Nitride laser diodes for quantum technologies

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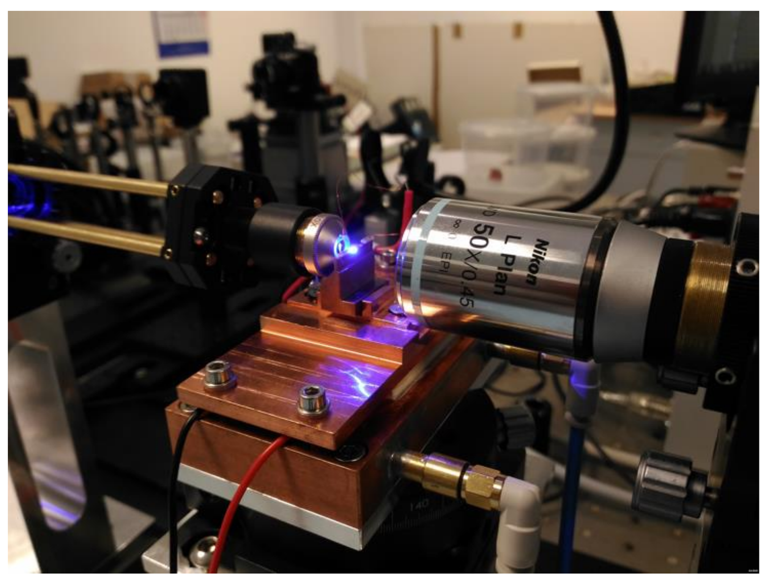
1. Motivation

Quantum technologies

Nontrivial applications of quantum phenomena

1. Optical Atomic Clock Applications:
   - Time-stamping of financial transactions
   - Navigation (precision GPS)
   - High speed internet (network timing)
2. Quantum Gravity Sensors:
   - Oil & Gas
   - Mineral exploitation
   - Underground investigation
3. Quantum Computing



Laser diodes light must be coupled (matched) to particular optical transitions of atoms or molecules hence laser must be tunable and spectrally narrow

2. Laser diodes for optical atomic clocks

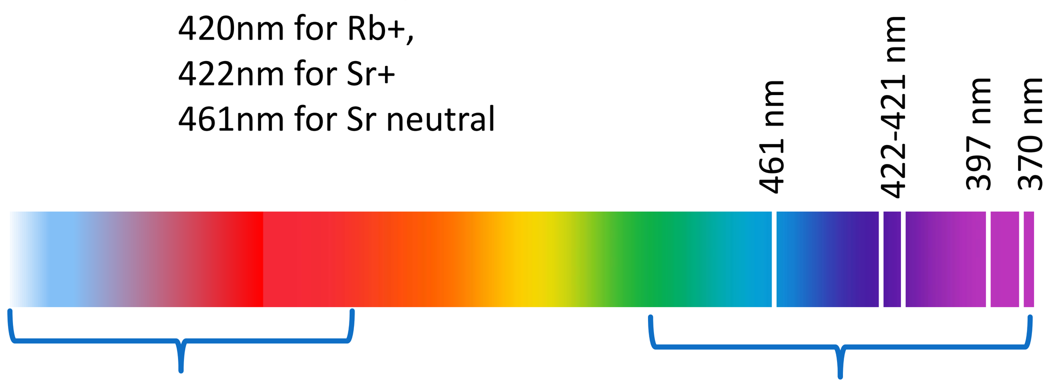
Atomic clocks have been so far based on microwave transitions in cavity containing cesium or rubidium atoms. Accuracy of such clocks are 10^{-12}-10^{-13}.

Optical atomic clock may improve time measuring accuracy by almost five orders of magnitude - 10^{-17}-10^{-18}

This accuracy requires cooling atoms by e.g laser Doppler cooling and their immobilization in the optical lattice

Wavelength important for super-cold atoms applications

The important wavelengths for super-cold atoms technologies, among the others, are:
369nm for Yb+,
397nm for Ca+,
420nm for Rb+,
422nm for Sr+
461nm for Sr neutral



Old technologies
Specialized laser diodes and amplifiers
Only infrared and red
Based on GaAlInAsP semiconductors

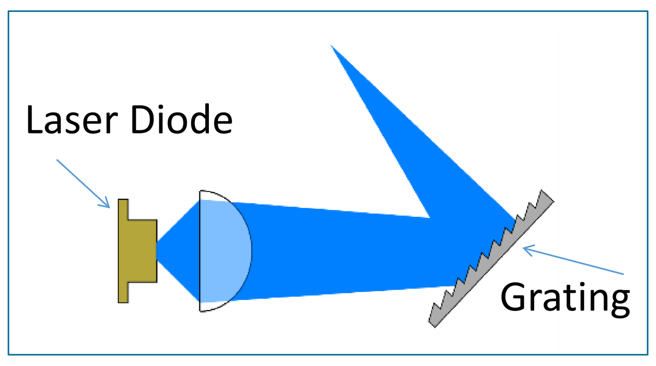
Proposed solutions operating from green to UV based on GaInAlN semiconductors

- **Requirements:**
  - Tunability of laser diodes in the range of few nanometers
  - Narrow linewidth = 1 MHz
  - Optical power even above 100mW

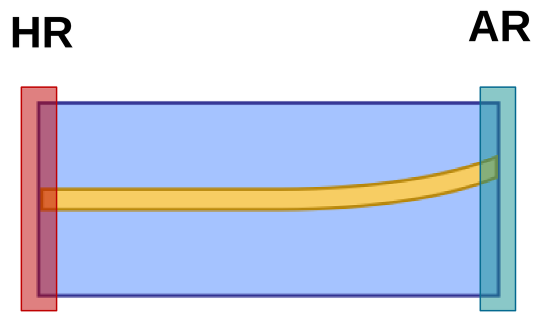
Further reading

1. Szymon Stanczyk Anna Kafar, Szymon Grzanka, Marcin Sarzyński, Robert Mroczynski, Steve Najda, Tadeusz Suski, Piotr Perlin „450 nm (Al,In)GaN optical amplifier with double 'j-shape' waveguide for master oscillator power amplifier systems" OPTICS EXPRESS, 26, 7351, (2018)).
2. Steffan Gwyn, Scott Watson, Thomas James Slight, Martin Knapp, Shaun Viola, Pavlo Ivanov, Weikang Zhang, Amit Yadav, Edik U Rafailov, Mohsin Haji, Kevin Edward Docherty, Szymon Stanczyk, Szymon Grzanka, Piotr Perlin, Stephen Najda, Mike Leszczynski, Anthony Kelly, "Dynamic Device Characteristics and Linewidth Measurement of InGaN/GaN Laser Diodes," in IEEE Photonics Journal, vol. 13, no. 1, pp. 1-10, Feb. 2021, Art no. 1500510, doi: 10.1109/JPHOT.2020.3045218.

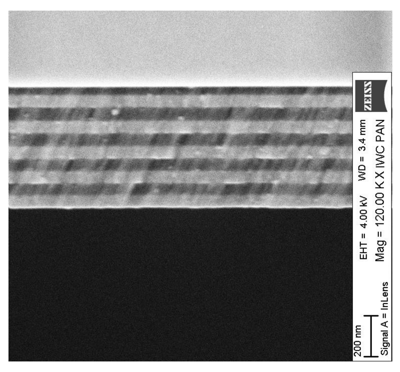
3. Making tunable laser diode for external cavity operation



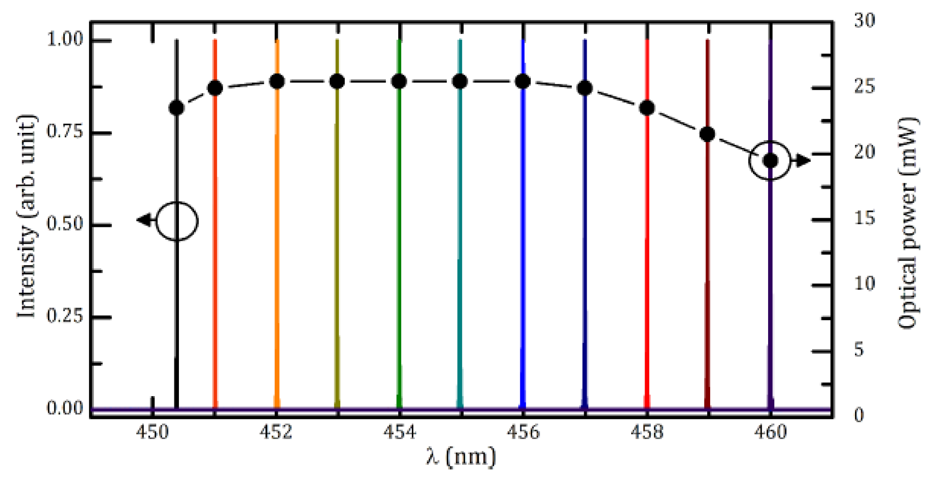
Littman or Liltrow External Cavity



Special chip design to suppress the internal cavity modes - bent waveguide configuration.
Achievable mirror losses above 40 cm^{-1}



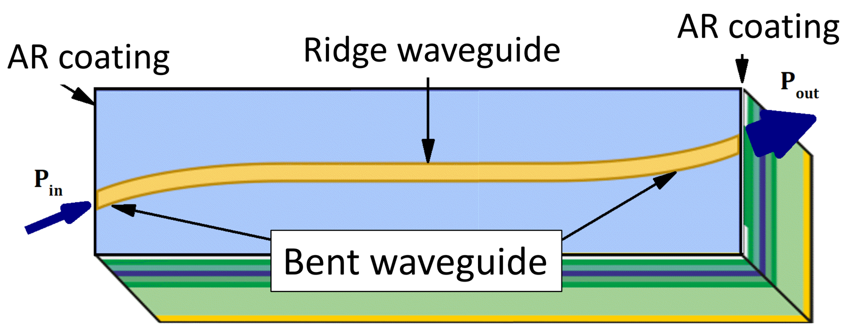
HR multilayer coating

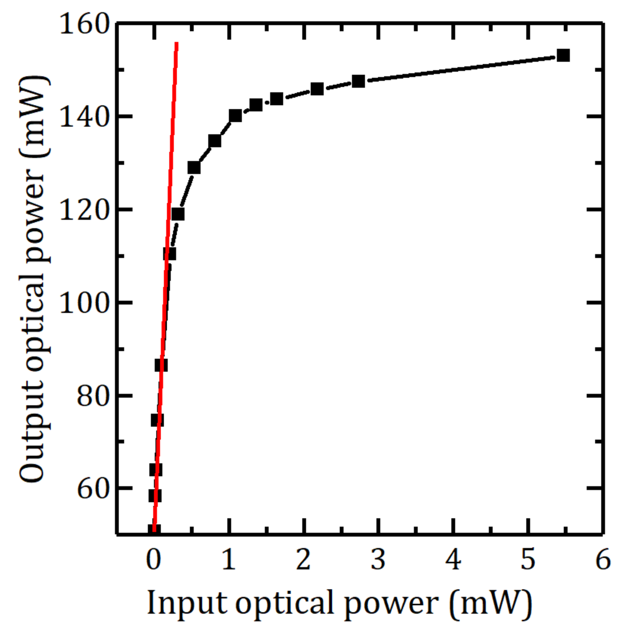


Optical power and spectra obtained for AR coated (on front facet) laser diode in Littman-Metcalf external cavity driven by I = 250 mA. The investigated laser diode was freely tuned in an almost 10 nm wide range. Single mode emission with SMSR larger than 30 dB was obtained through the whole presented tuning range.

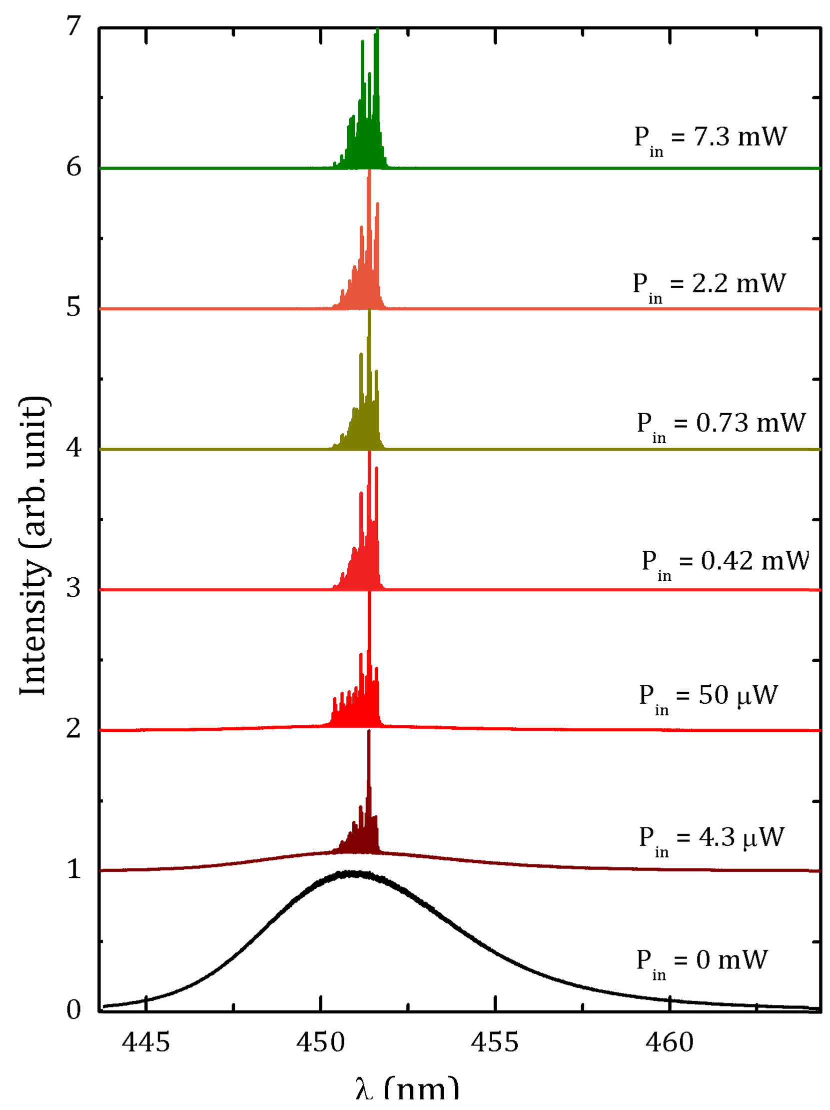
4. Adding power to tunability – semiconductor optical amplifiers (SOA)

Double j-shape optical amplifier





1-2 mW of the input power is sufficient to get maximum emission from SOA



Amplifier reproduces exactly the spectrum of the seed laser

Summary

- Tunable laser diodes for quantum technologies fabricated.
- Semiconductor optical amplifiers with output power above 100 mW demonstrated
- Building blocks for quantum technology systems available.

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