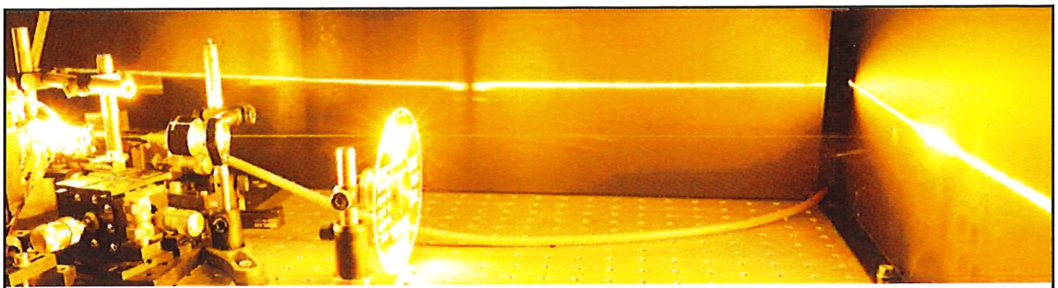

Progress in VECSEL technology for laser guide stars

Jussi-Pekka Penttinen[1,2], Emmi Kantola[1,2], Sanna Ranta[1,2], Mika Mäki[1,2], and Mircea Guina[1,2]

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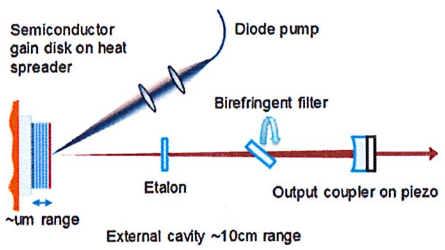
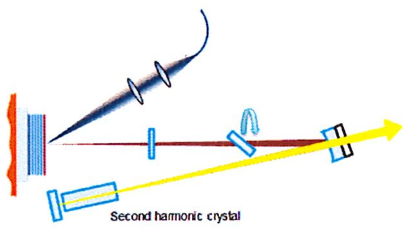
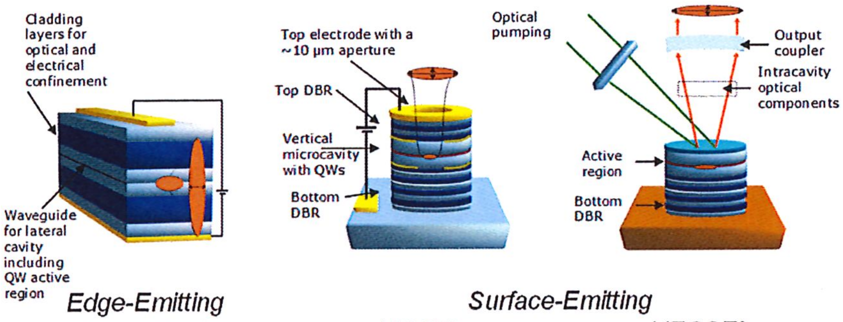
VECSEL

- Vertical External-Cavity Surface-Emitting Laser
  - *Kuznetsov, M., et al. IEEE Photonics Technology Letters 9.8 (1997): 1063-1065.*
  - M. Guina et al, "Optically pumped VECSELs: review of technology and progress" J. Phys. D: Appl. Phys., 2017, 50, p. 3830001
- Also known as SDL (Semiconductor Disk Laser) or OPSL (Optically Pumped Semiconductor Laser)
- Main features
  - High brightness
  - High power
  - Wavelength versatility
  - Compact
  - Robust
  - Efficient frequency conversion





Comparison with other semiconductor lasers



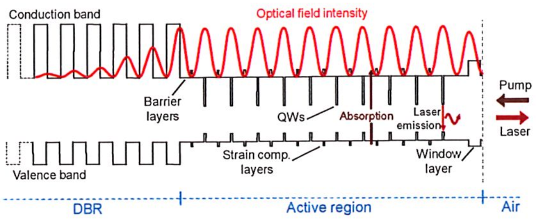
Edge-Emitting
Laser Diode

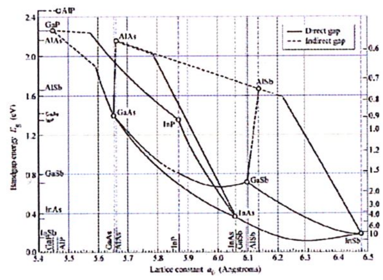
Surface-Emitting
VCSEL
VECSEL

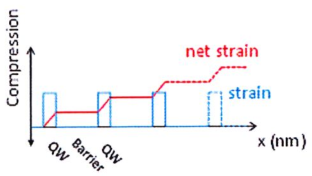
Edge-Emitting Laser Diode	VCSEL	VECSEL
Power level: <10 W per emitter	**Power level**: 1 - 10 mW	**Power level**: up to 100 W
Beam quality: poor	**Beam quality**: excellent	**Beam quality**: good-excellent
Wavelength range: broad	**Wavelength range**: narrow (DBR limited)	**Wavelength range**: very broad (efficient SHG)
Size: mm range	**Size**: mm range	**Size**: tens of cm

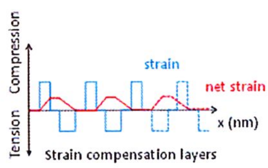
Semiconductor materials engineering

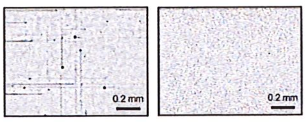
- Wavelength is defined by the band gap of the quantum wells
  - Pump absorption in barriers
  - High reflection DBR











Semiconductor materials engineering

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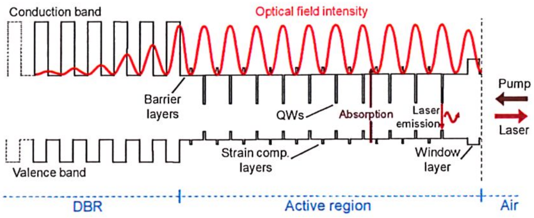
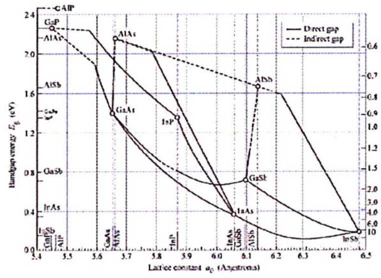
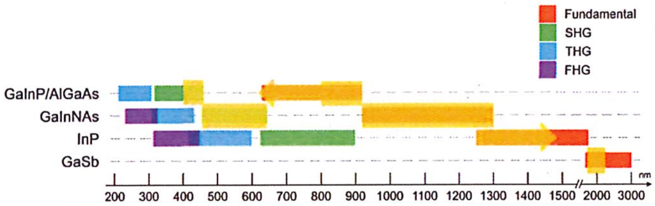
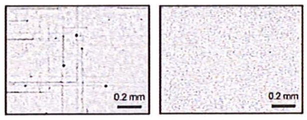
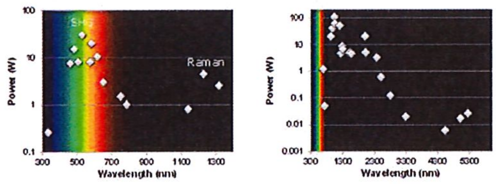








Power scaling



General trend of output powers vs. wavelength covered by major types of VECSEL technologies

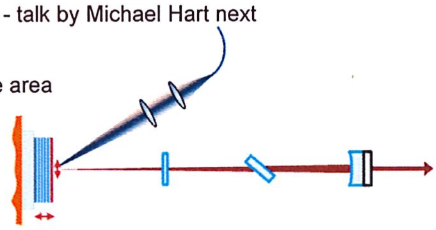
- By increasing the volume of the amplifying medium

Longitudinal power scaling

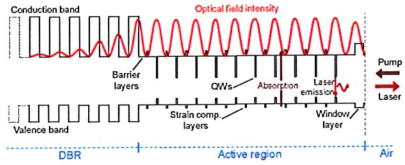
- Increasing the thickness of the lasing material by
  - adding more quantum wells in one gain mirror – limit from pump absorption and strain
  - adding more gain mirrors into the cavity - talk by Michael Hart next

Lateral power scaling by increasing the surface area

- increasing the pump spot and the mode size on the gain mirror
- thermal management important

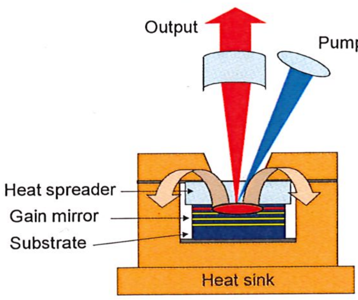


Thermal management

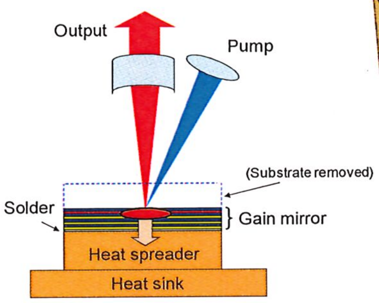


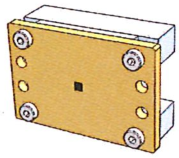
- Removal of the excess heat from optical pumping
- Two main approaches

Intra-cavity cooling



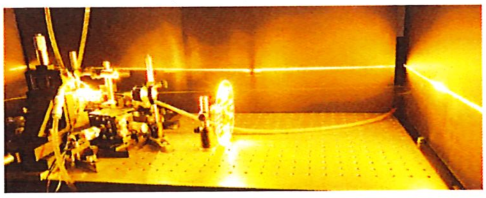
Flip-chip cooling

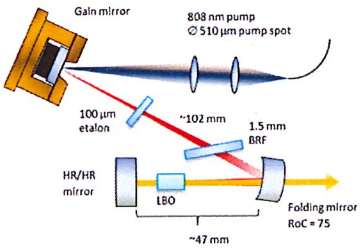


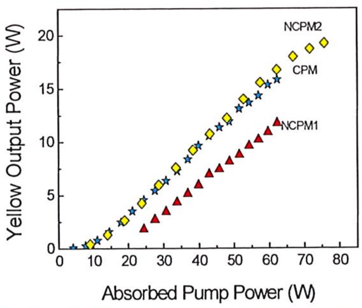


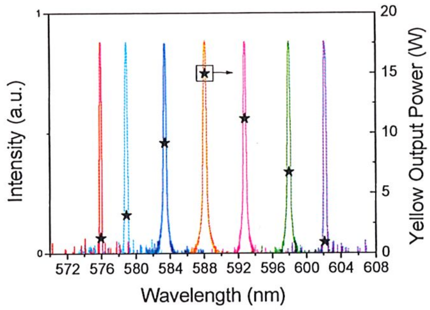
20 W @ 589 nm (from ~20 W @ 1178 nm)

E. Kantola et al. *Optics Express* 22.6 (2014): 6372-6380.



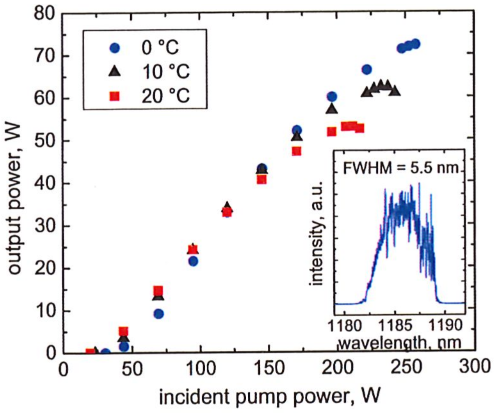


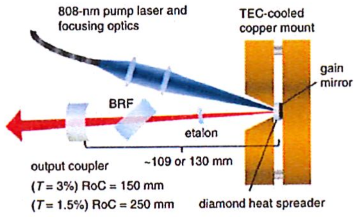


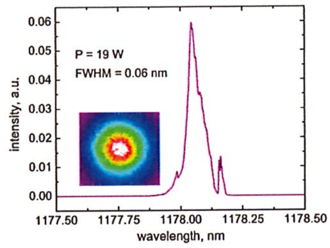


72 W @ 1178 nm

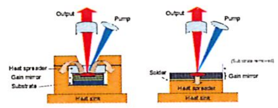
E. Kantola et al. Electronics Letters 54.19 (2018): 1135-1137.





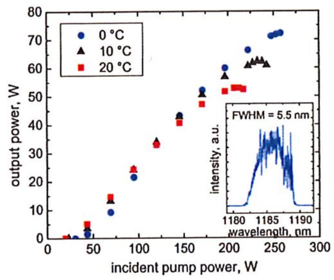


High-efficiency 1178 nm flip-chip



Intra-cavity cooling

Flip-chip cooling

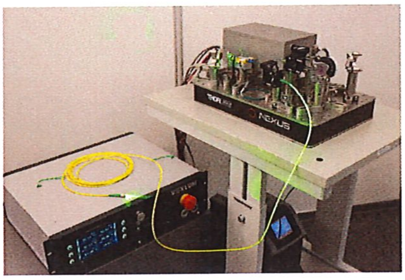


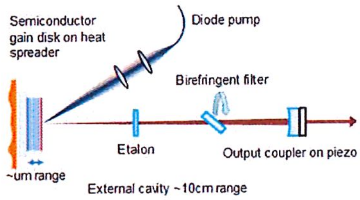
Temperature set point	°C	20
Max output power	W	53
Incident pump power	W	211
Optical-to-optical efficiency	%	25
Slope efficiency	%	33

			% of top emitter
Temperature setpoint	°C	20	
Max output power	W	49.5	93.3
Incident pump power	W	130.1	61.6
Opt-to-opt efficiency	%	38.0	**152**
Slope efficiency	%	45.7	**138**

Progress in systems development

- **VALO SF** – robust multiwatt single-frequency infrared VECSEL
  - 100 kHz linewidth, excellent beam, up 10 THz tuning range
  - Turn-key setup with control electronics, tunable with cavity piezo





- In the next few months: first multiwatt visible single-frequency VECSEL – **VALO SHG**
- Continue with **power scaling of VALO SHG** with target >10 W 589

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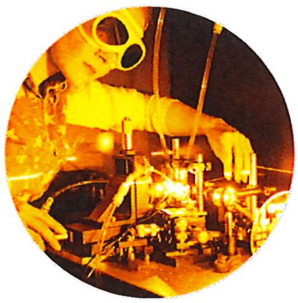
Summary

- VECSELs are the most versatile laser systems
- Progress in 1178 nm gain mirror technology thanks to

  50% Improvements in the semiconductor structure

  50% Improvements in thermal management

- VEXLUM is a VECSEL company
  - Lasers and gain mirrors with wavelengths on demand
  - Specialized in high-power 1178 nm
  - Focus on systems development for high power 589 nm



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Thank you!

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