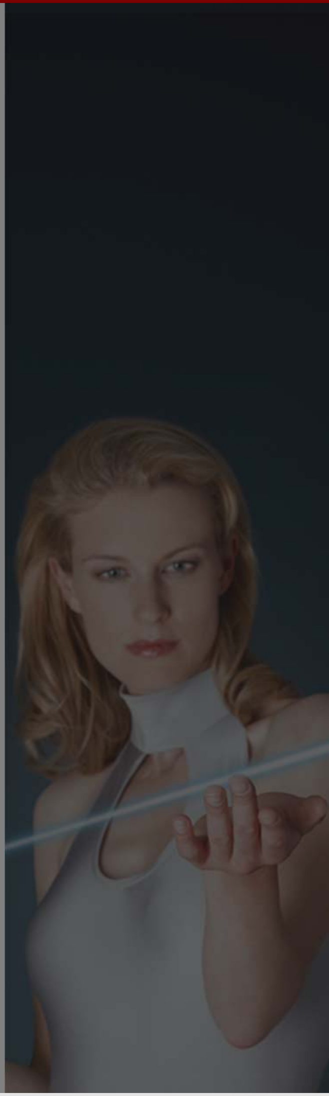
International Symposium on Cold Atom Physics

LASER DIODES FOR LASER COOLING AND TRAPPING

Herwig STANGE [1)], Michael KNEIER [1)], LUO Yafei [2)], TAN Zhiguo [2]

[1)] eagleyard Photonics GmbH , Rudower Chaussee 29, 12489 Berlin, Germany
www.eagleyard.com

[2)] Photonteck Co. Ltd., No. 3 Haide Road, Nanshan District, Shenzen, Guangdong, China 518054
www.photonteck.com



eagleyard AT A GLANCE

- Products: High Power Laser Diodes (Single Emitter)
- Location: Berlin / Germany
- Founded: 2002
- Origin: Spin-off from the Ferdinand-Braun-Institute (FBH)/Berlin





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LASER COOLING OF ATOMS

eagleyard PHOTONICS
We focus on power.

- A large variety of atomes can be used as object of laser cooling
  - He, Li, Ne, Na, Mg, Al, Ar, K, Ca, Cr, Fe, Ga, Kr, Rb, Sr, Ag, Cd, In, Xe, Cs, Ba, Dy, Er, Tm, Yb, Hg, Fr, Ra, ...

- Different cooling schemes can be applied
  - Doppler Cooling
  - Side Band Cooling
  - Polarization Cooling
  - Raman Laser Cooling
  - Velocity Selective Coherent Population Trapping
  - Depolarization / Demagnetization Cooling
  - ...

REQUIREMENTS FOR LASER COOLING

- Wavelength

  The emission wavelength has to match with the atomic transition

- Linewidth

  The linewidth of the laser has to be below the linewidth of the atomic transition

- Tunability

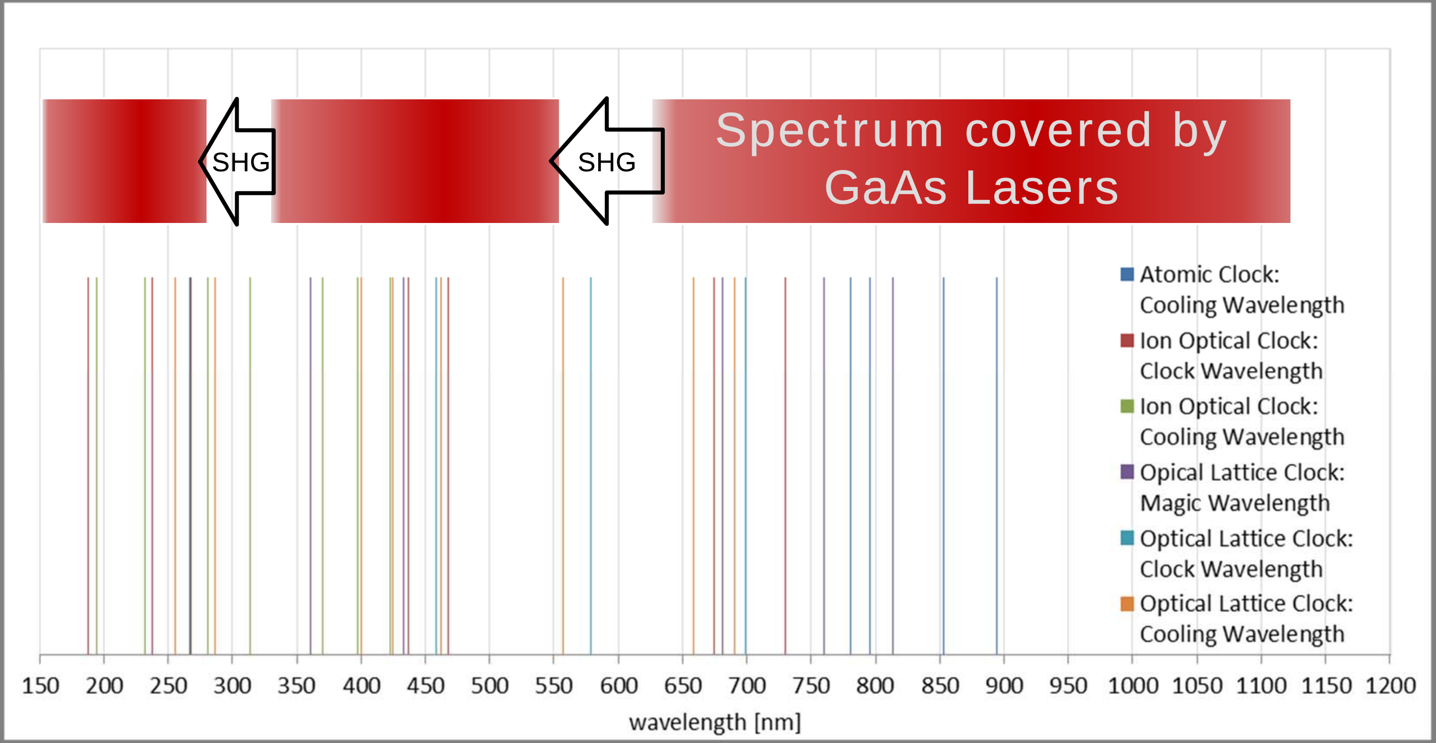
  Mode-hop free operation should allow wavelength tuning to the wavelength of the atomic transition

- Wavelength Stability

  The wavelength drift due to changes of laser current and temperature has to be kept low

SPECTRAL COVERAGE

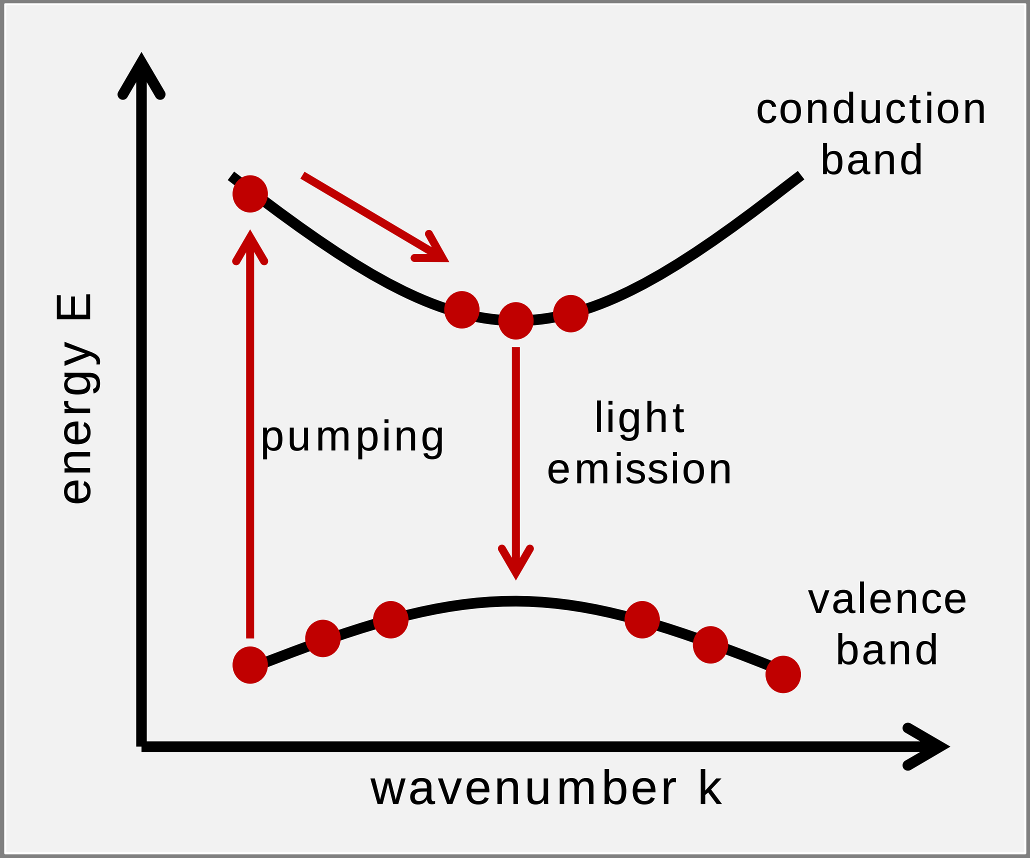
- GaAs Semiconductor Lasers and subsequent Second Harmonic Generation cover a wide Spectral Range



SEMICONDUCTOR LASERS

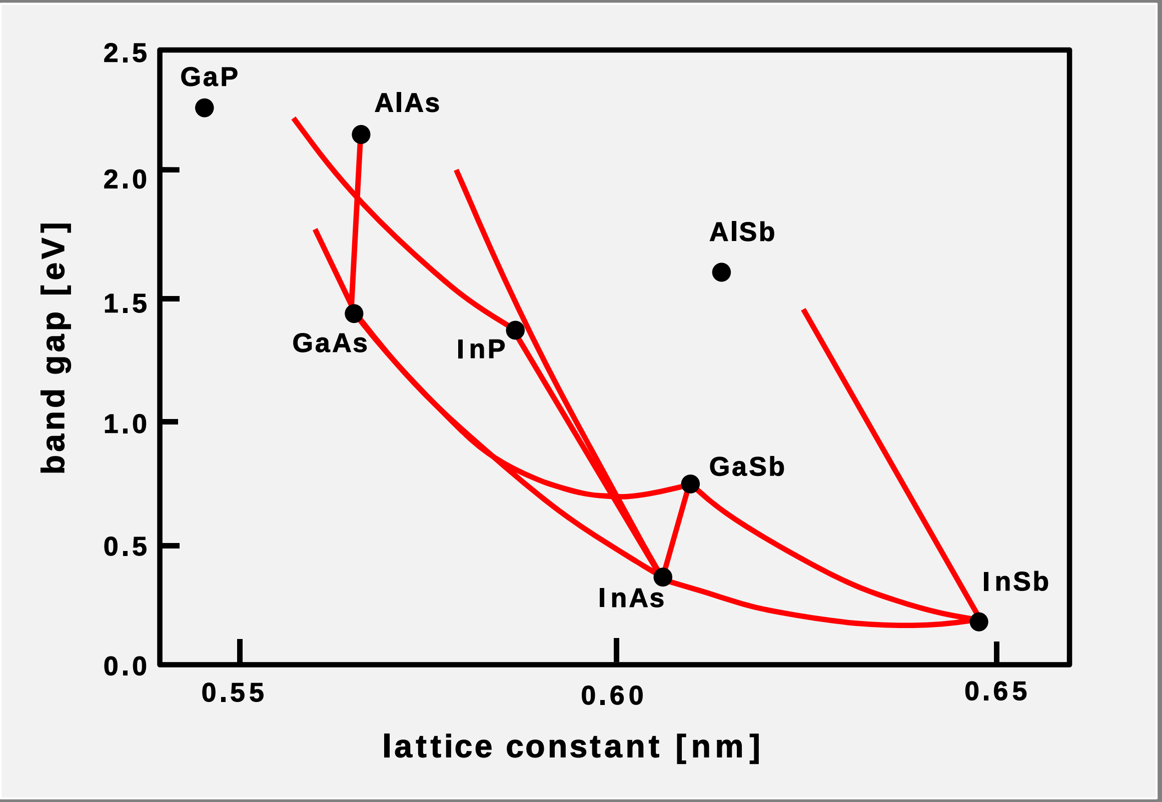
Introduction
Laser Cooling
Laser Technology
DFB Lasers
External Cavity Lasers
Tapered Amplifiers
Laser Systems
Applications
Summary

- Band gap determines the emission wavelength



SEMICONDUCTOR LASERS

- Mixing the semiconductor compounds allows continuous variation of the bandgap

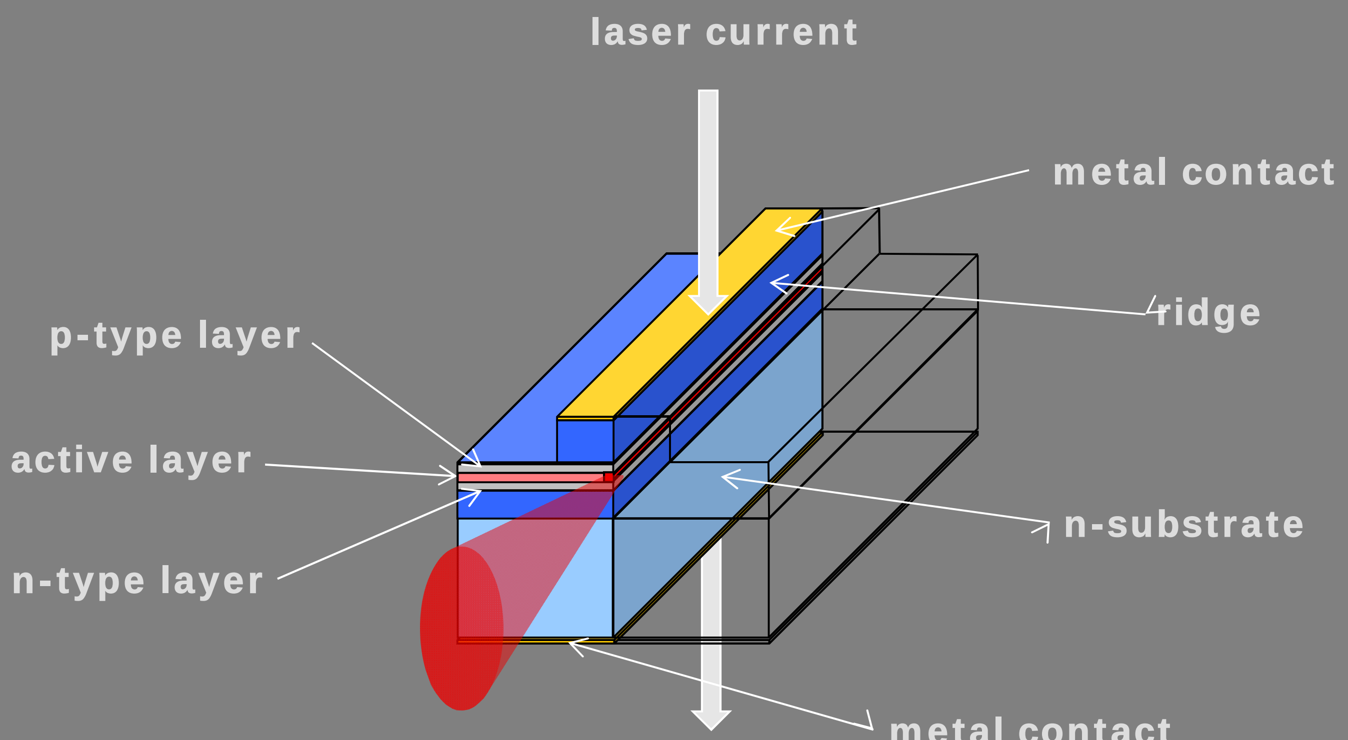


SEMICONDUCTOR LASERS

- Semiconductor compounds with different bandgap and emissson wavelength

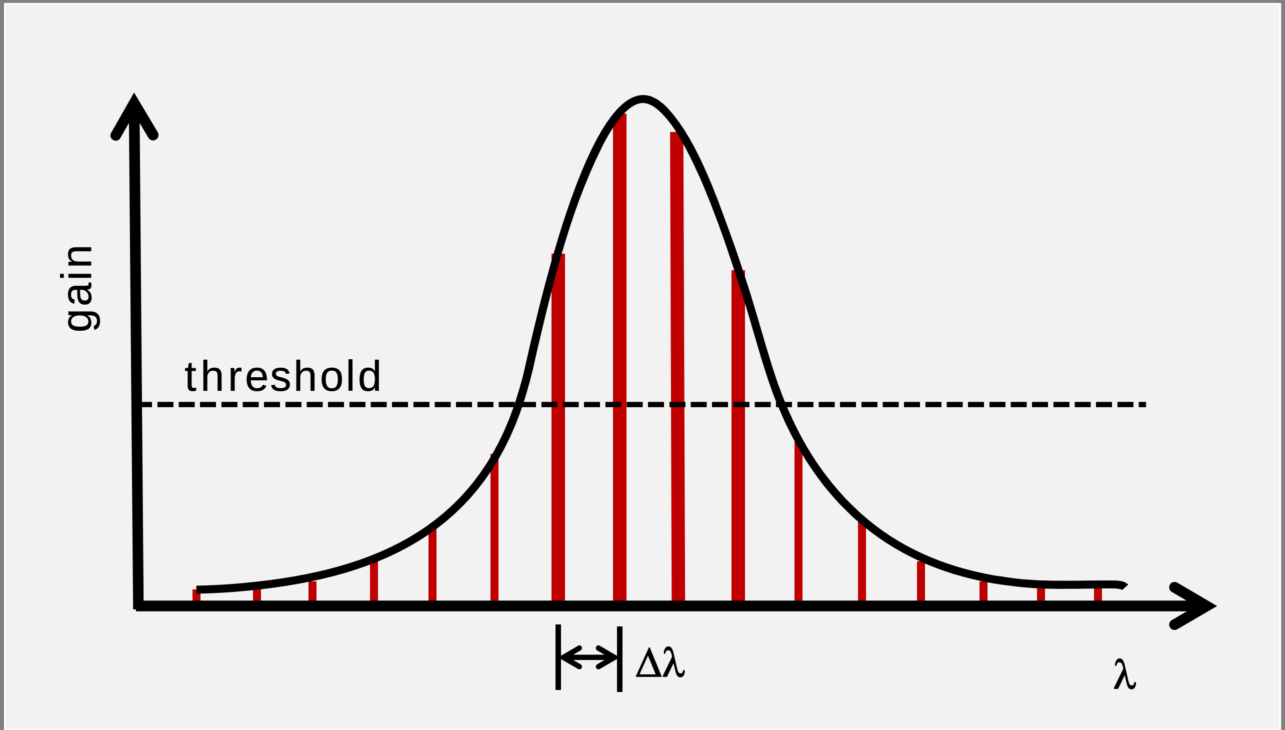
Laser diode material (active region / substrate)	Typical emission wavelength
InGaN / GaN, SiC	380 - 470 nm
AlGaInP / GaAs	630 - 670 nm
AlGaAs / GaAs	720 – 850 nm
InGaAs / GaAs	900–1100 nm
InGaAsP / InP	1000–1650 nm

- Design of an edge emitting laser diode



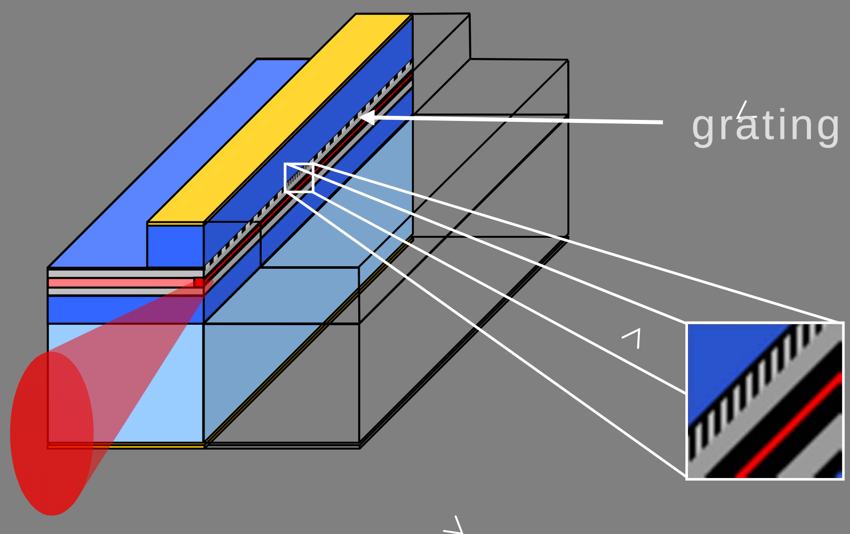
RESONATOR MODES

- The natural gain bandwidth is restricted to discrete cavity modes



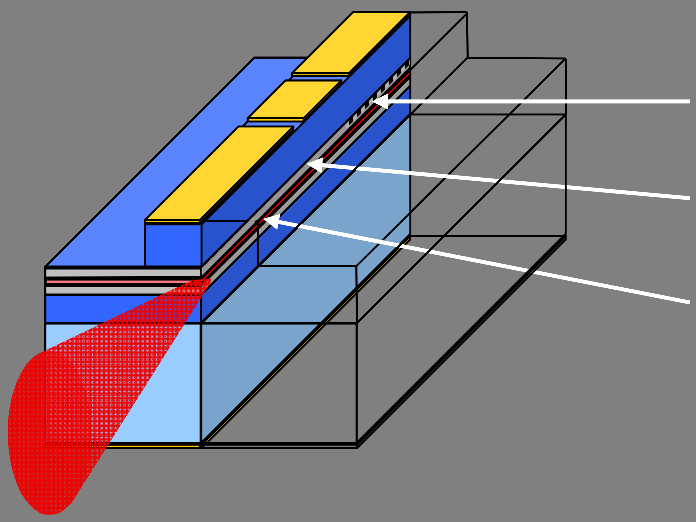
DFB LASER

- **DFB Distributed Feed Back**
  - Wavelength stabilized with in-build grating
  - single section laser with grating in on-chip laser cavity



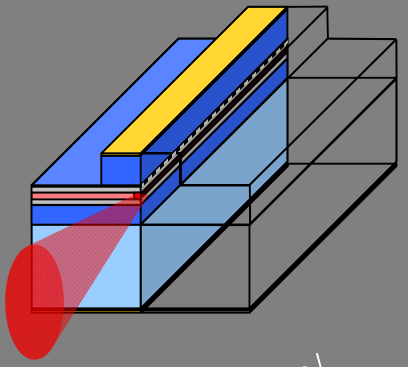
DBR LASER

- **DBR Distributed Bragg Reflector**
  - Wavelength stabilized with in-build grating
  - multi-section laser with Gain, Phase and DFB Section



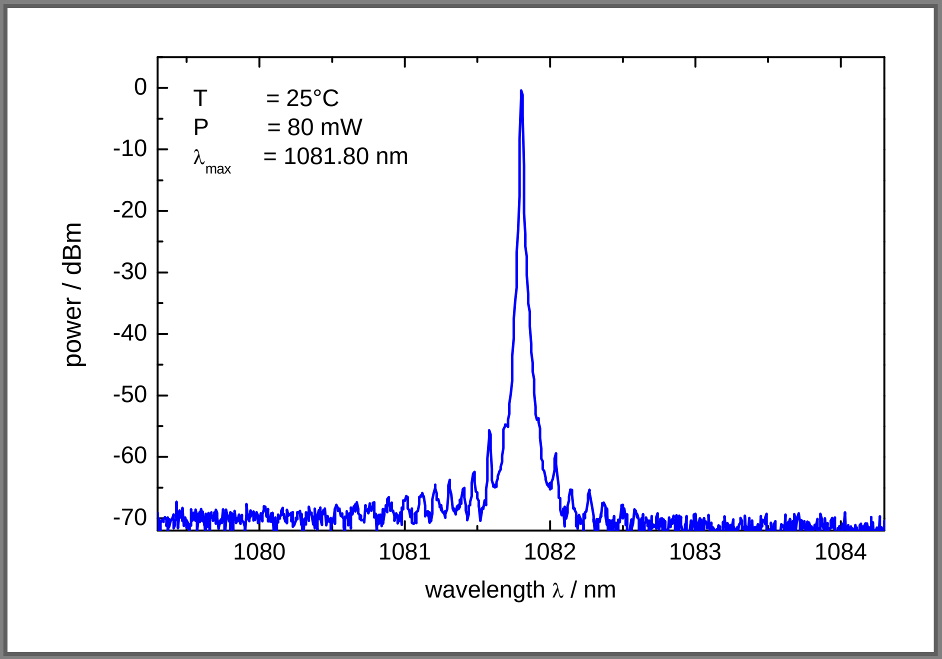
DFB AND DBR LASERS

- **Characteristics**
  - Edge-emitting laser diode
  - Chip length: 0.75 mm to 4 mm
  - Small emitting region (typ. 1 µm x 4 µm)
  - Good beam quality (typ. $M^2 = 1.1$)
    - parallel (slow axis): 8° FWHM
    - perpendicular (fast axis): 20° FWHM
  - Output power: 50 mW up to 400 mW



SPECTRAL CHARACTERISTICS

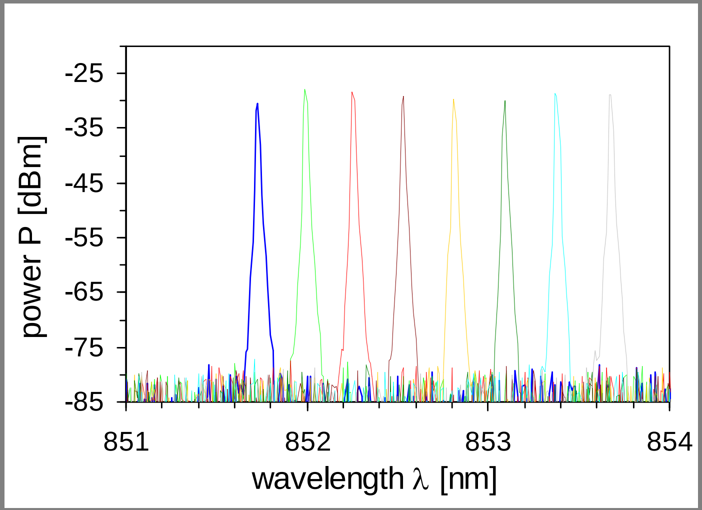
- Spectral Single Mode
- High Side Mode Suppression > 50 dB
- Narrow Linewidth < 1 MHz

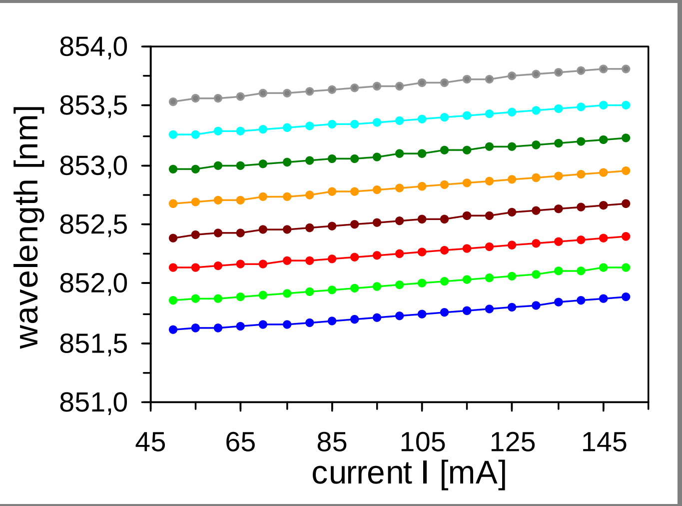


eagleyard PHOTONICS
We focus on power.

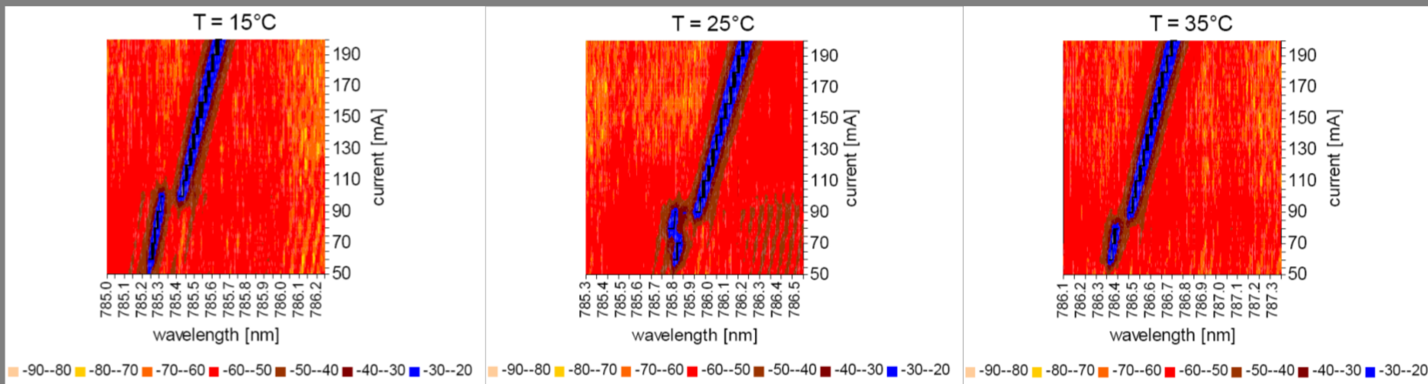
Excellent Wavelength Stability

- over Temperature < 0.06 nm/K
  15°C to 50°C < 2.0 nm
- over Current < 0.003 nm/mA
  50 mA to 150 mA < 0.3 nm

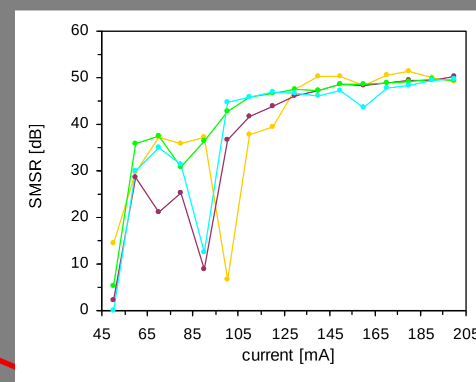




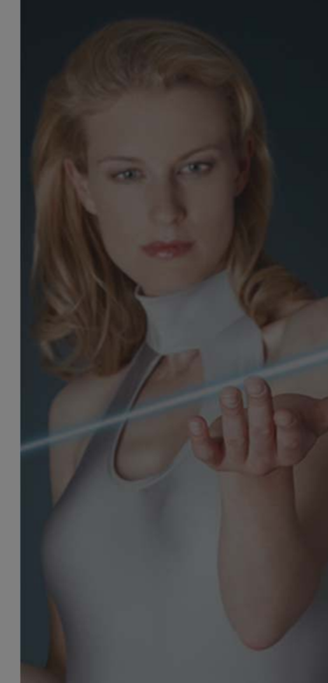
MODE HOP BEHAVIOR I



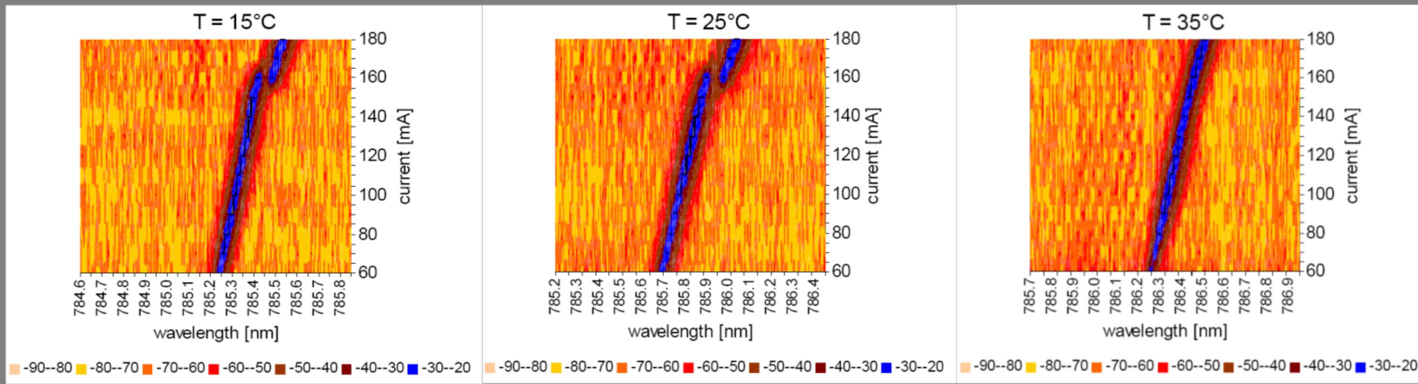
- Single mode operation
  at nominal power
  at one temperature



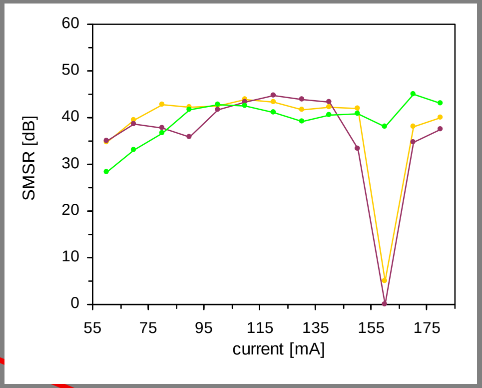
	type	λ [nm]	Popt [mW]	chip size	package	header	variant
EYP	- DFB	- nnnn -	nnnnn	- nnnn	- xxx	nn	- **0000**



MODE HOP BEHAVIOR II

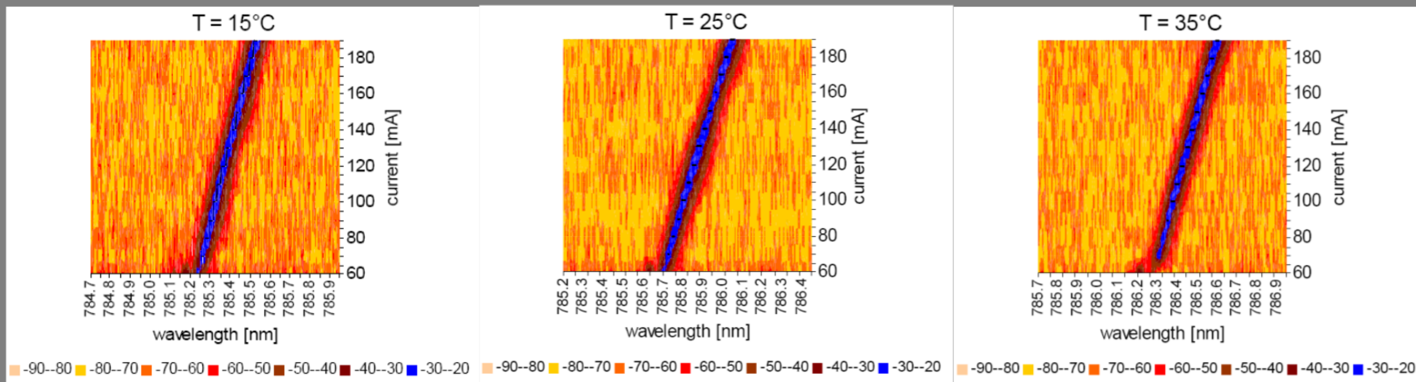


- Single mode operation at every laser current at one temperature

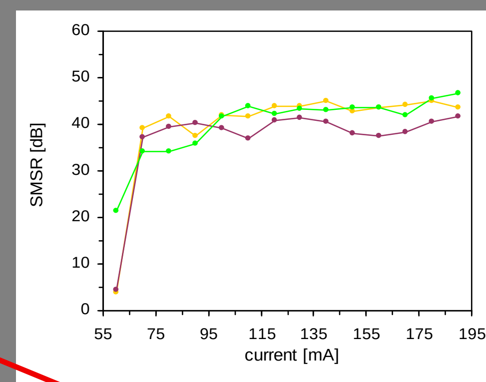


	type	λ [nm]	Popt [mW]	chip size	package	header		variant
EYP -	DFB -	nnnn -	nnnnn -	nnnn -	xxx	nn	-	**0001**

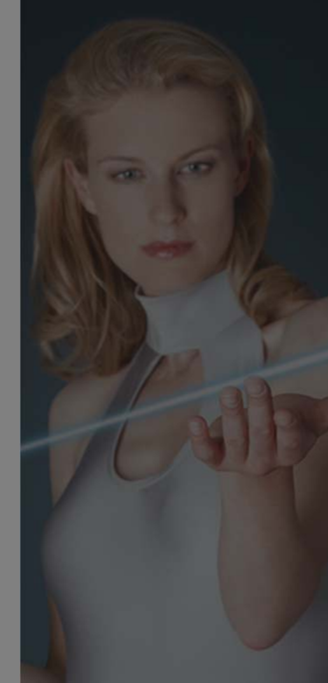
MODE HOP BEHAVIOR III



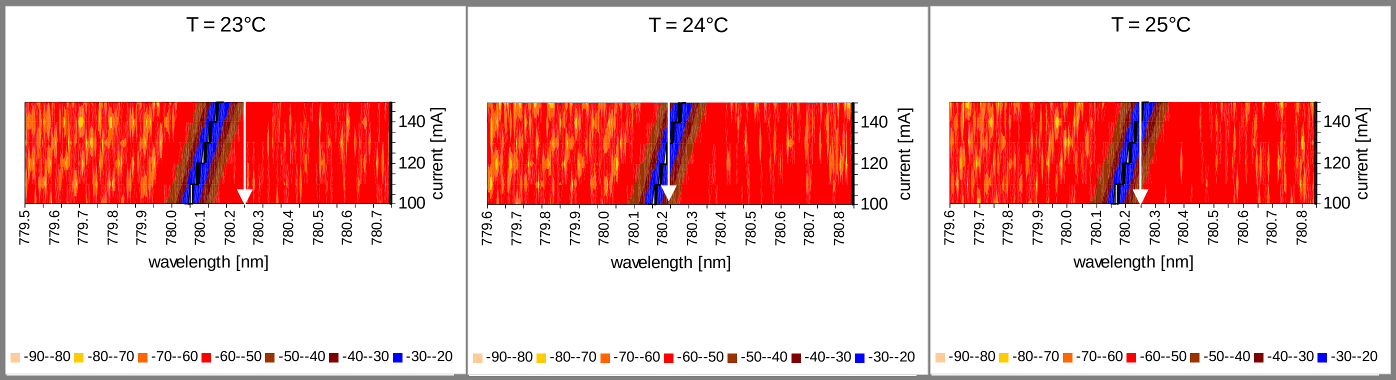
- Single mode operation at every laser current at every temperature



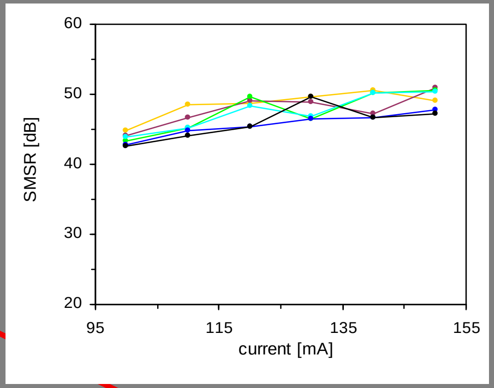
	type	λ [nm]	Popt [mW]	chip size	package	header	variant
EYP	- DFB	- nnnn	- nnnnn	- nnnn	- xxx	nn	- **0002**



MODE HOP BEHAVIOR IV



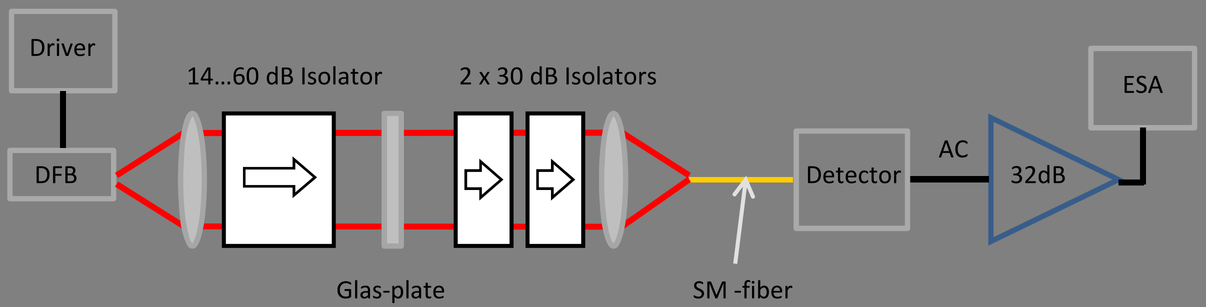
- Single mode operation
  at target wavelength
  at nominal power
  reached inside temperature range

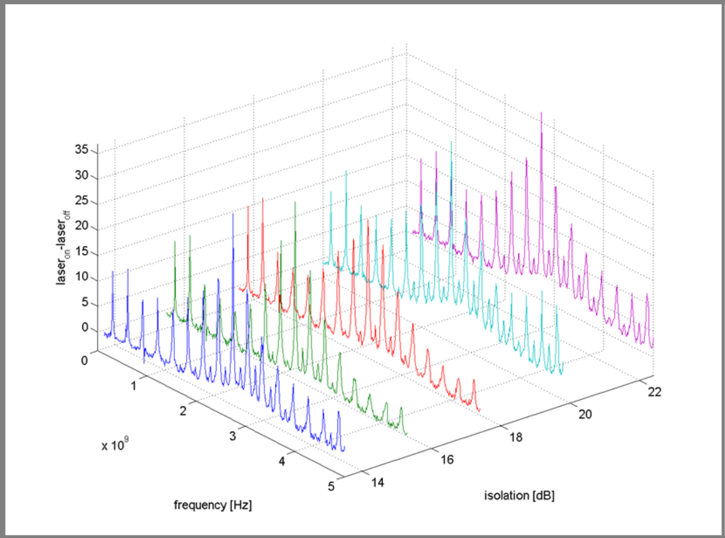


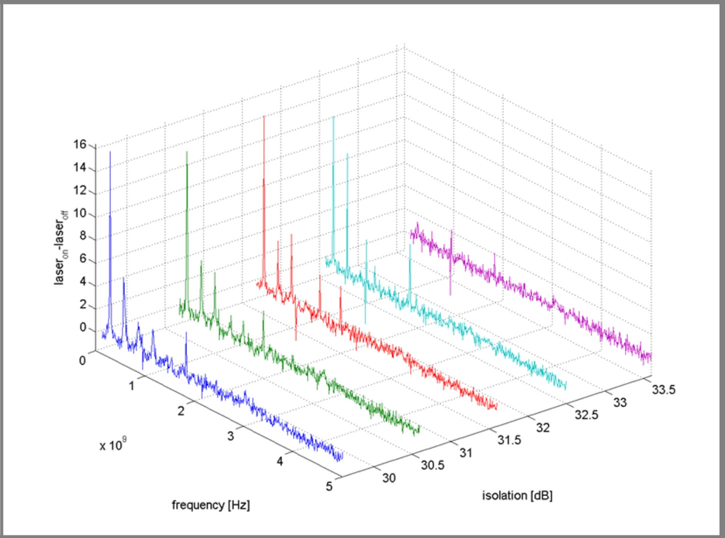
	type	λ [nm]	Popt [mW]	chip size	package	header	variant
EYP -	DFB -	nnnn -	nnnnn -	nnnn -	xxx	nn -	**0005**

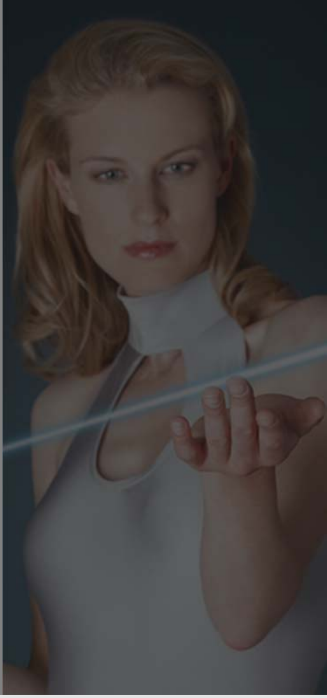
BACKREFLECTION

- External backreflection can disturb the spectrum

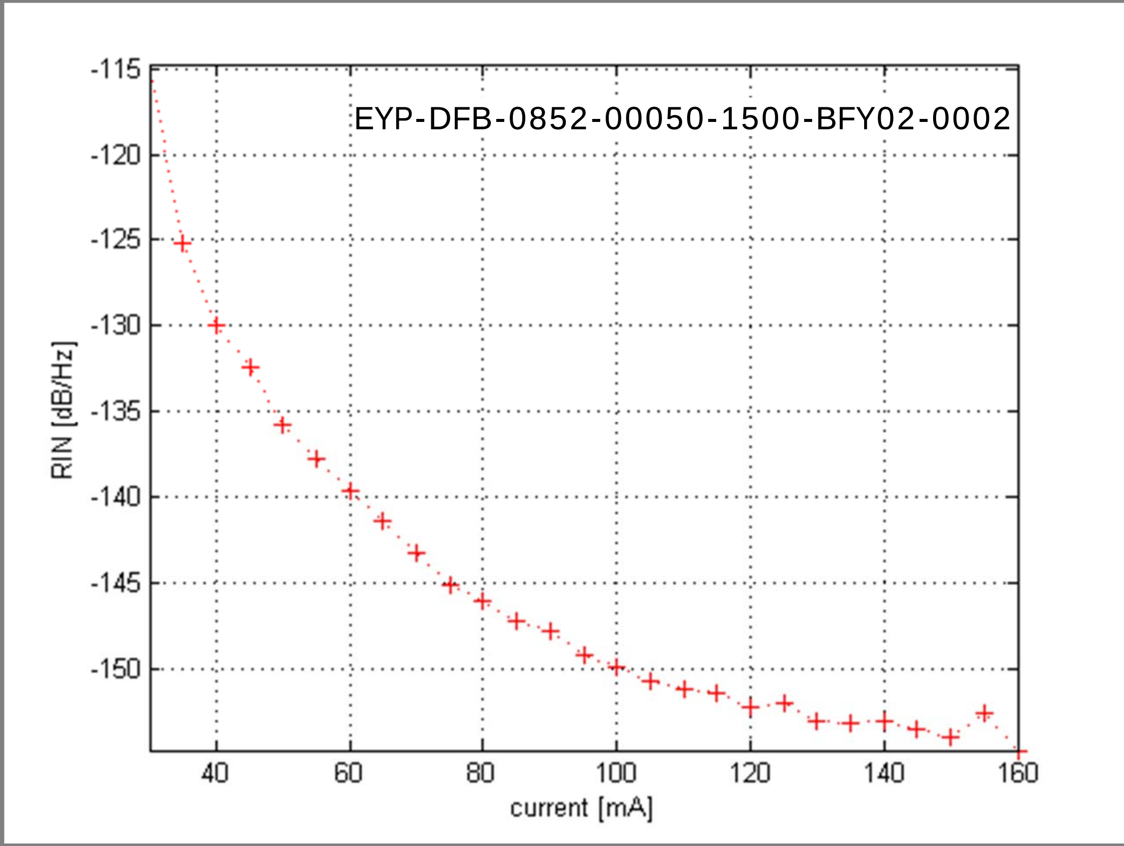






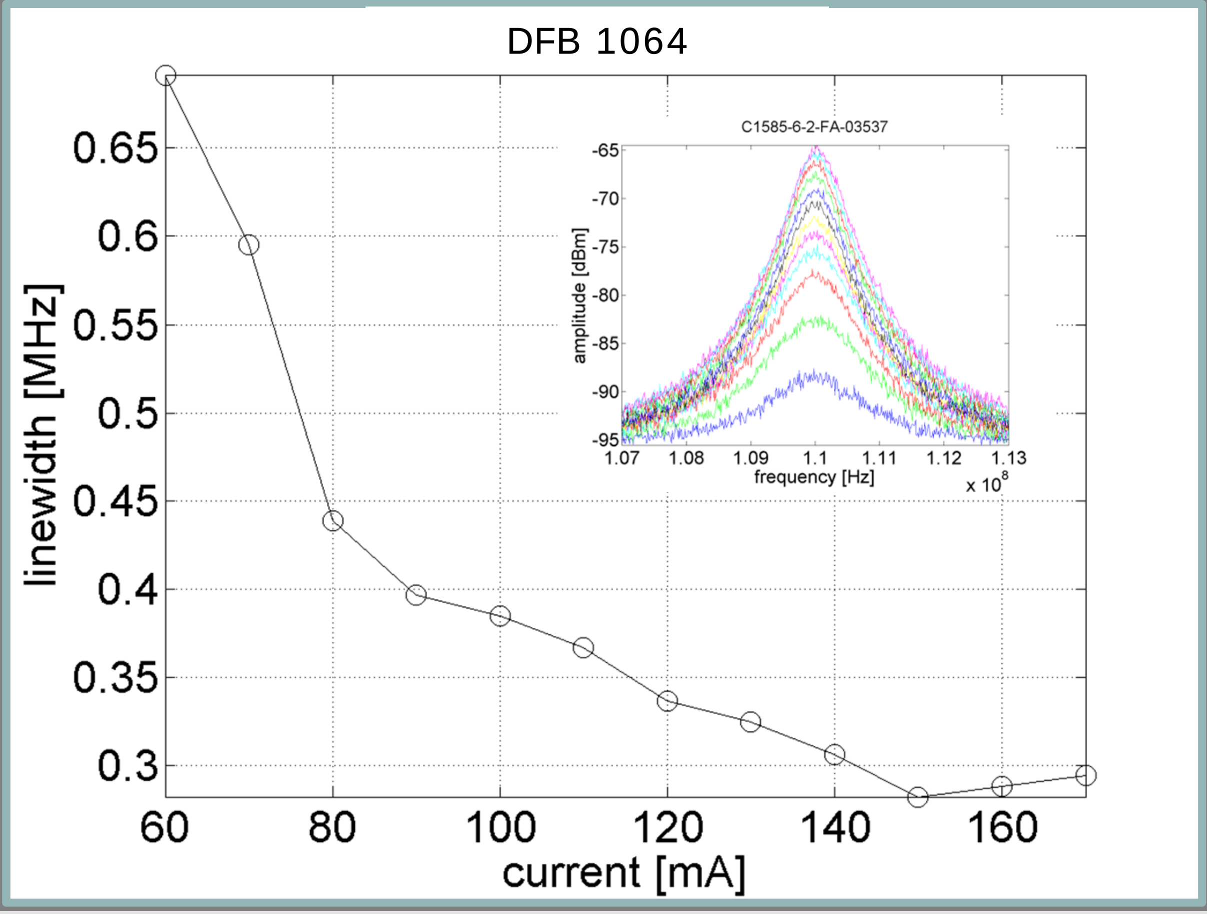


- RIN Measurement of a DFB laser



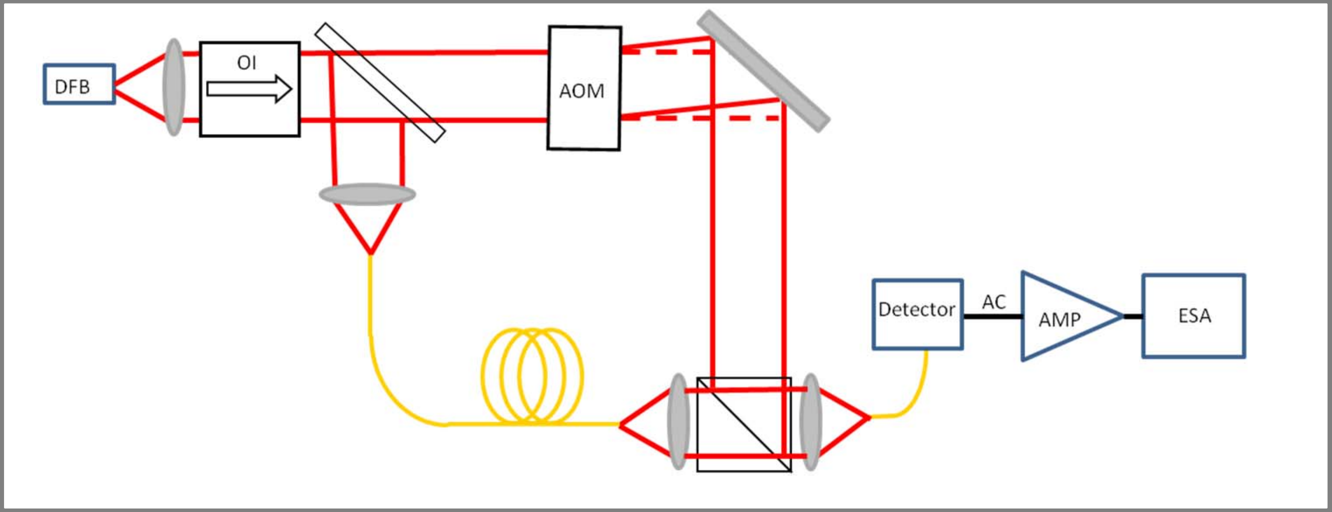
DFB LINEWIDTHS PERFORMANCE

- 300kHz at nominal operating current



LINEWIDTH MEASUREMENT

- Delayed self heterodyne measurement
  - superimposes a frequency shifted fraction with a delayed fraction of the laser emission
  - converts the optical phase and frequency fluctuations into variations of the optical intensity

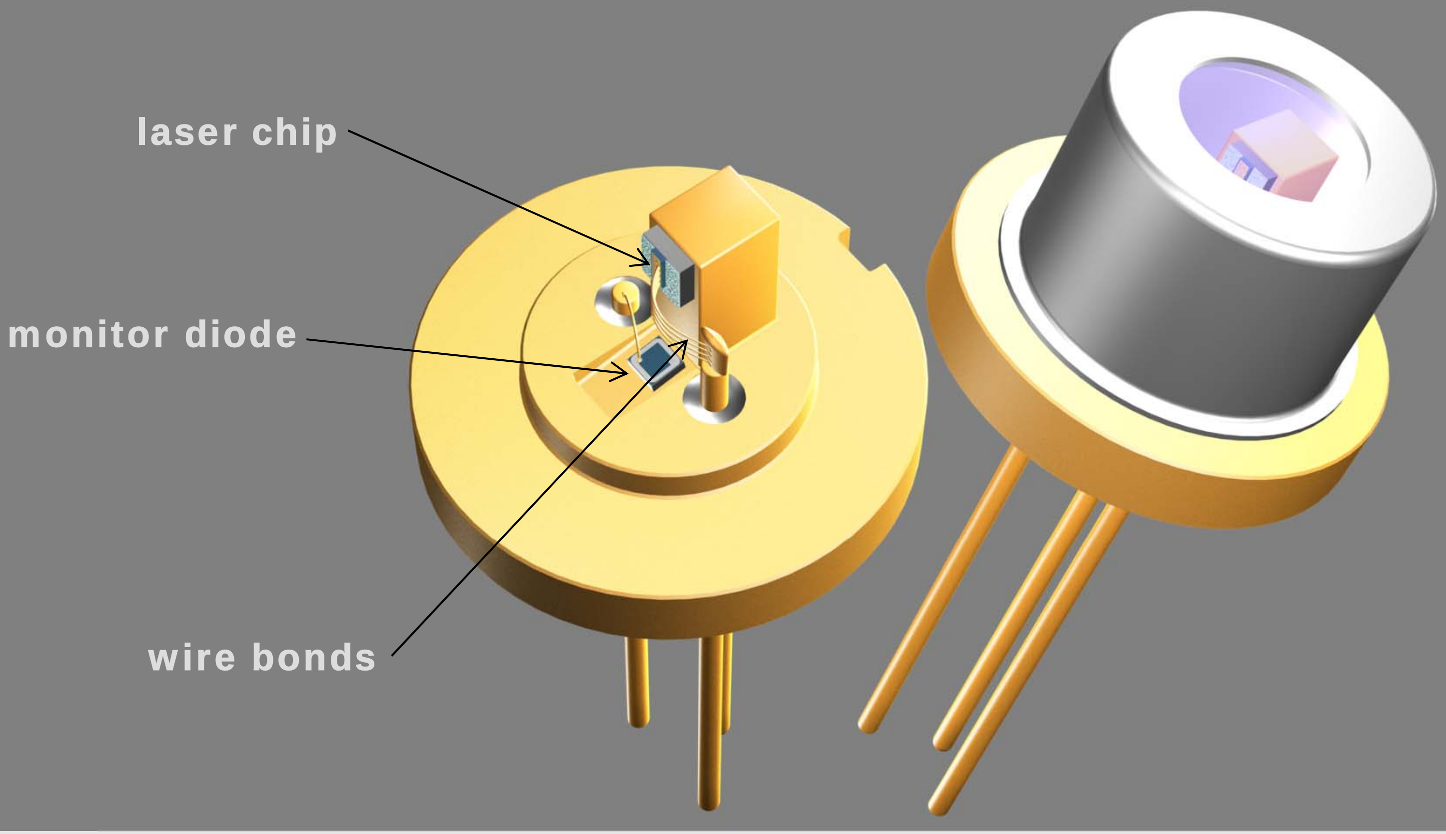


App note: ***Measurement and analysis of the linewidth***
http://www.eagleyard.com/en/support/application-notes

LASER PACKAGING

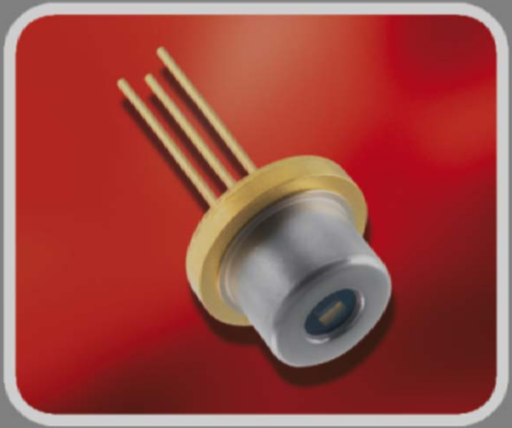
eagleyard PHOTONICS
We focus on power.

- Example: TO Package



DFB LASER PACKAGE TYPES I

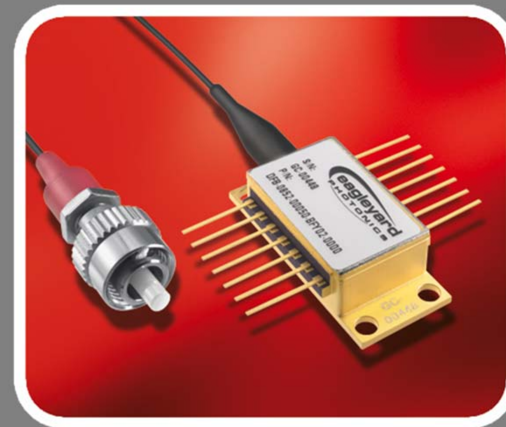
- SOT
  - TO-Housing with
    - Monitor Diode

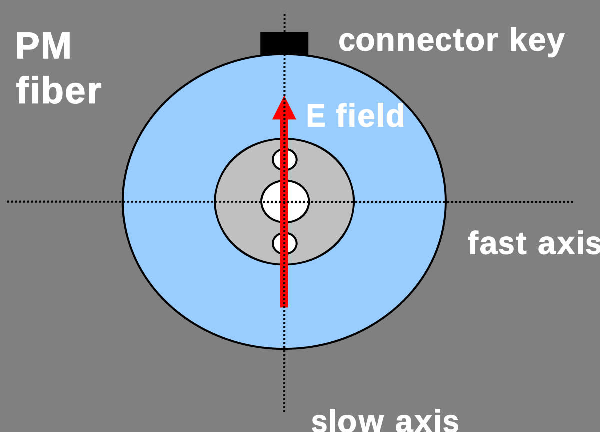


- TOC
  - TO-Housing with
    - Monitor Diode
    - Thermoelectric Cooler
    - Thermistor

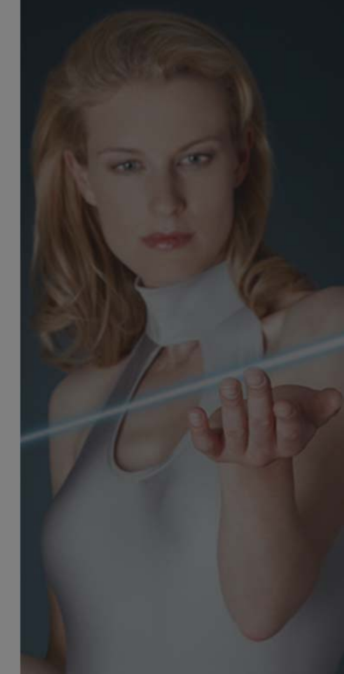
DFB LASER PACKAGE TYPES II

- BFY
  - Butterfly Package with
    - Monitor Diode
    - Thermoelectric Cooler
    - Thermistor
    - Single Mode Fiber Pigtail





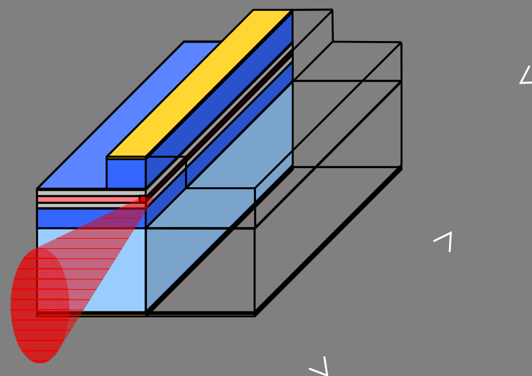
- The polarization is given by the characteristics of the laser
- Polarization maintaining (PM) fibers preserve the polarization



RIDGE WAVEGUIDE LASER

eagleyard PHOTONICS
We focus on power.

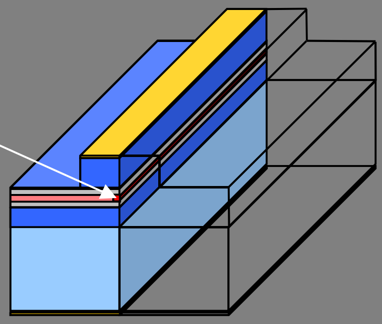
- **Synonyms**
  - Fabry Perot Laser
  - Single Emitter Laser



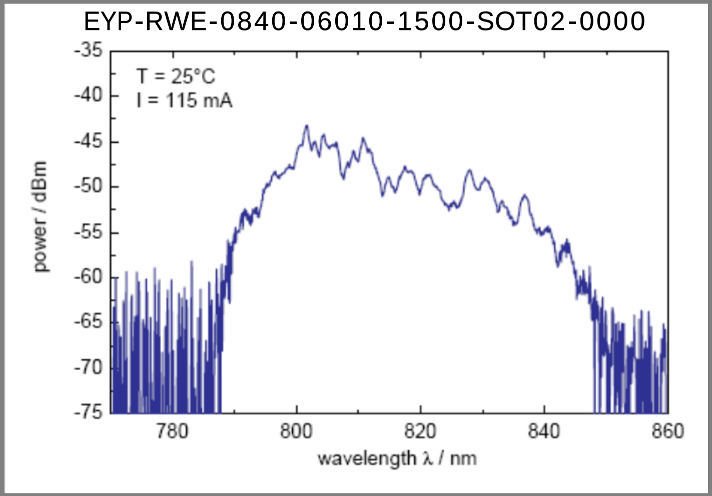
- **Characteristics**
  - Edge-emitting laser diode
  - Chip length: 0.75 mm to 4 mm
  - Small emitting region (typ. 1 µm x 4 µm)
  - Good beam quality (typ. $M^2 = 1.1$)
    - parallel (slow axis): 10° FWHM
    - perpendicular (fast axis): 30° FWHM
  - Output power: 50 mW up to 1000 mW
  - Spectral width: typ. 1 nm

RWE TYPE

- Ridge Waveguide Laser with Anti-Reflection Coating at the Front Facet for use in an ECDL (External Cavity Diode Laser)

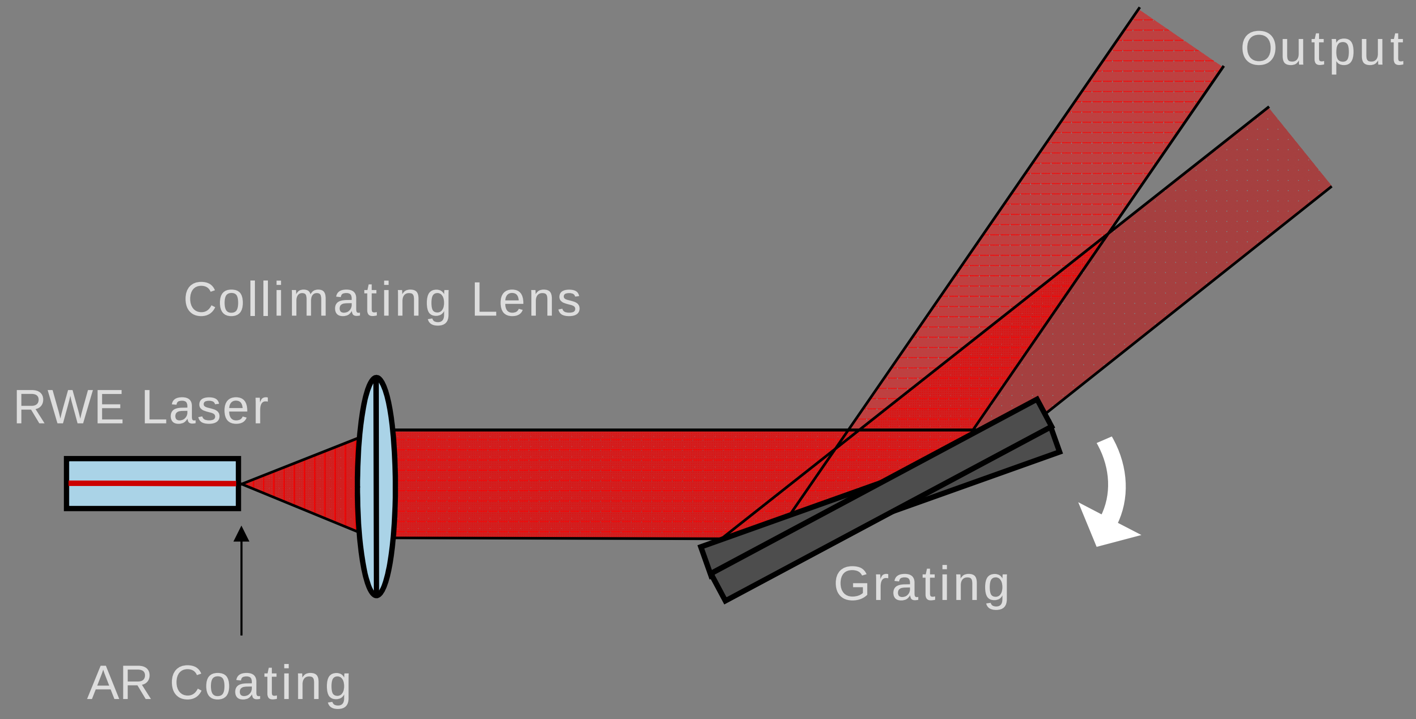


- Broad tuning range given by the gain profile of the laser

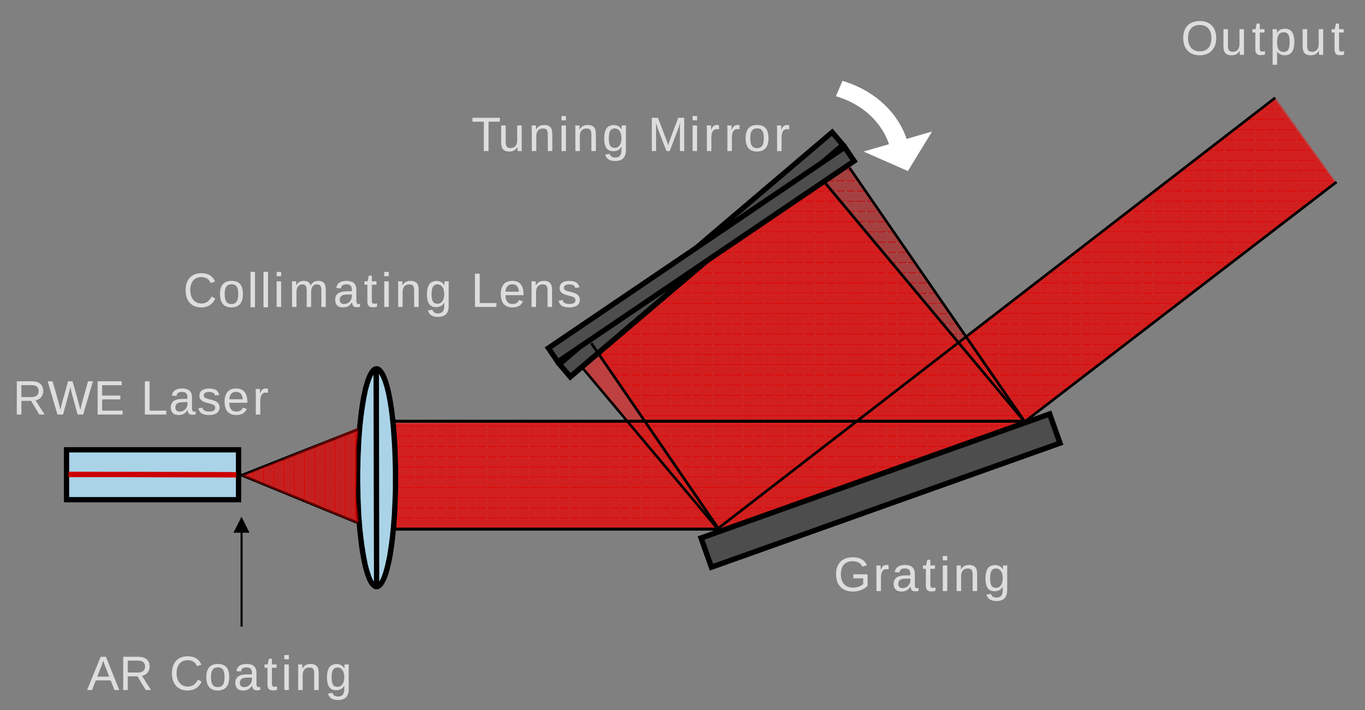


EXTERNAL CAVITY LASER

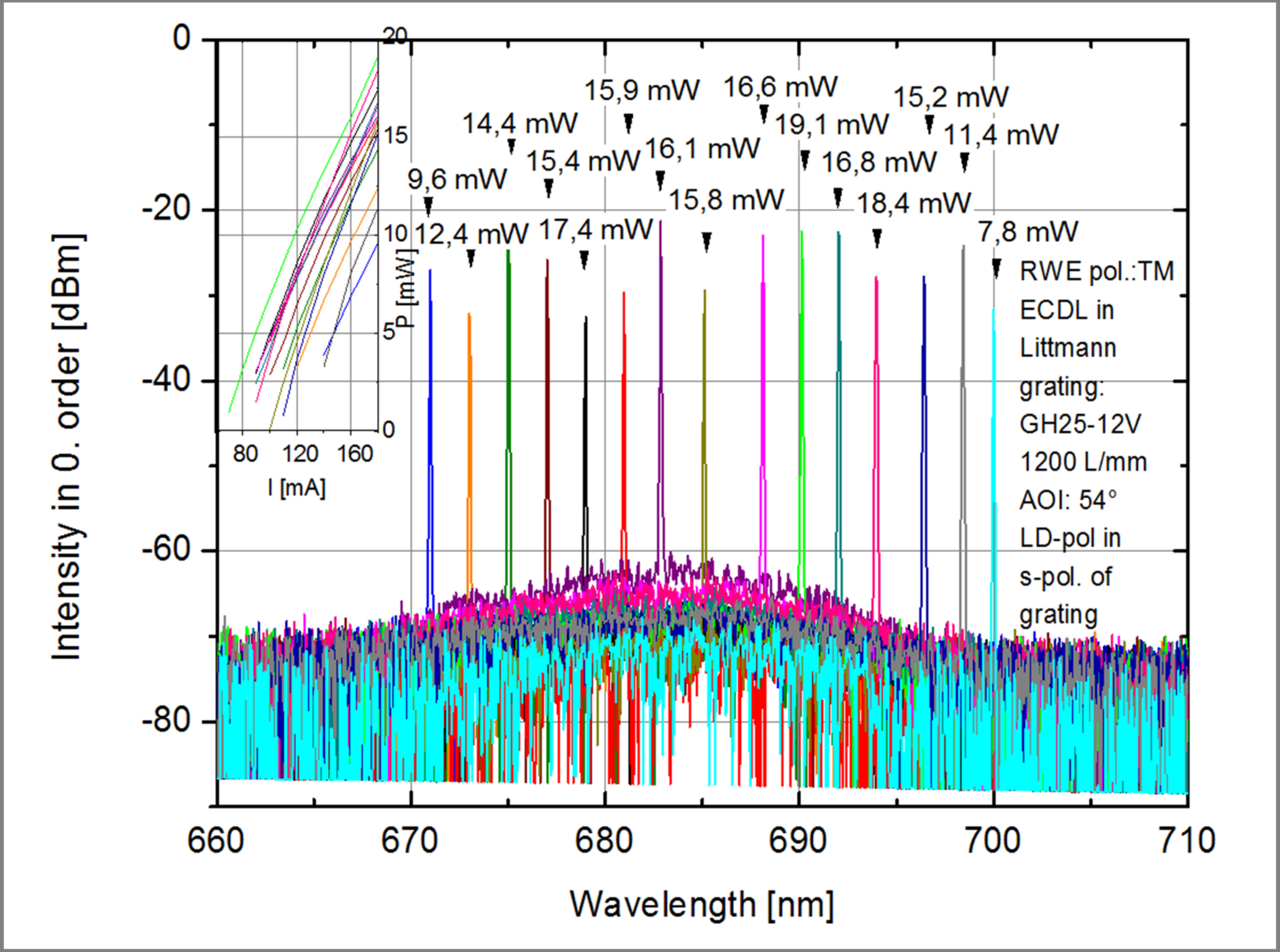
Littrow Configuration



Littman-Metcalf Configuration



EXAMPLE: WAVELENGTH TUNING



RWL / RWE PACKAGES

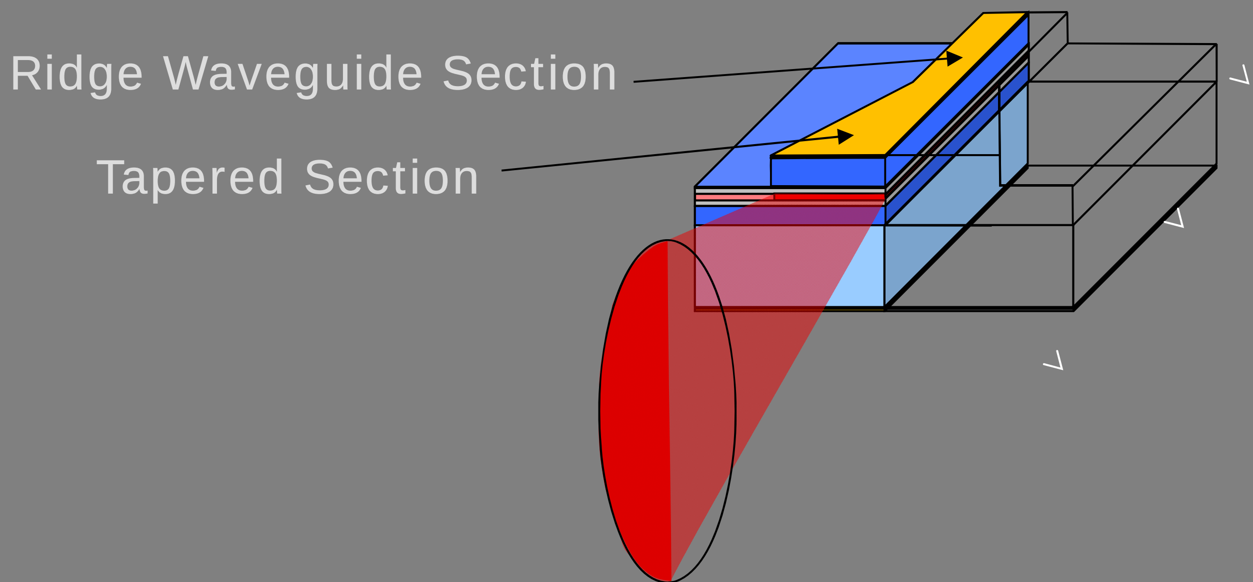
- SOT
  - TO-Housing with
    - Monitor Diode

- TOC
  - TO-Housing with
    - Monitor Diode
    - Thermoelectric Cooler
    - Thermistor

- Other Packages available on request

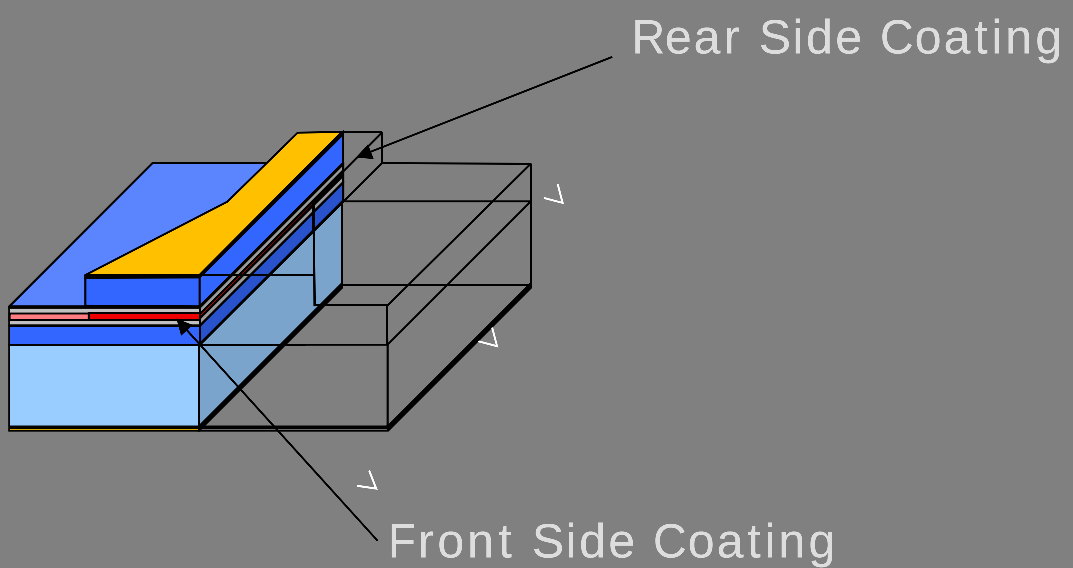
TAPERED LASER

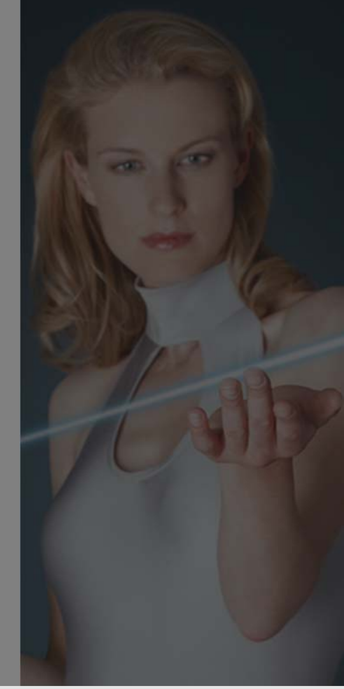
- **Design**
  - Comprises a single mode ridge waveguide section and a tapered section
  - Combines good beam quality with high output power



TAPERED LASER DESIGN

- **Variants by different coatings**
  - Tapered Laser (TPL)
  - Tapered Amplifier (TPA)
  - Tapered Laser for External Cavities (TPR)

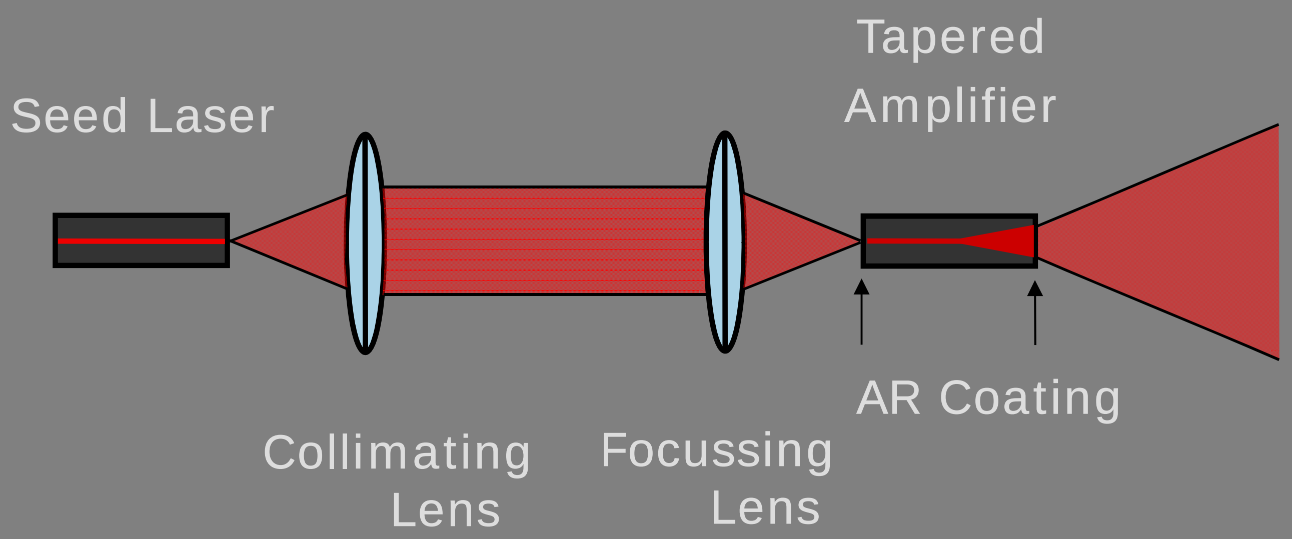




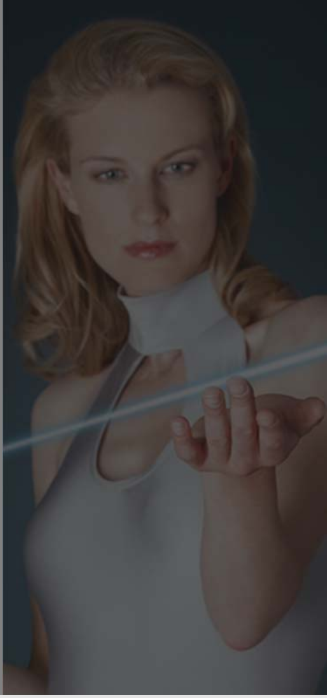
TPA TYPE

- **Tapered Amplifier**
  - Amplifier for (transversal) single mode lasers
    - AR coated front facet (Tapered Section)
    - AR coated rear facet (Ridge Waveguide)
  - typ. input power between 10 mW to 50 mW
  - typ. output power between 0.5 W and 2 W
  - good beam quality
  - TPA maintains the spectral characteristics of the seed laser

Master-Oscillator Power-Amplifier



App note: *Setup and alignment of a MOPA system with a DFB TPA configuration*
http://www.eagleyard.com/en/support/application-notes/



TPA TYPE

Introduction
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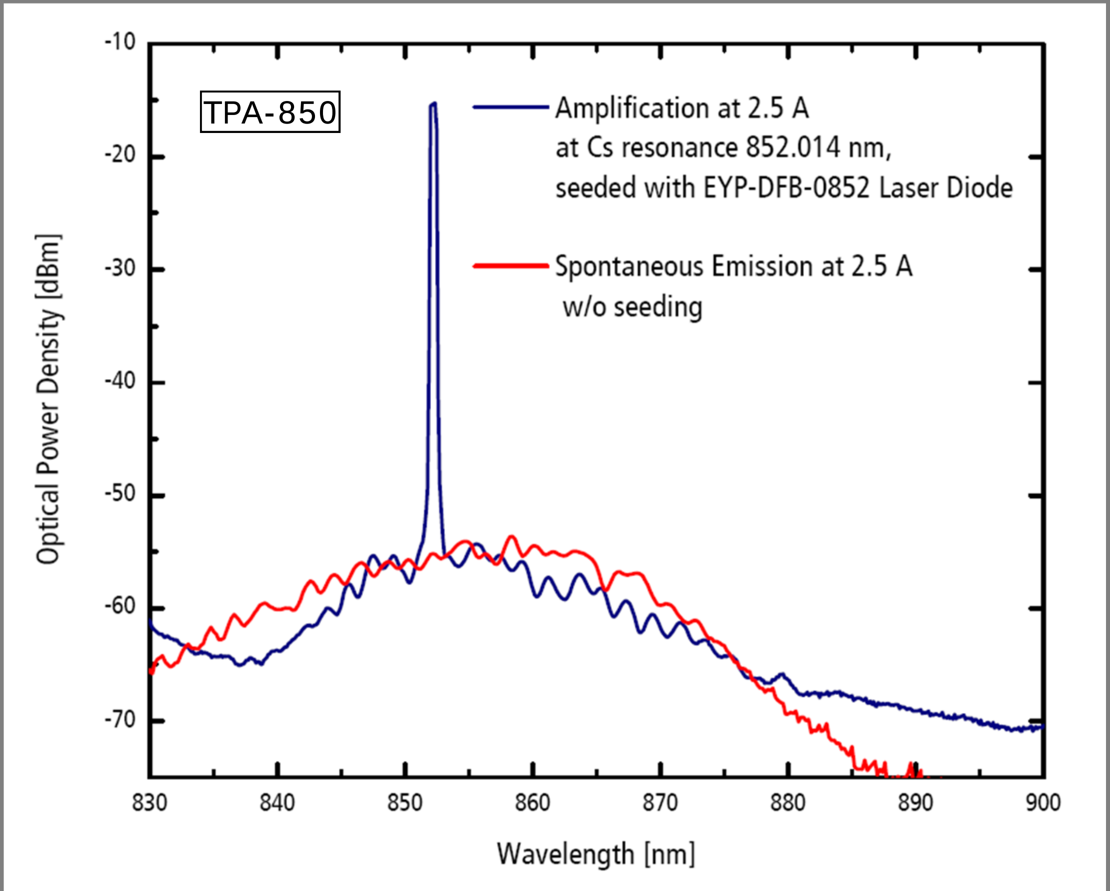
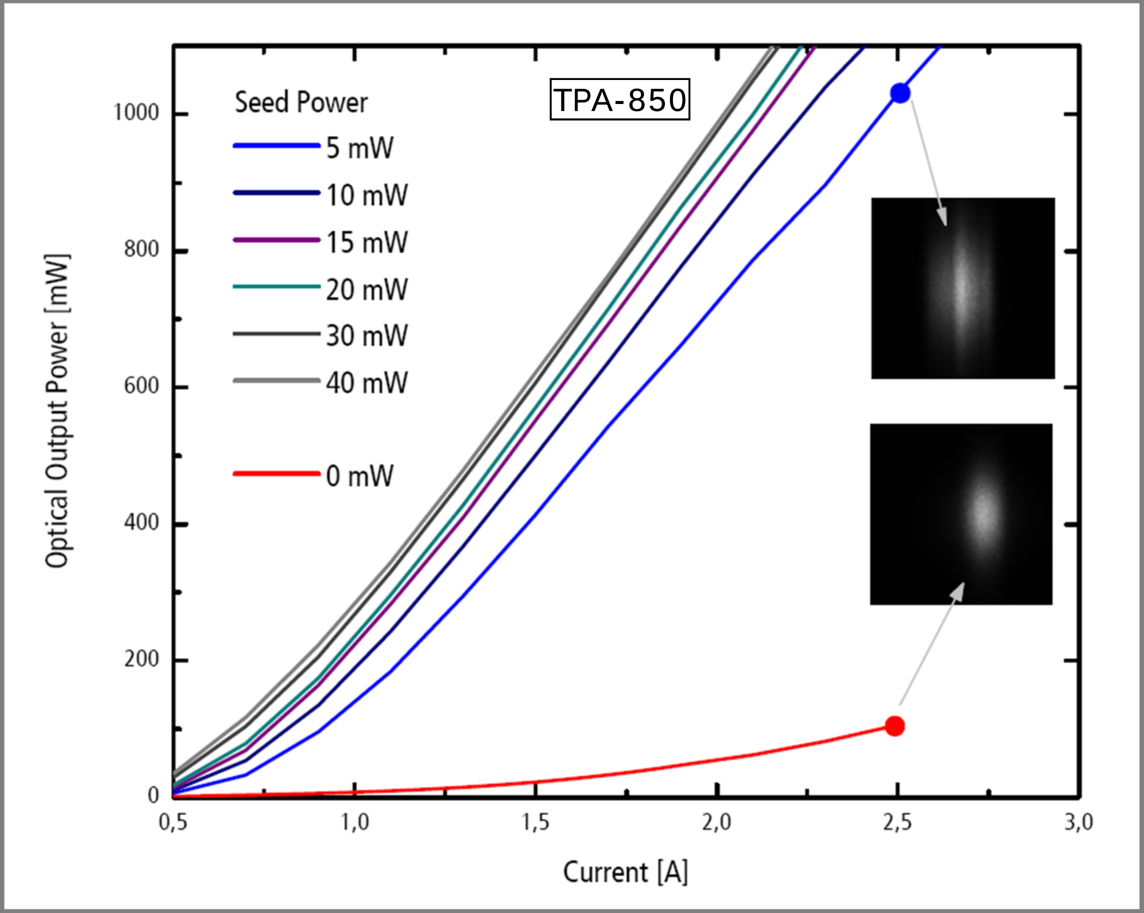
Tapered Amplifiers
Laser Systems
Applications
Summary

Emission wavelength defined by seed laser



P-I-Curve at different seed power



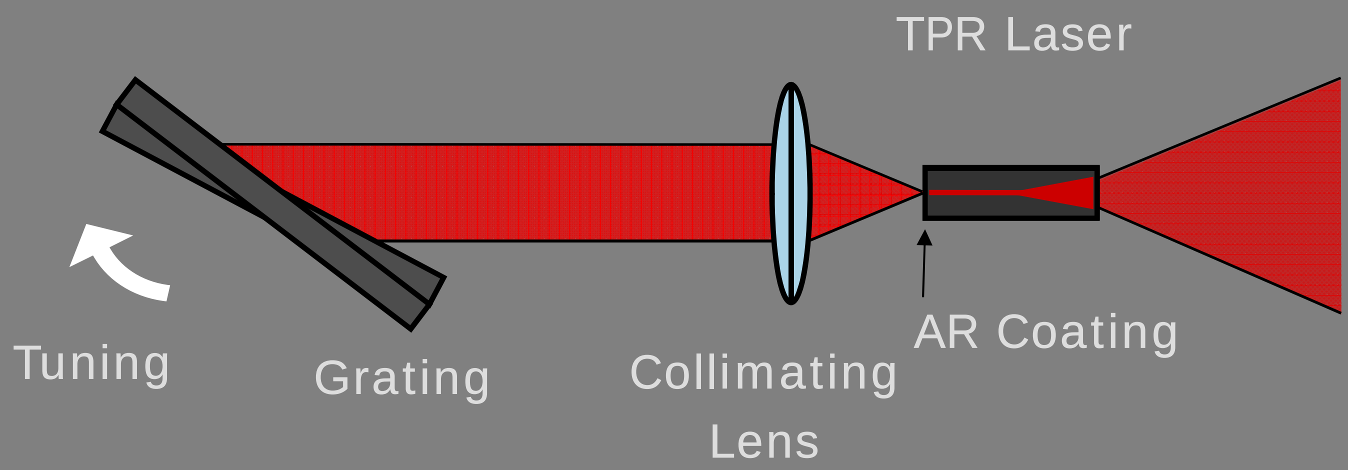
TPR TYPE

- **Tapered Laser for External Cavity**
  - designed for External Cavity Setups (Littrow Design)
    - AR coated Rear Facet at the Ridge Waveguide
    - Medium Reflectivity at the Facet of the Tapered Section (Laser Output)
  - tunable Emission Wavelength
  - typ. Output Power between 0.5 W and 2 W
  - good Beam Quality

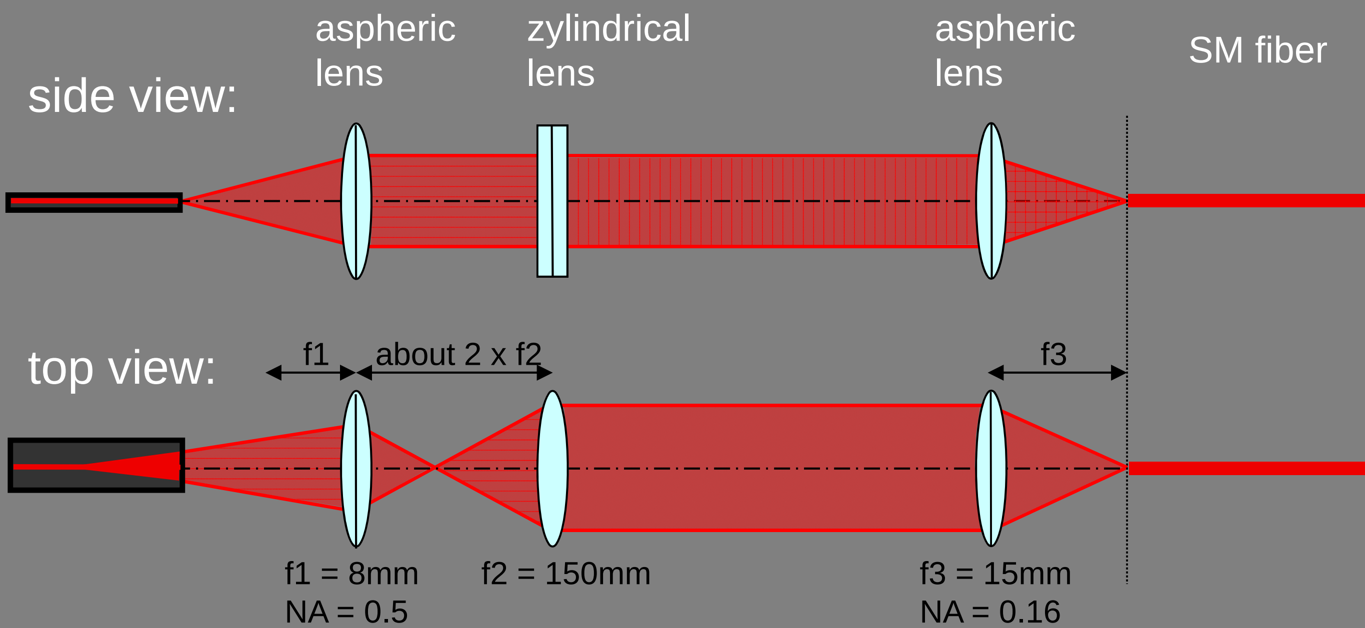
TPR LASER SETUP

TPR laser in an external cavity

Littrow Configuration



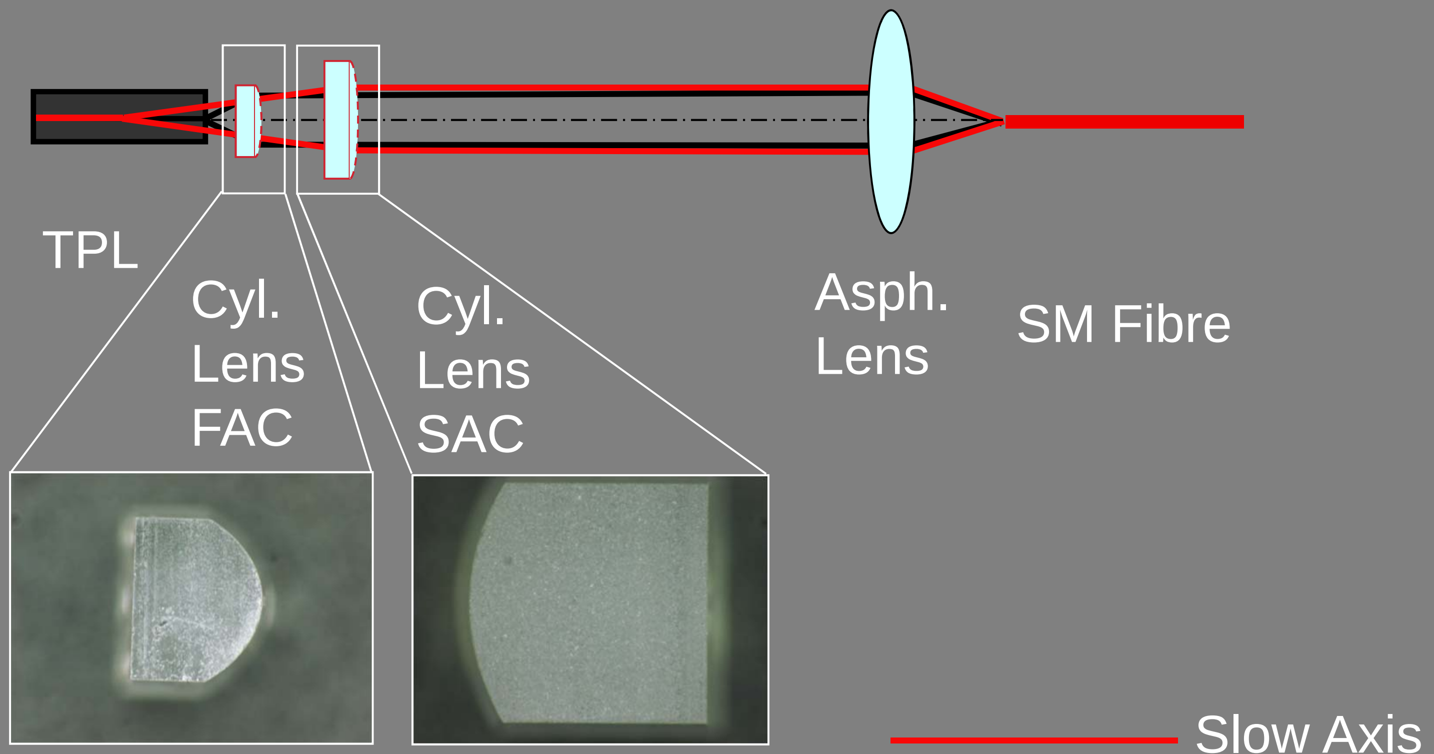
OUTPUT SETUP FOR FIBER COUPLING



Compenstaion of
Laser Astigmatism

distance between horizontal and vertical focus should be zero

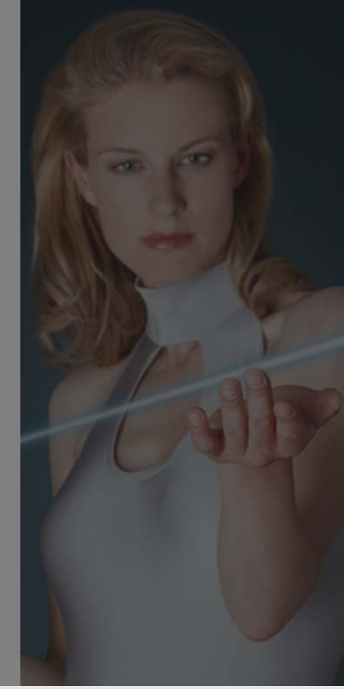
BEAM COLLIMATION BY MICRO OPTICS



TAPERED LASER DESIGN - PACKAGE

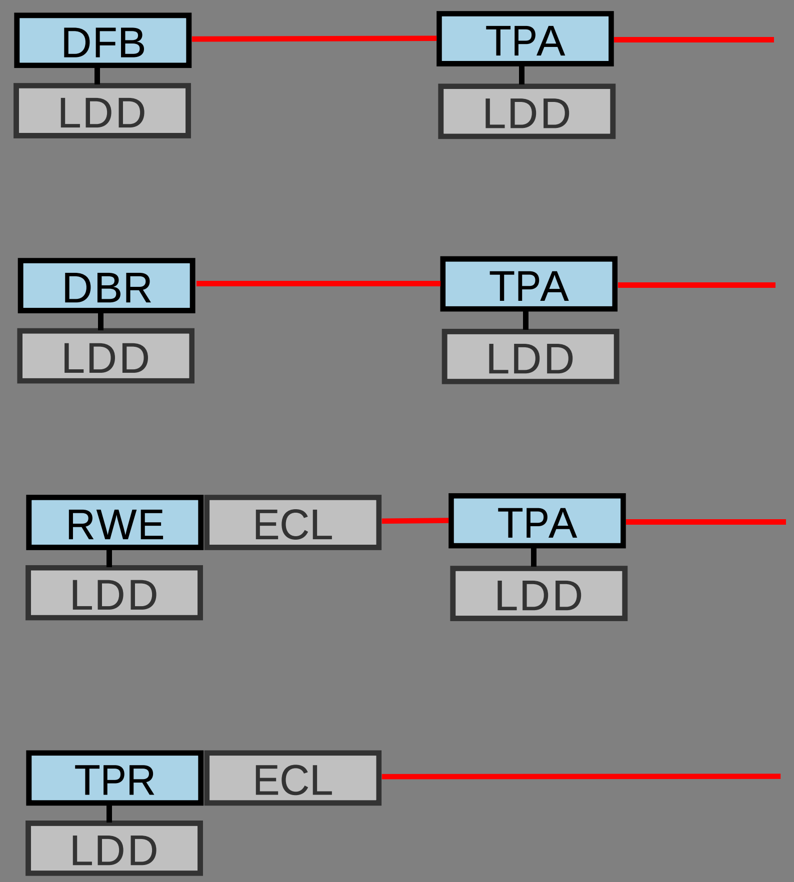
- **C-Mount**
  - Access to front and rear facet
  - designed for mounting on a heat sink
  - adapted for different chip lengths

- **CR-Mount**
  - Compatible to standard mounting systems
  - Improved thermal management for > 1 Watt
  - Easy optical input coupling with standard lenses



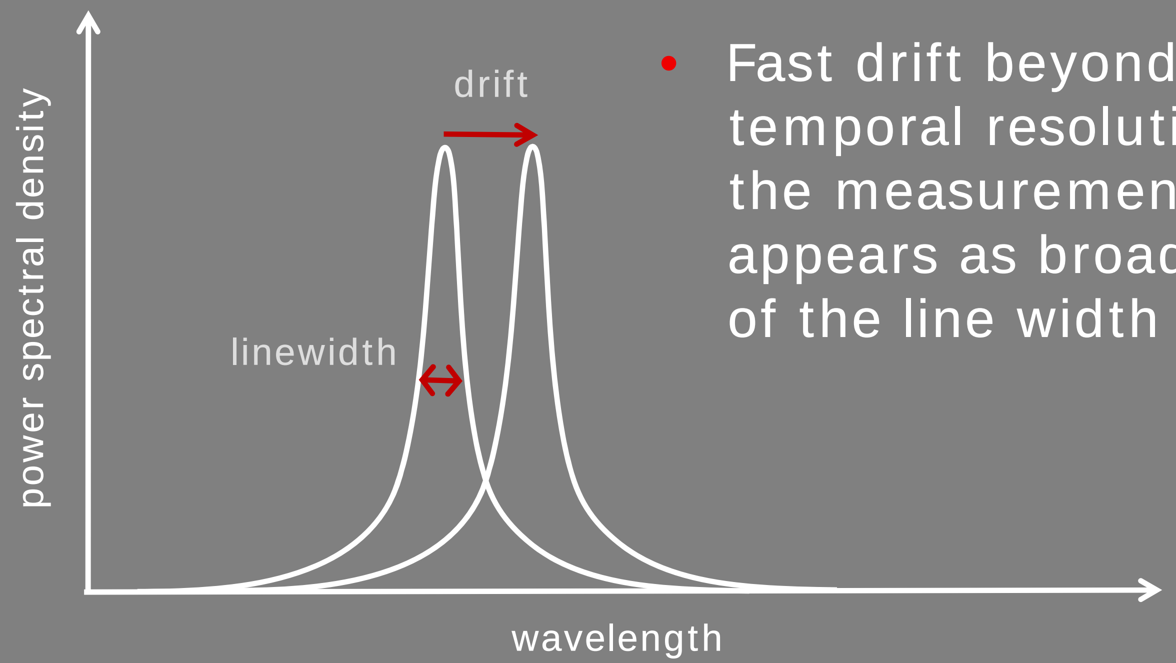
SYSTEM CONFIGURATIONS

1. DFB-TPA System
2. DBR-TPA System
3. RWE-TPA System
4. TPR System



LINEWIDTH AND DRIFT

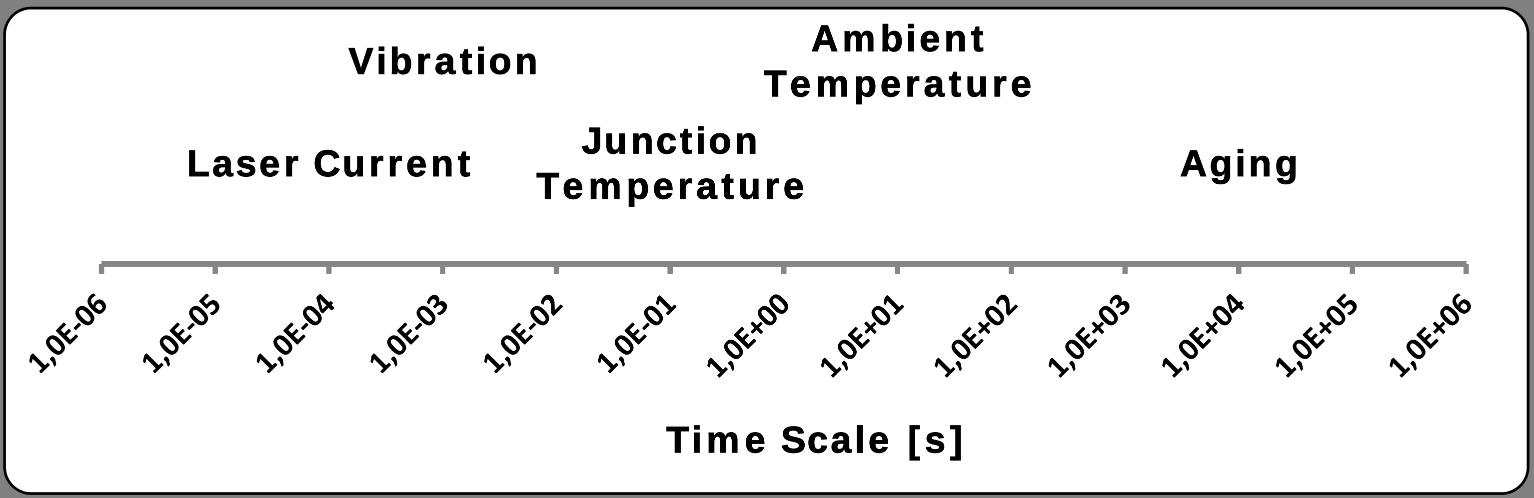
- Linewidth and drift are two aspects of frequency noise depending on the time scale of the measurement



- Fast drift beyond the temporal resolution of the measurement appears as broadening of the line width

SOURCES OF NOISE

- Besides quantum noise other sources of noise influence the linewidth of the laser (technical noise)



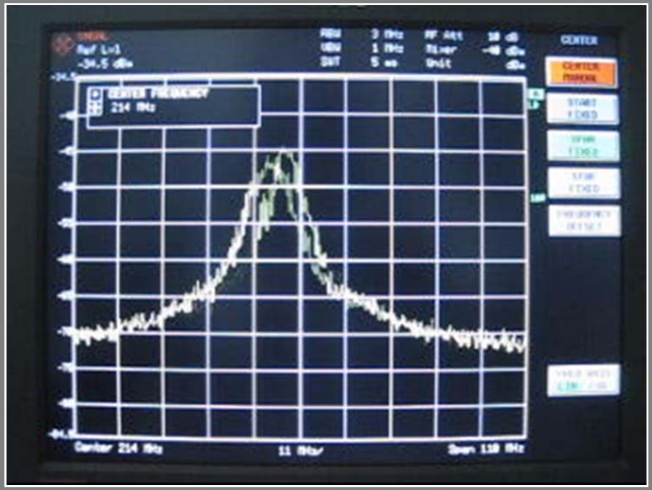
IMPACT OF CURRENT CONTROLLER

Introduction
Laser Cooling
Laser Technology
DFB Lasers
External Cavity Lasers
Tapered Amplifiers
Laser Systems
Applications
Summary

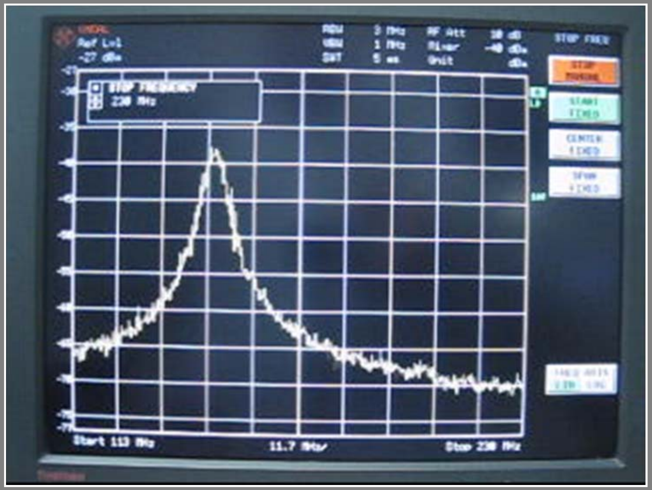
- Noise of the current source has an impact of the wavelength stability

  A fluctuation of 1 µA leads to a spectral drift of approx. 1 MHz

without electrical filter



with electrical filter



IMPACT OF TEMPERATURE

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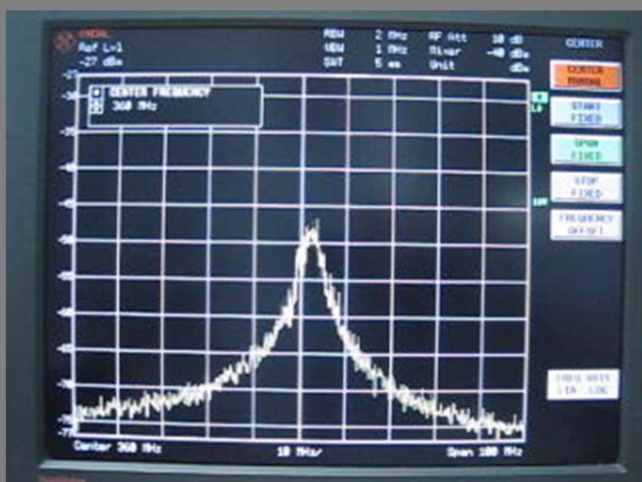
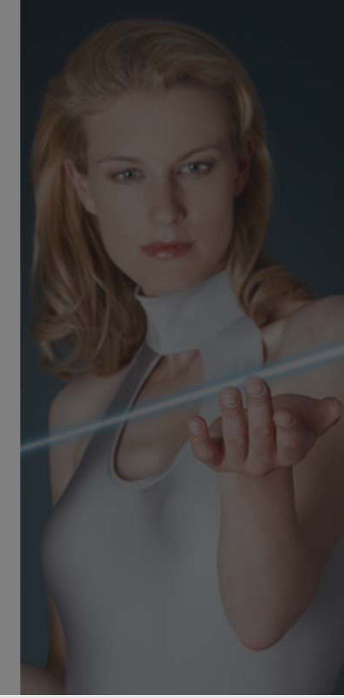
- A change of temperature leads to spectral drift

  A temperature shift of 1 mK at the p-n-junction of the laser diode leads to a spectral drift of approx. 25 MHz



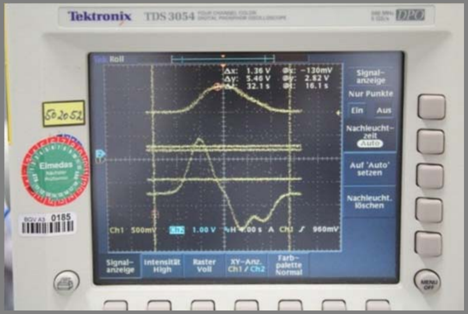
60 MHz

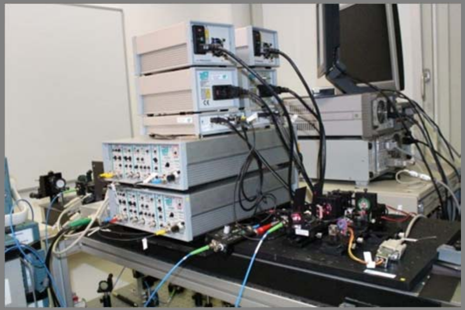
constant TEC current



ACTIVE WAVELENGTH STABILIZATION

- An actively controlled laser current and TEC current can keep the laser emission at the required wavelength
- The absorption of an atomic transition or a wavelength meter can be used for locking





TECHNICAL NOISE

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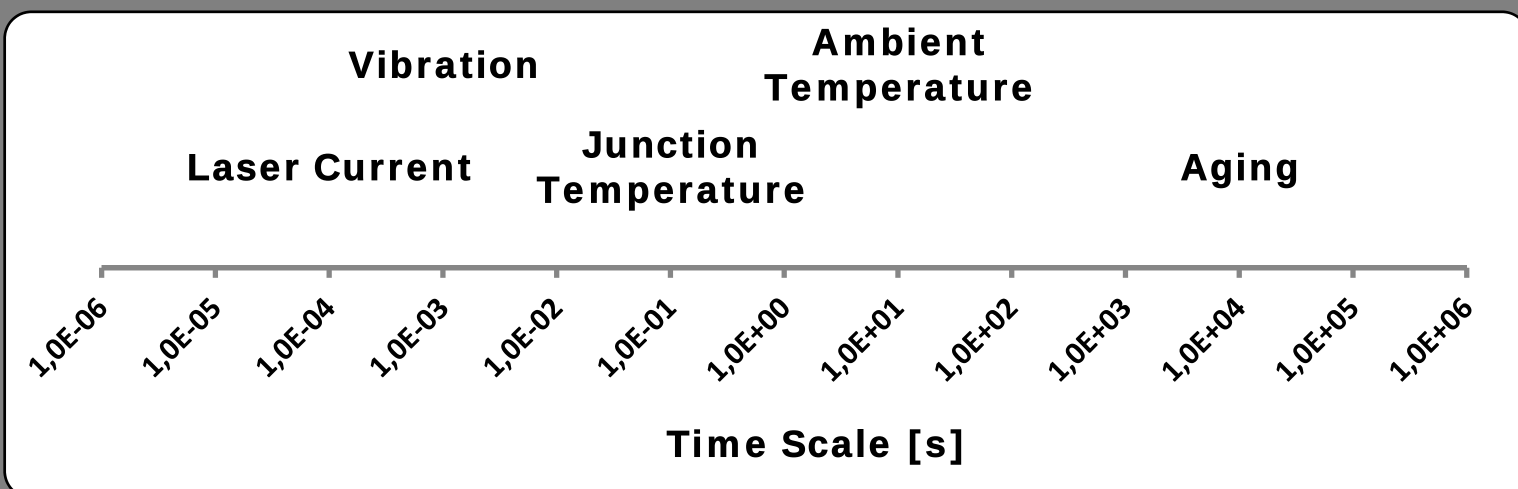
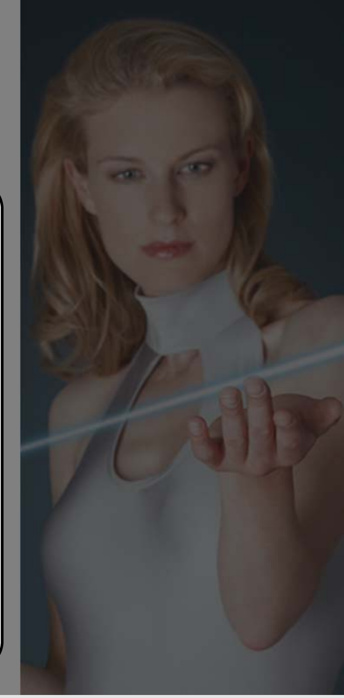
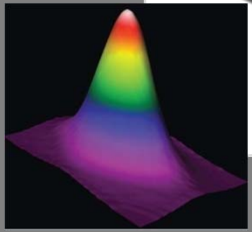
- Usually technical noise dertermines the linewidth of the laser diode
- It is important to keep the impact of technical noise low in order to achieve small linewidth and high wavelength stability





REFERENCE APPLICATIONS

- TPA family in CMT package
- Chosen Component in New Focus VAMP™ Series



- RWE family in SOT 9 mm package
- Chosen Component in New Focus Vortex™ and Velocity™ Series

•Photos and Images courtesy of NewFocus

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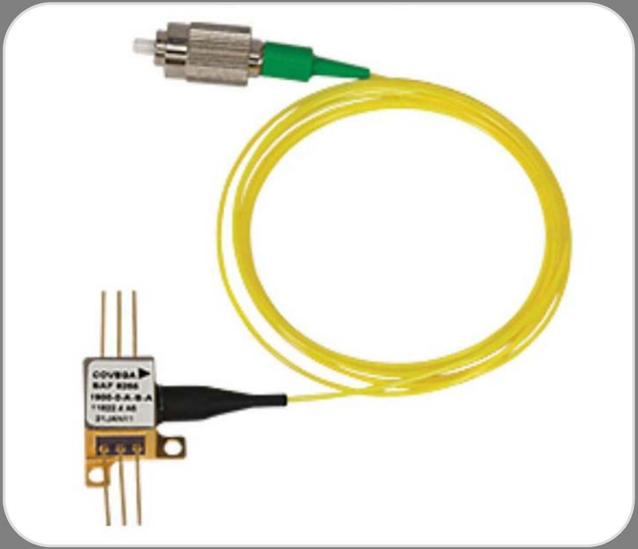
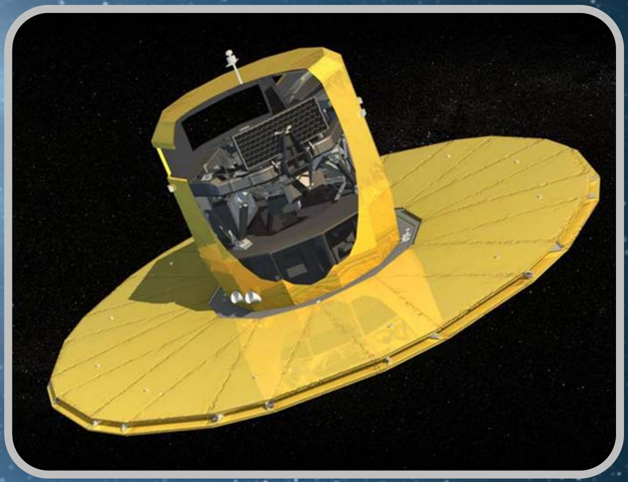
- TPA family
- Chosen Component in THORLABS Half Butterfly Gain Chips

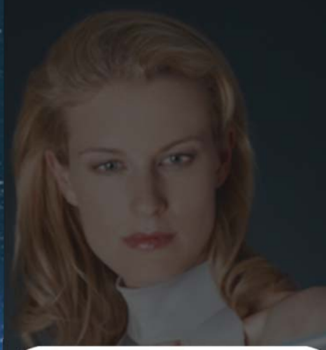


•Photos and Images courtesy of Thorlabs

REFERENCE APPLICATIONS

We focus on power.





- DFB-1064nm as pulsed seed source for fiber laser application
- To be used in ISS

- DFB-850nm for interferometric setup to align two telescopes in orbit
- GAIA Satellite program by esa

SUMMARY

- Laser diodes are versatile light sources for laser cooling and trapping
- DFB Lasers and RWE Lasers for ECDLs meet the requirements in terms of
  - Emission wavelength
  - Linewidth
  - Tunability
  - Wavelength Stability
- TPAs enable amplification of the power preserving the good spectral performance of the seed laser

We focus on power.

eagleyard Photonics GmbH
Rudower Chaussee 29
12489 Berlin

fon: +49.30.6392 4520
fax: +49.30.6392 4529
e-Mail: info@eagleyard.com
web: www.eagleyard.com

谢谢