Diode lasers for sensor applications

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Outline

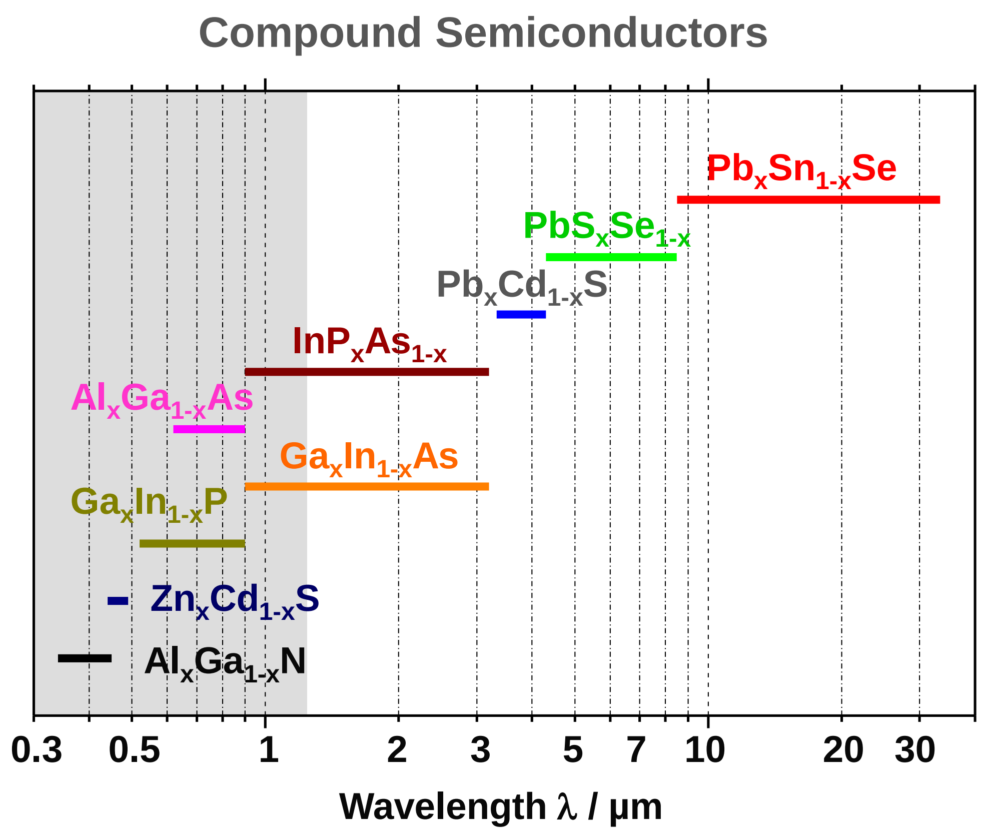
1. **Diode Lasers – Basic Properties**

2. **Diode Lasers for Sensor Applications**
   - Diode lasers with internal grating
   - Diode lasers in external cavities
   - Diode lasers as pump sources for non-linear frequency conversion
   - Hybrid integrated laser module for ps- and ns-pulses

3. **Summary**

Diode lasers – Features

- Wide spectral range: 0.34 nm ... 33 µm
  - FBH: 630 nm ... 1.2 µm
- High wall-plug efficiency
- Easy excitation
- Direct Modulation
- Small size
- Mechanical robustness
- Lifetime (> 10^7 h)
- Tuneability
  - Current
  - Temperature
  - External grating



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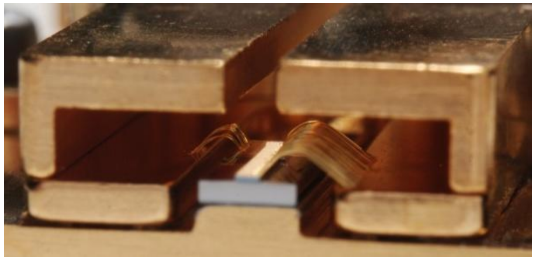
Laser diodes: High Output Power

Laser diode



P **= 20 W**

200 µm x 2 µm

Power density
p **= 5 MW / cm²**

Coal-fired power plant

600 MW

Same power density in a 12 cm cable

Surface of the sun

6 kW / cm²

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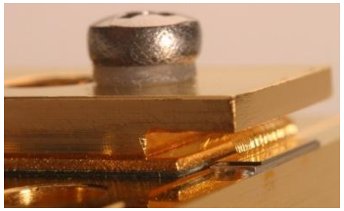
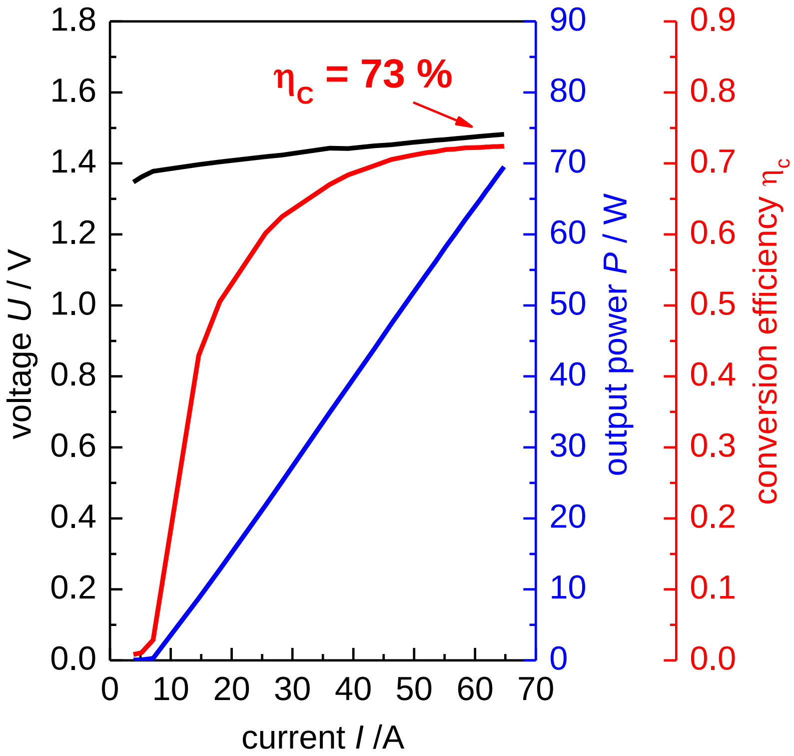
Laser Diodes: High efficiency

Efficiency ≈ 73%





Light bulb:

< 5%

Energy-saving lamp:

< 20%

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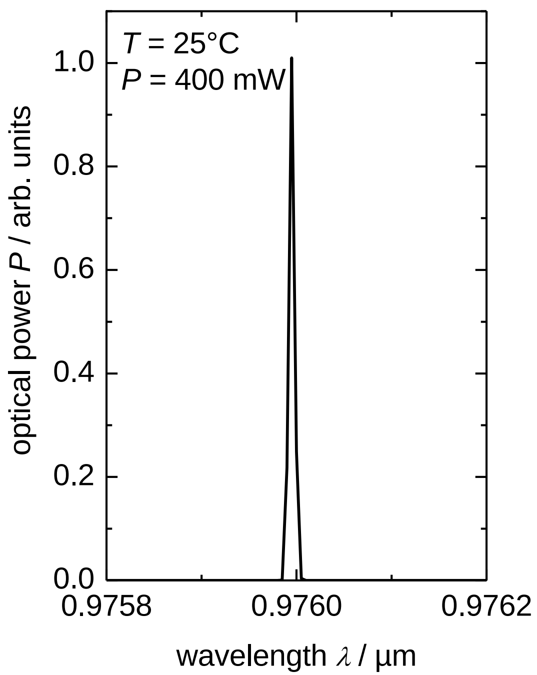
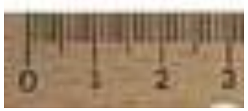
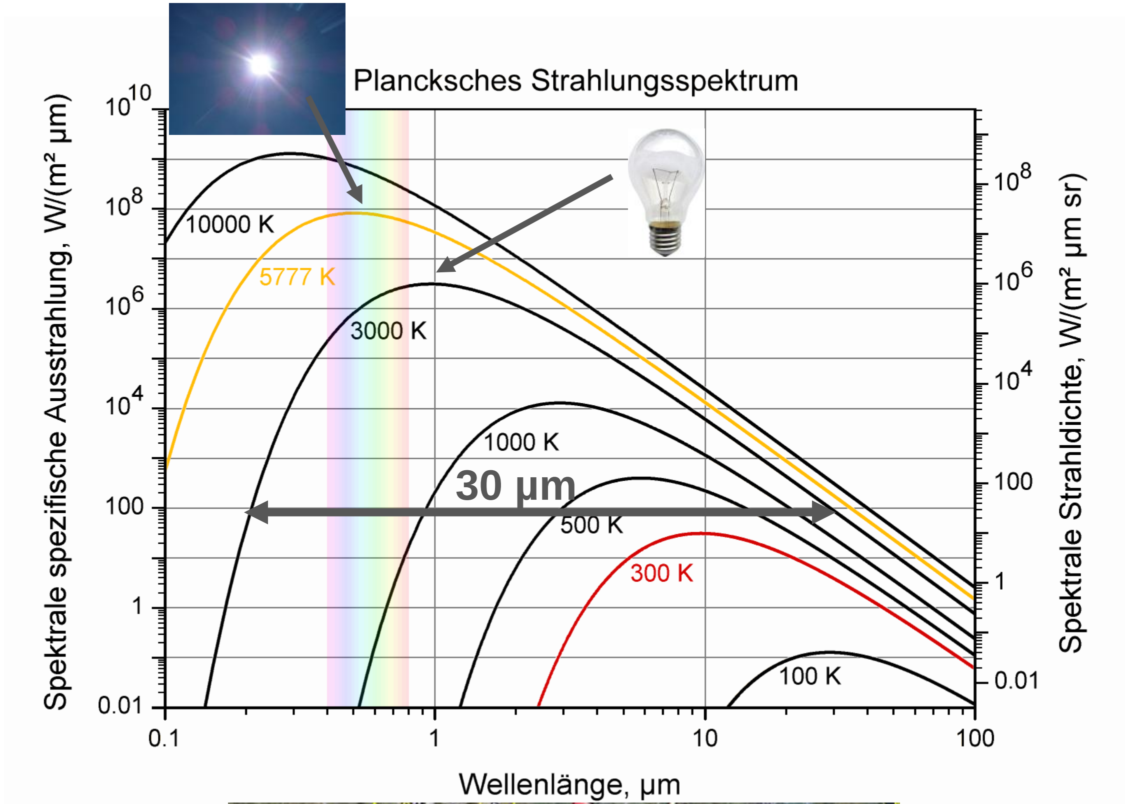
Laser Diodes: Narrow spectral linewidth

$\Delta\lambda_{min} \leq 10^{-6}$ µm





3 cm



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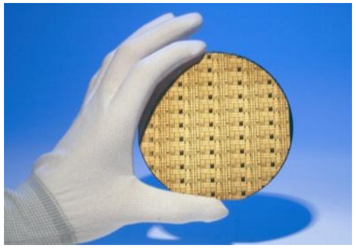
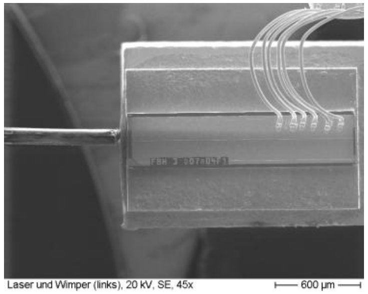
Overview: Fabrication Process of a Laser Diodes

- Deposition of very thin crystalline layers on a GaAs substrate
  - *Epitaxy*

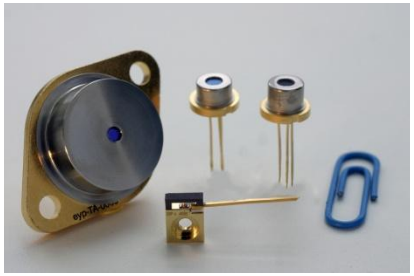
- Structuring of devices on the wafer
  - *Processing*



- Separation of single devices
  - *Cleaving*



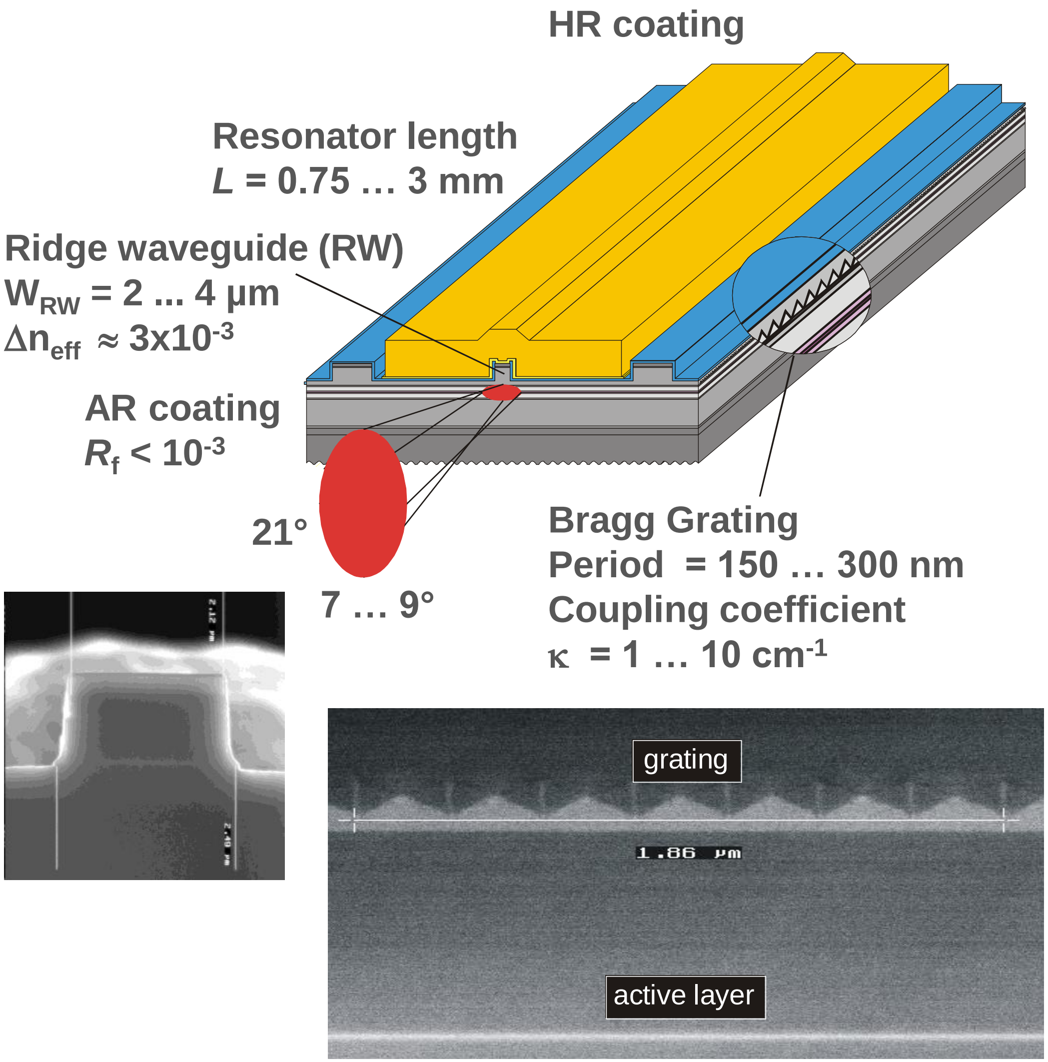
- Mounting of devices on heat sinks



- Housing of devices

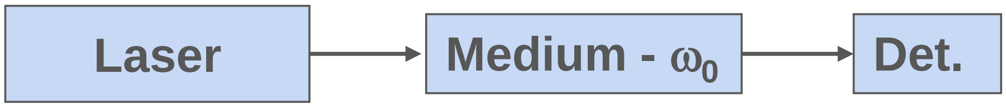
Schematic view of a high-power DFB laser

- Design epitaxial structure
- First epitaxy
- Manufacturing
  of the grating
  e.g. using holographic
  eposure
- Second epitaxy
- Process
- Facet coating
- Mounting



940 nm DFB lasers for H_2O absorption spectroscopy

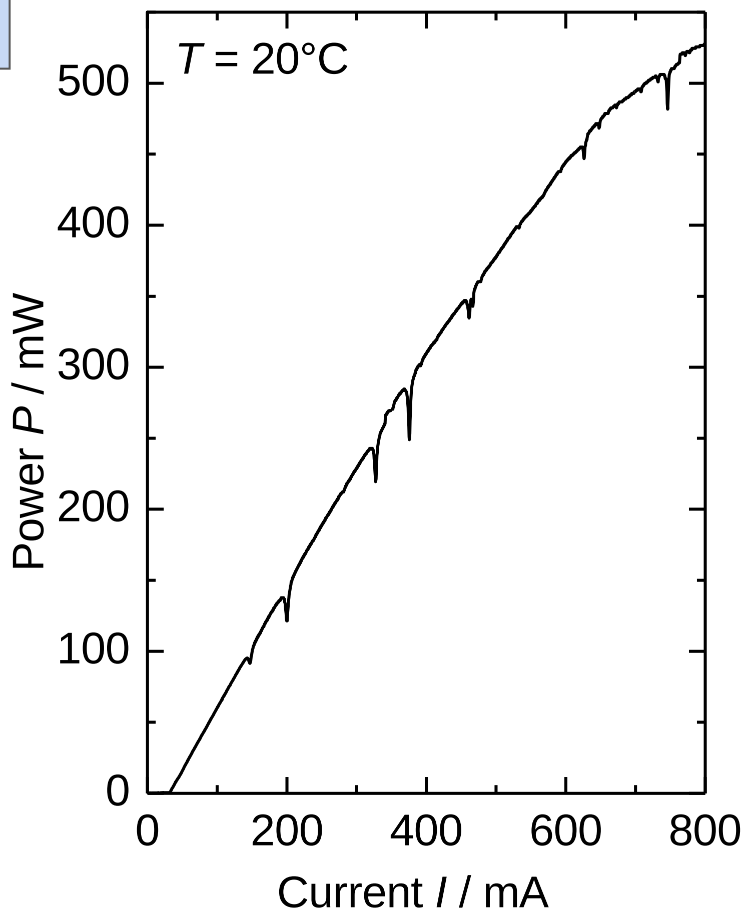
Transmission measurement



- Tuneable Laser
- Lambert-Beers-Law

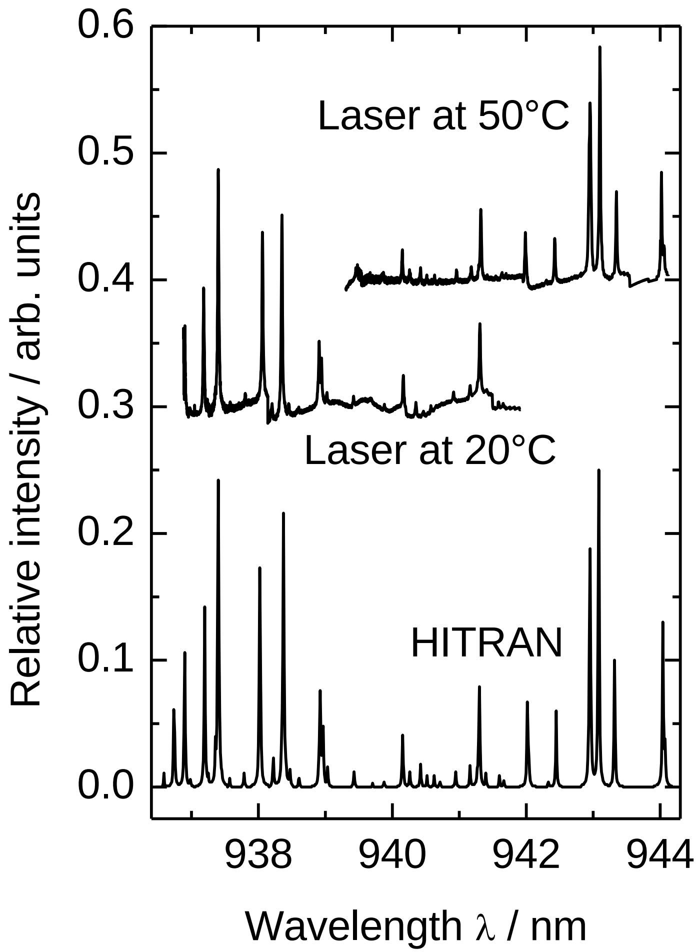
$$I(\omega) = I_0 \cdot \exp[-\alpha(\omega) \cdot L]$$

- Threshold current I_{th} = 35 mA
- Slope efficiency S = 0.9 W/A
- Maximum output power
  $P_{max} \approx 500$ mW
- Dips in the characteristic due to water absorption



940 nm DFB laser: Absorptions spectroscopy of water vapour

- Spectra calculated based on Lambert-Beers-law
- Comparison of calculated spectra to the data from the HITRAN database
- Excellent agreement
- Continuous tuning over 5 nm at one temperature



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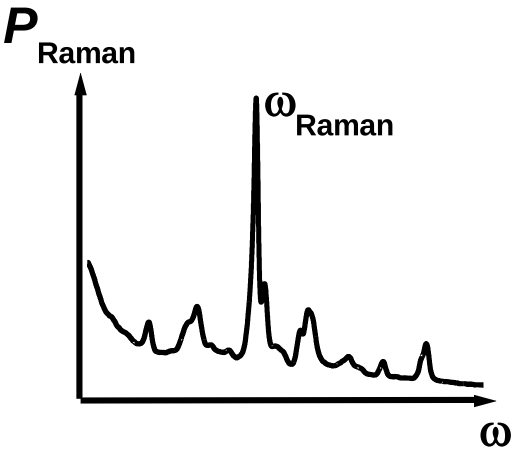
Diode lasers in external cavities for Raman spectroscopy

Raman measurement

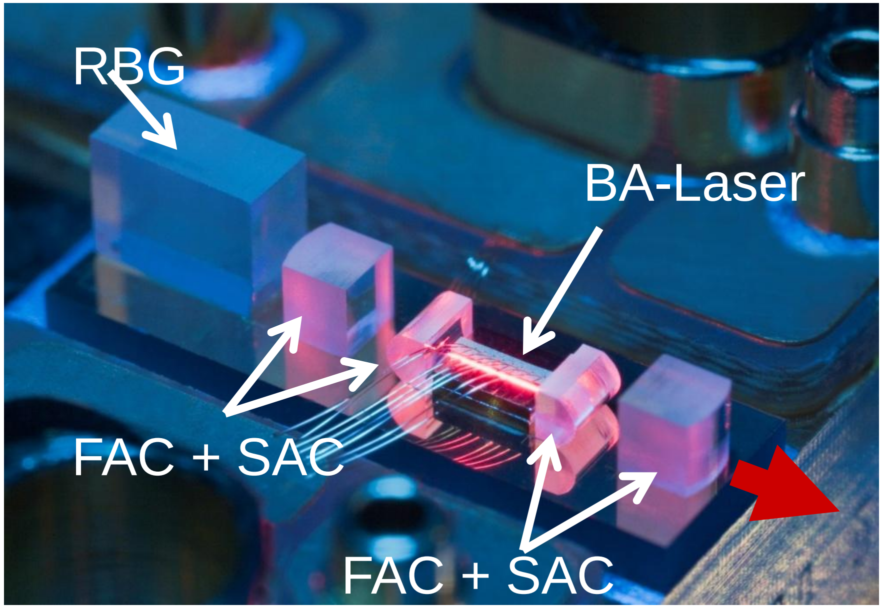
Laser → Raman ω_R → Det.

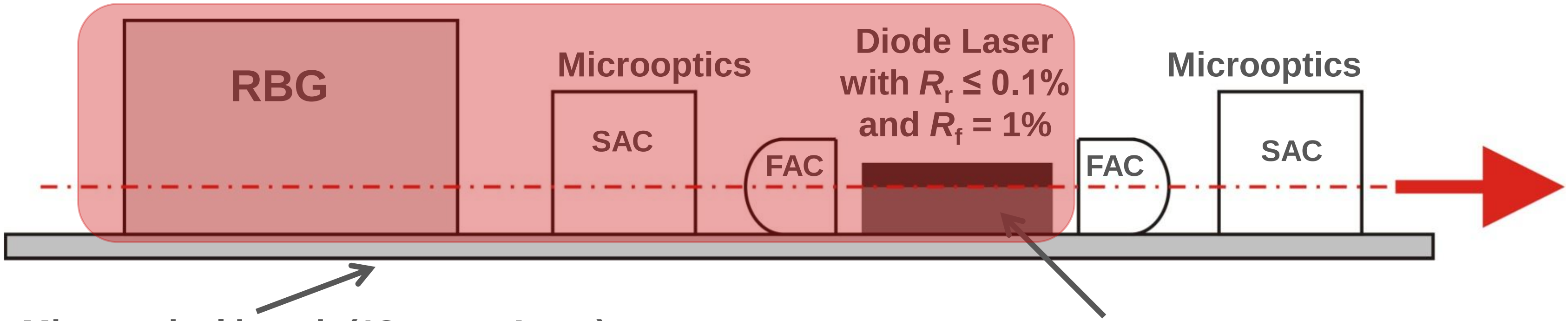
- Fixed frequency laser (e.g. 488 nm, 671 nm, 785 nm)
  - Spectral emission width: $\Delta\nu \leq 10\ \text{cm}^{-1}$
  - Spectral stability $\delta\nu \leq 1\ \text{cm}^{-1}$
- Well-established contact free method
  - for material analysis, food safety control, clinical diagnostic.
- Excitation in the visual spectral range
  - Advantages:
    - Higher Raman signals due to a λ^{-4} – dependence
    - Resonance Raman
    - Stokes lines in the maximum of the sensitivity of CCDs
  - Disadvantages:
    - Possible fluorescence background
- Shifted excitation Raman difference spectroscopy
  - Spectral distance for SERDS $\Delta\nu_{SERDS} \approx 10\ \text{cm}^{-1}$



671 nm microsystem light source

- Gain medium:
  - Broad area laser
    w = 30 µm, 60 µm, 100 µm; L = 2 mm
  - Output power up to 1.5 W
- Resonator
  - Front facet of the diode laser and
    Reflection Bragg Grating
  - Emission width below 100 pm (10 cm^{-1})
- Active adjustment necessary





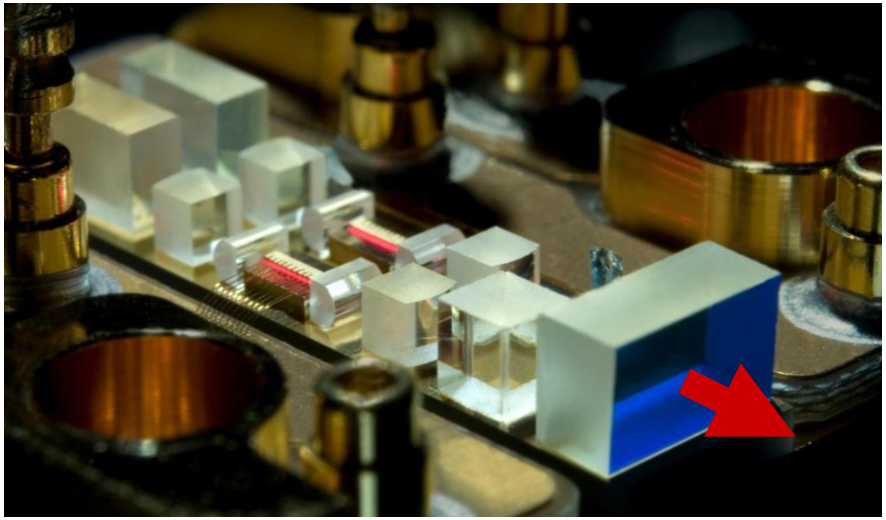
IEEE Phot. Tech. Lett. Vol. 20(19), pp. 1627 (2008).

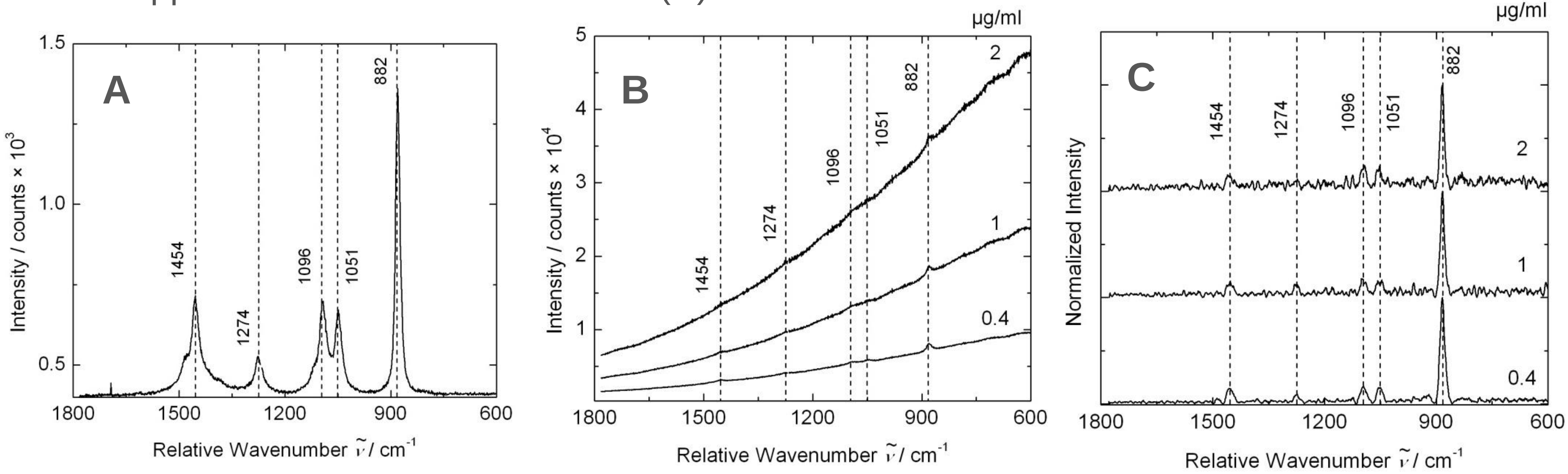
671 nm module – application in Raman-Spectroscopy

- Ethanol as analyte (A):
  Raman-signals spectrally resolved

- Fluorescent interference introduced (B)
  - Laser dye Cresyl violet

- Application of SERDS successful (C)





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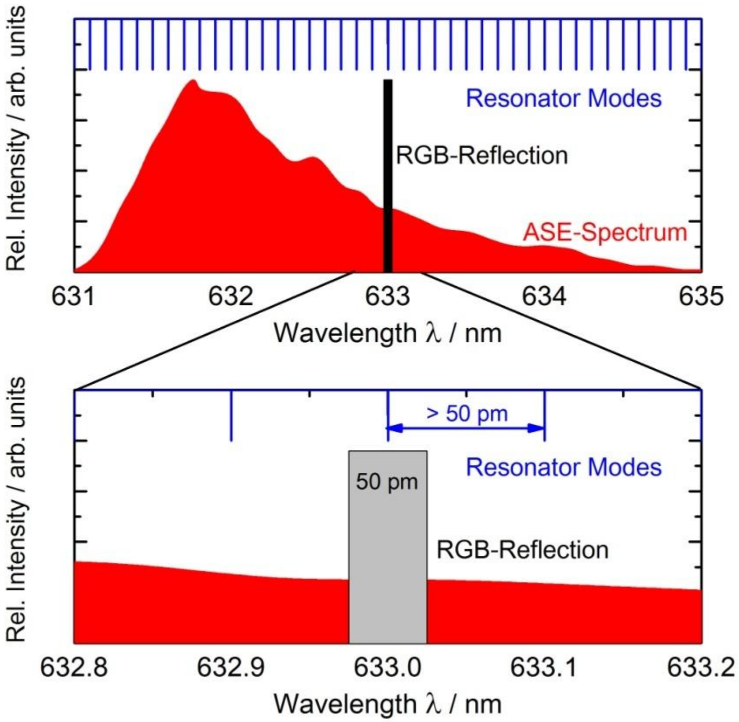
Diode lasers in external cavity for interferometry

Absolute distance interferometry (ADI) with 10^{-6} accuracy requires tunable red emitting diode lasers:

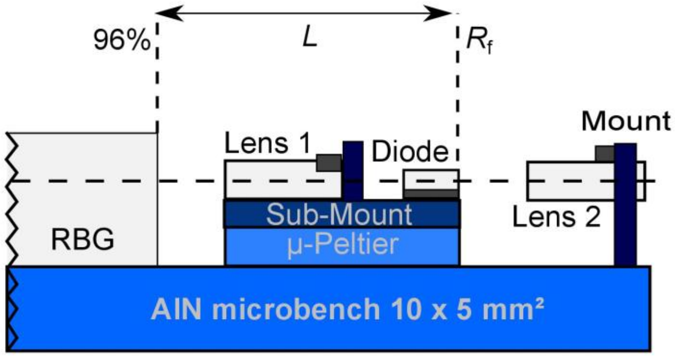
- Preferred wavelength ≈ 633 nm
- Single-mode operation
- Tuning range ≥ 50 pm (40 GHz)
  - Determines the smallest measurement distance about 4 mm
- Narrow spectral line width ≤ 10 MHz (0.015 pm)
  - Determines the maximal measurement distance about 15 m
- Output power ≥ 5 mW
- Current tunable, no moving parts

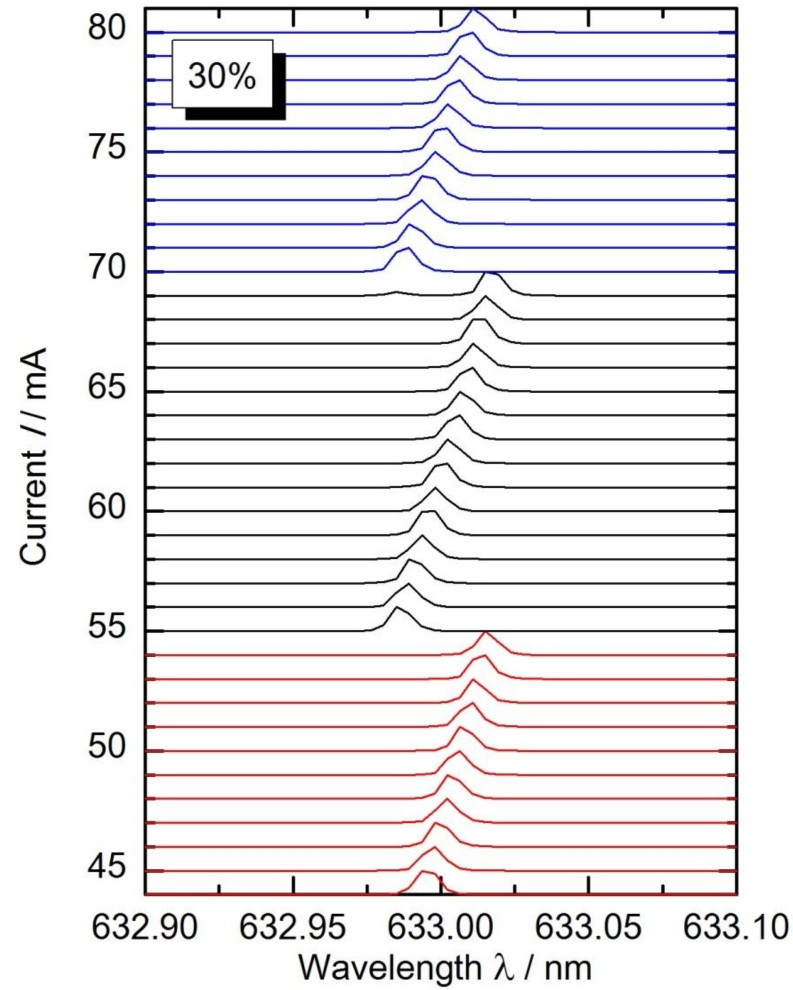


Solution:

- ECDL with mode spacing larger the spectral width of the RBG $\Delta\lambda_{RBG} \approx 50$ pm
  $n\,L \leq 4$ mm ⇨ $\Delta\lambda_{FP} \geq 50$ pm - within RBGs spectral width only one mode!
- Narrow line width due to high quality resonator (High facet reflectivity)

Scheme of the external cavity laser





Single mode operation

- 34 pm, i.e. 25 GHz

Emission line width (self-delayed heterodyne)

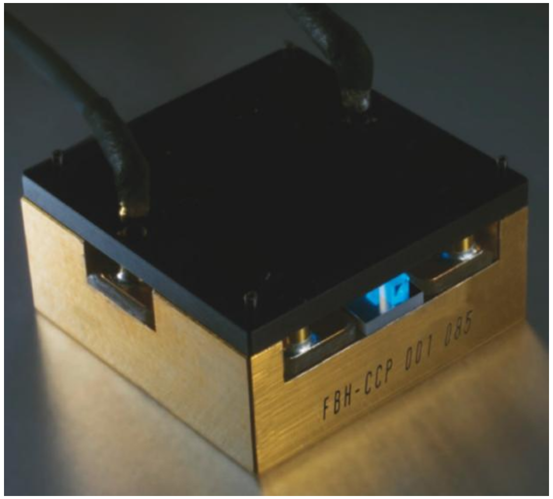
- Between mode hops smaller 10 MHz
  - coherence length of 30 m
- At mode hop increase to about 15 MHz

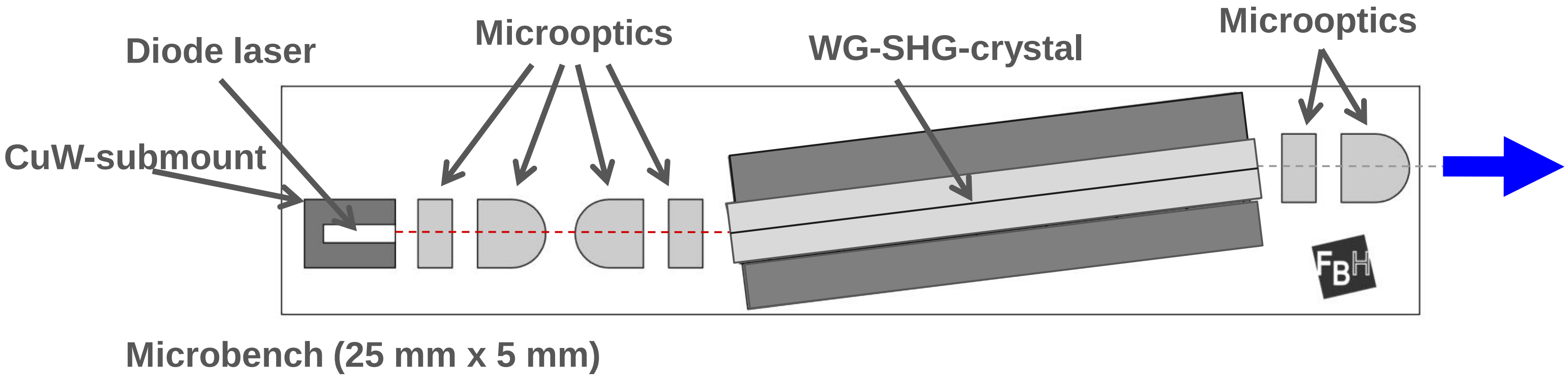
Side mode suppression ratio: Better than 25 dB

Diode lasers as pump sources for non-linear frequency conversion, e.g. SHG

Low power application (25 mW) for Raman spectroscopy

- Non-linear frequency conversion – Second Harmonic Generation (SHG)
  - Pump source
    - → Distributed Feedback (DFB) RW Laser
  - SHG-crystal
    - → periodically poled MgO:LiNbO_3 for 488 nm at 25°C
  - RW-SHG-Waveguide (3 µm x 5 µm x 11.5 mm)
    - → higher efficiency

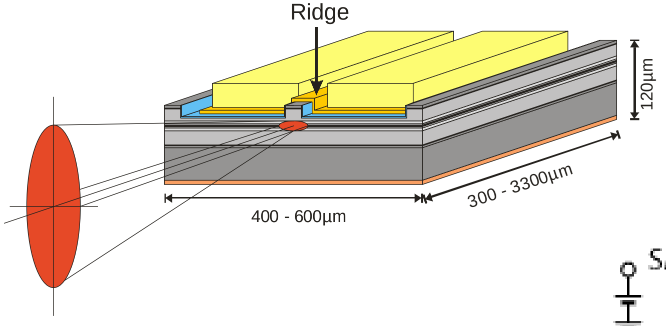


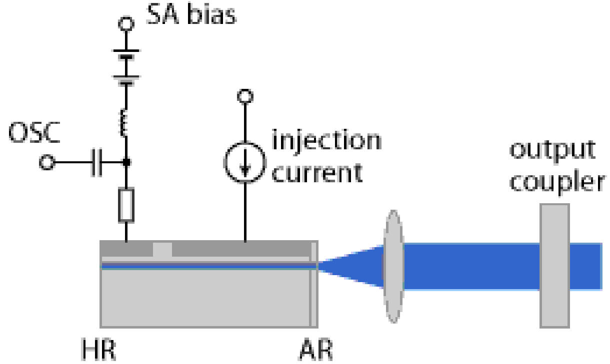


Diode lasers for the generation of ps- and ns-pulses

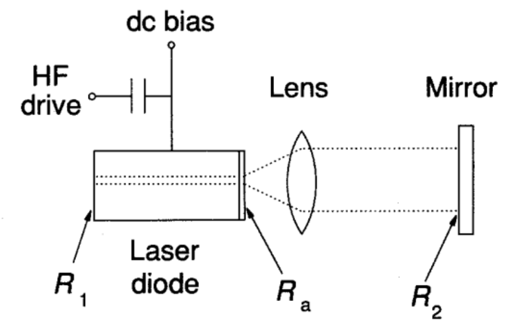
Methods:

- Gain switching
  - Current injection
  - Pulse length: 1 ns – 1 s
- Q-switching
  - Changing the properties of the laser cavity
  - E.g. implentation of an absorber section
  - Pulse length: 50 ps – 150 ps
  - Rep. Rate: up to 0.5 GHz
- Mode locking
  - Coupling of longitudinal modes
    - Passively (saturable absorber section)
    - Actively
  - Pulse length: 1 – 20 ps
  - Resonator length determines the rep. rate in the GHz-range



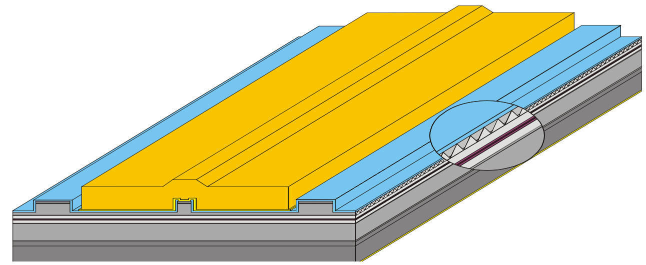


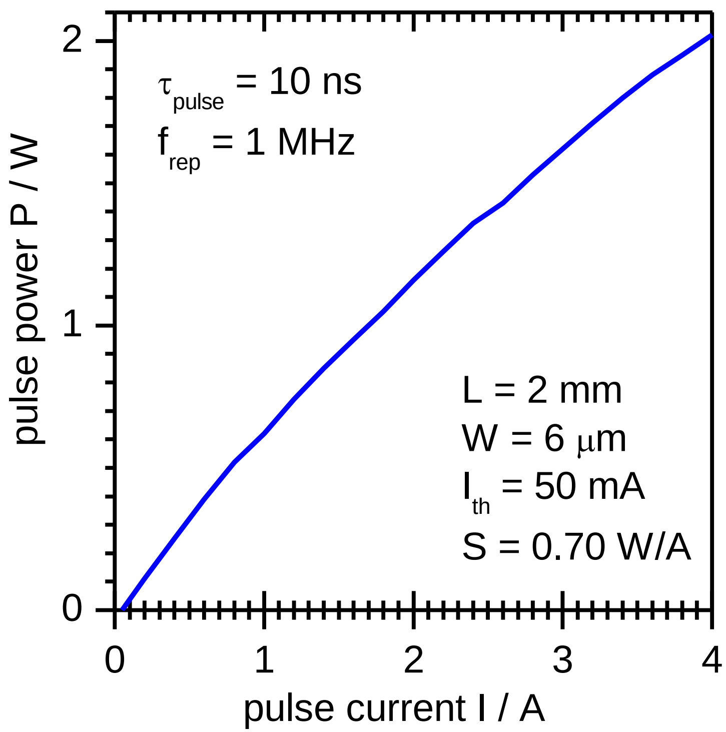
(b) device with modulated absorber section

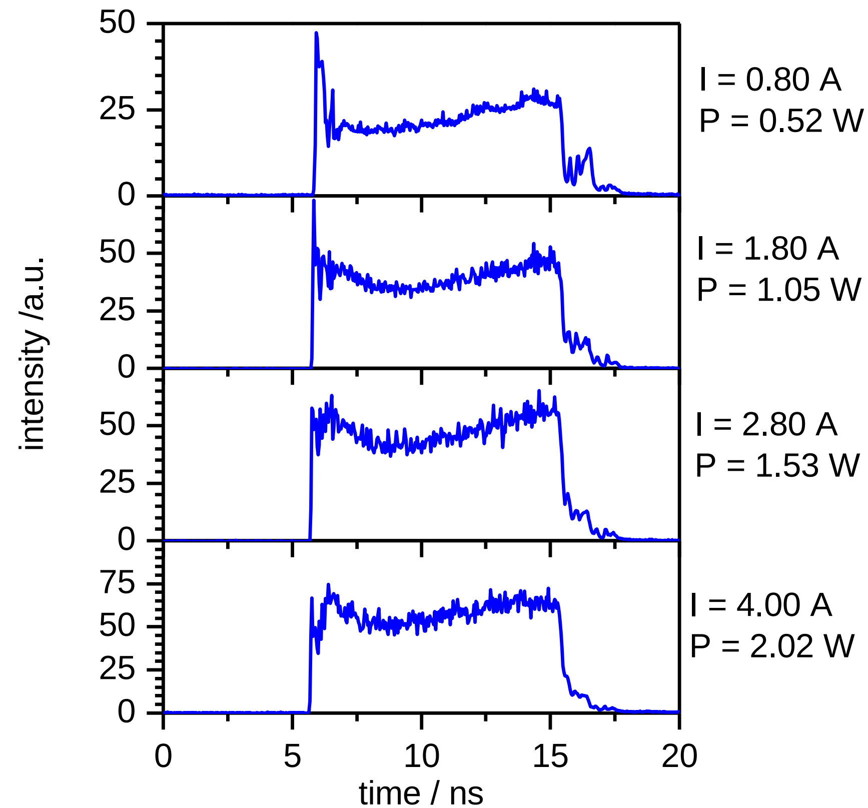


Gain Switching – DFB laser

- Geometry: L = 2 mm, W = 6 µm
- Pulse length 10 ns … 1 ms; Rep. rate 1 MHz
- DFB laser with P_{opt} = 2 W at I = 4 A
- MOPA system with up to P_{opt} = 10 W

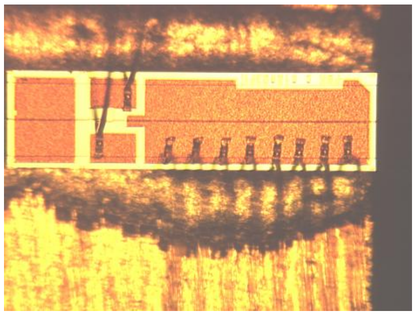


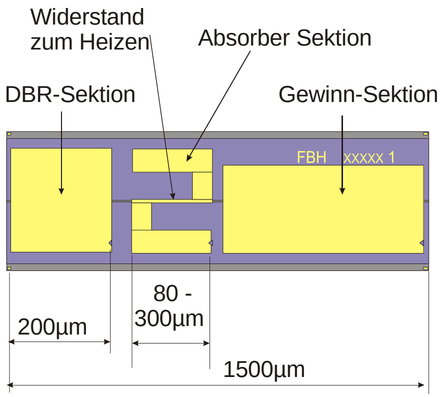


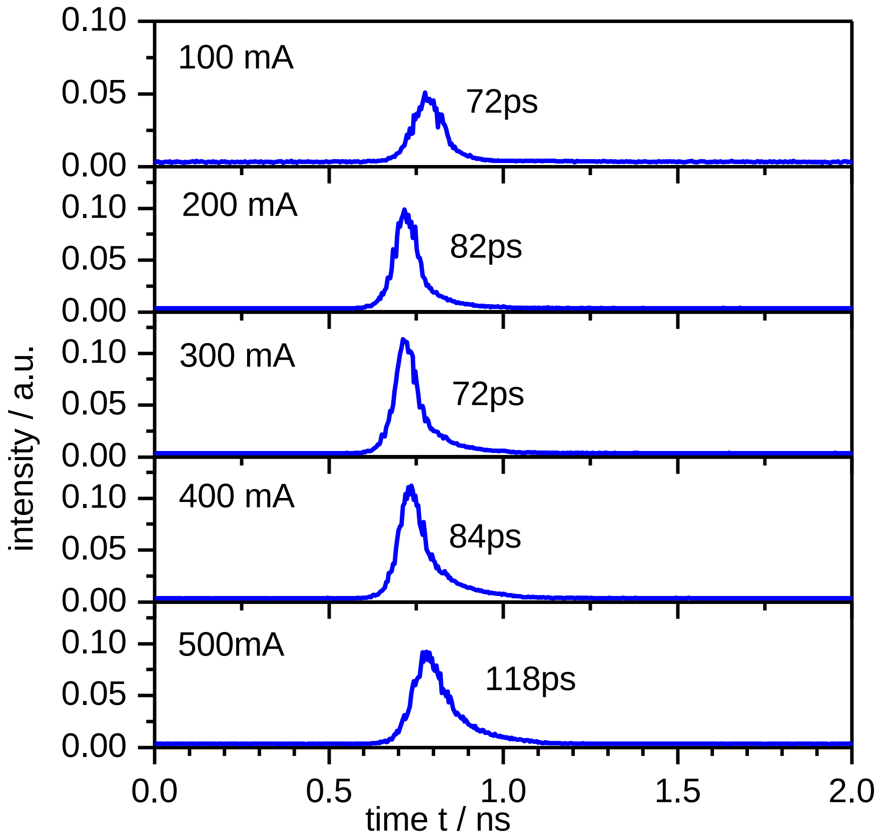


Q-Switching – Multi-Section RW- and DBR Lasers

e.g. 3 – section DBR laser with gain, absorber, and grating section – length 1.5 … 4.0 mm







- Current through gain section varied
- Output power can be modulated using the absorber section
  - V_{SAB} = -2.0 V; t_{mod} = 1 ns; f_{rep} = 40 MHz
- Pulse length ≤ 100 ps
- Pulse power ≈ 300 mW
- Amplified power: 20 W

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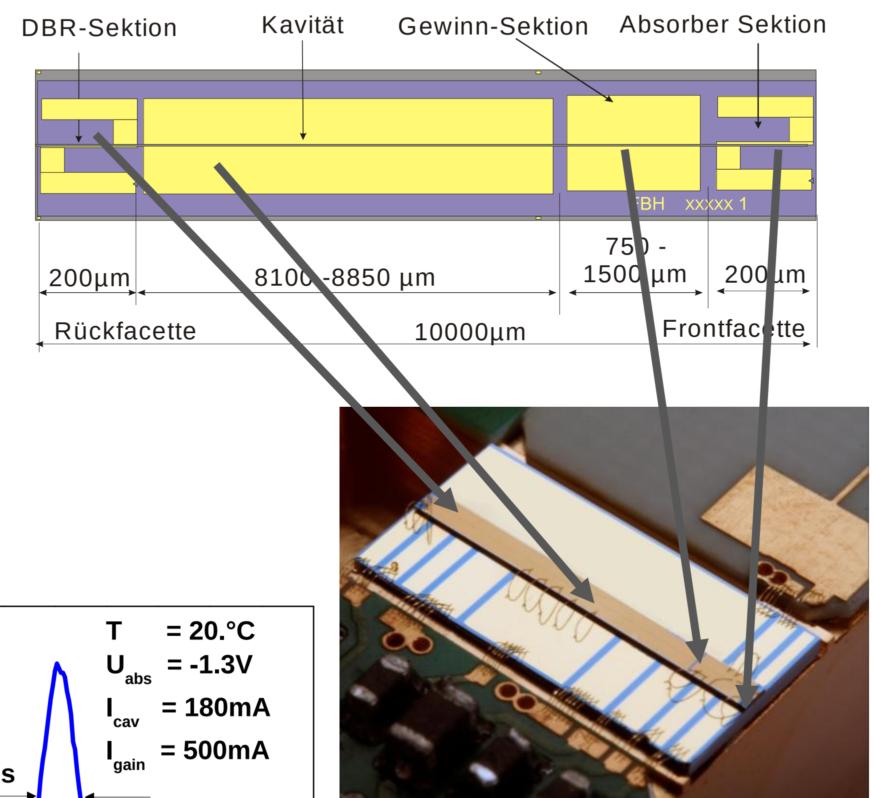
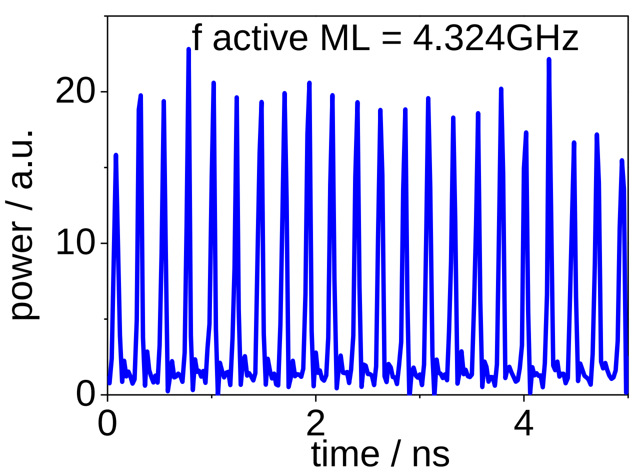
Monolythic devices for mode locking

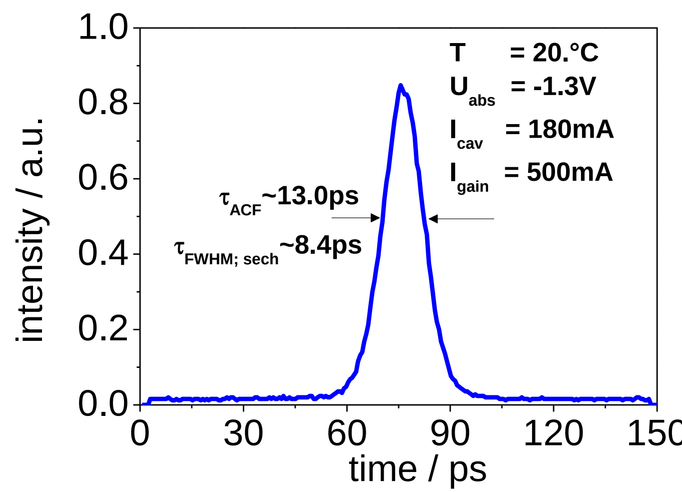
4 section DBR-Laser

- DBR grating determines wavelength
- Fast saturable absorber for mode locking
  - Passive and active mode locking possible



- Round trip: ~ 230 ps, rep. rate ~ 4.3 GHz
- Pulse length ~ 8 ps, Jitter: < 1 ps
- Peak power: 1 W at 8 ps Pulse length





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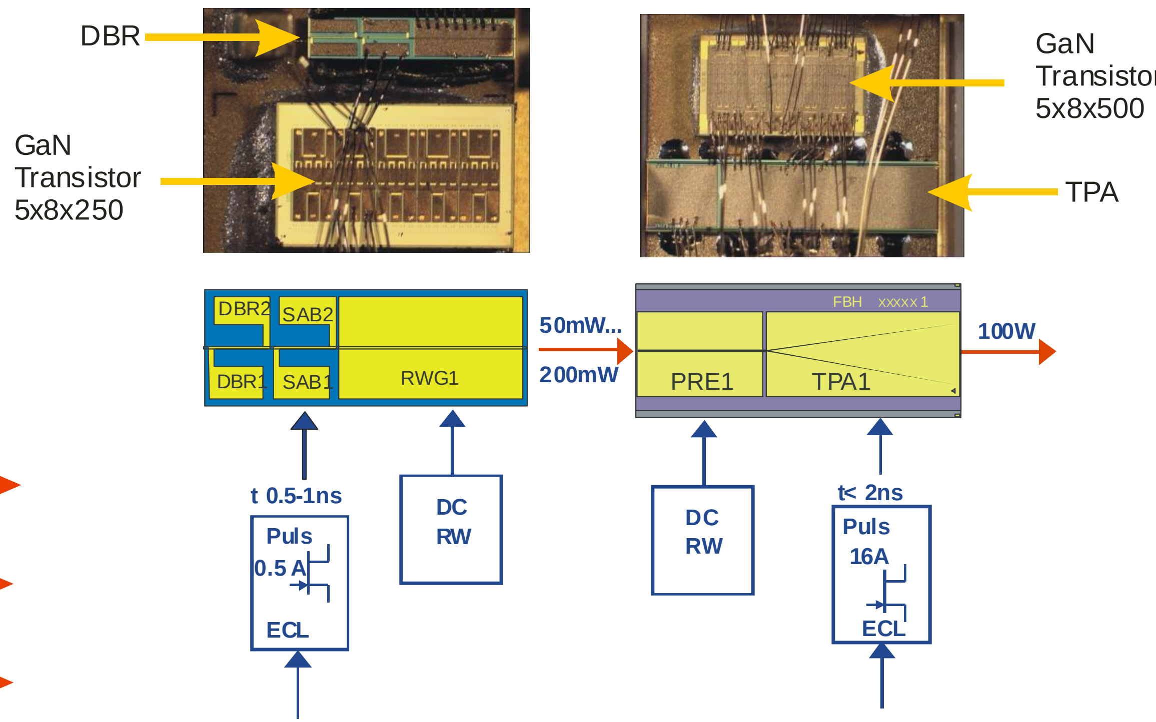
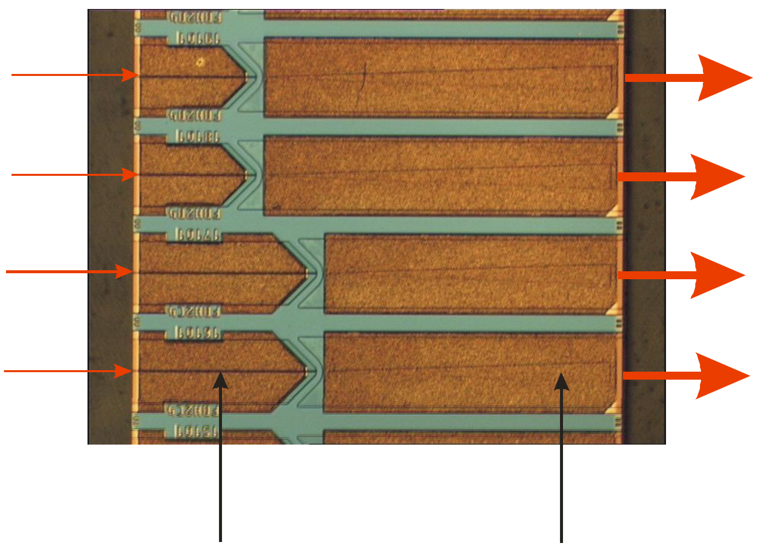
MOPA system with tapered amplifier for Q-switched ps-pulses

- Master Oscillator: Q-switched DBR
- Power Amplifier: Tapered Laser
  - Amplification of short pulses
  - Maintaining Beam Quality
  - Seperate Excitation of RW and Tapered Section

DBR Laser mit GaN Transistor

Trapezverstärker mit GaN Transistor





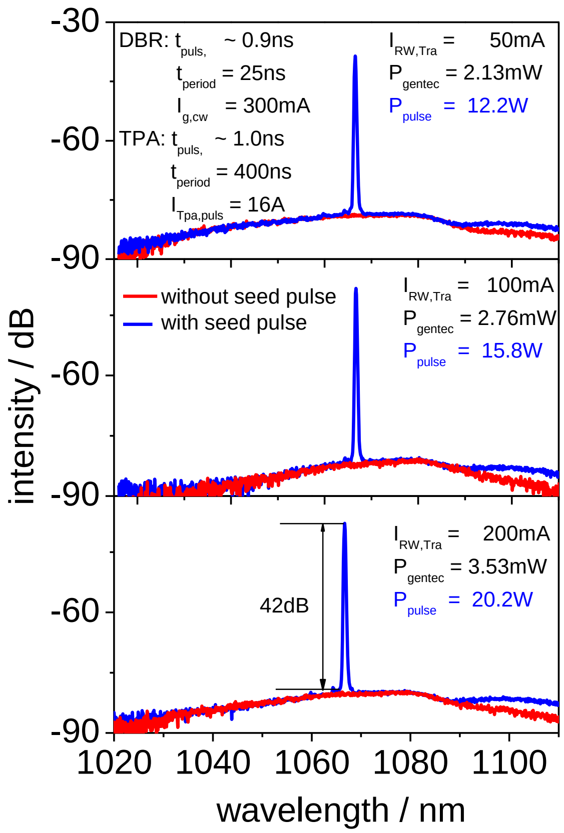
Generation of current pulses

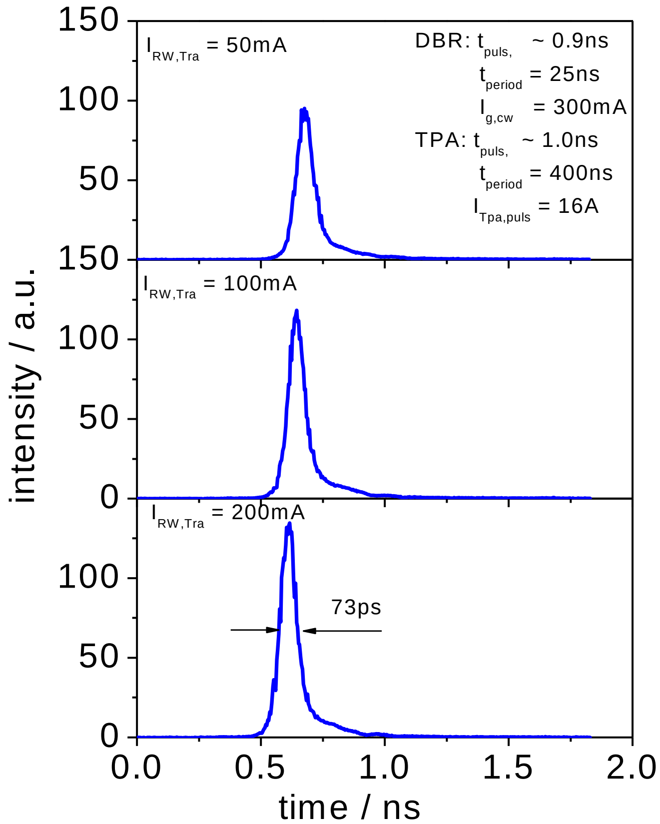
- MO <1 ns, ≤ 1 A
- PA < 2 ns, ≤ 20 A

Electronics also developed at FBH

Results: MOPA system for Q-switched ps-pulses

- Pulse length (FWHM) = 73 ps
- Pulse power: 20 W
- Wavelength defined by MO with emission width (FWHM ~ 0.2 nm)

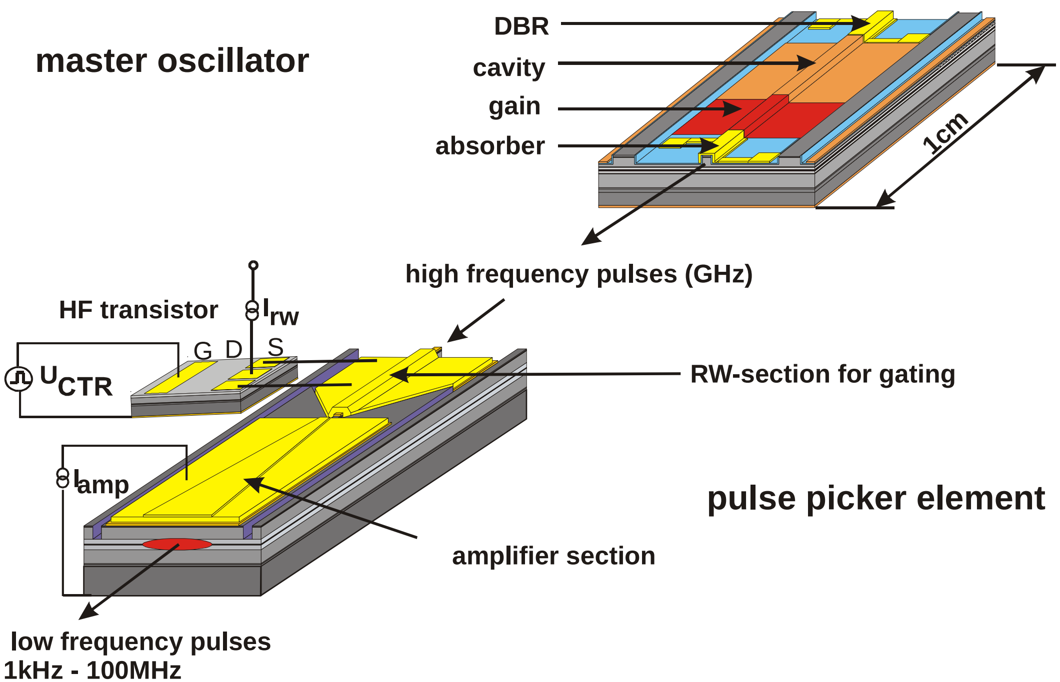


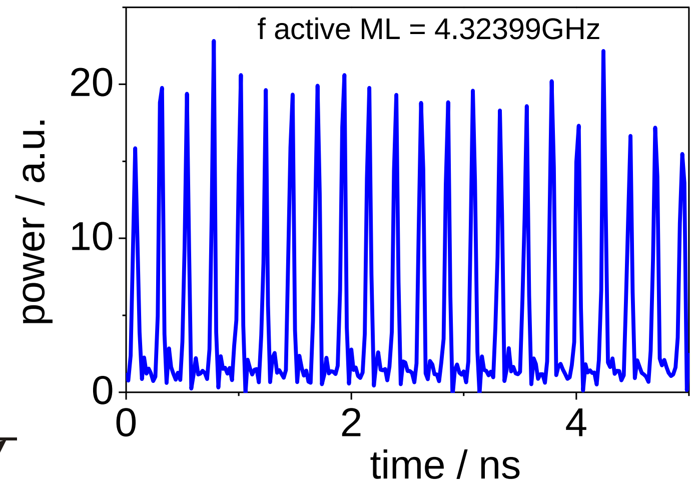


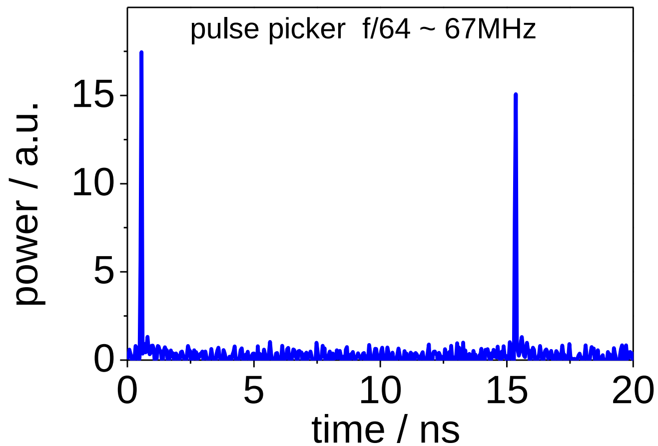
Pulse picking using tapered amplifier

Basic principle:

- RW-section of TPA as selector
  - Transparent or absorbing
  - Controlled with GaN-HF-transistor
  - Selectable duty cycle
- Amplification in tapered section

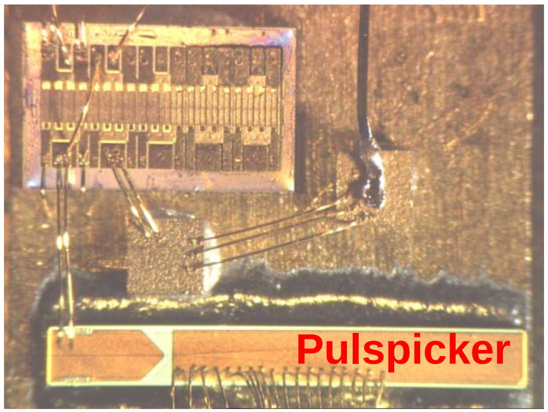


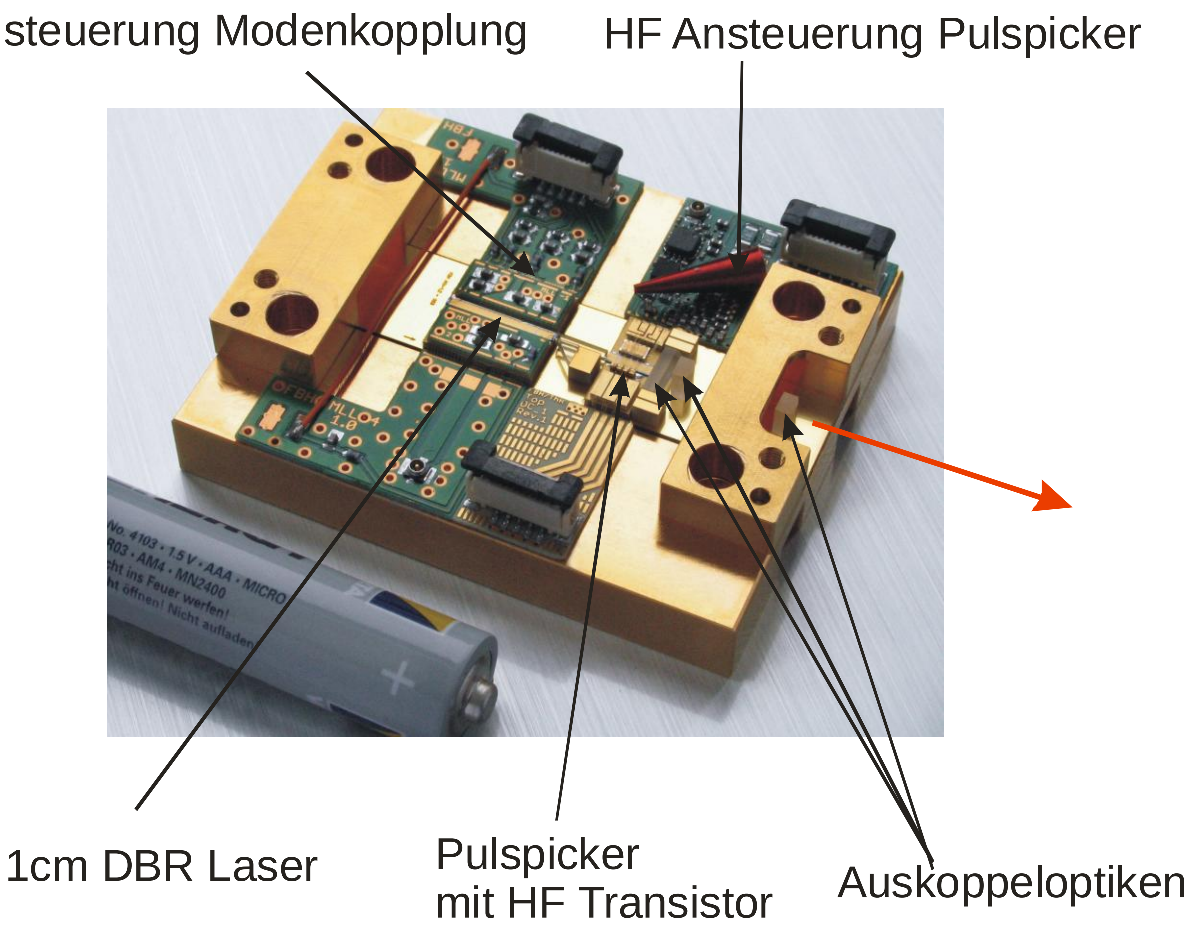




Pulse picker – optical micro bench

GaN high electron mobility transistor HEMT





- Integeration of
  - optical elements
  - high-frequency electronics
    - 500 mA current pulses
    - 200 ps pulse width
    - Adjustable rep.rate 1 kHz – 333 MHz
    - Jitter smaller 25 ps
- Small inductivity – short wires

Summary and Acknowledgments

Diode lasers:

- Compact, reliable, high-power light sources for different applications
- Features can be optimized with respect to the application:
  - Wavelength
  - Power
  - Emission width
  - Beam quality
  - Pulse parameter

Acknowledgments:

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