New Wavelength Generation in T-Cavity Vertical-External-Cavity Surface-Emitting Lasers

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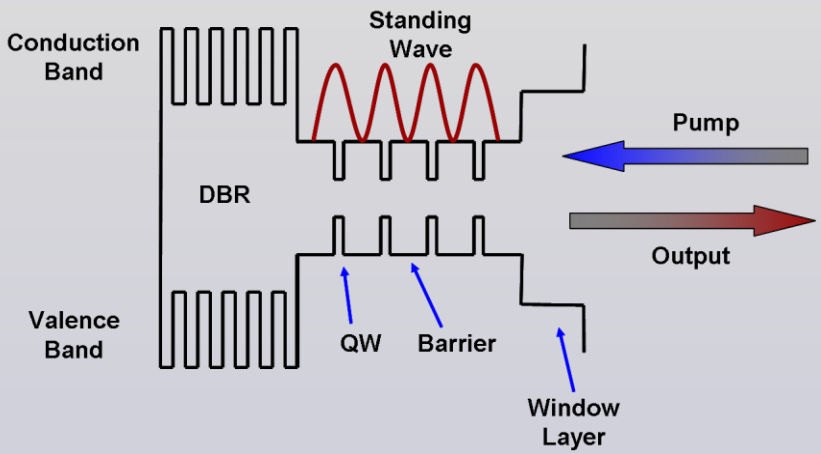
Acknowledgement: NSF
NSF-ECCS and IIP-PFI Air

Outline

- **Introduction to High Power VECSELs**
- **Single Chip Characteristics**
- **T-Cavity Configuration**
- **Sum Frequency Generation**
- **Difference Frequency Generation**
- **Concluding Remarks**

Design of High Power VECSEL

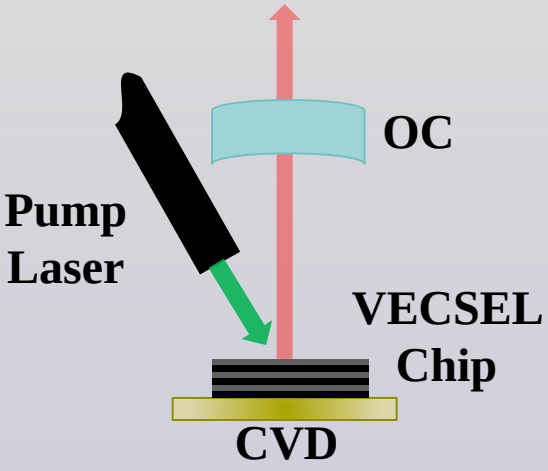


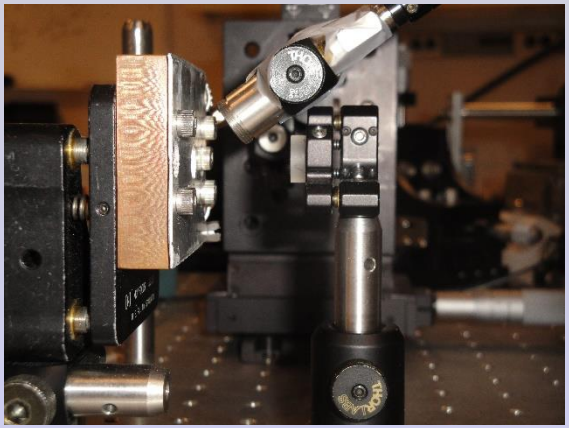
Approach

- Large number of QWs with Resonant Periodic Gain
- Active region close to effective heat sink
- Thermal management by substrate removal, heat spreader approach

- InGaAs/GaAs /GaAsP strained compensated MQW
- Resonant periodic gain (RPG) MQW
- DBR on Chip
- Barrier Optical Pumping

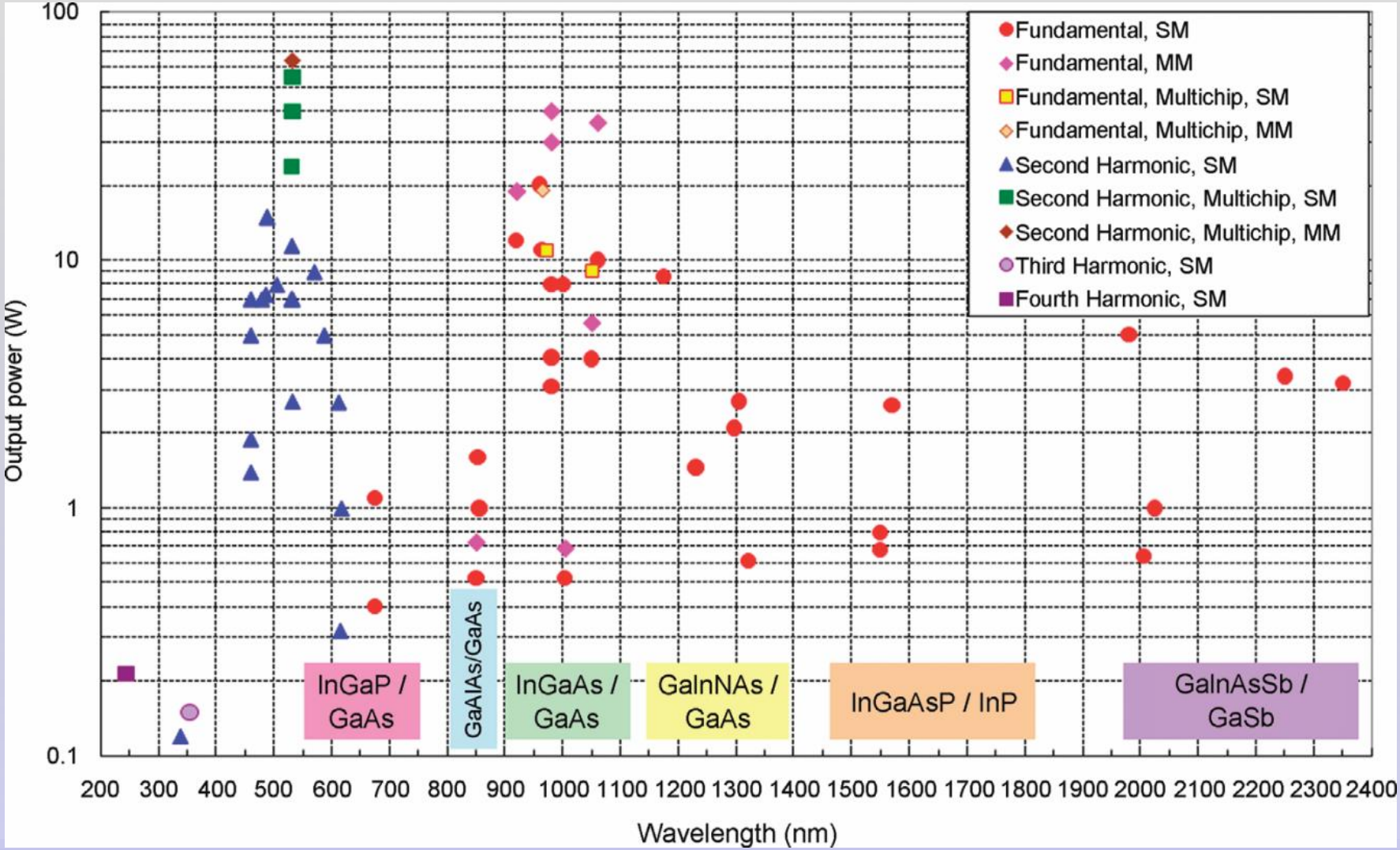
Linear Cavity Configuration



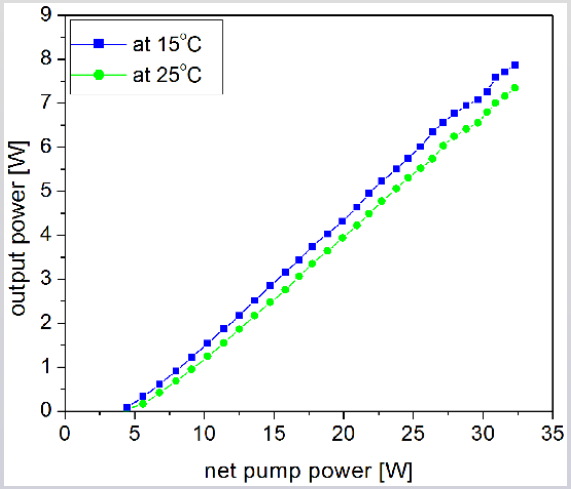


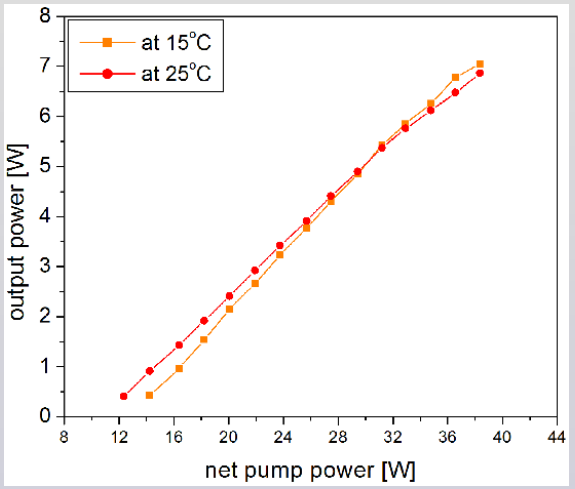
- High power and high beam quality (TEM_{00})
- Wavelength tolerant barrier pumping
- Power scaling by increased beam diameter
- Access to intracavity radiation

VECSEL History and Progress

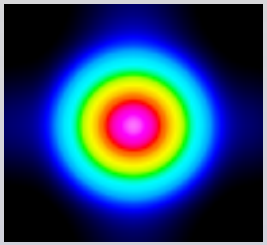


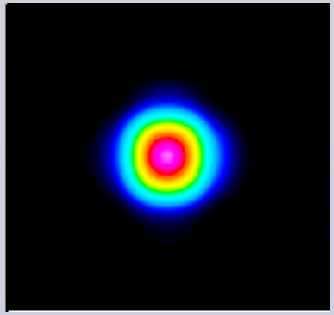
Fundamental Performance



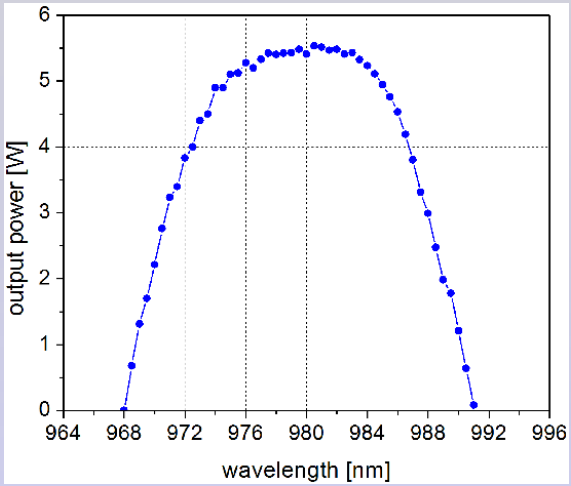


$M^2 < 1.4$

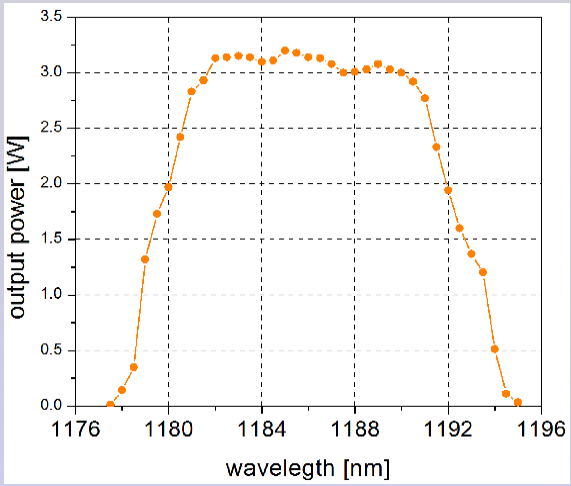




$M^2 < 1.3$



980nm VECSEL



1180nm VECSEL

T-Cavity Configuration

T-cavity Two-chip VECSEL:

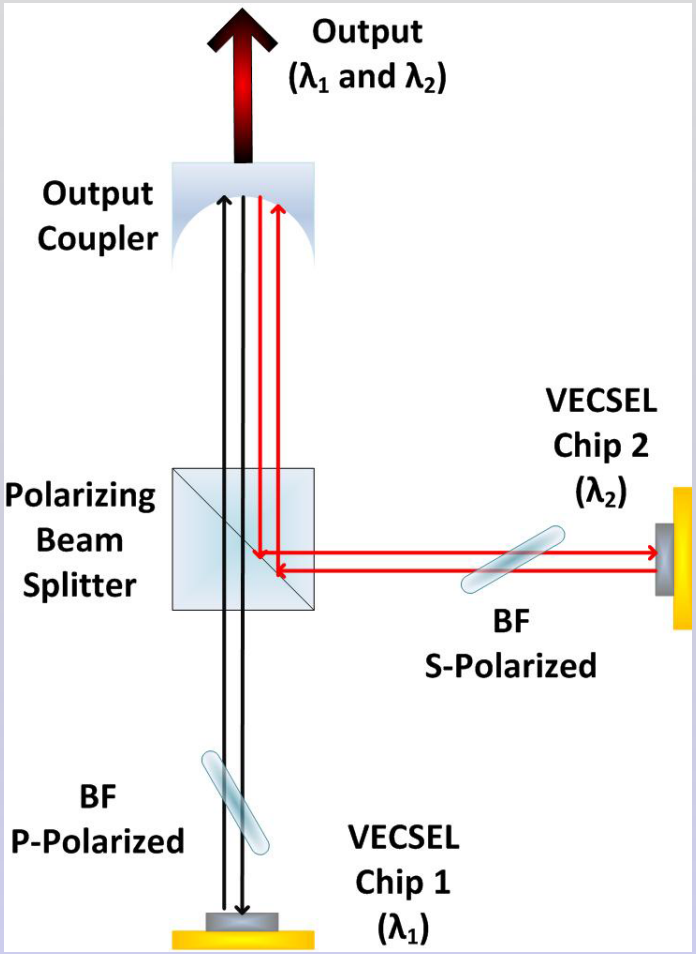
- **TEM_{00}, narrow linewidth for each wavelength**
- **Ease of wavelength tuning**
- **High intracavity intensity**

Chip 1: P-Polarized Cavity

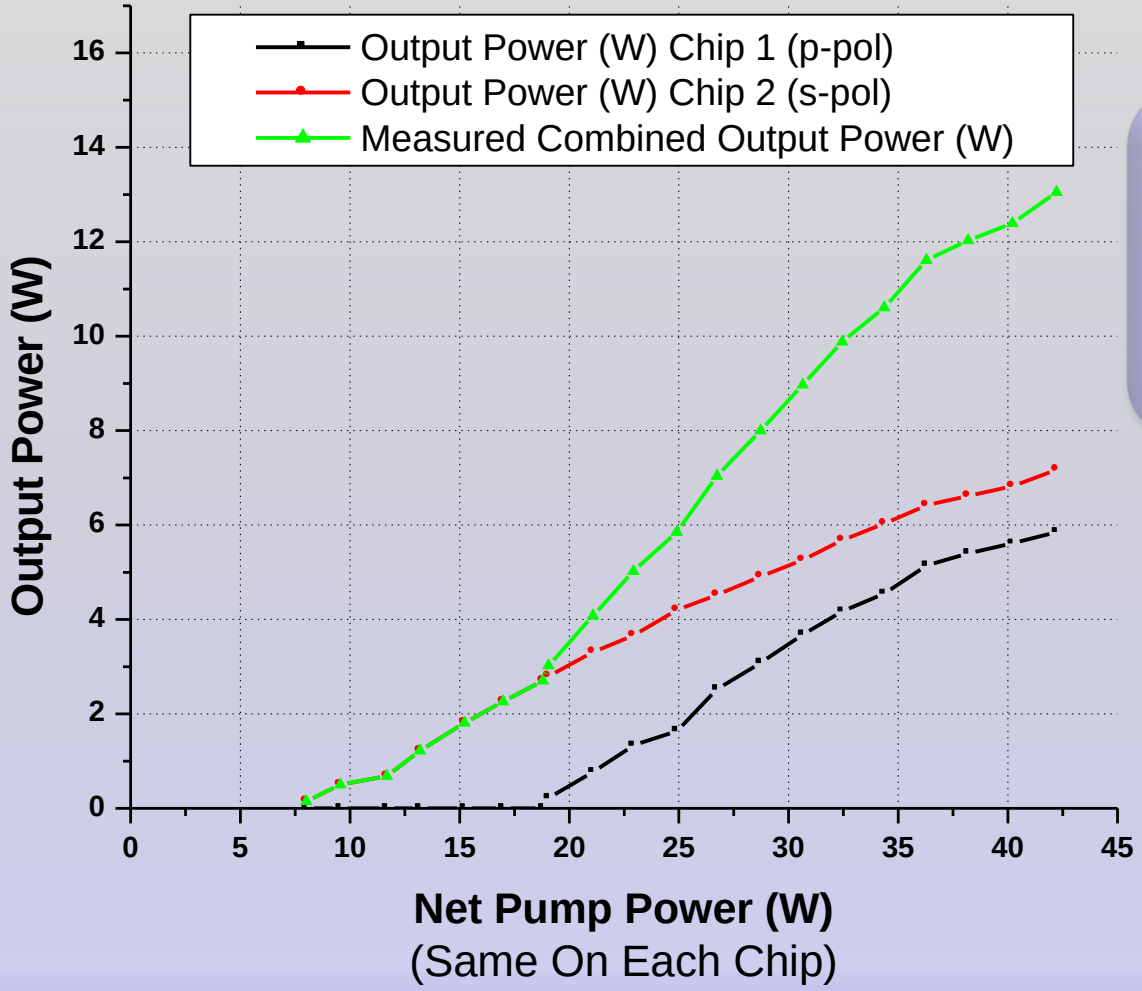
- Pump Spot Diameter ~ 500um
- 1mm thick BF included in Cavity

Chip 2: S-Polarized Cavity

- Pump Spot Diameter ~ 500um
- 2mm thick BF included in Cavity

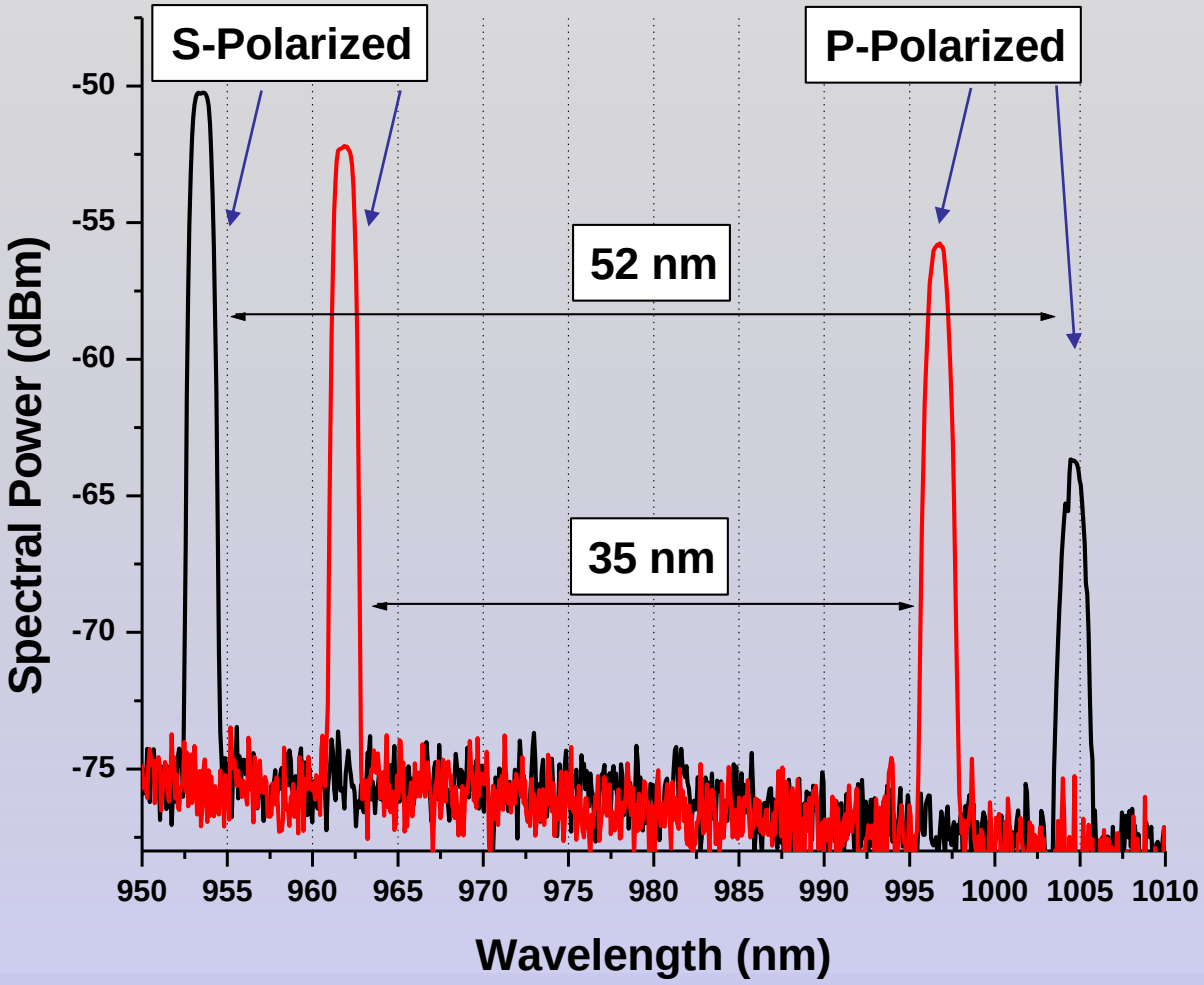


Combined Output

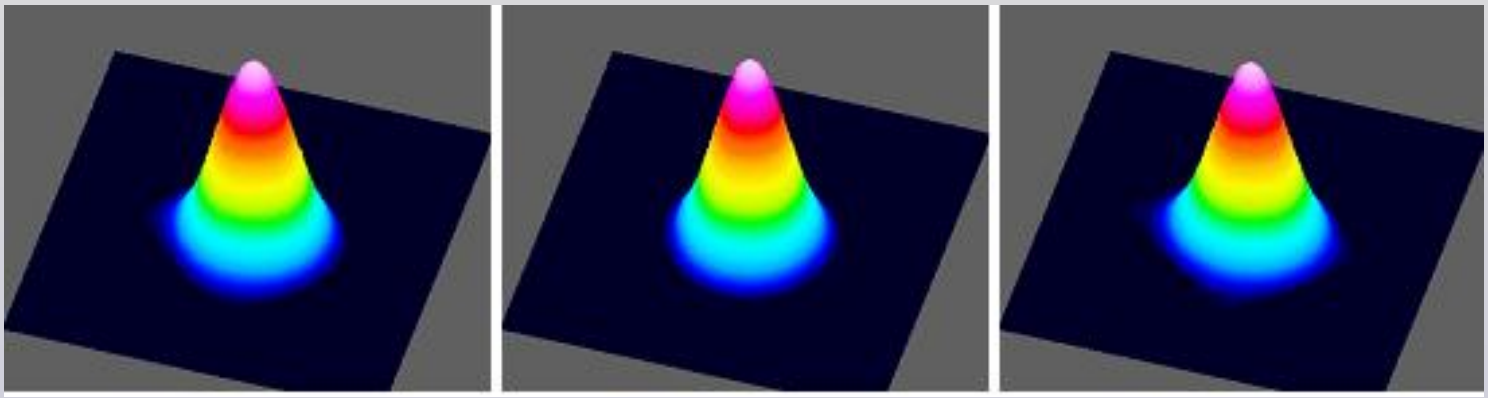


- Output measured for each cavity individually.
- Then the output was measured for the combined operation.

Independent Tuning of Each Wavelength



Output Profiles of Collinear Operation



A) B) C)

Measured outputs beam profiles

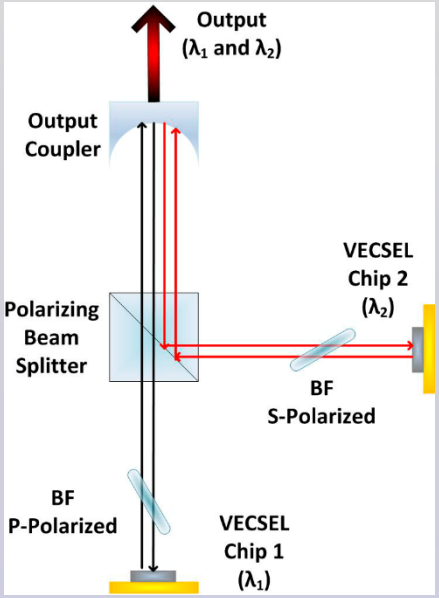
a) P-polarized beam profile.

b) S-polarized beam profile.

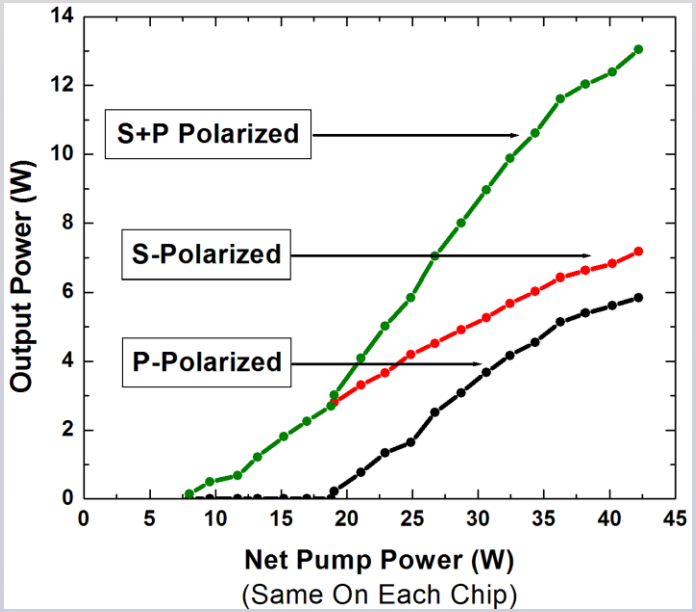
c) Combined S and P output beam profile.

T-Cavity Configuration Summary

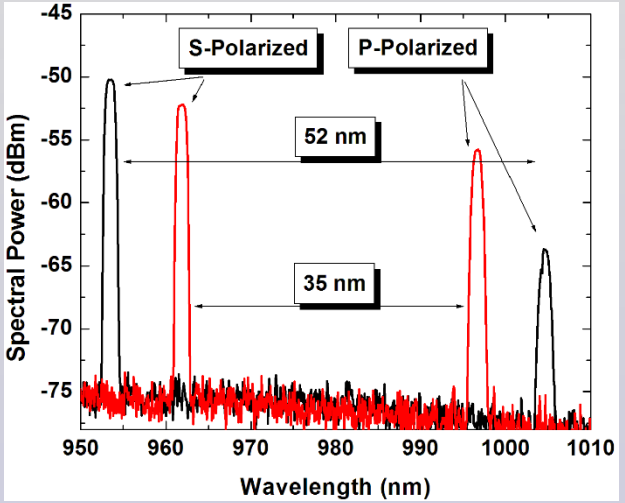
Cavity Design

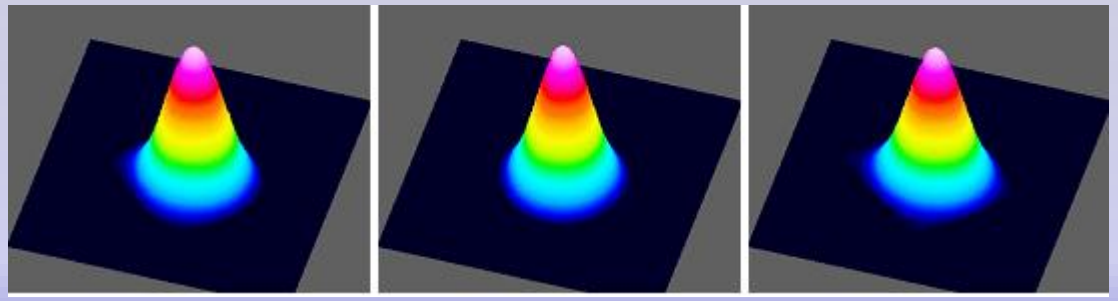


Total Output is Sum of Both Cavities



Individual Tuning of Each Wavelength

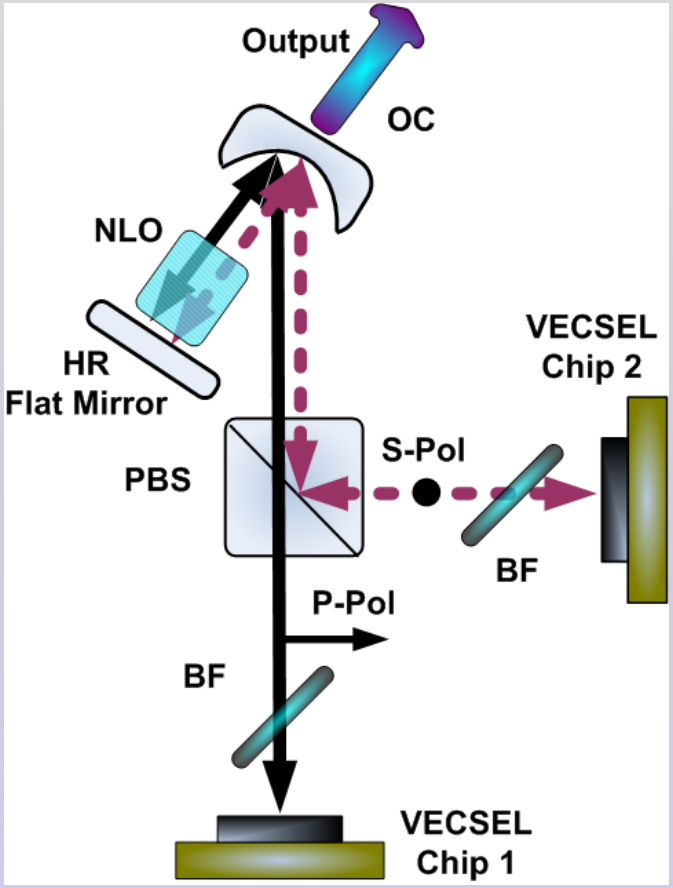


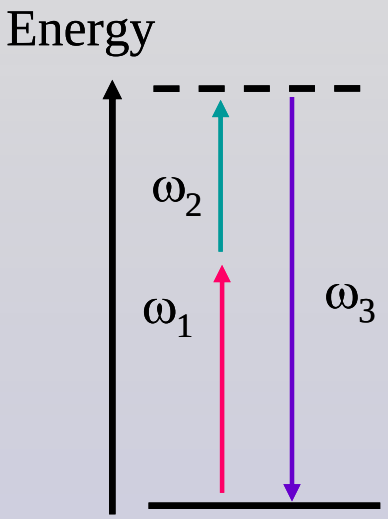


P-Pol S-Pol Combined

Excellent Beam Overlap is Demonstrated

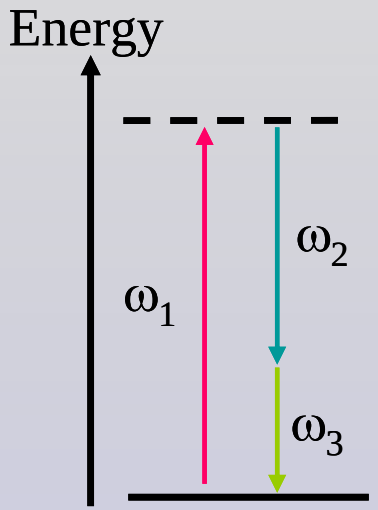
SFG and DFG





SFG

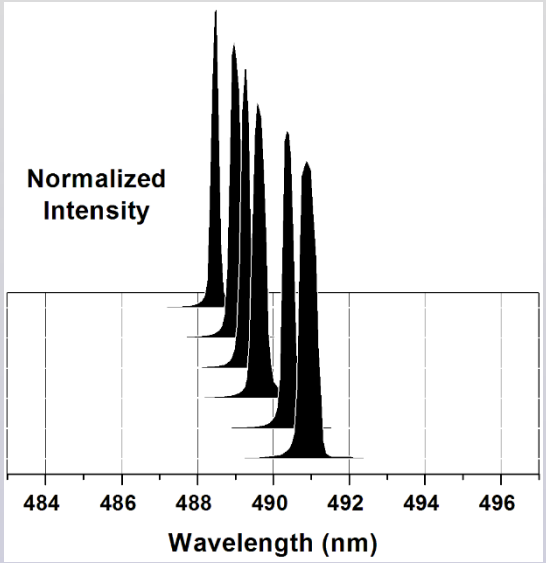
$\omega 3 = \omega 1 + \omega 2$



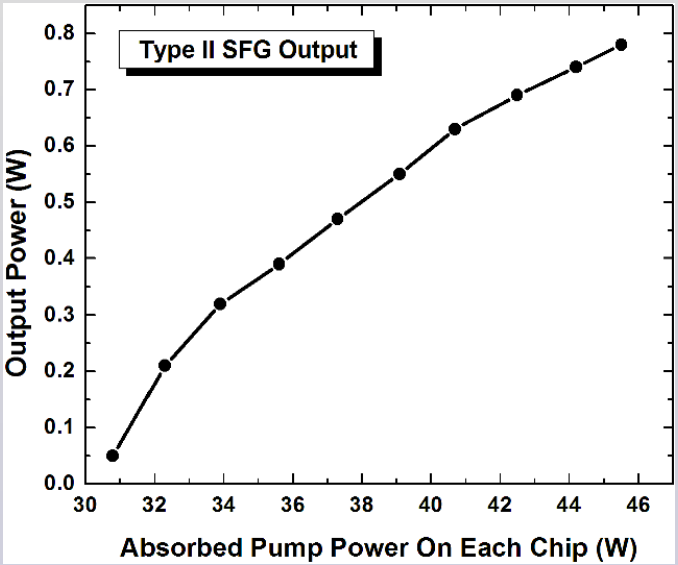
DFG

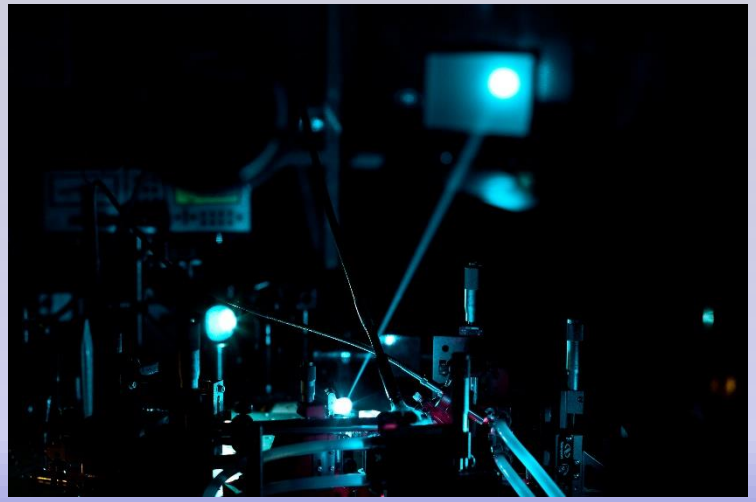
$\omega 3 = \omega 1 - \omega 2$

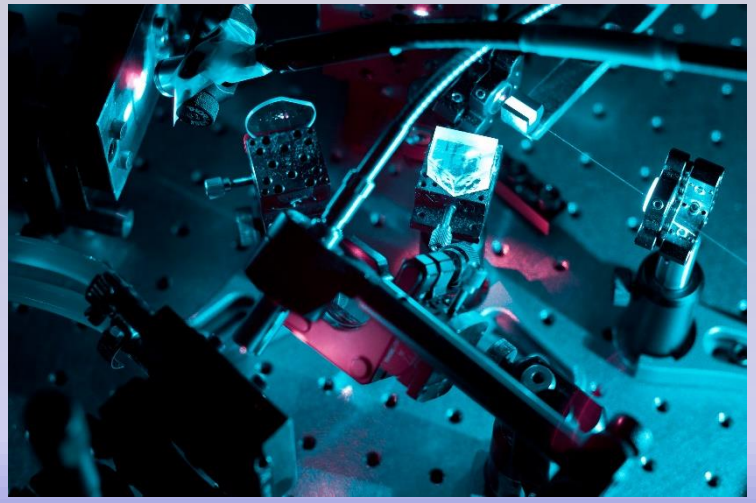
Type II SFG in T-Cavity



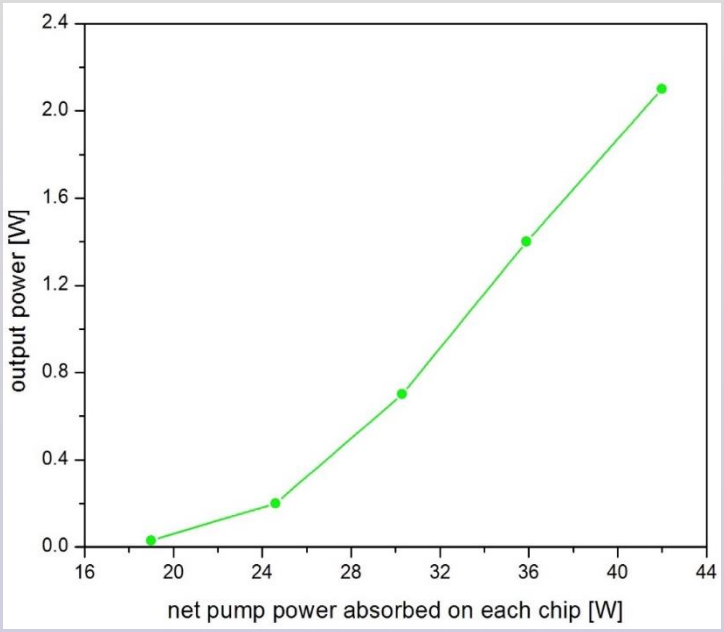
- Combine two VECSEL chips with similar 980nm outputs
- Tunable type II blue



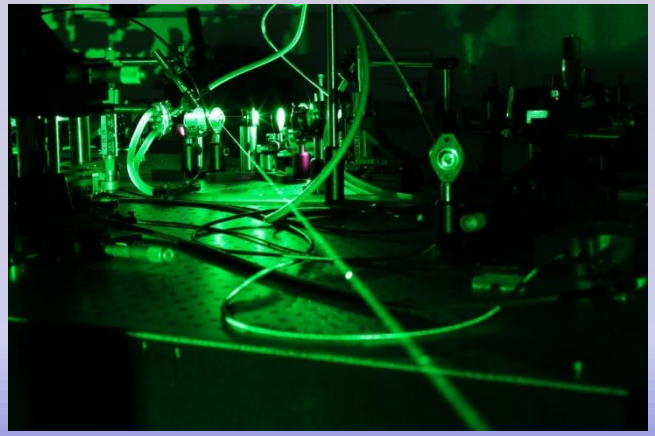


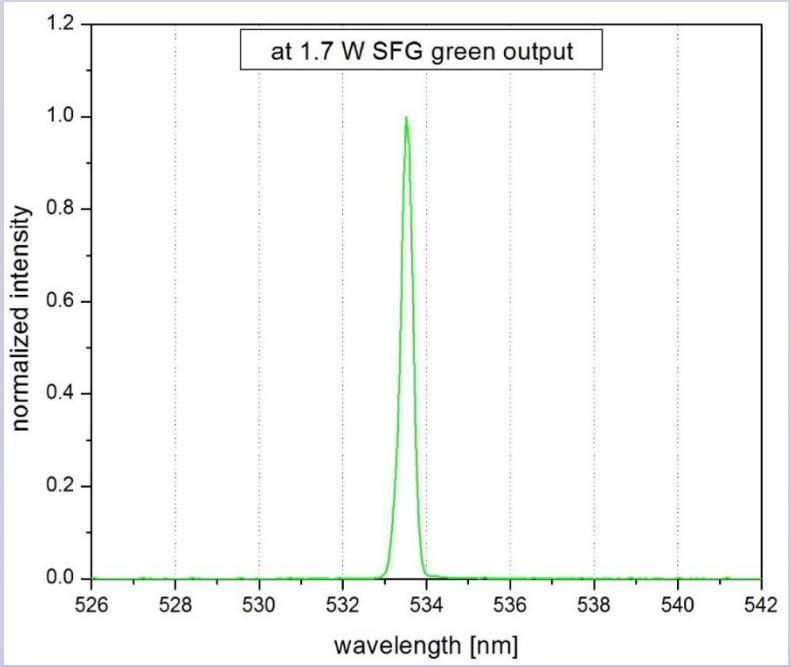


Type II Green Output

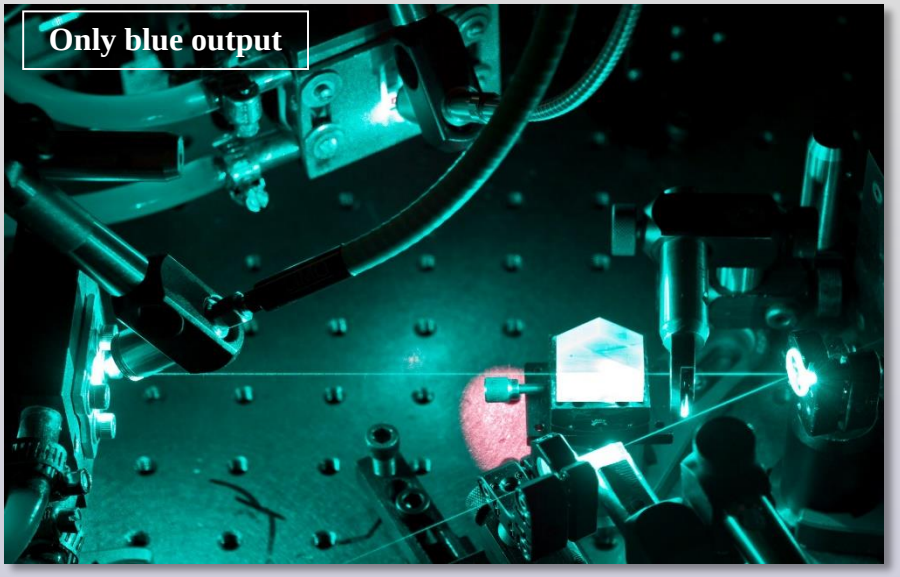


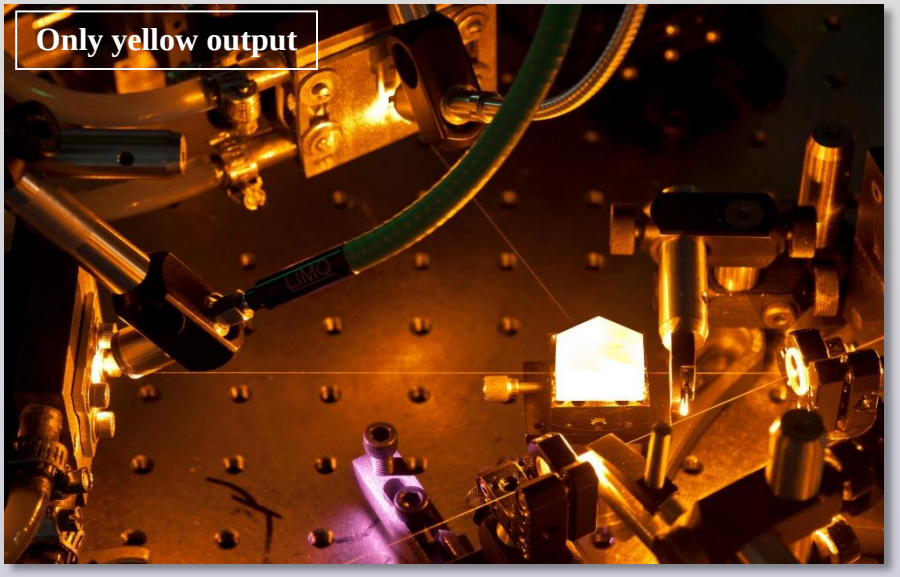
Can mix 1180nm and 980nm VECSEL chips to generate green outputs

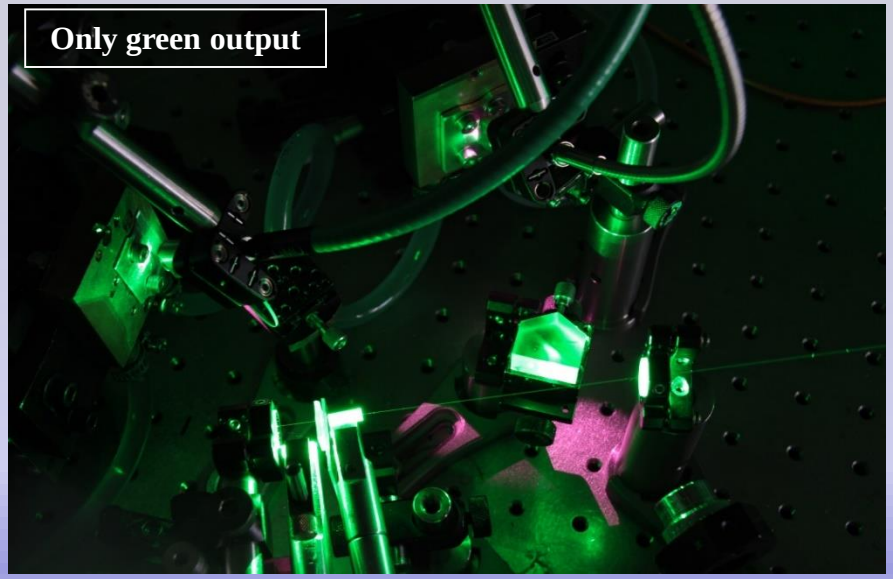


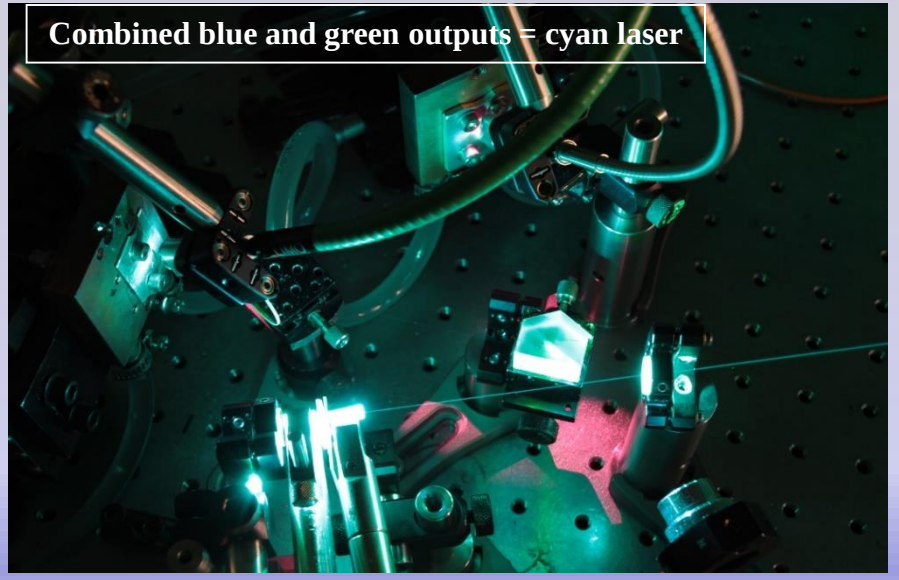


Multiple Color Generation

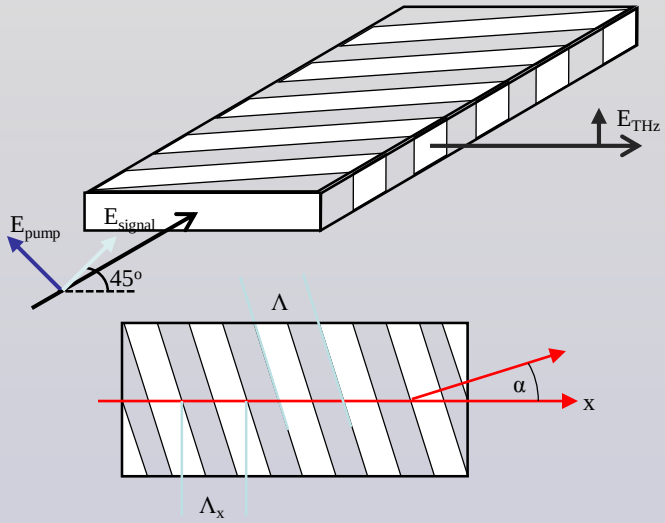




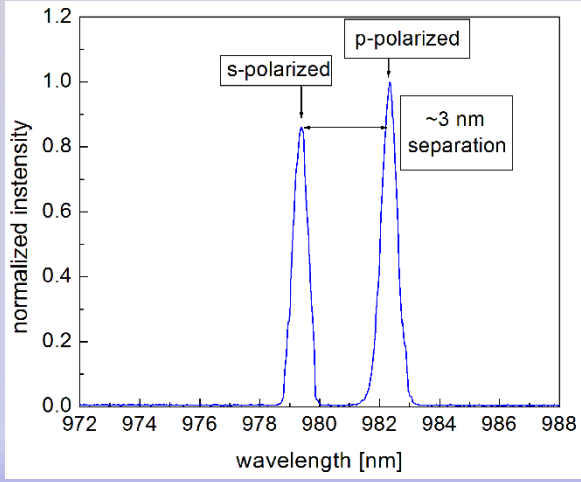




THz by Type II DFG

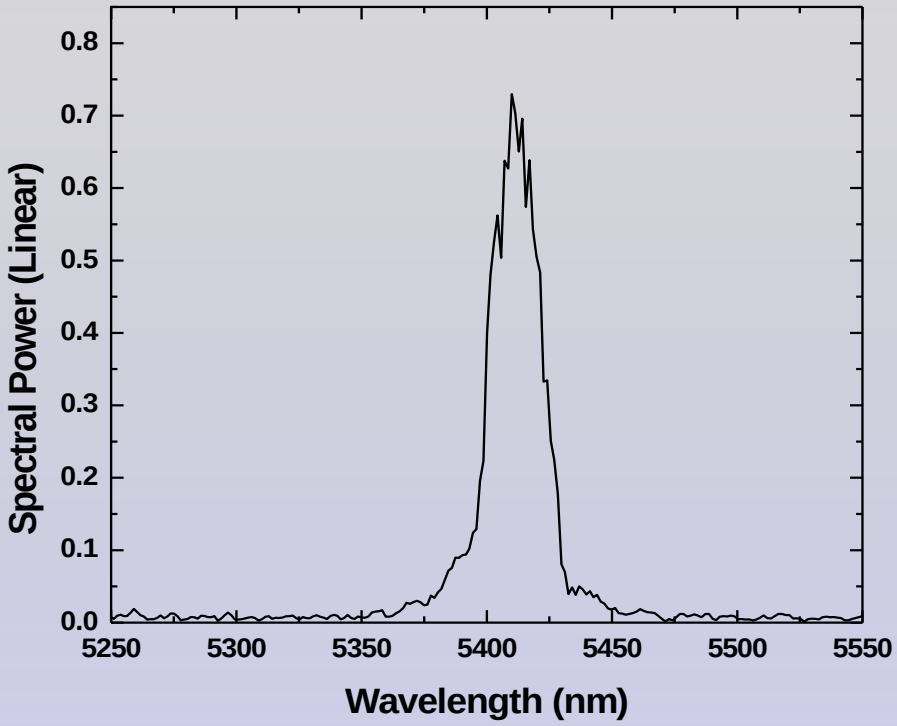


PPLN with tilted poling period for perpendicular THz extraction



Fundamental separation ~3nm for ~1 THz output

Mid-IR by Type II DFG



Same configuration for green SFG yields mid-IR via DFG

Fundamentals at ~968nm and ~1179nm produced output at ~5400nm

Concluding Remarks

- **VECSELs offer a flexible platform for a wide range of fundamental lasing wavelengths**
- **Can be a viable and affordable alternative for widely tunable Visible and IR high-power sources**
- **Intracavity access can allow for new operating features**
- **Two-chip T-cavity can provide efficient SFG and DFG pulsed operation**