Recent advances in high-performance 2.X µm Vertical External Cavity Surface Emitting Laser (VECSEL)

Joachim Wagner*, M. Rattunde, S. Kaspar, C. Manz, A. Bächle

Fraunhofer-Institut für Angewandte Festkörperphysik IAF
Tullastrasse 72, D-79108 Freiburg, Germany

*joachim.wagner@iaf.fraunhofer.de

© Fraunhofer IAF

Fraunhofer IAF

Applications of 2.X µm VECSEL

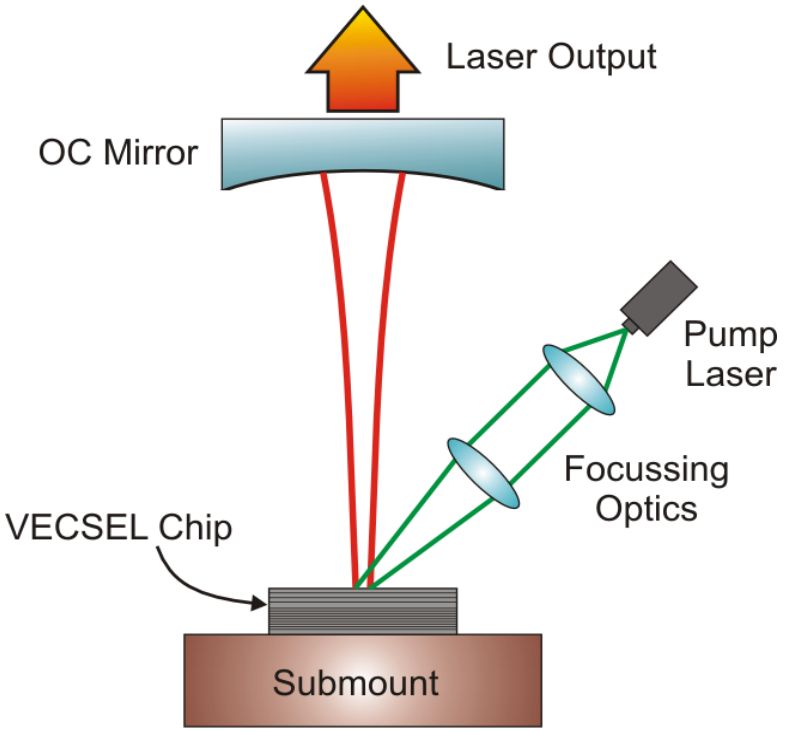
- Medical therapy and diagnostics
- Materials processing
  (e.g. welding of transparent plastics)
- Remote sensing
  (e.g. wake-vortex detection)
- Directed infrared countermeasures
  (DIRCM)

- Optical pumping of solid-state lasers
  (e.g. ZnSe:Cr^{2+}) and OPOs
- Seeding of solid-state lasers and OPAs





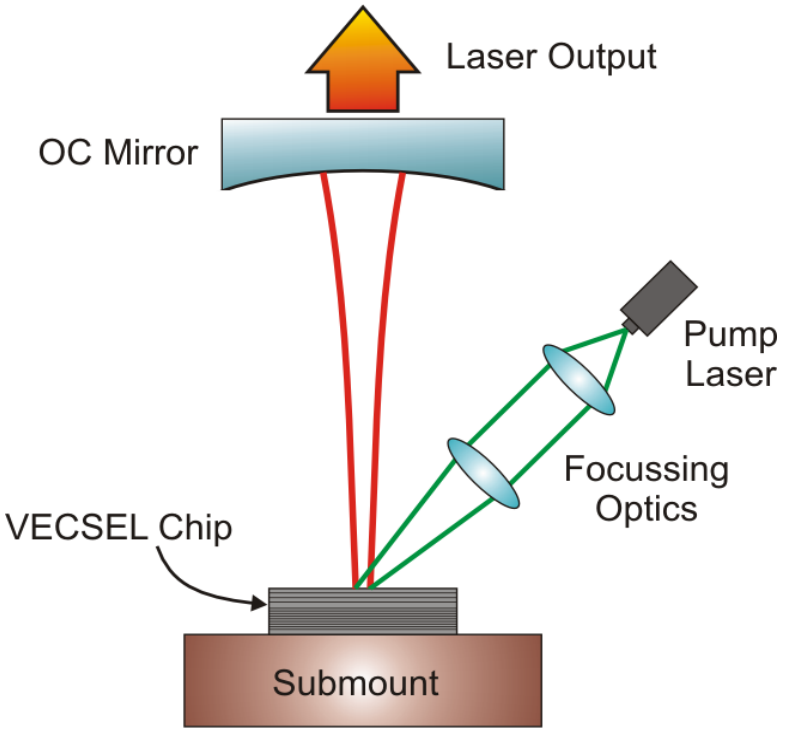
Semiconductor disk laser: Basic setup



- **VECSEL** = Vertical External Cavity Surface Emitting Laser
- (OP)SDL = Optically Pumped Semiconductor Disk Laser

Fraunhofer IAF

Semiconductor disk laser: Basic setup



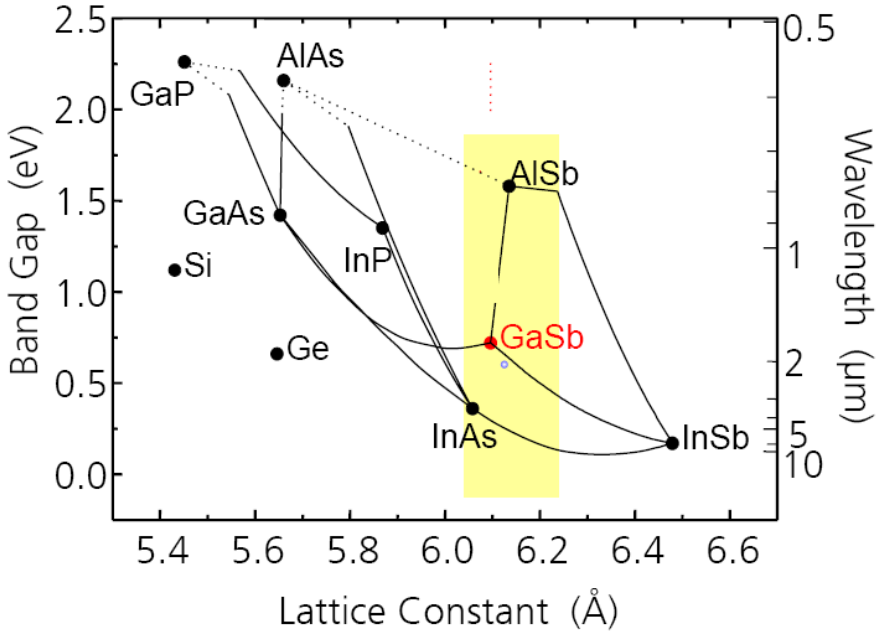
- **VECSEL** = Vertical External Cavity Surface Emitting Laser
- (OP)SDL = Optically Pumped Semiconductor Disk Laser

Advantages:

- circularly symmetric TEM_{00} output possible
  → high high brightness source
- Semiconductor QW active region
  → wide wavelength coverage
  → efficient pump absorption
  (no pump recycling optics)
  → compact laser modules
- Intra-cavity optical elements yield
  → short pulse
  → narrow linewidth

Fraunhofer IAF

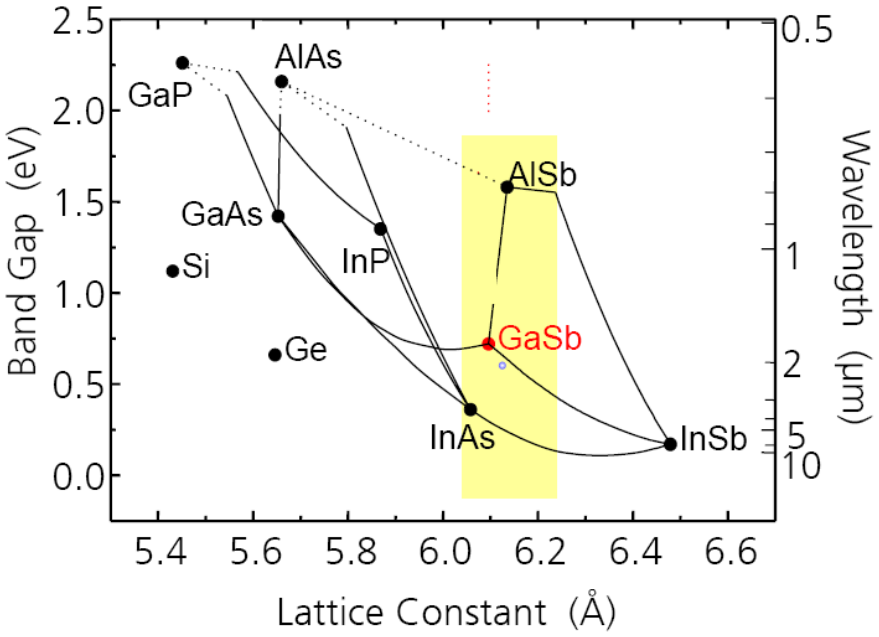
GaSb-based semiconductor disk lasers

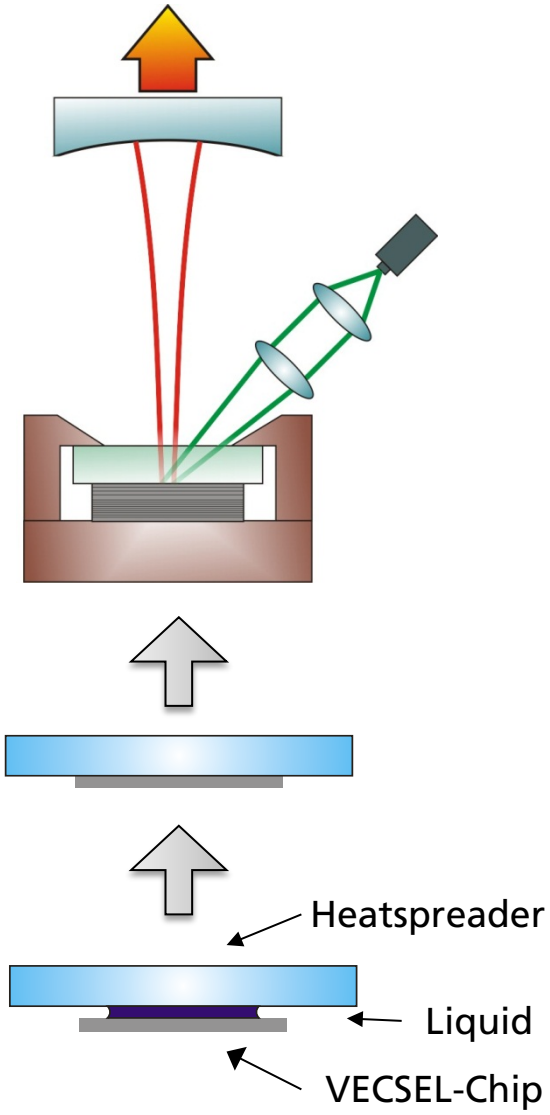


- (AlGaIn)(AsSb)-based VECSEL, grown by MBE
- 2 – 3 µm wavelength range

Fraunhofer IAF

GaSb-based semiconductor disk lasers

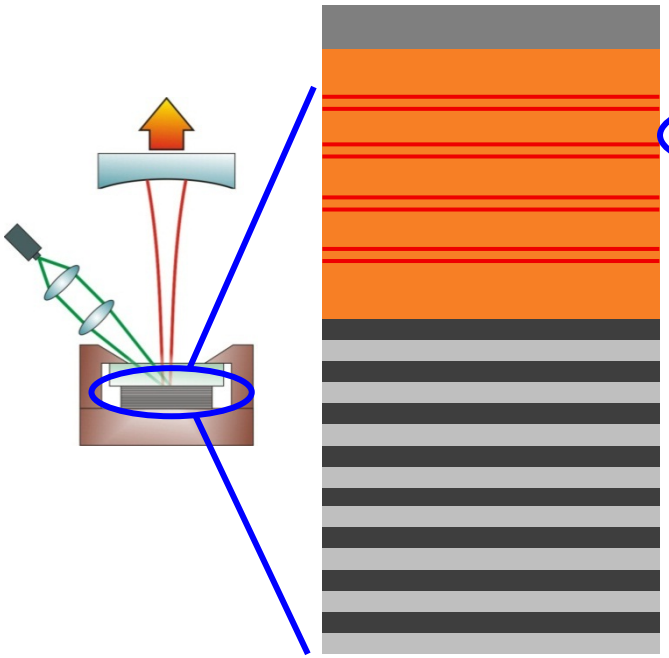




- (AlGaIn)(AsSb)-based VECSEL, grown by MBE
- 2 – 3 µm wavelength range
- Intra-cavity heatspreader (SiC or diamond) for efficient heat extraction

Fraunhofer IAF

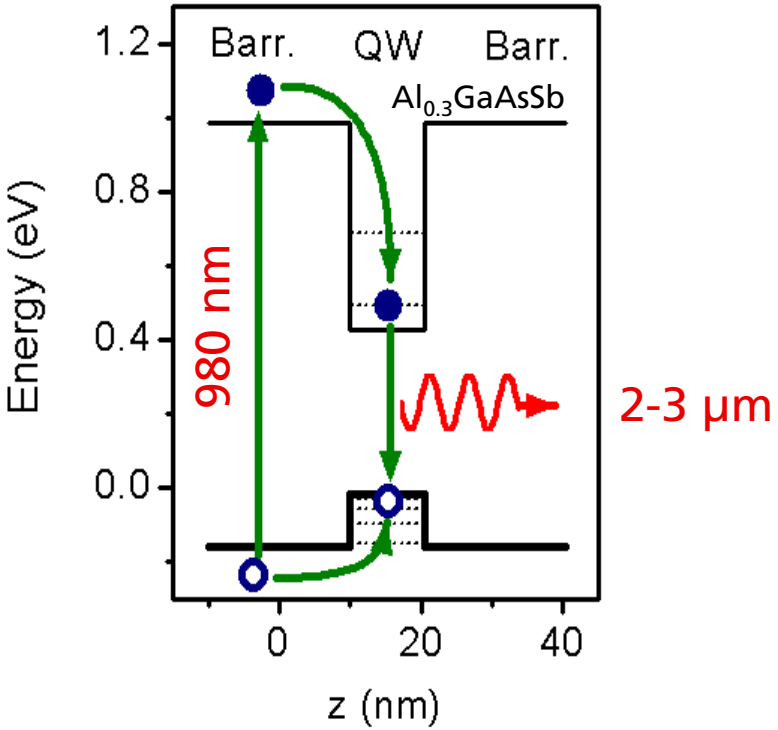
GaSb-based semiconductor disk lasers



Window layer

Active region
→ Barrier and spacer layer
→ QWs

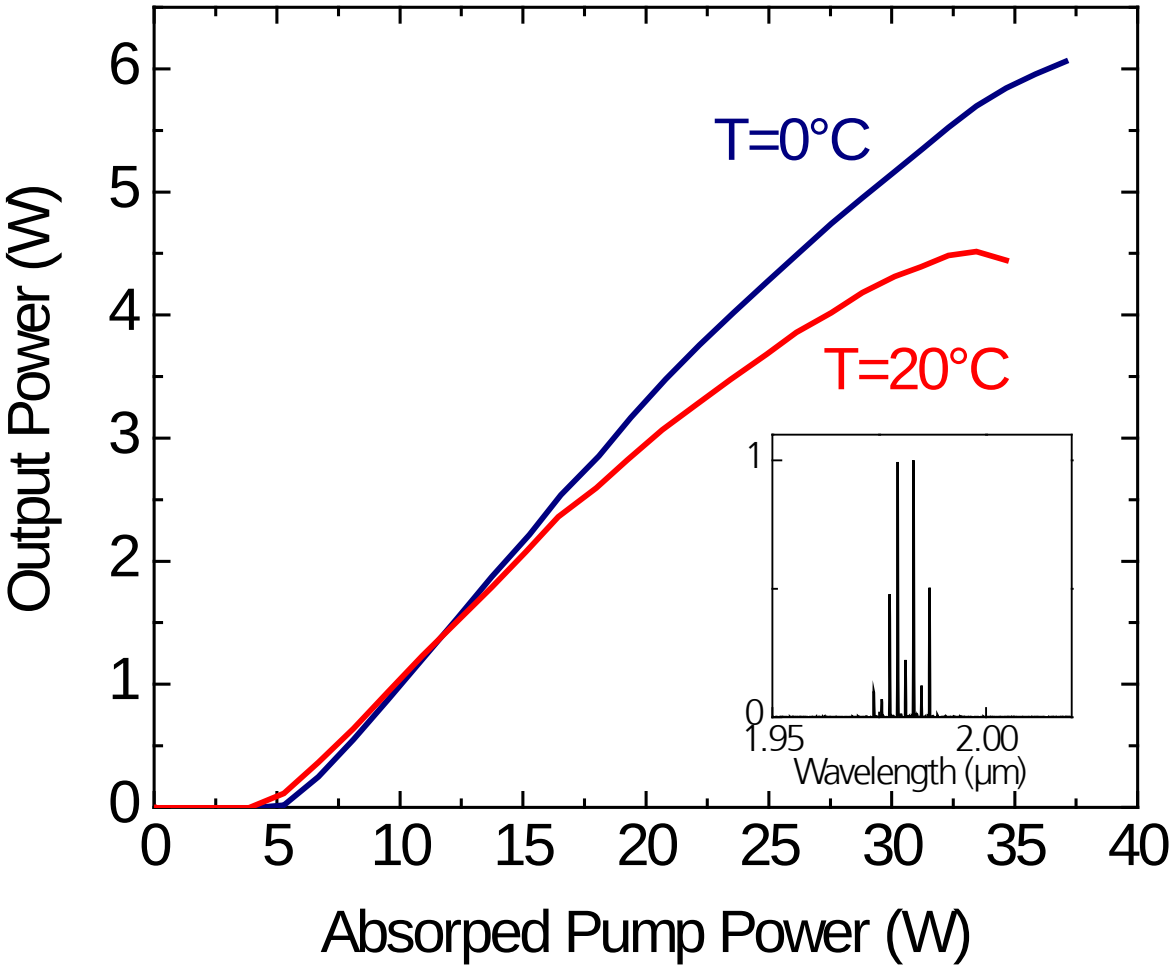
DBR-mirror
→ 21 pairs GaSb/AlAsSb



- $Al_{0.3}GaAsSb$ barriers optimized for 980 nm pumping
- > 90% pump absorption
- large quantum deficit > 50 %
- internal heating limits performance

Fraunhofer IAF

2.0 µm VECSEL – CW lasing characteristics



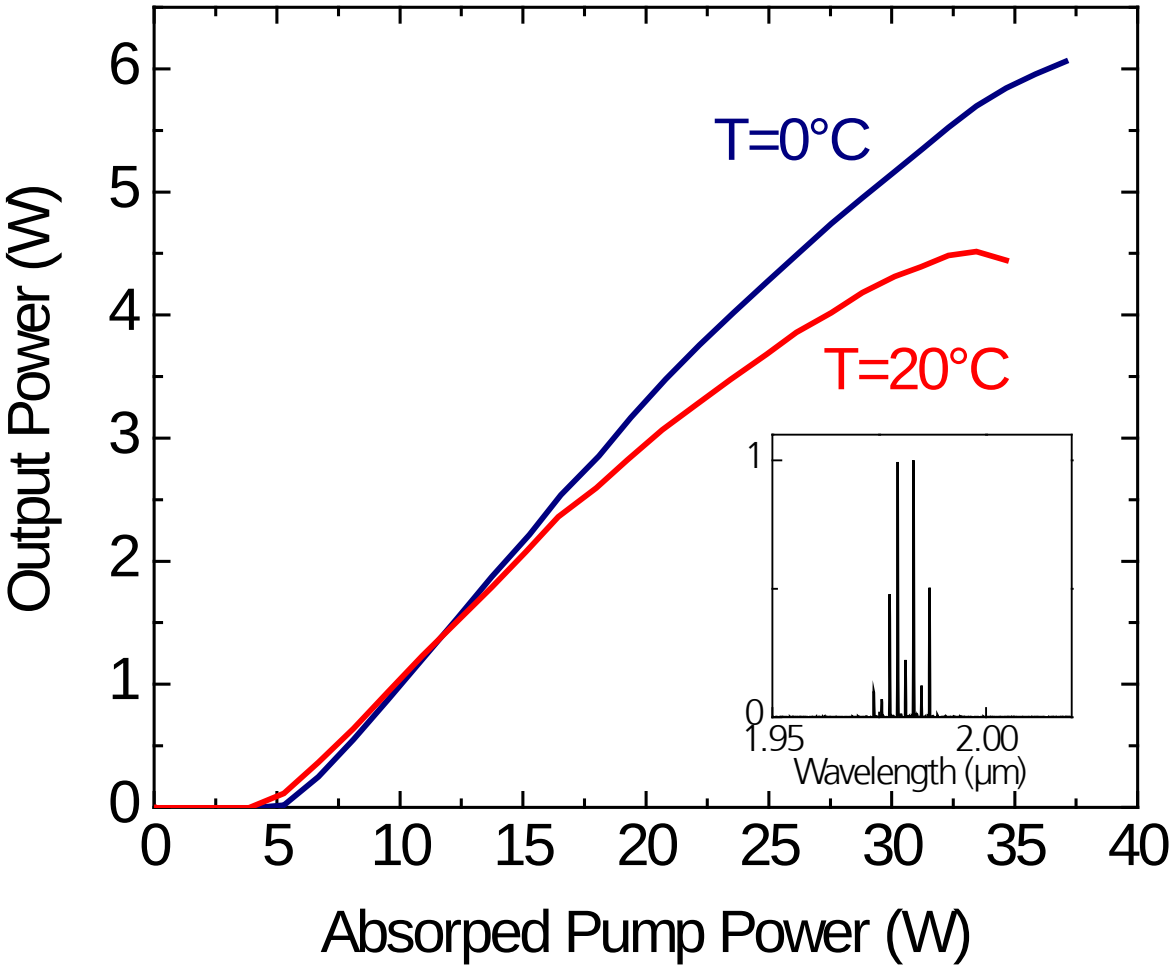
- **2.0 µm SDL**
- ternary GaInSb QWs
- SiC heatspreader
- diode pumped @ 980 nm

- **4.5 W, CW, 20 °C**
- η_{diff} = 20 %, 20 °C

- **6 W, CW, 0 °C**

Fraunhofer IAF

2.0 µm VECSEL – CW lasing characteristics



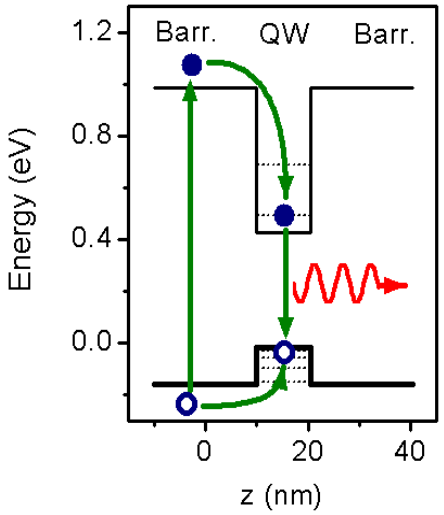
- **2.0 µm SDL**
- ternary GaInSb QWs
- SiC heatspreader
- diode pumped @ 980 nm

- **4.5 W, CW, 20 °C**
- η_{diff} = 20 %, 20 °C

- **6 W, CW, 0 °C**
- **output power limited by heat extraction from active region**

Fraunhofer IAF

Active region design: reducing the quantum deficit

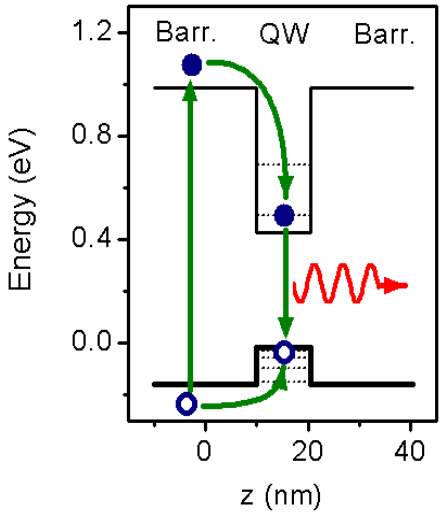


Barrier pumping
@ 980 nm

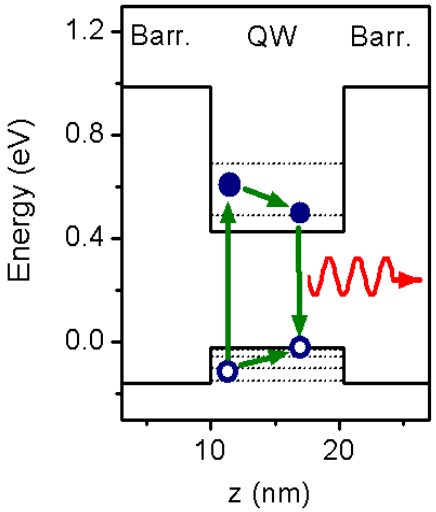
- Quantum-deficit **:** > 50 %
- Pump absorption efficiency > 90 %

Fraunhofer IAF

Active region: reducing the quantum deficit



Barrier pumping
@ 980 nm

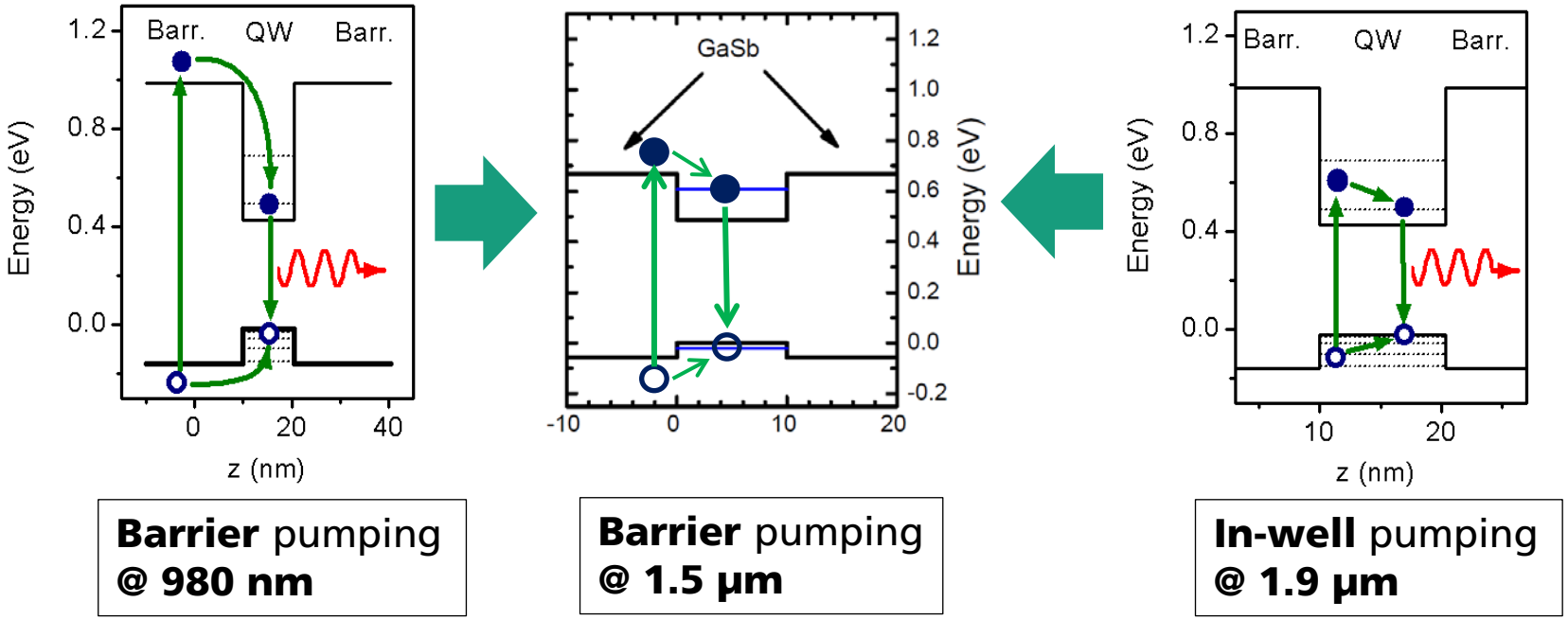


In-well pumping
@ 1.9 µm

Quantum-deficit :	> 50 %	~20 %
Pump absorption efficiency	> 90 %	30 %

Fraunhofer IAF

Active region: reducing the quantum deficit



Barrier pumping **@ 980 nm**

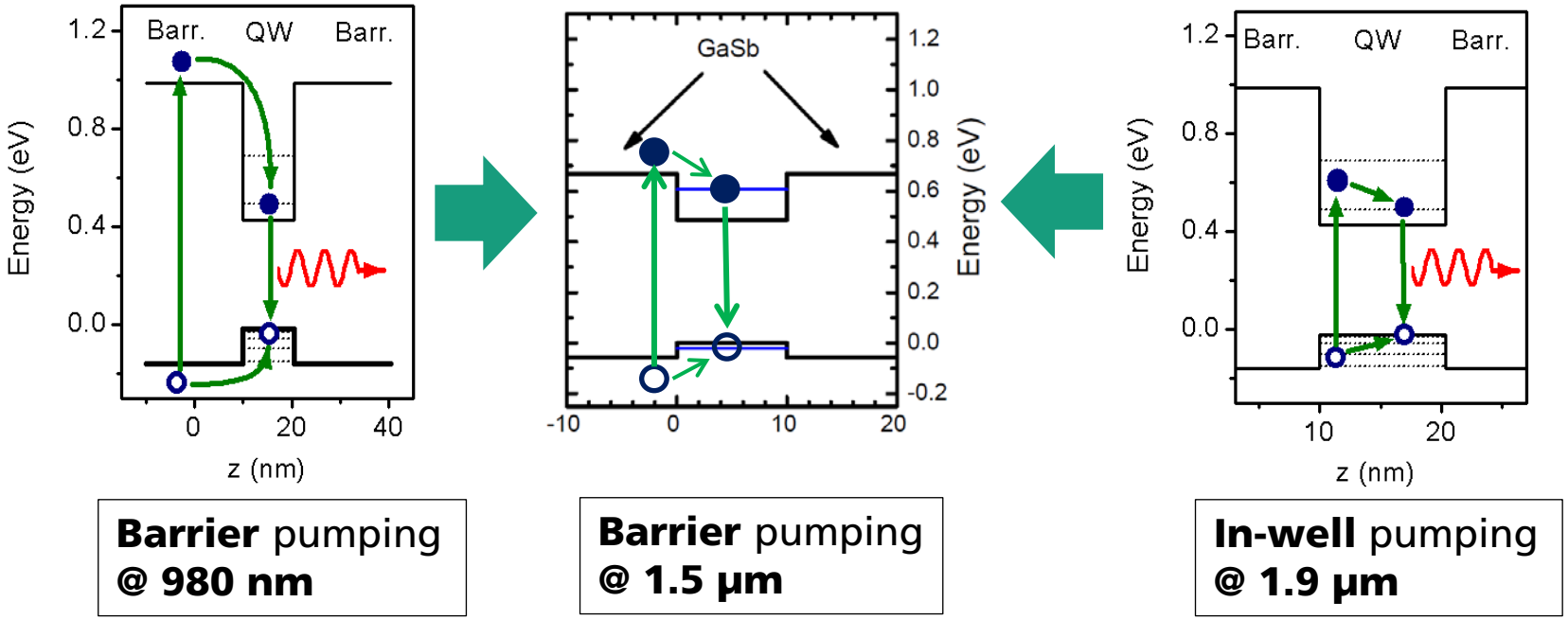
Barrier pumping **@ 1.5 µm**

In-well pumping **@ 1.9 µm**

- Quantum-deficit **:** > 50 % ~30 % ~20 %
- Pump absorption efficiency > 90 % > 90 % 30 %

Fraunhofer IAF

Active region: reducing the quantum deficit

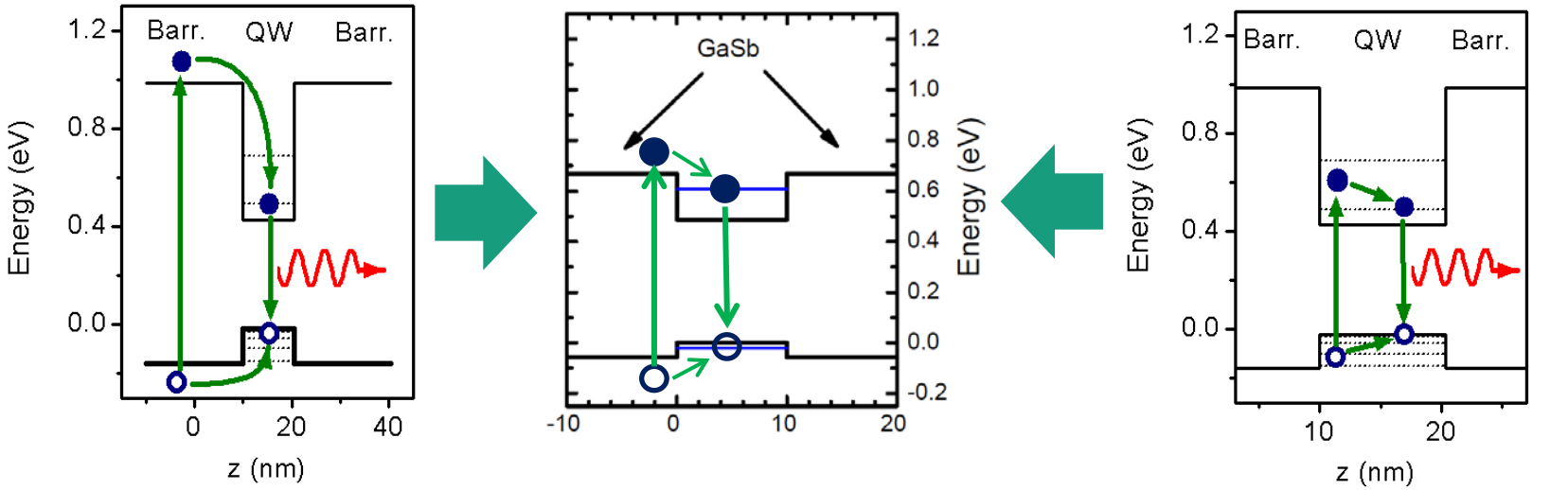


Barrier pumping **@ 980 nm**	**Barrier** pumping **@ 1.5 µm**	**In-well** pumping **@ 1.9 µm**

Quantum-deficit:	> 50 %	~30 %	~20 %
Pump absorption efficiency:	> 90 %	> 90 %	30 %
Pump laser diode: diff. efficiency η_d	80 %	45 %	20 %

Fraunhofer IAF

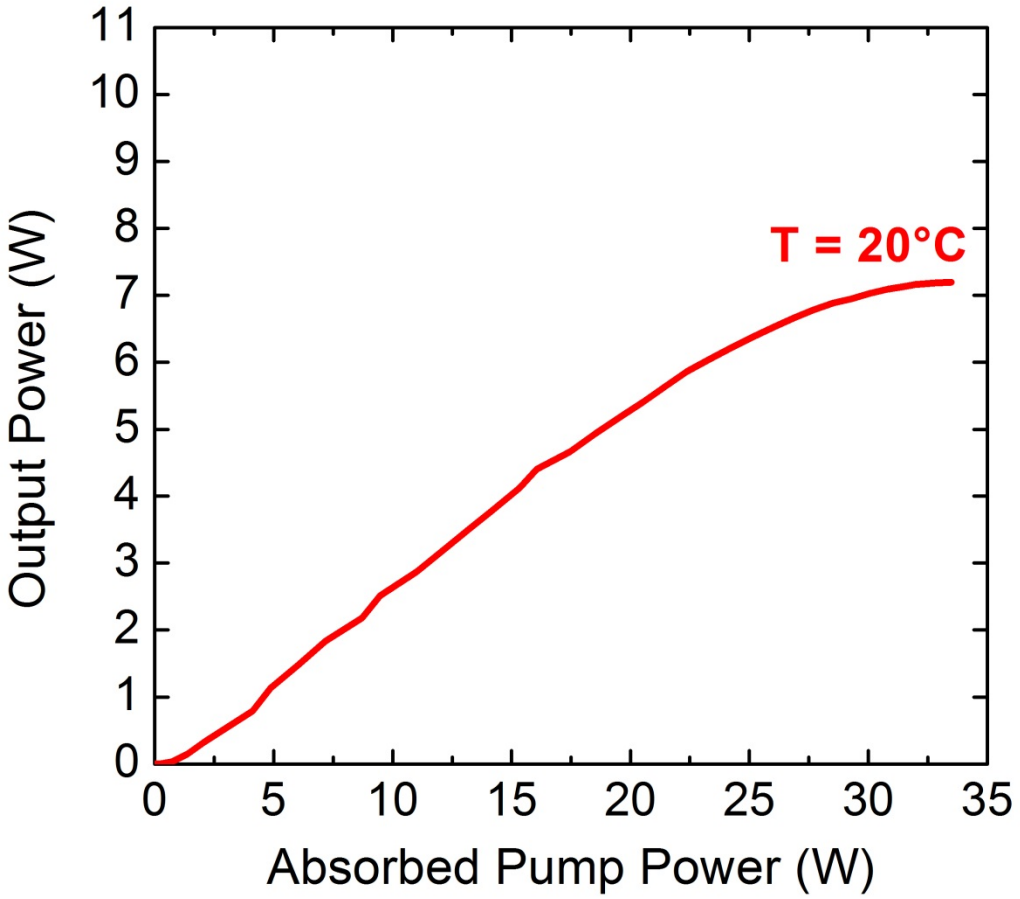
Active region: reducing the quantum deficit



Barrier pumping **@ 980 nm**	**Barrier** pumping **@ 1.5 µm**	**In-well** pumping **@ 1.9 µm**
Quantum-deficit: > 50 %	~30 %	~20 %
Pump absorption efficiency: > 90 %	> 90 %	30 %
Pump laser diode: diff. efficiency η_d 80 %	45 %	20 %

Fraunhofer IAF

2.0-µm VECSEL pumped @ 1.5 µm – CW lasing characteristics

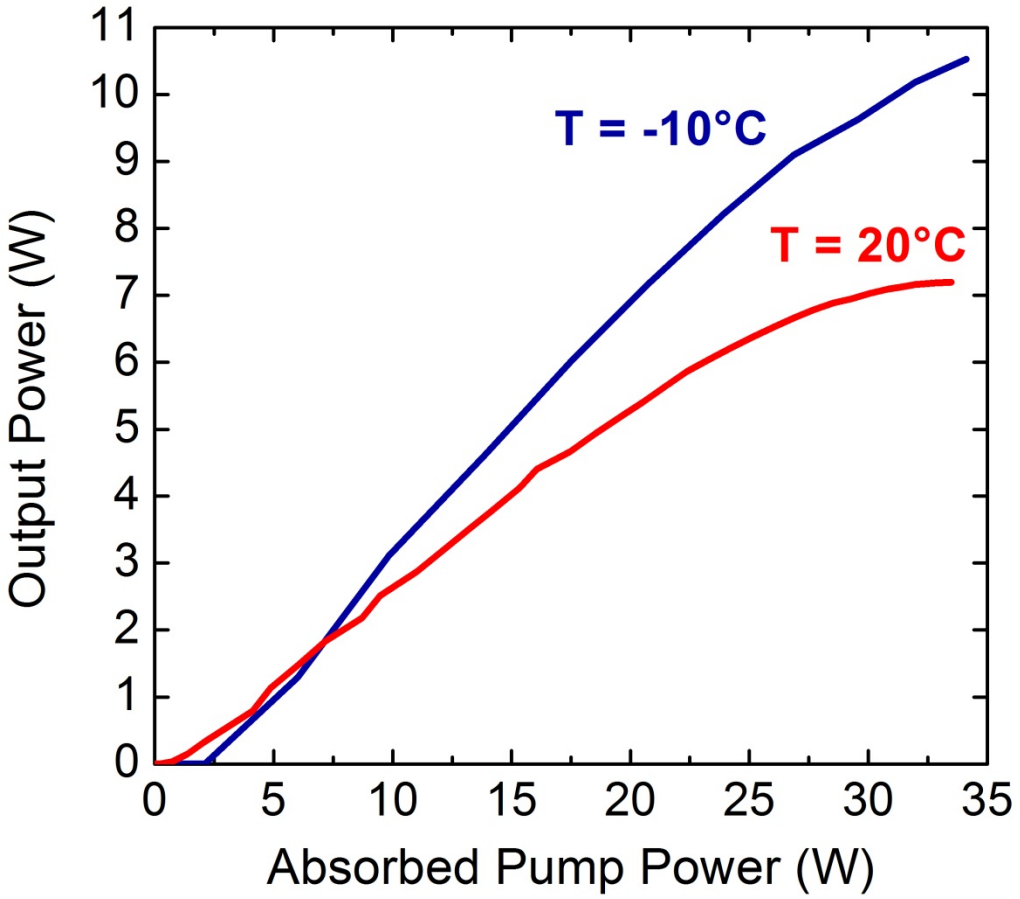


- **New VECSEL structures**
  - → GaSb barriers
  - → diode pumped @ 1.5µm
- Ternary GaInSb QWs
- SiC heatspreader

- **7.2 W,** CW, **20 °C**
- η_{diff} = 29 %, 20 °C
- η_{quant} = 39 %, 20 °C

Fraunhofer IAF

2.0-µm VECSEL pumped @ 1.5 µm – CW lasing characteristics



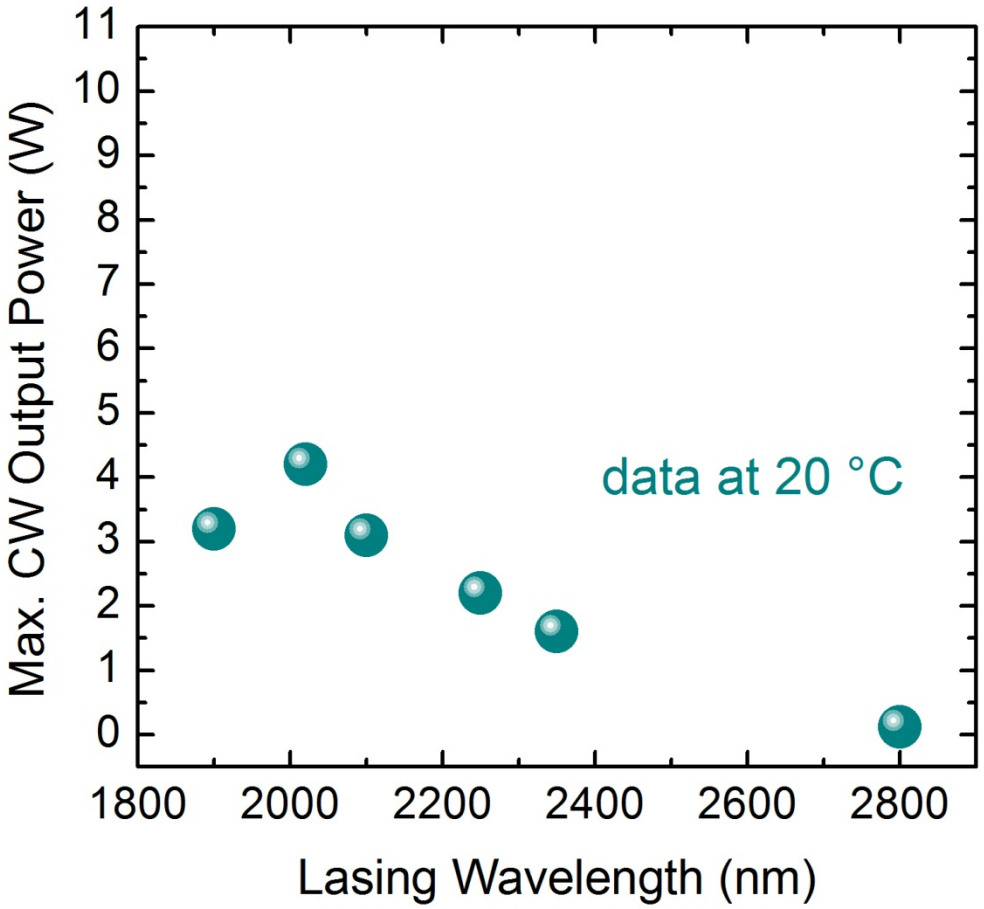
- **New VECSEL structures**
  - → GaSb barriers
  - → diode pumped @ 1.5µm
- Ternary GaInSb QWs
- SiC heatspreader

- **7.2 W,** CW, **20 °C**
- η_{diff} = 29 %, 20 °C
- η_{quant} = 39 %, 20 °C

- **10.5 W,** CW, **-10 °C**
  TE-cooled

Fraunhofer IAF

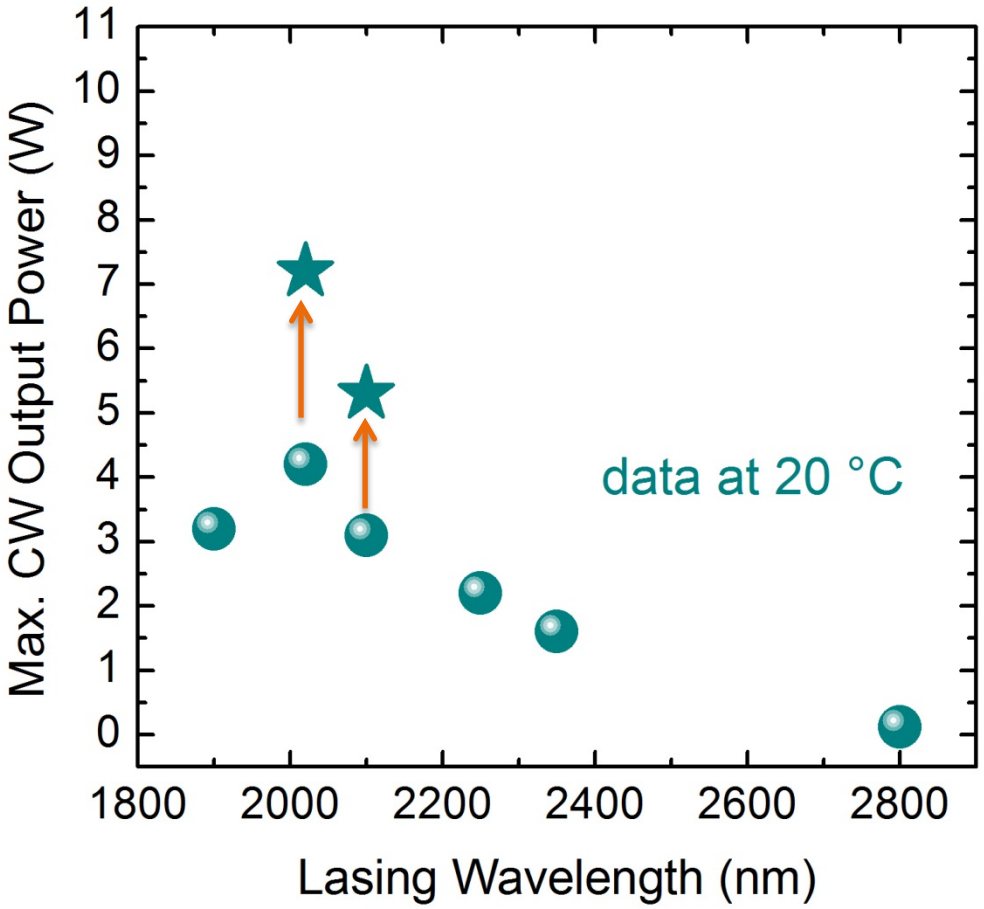
2.X µm VECSEL - wavelength coverage so far



- GaSb-based VECSEL
- SiC intracavity heatspeader
- CW operation
- emission wavelength: 1.9 - 2.8 µm
- 980 nm barrier pumping

Fraunhofer IAF

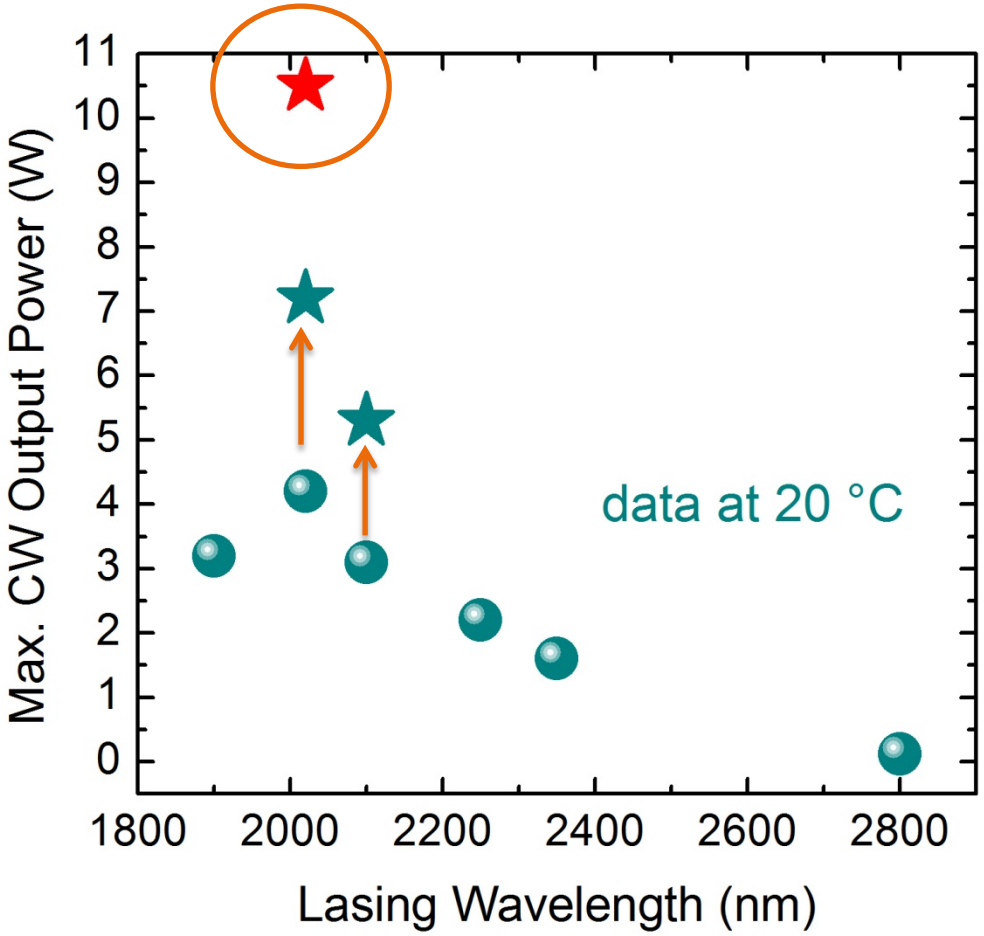
VECSEL structures with reduced quantum deficit



- GaSb-based VECSEL
- SiC intracavity heatspeader
- CW operation
- emission wavelength: 1.9 - 2.8 µm
- **1.5 µm barrier pumping**
- **2.0 µm**
  P_{max}: 4.2 → **7.2 W**
  η_d: 20 → **28%**
- **2.1µm**
  P_{max}: 3.0 → **5.3 W**
  η_d: 20 → **30 %**

Fraunhofer IAF

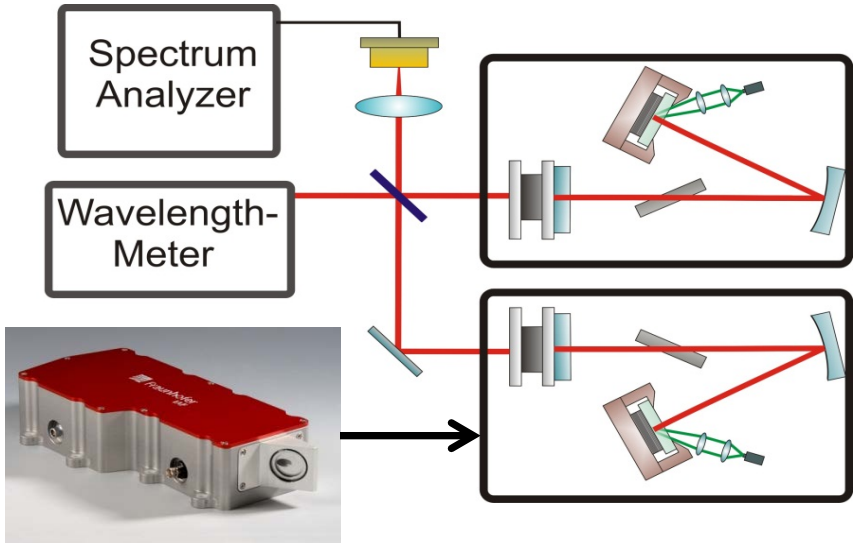
VECSEL structure with reduced quantum deficit

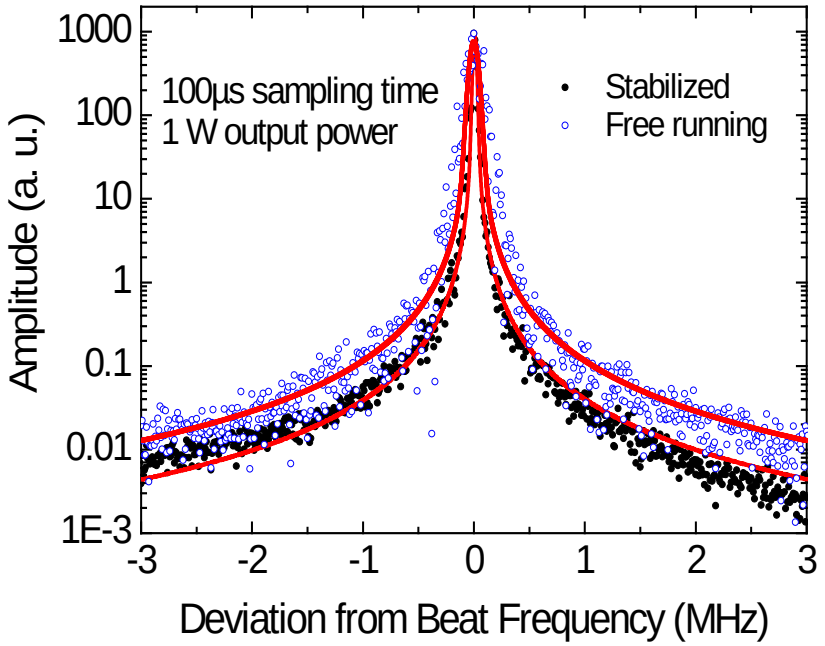


- GaSb-based VECSEL
- SiC intracavity heatspeader
- CW operation
- emission wavelength: 1.9 - 2.8 µm
- 1.5 µm barrier pumping
- **Lowering operating temperature to -10 °C (TE-cooled)**
- **2.0 µm**
  P_{max}: 7.2 → **10.5 W**

Fraunhofer IAF

Exploiting cavity versatility: 2.05 µm single-frequency VECSEL with V-shaped cavity

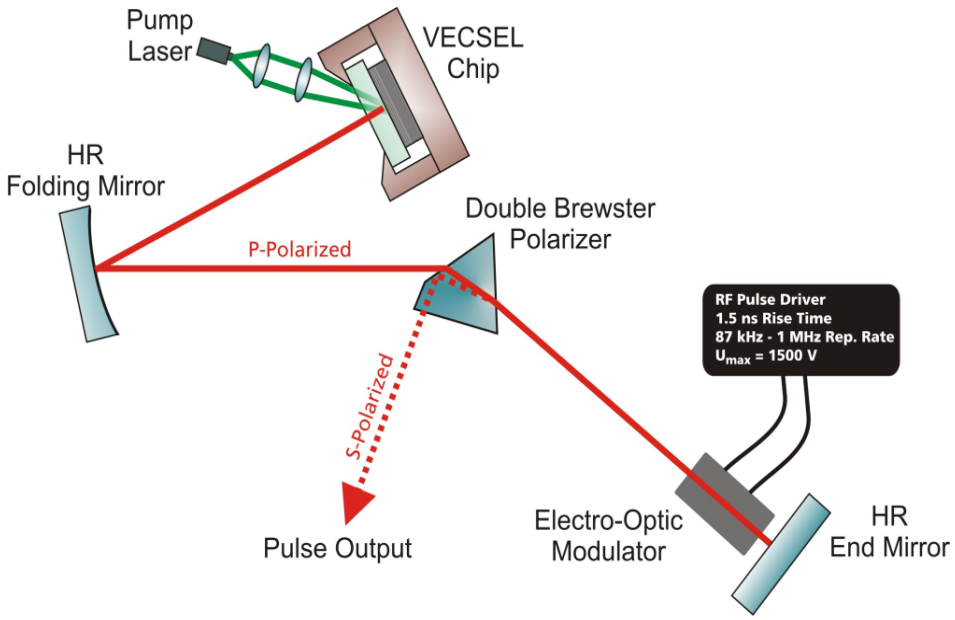


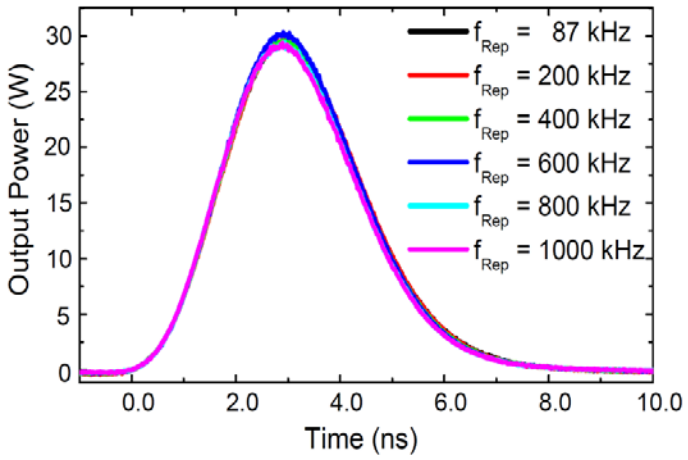


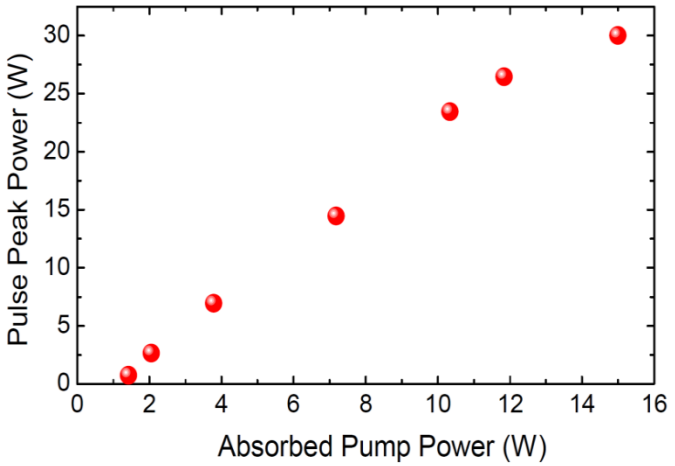
- Heterodyne beat-note measurements using two identical VECSEL modules
- 1 W output power at 20 kHz (60 kHz) actively stabilized (free running) @ 100 µs sampling time
- Max. single-mode output power 2.2 W (3.2 W) @ 20 °C (3 °C) heatsink temp.

Fraunhofer IAF

Exploiting cavity versatility: cavity dumped 2 µm VECSEL



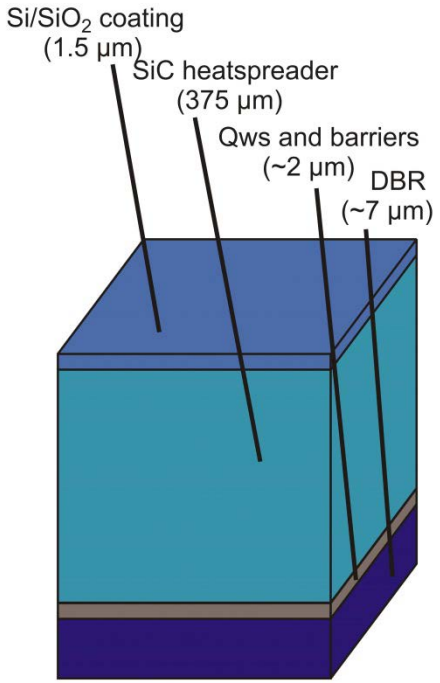




- Electro-optically cavity dumped 2 µm VECSEL with 35 cm long cavity
- 3 ns pulses with 30 W peak power @ 20 °C (100 nJ pulse energy) for repetition frequencies up to 1 MHz

Fraunhofer IAF

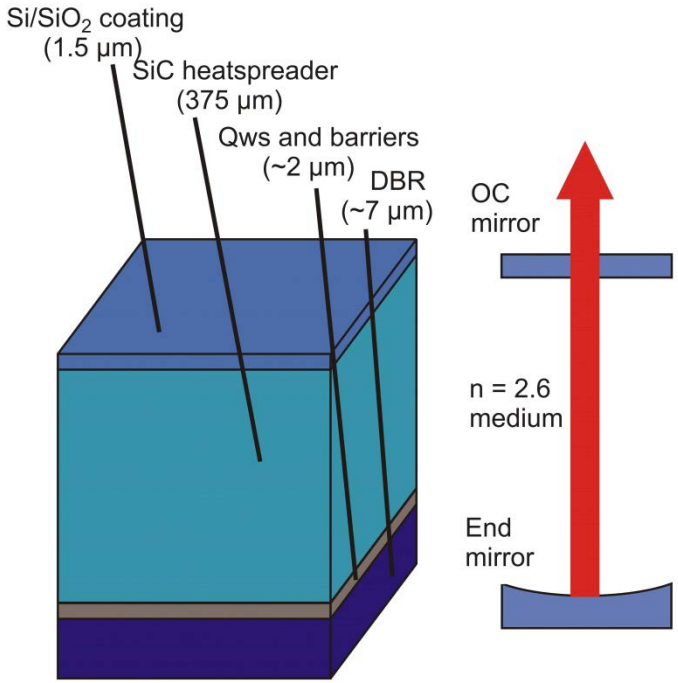
Miniaturizing VECSEL technology: µ-cavity VECSEL



- Top mirror coated onto SiC heatspreader

Fraunhofer IAF

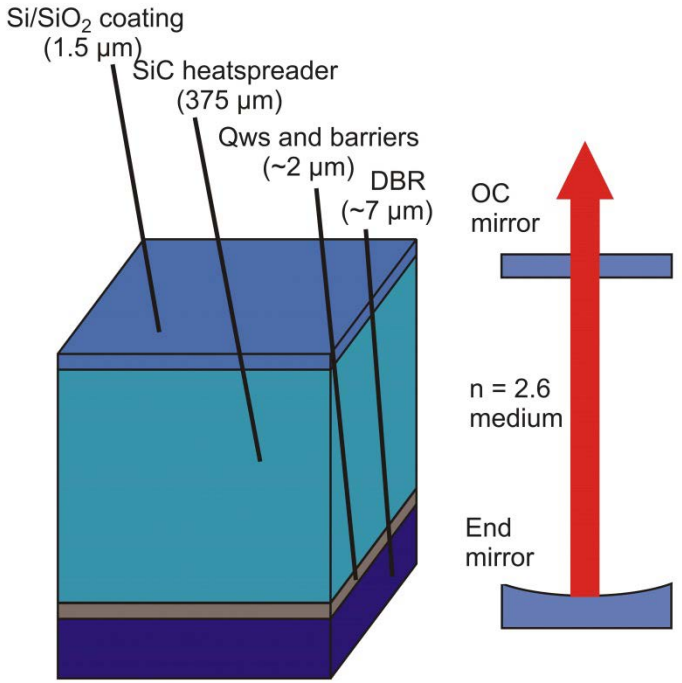
Miniaturizing VECSEL technology: µ-cavity VECSEL

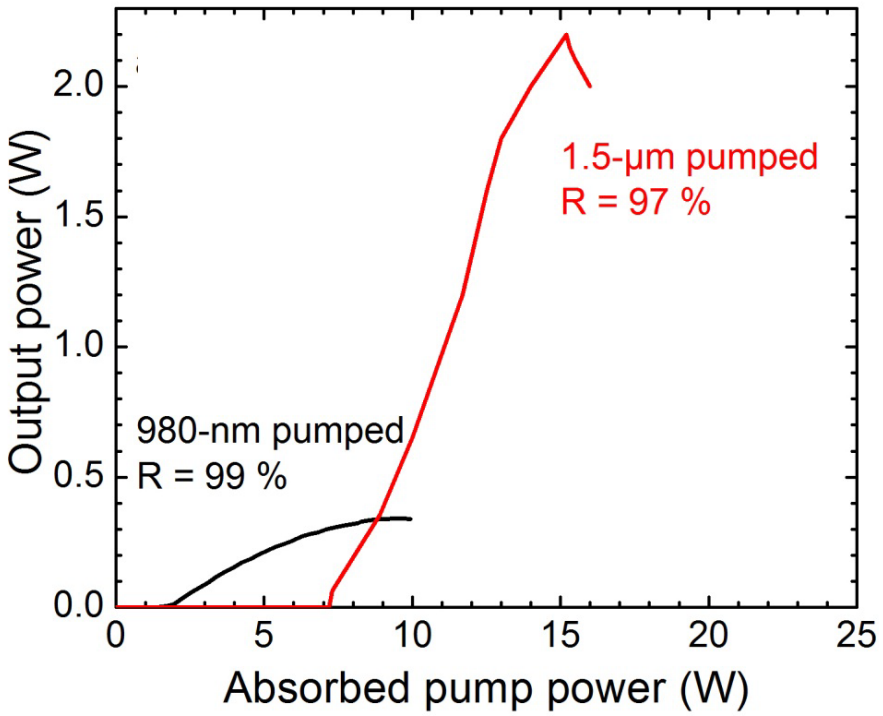


- Top mirror coated onto SiC heatspreader
- Stable cavity due to gradient index lens (thermal effects)

Fraunhofer IAF

Miniaturizing VECSEL technology: µ-cavity VECSEL





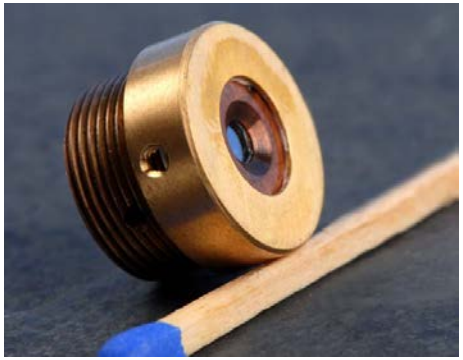
- Top mirror coated onto SiC heatspreader
- Stable cavity due to gradient index lens (thermal effects)
- P_{max} for 1.5 µm pumping (@ 20 °C): 2.2 W (multi-mode)
  750 mW (TEM_{00})
- Tunable with temperature (coarse & mode-hop free fine tuning)

Fraunhofer IAF

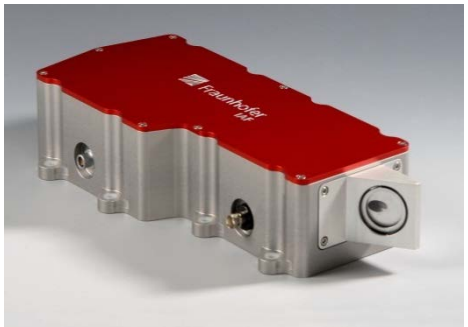
Summary and Outlook

- (AlGaIn)(AsSb)-based VECSEL covering the 1.9 – 2.8 µm wavelength span demonstrated
- Multi-mode operation with 7.2 W (10.5 W) max. output power @ 20 °C (-10 °C) demonstrated
- Single-mode operation (<100 kHz linewidth) up to 2.2 W (3.2 W) output power @ 20 °C (3 °C)
- Cavity-dumped VECSEL with 3 ns 30 W pulsed output up to 1 MHz rep. rate demonstrated
- µ-cavity VECSEL with 2.2 W max. output power realized

- Next to come: 2.X µm VECSEL as pump source for Ho:YAG laser and ZGP OPO







Fraunhofer
IAF