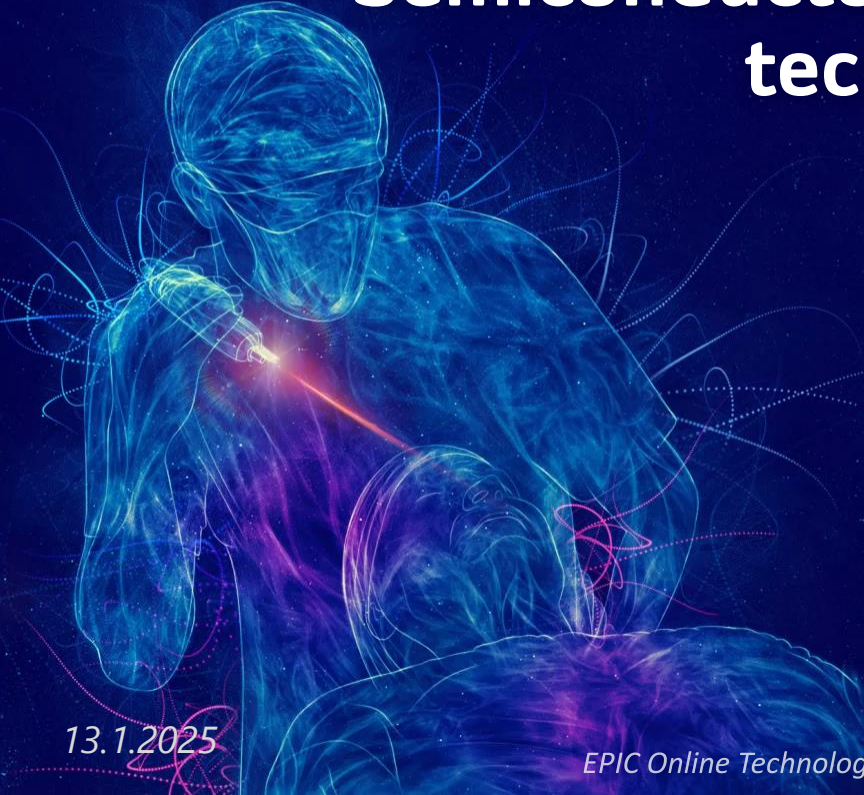


# Semiconductor lasers enabling quantum technology commercialization



13.1.2025

Luukas Kuusela  
EPIC Online Technology Meeting on Photonics for Quantum Industry

# Agenda

- Modulight company introduction
- Lasers for quantum
- Modulight laser technologies
- Summary and Q&A

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# This is Modulight

## 20+ years track record of lasers & optics

- We are a laser and laser system manufacturer
- 20+ years track record of lasers & optics (UV – 2000+ nm) for medical and high value-add applications
- We utilize various laser technologies to address customer needs: semiconductor (FP, DBR/DFB, VCSEL, VECSEL, TA), fiber laser and DPSSL
- Our own laser fab provides the full vertical path from semiconductor epitaxy to turn-key laser systems
- Exclusive supplier to 10+ pharma, other Fortune 500 companies & well-known cancer centers
- Modulight is listed in NASDAQ First North Helsinki

### Life sciences

- Oncology •
- Ophthalmology •
- Genetics & diagnostics •

### Other high value-add applications

- Quantum computing •
- Flow cytometry •
- Digital press •

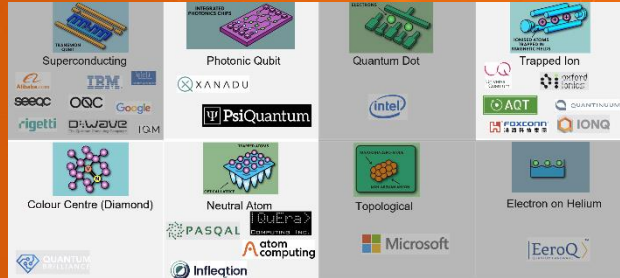
### Services

- AI & Cloud for improving treatment efficacy •
- Pay-per-treatment •
- On-site/online training and annual maintenance •
- Lifecycle support with recurring service plans •
- Regulatory design & approvals •
- Regulatory and feature software updates •

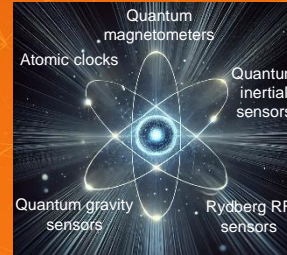
# Lasers for Quantum

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## Quantum computing

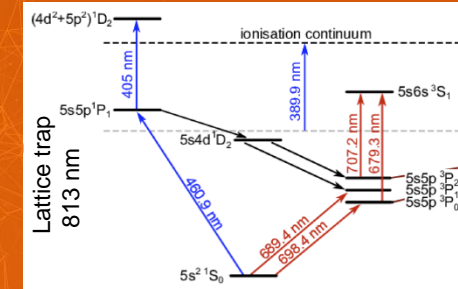


## Quantum sensing



And much more:

- Quantum networks
- Pumping entangled photon sources
- Pumping fiber lasers and DPSSLs



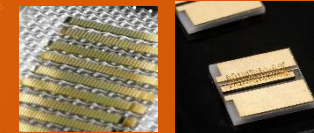
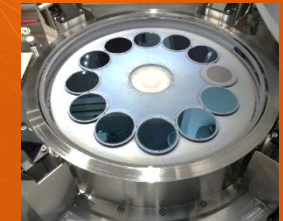
Neutral Strontium → Up to 7 lasers

## Semiconductor lasers

Laser requirements:

- Precise wavelength selection
- Low phase noise
- Long lifetime
- SWAP-C

- ❑ Scalable process
- ❑ Compact size, low power consumption
- ❑ Bandgap engineering + SHG and THG: UV-1.8 um
- ❑ DBR/DFB
- ❑ VCSELS
- ❑ Tapered amplifiers
- ❑ Gain chips
  - ❖ External cavity configurations (VECSEL, ECDL)
  - ❖ PIC integration



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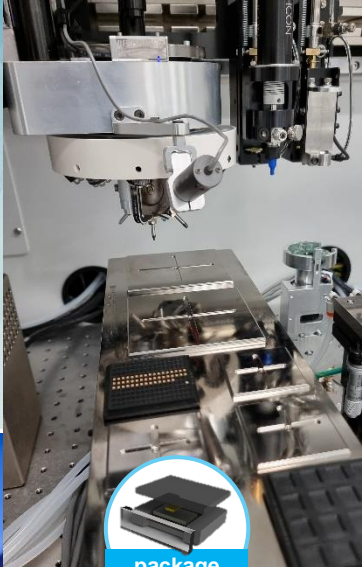
# Modulight laser manufacturing



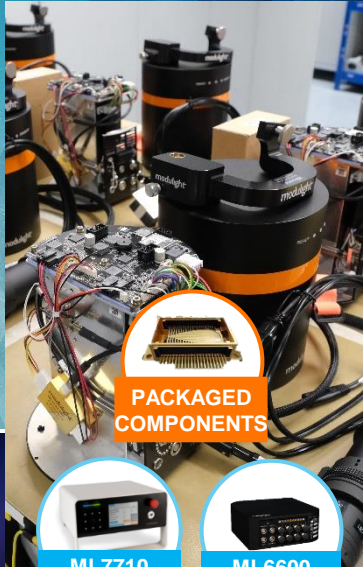
Epitaxial wafer



laser chips



package



PACKAGED COMPONENTS



ML7710



ML6600

## 20 years experience

- Structure and device design •
- Application knowledge •
- Quality & capability •

## Epitaxy growth

- GaAs/InP •
- Growth and characterization •
- Tailored structures •

## Wafer processing

- Lithography •
- Etching •
- Metallization and coating •

## Packaging and testing

- Array testing and screening •
- Burn-in and testing •
- Assembly & wire bonding •

## Vertical integration

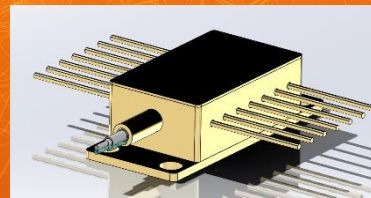
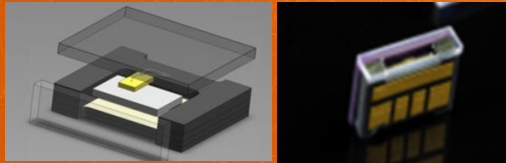
- Packaged chips and arrays •
- Electronics – optics – devices •
- CE & FDA approved •

## Modulight laser technologies - Enabled by in-house fab

- ❑ Providing more specific, compact and robust products
- ❑ Finding the optimal solution for some instead of trying to have a one-suits all solution resulting in performance compromises

<p><b>Multimode lasers</b></p> <p><b>Multimode laser diodes</b> use wide emitters to achieve high output power. Their optical beam allows for exceptional performance in optical pumping. The beam diameter can be controlled well, laser design and integration, and the power can be increased by combining multiple lasers into one package.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1111 - 800 nm 20 chip for CW operation</li> <li>ML1112 - 900 nm high-power CW laser chip</li> <li>ML1886 - 650 nm high-power laser bar</li> </ul>	<p><b>Wavelength-stabilized multimode lasers</b></p> <p><b>Wavelength-stabilized multimode laser diodes</b> use an integrated design to maintain narrow operation. This allows the laser to operate in a single longitudinal mode with minimal wavelength drift, even as temperature changes.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML5073 - 633 nm 200 mW DBR stabilized multimode laser in 4-pin BFP package</li> </ul>	<p><b>Laser arrays</b></p> <p><b>Laser bars or arrays</b> contain multiple emitters and deliver high output power with uniformity across the array. For even greater power, stacks of laser bars can be used, with the option of co-emitting different wavelengths. Arrays can also be tailored to be <b>individually addressable (IAD)</b> with custom emitter number and spacing.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML2862 - 40 emitter array at 650 nm wavelength</li> </ul>	<p><b>Tapered lasers</b></p> <p><b>Tapered amplifiers and tapered lasers</b> work as a middle ground between single mode and multimode lasers. The output power of single mode is achieved with much lower beam quality than what is possible from multimode diodes, making efficient single mode fiber coupling. Tapered amplifiers amplify the output power of a seed laser while maintaining the spectral linewidth and mode suppression ratio of the seed laser.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1367 - The new tapered amplifier chip-on-carrier</li> <li>ML1377 - The new tapered laser - chip-on-carrier laser with a monolithically integrated tapered amplifier</li> </ul>
<p><b>Single-mode lasers</b></p> <p><b>Single-mode lasers</b> offer an optimized waveguide structure to ensure single transverse mode operation. The laser can be configured to a diffraction limited beam and couple to single mode fiber with high efficiency.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML2622 1310 - 1310 nm pulsed FP laser in a 4-pin BFP package</li> <li>ML1976 - 1420 nm pulsed FP laser in a 3-pin chip</li> </ul>	<p><b>Single-frequency lasers</b></p> <p><b>DBR and DBR lasers</b> use an internal grating for single longitudinal mode operation, offering narrow linewidth and low phase noise. This integration ensures reduced optical external reflections, a 40% gain from fiber, and stability for high-power production. These lasers can be made over a broad range of wavelengths and are available in standard and custom packaging including the option for integrated optical isolators and fiber coupling.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML2060 - 780 nm DBR laser diode in 4-pin BFP package</li> <li>ML2064 - 633 nm DBR laser diode in 4-pin BFP package</li> </ul>	<p><b>Gain chips</b></p> <p><b>Gain chips</b> feature a low efficiency output. Lock the external cavity, within the semiconductor laser, allows for an optical feedback from an external cavity, allowing for wide wavelength tuning and low threshold operation. These chips can be integrated into photonic circuits with tailored wave driver and preamplifiers.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML3071 - 780 nm curved surface gain chip on carrier</li> </ul>	<p><b>VCCSLs</b></p> <p><b>Vertical cavity surface emitting lasers (VCCSLs)</b> emit light perpendicularly from the active surface. They offer a compact design with high power density, low heat dissipation, single-transverse operation, and high-frequency modulation. Output power can be increased by using large VCCSL arrays with microchannel cooling.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1600 - 940 nm VCCSL array</li> </ul>
<p><b>VCCSLs</b></p> <p><b>Vertical External Cavity Surface Emitting Lasers (VECSLs)</b> combine a vertical external gain medium with an external cavity. The combination enables high output power, broad wavelength tunability, narrow linewidth and high beam quality.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1600 utilizing 332 nm InGaAs VECSEL technology</li> </ul>	<p><b>Fiber lasers</b></p> <p><b>Fiber lasers</b> use optical fibers as the gain medium, allowing high power output with excellent beam quality and efficiency. The fiber infrastructure makes these lasers alignment insensitive and highly stable against external disturbances.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML4002 platform tailored to support fiber laser technologies: Ytterbium (1064 nm), Erbium (1550 nm) and Thulium (1940 nm) lasers.</li> </ul>	<p><b>DPSLs</b></p> <p><b>Diode Pumped Solid State Lasers (DPSLs)</b> are powered by laser diodes that pump a solid state gain medium, such as a crystal. They offer high efficiency and excellent beam quality, making them suitable for precision applications requiring stable and high-powered output.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1600 - versatile laser platform supporting all laser technologies</li> </ul>	<p><b>Lasers solution platform</b></p> <p><b>Modulight's ML1600</b> is a laser solution platform designed for maximum flexibility and ease of use. It integrates advanced laser systems with controllers and interfaces for both analog and digital signals, ensuring seamless operation. All laser technologies can be combined further into a solution to provide the user with reliable performance over a long lifetime for preventive maintenance with predictive analysis.</p> <p>Example products</p> <ul style="list-style-type: none"> <li>ML1600 - product platform with support to wavelengths ranging from UV to 2000+ nm</li> </ul>

+ Packaging / system integration

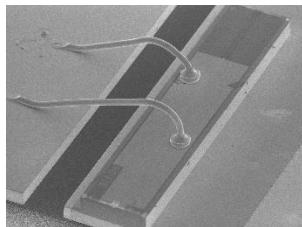


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# DBR lasers

- Compact, robust and stable
- Less sensitive to environmental perturbation than external cavity lasers
- <MHz linewidth, as low as <200 kHz

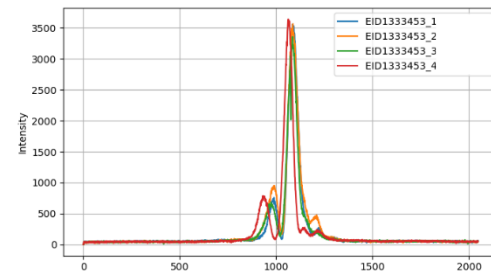
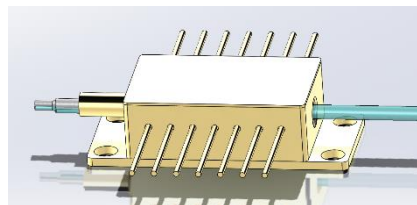
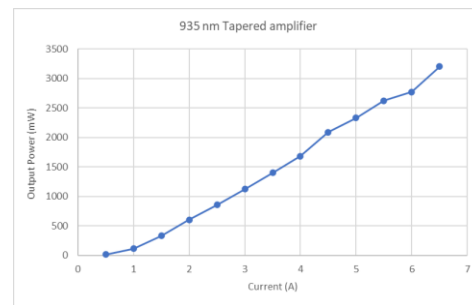


DBR output powers at selected wavelengths

Wavelength (nm)	Current (mA)	Maximum output power (mW)
633	150	25
650	150	45
760	350	200
780	350	240
795	350	240
935	450	325

# Tapered amplifiers

- Amplification of seed laser output power while preserving seed laser spectral characteristics and good beam quality
- System design employs permanent fiber coupling of seed laser to tapered amplifier for robust operation



MO DBR + PA Tapered Amplifier



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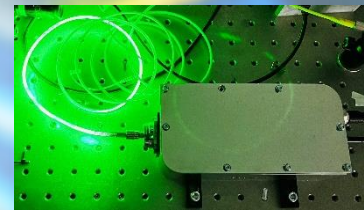
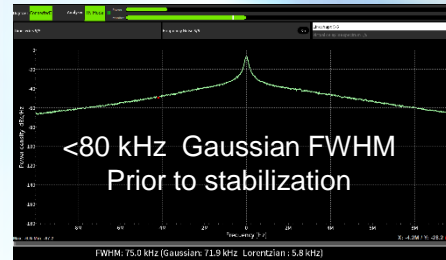
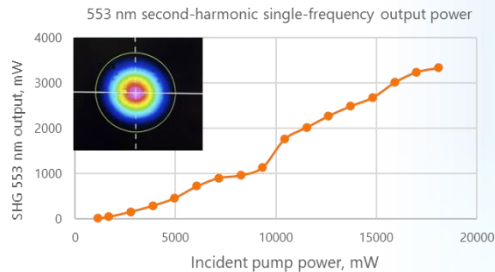
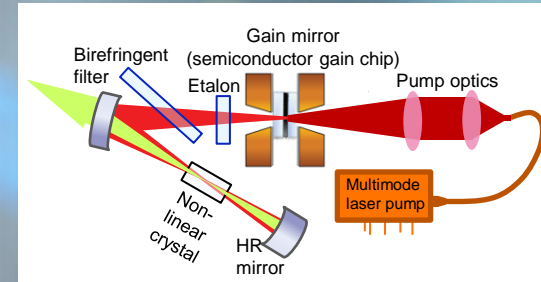
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# Optically-pumped vertical-external-cavity surface-emitting laser (OP-VECSEL)

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## Advantages of OP-VECSEL technology:

- ❑ High power, scalable emission with excellent beam quality
- ❑ Efficient intracavity frequency conversion to visible and UV
  - ❖ More compact and robust compared to second harmonic generation in an enhancement cavity
- ❑ Ultranarrow linewidth and low-noise operation
- ❑ Wavelength engineerable (~350-2000 nm) and tunable emission



VECSEL laser core

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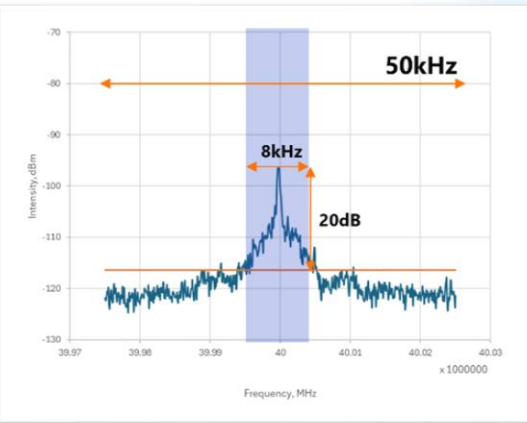


# Modulight high-power 1762 nm fiber laser for Barium applications

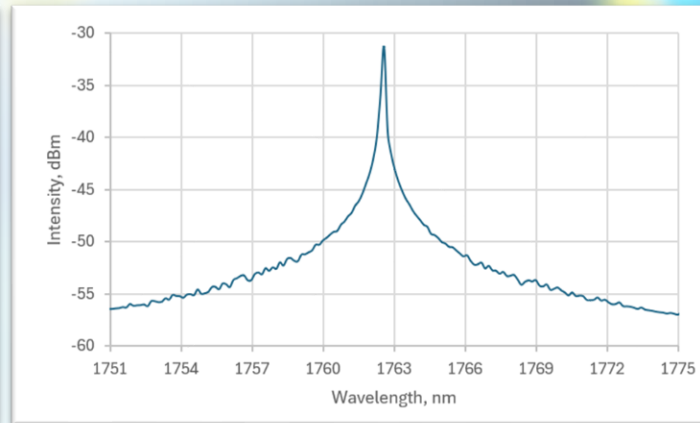
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## Key characteristics

Parameter		Unit
Operating Wavelength	1762.17	nm
Optical Output Power	1000	mW
Free-running Linewidth	<10	kHz



Self-heterodyne linewidth characterization



Optical spectrum

## Modulight ML6600 Fiber laser implementation

- Fiber lasers are great for certain transitions where high power and stable narrow-linewidth emission is required, fiber laser technology
- Wavelength stabilization via piezo, <150 V, <20kHz BW



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Thank you

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