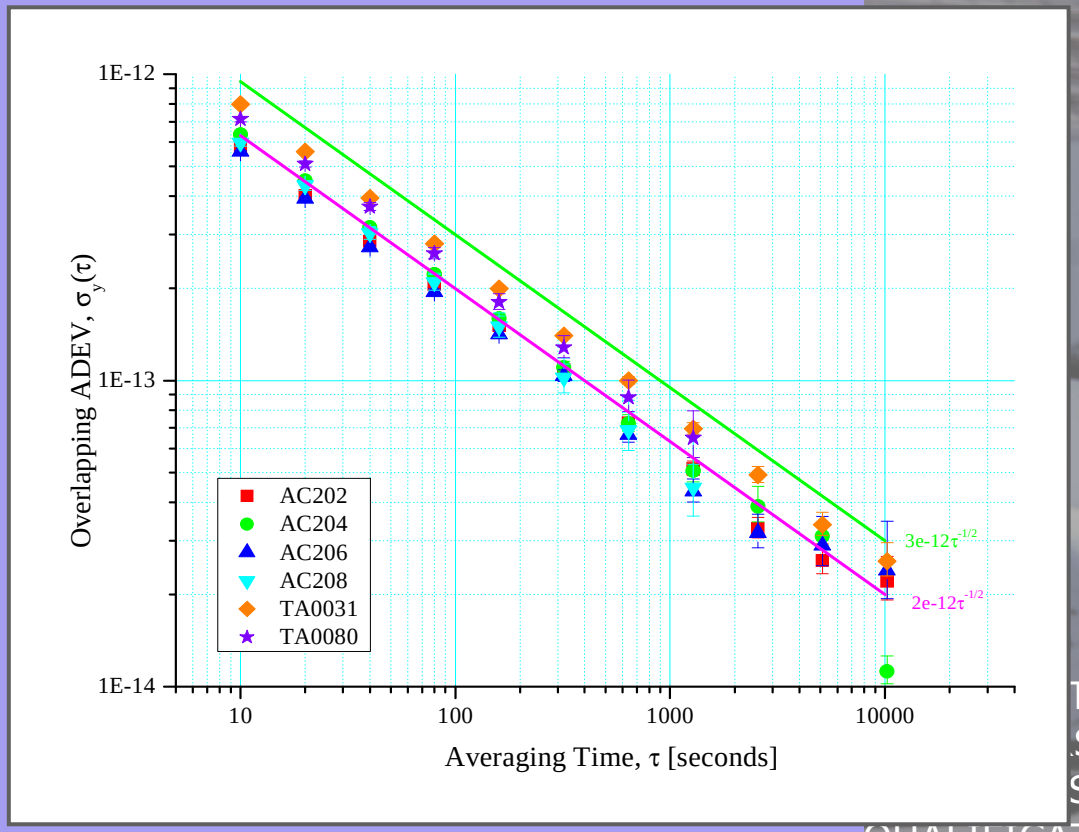
PERFORMANCE

- System Performance Data
  reported by Symmetricom, Inc.
  - Allan Deviation vs. Averaging of six DFB diodes in an optical pumped cesium clock prototype
  - **< 3 $e^{-12/\sqrt{\tau}}$**
- To compare
  - 3 $e^{-11/\sqrt{\tau}}$ *Standard*
  - 8.5 $e^{-12/\sqrt{\tau}}$ *High Performance*



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QUALIFICATION
PERFORMANCE

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THANK YOU