



Integrity ★ Service ★ Excellence

Lasers and Optics

05 MAR 2013

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Program Officer
AFOSR/RTB**

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2013 AFOSR SPRING REVIEW 2301A PORTFOLIO OVERVIEW



NAME: Dr. Howard Schlossberg

BRIEF DESCRIPTION OF PORTFOLIO:

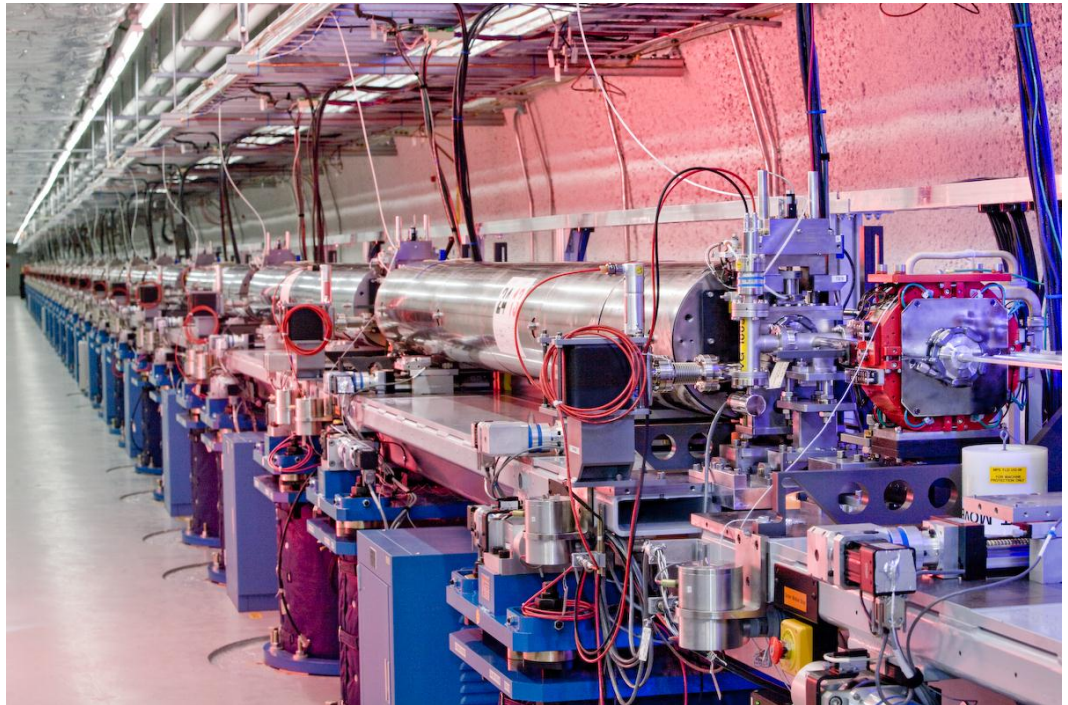
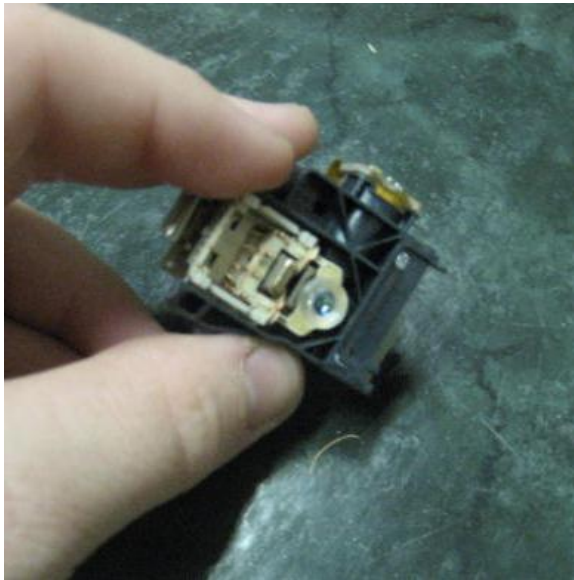
RESEARCH IN LASERS, OPTICS, AND THEIR APPLICATIONS

LIST SUB-AREAS IN PORTFOLIO:

- LASERS
- NON-LINEAR OPTICS
- LASER-MATTER INTERACTIONS
- MICRO-SYSTEMS



LASERS





Portfolio Summary (Detail)

- **High Average Power Solid-State Lasers**
 - Ceramic Solid-State Laser Materials
 - Fiber Lasers
 - Thin Disk Semiconductor Lasers
 - X-PALS
- **Modest Power Lasers**
 - Mid-Infrared Semiconductor Lasers
 - Mid-Infrared Fiber Lasers
- **Nonlinear Optics**
 - Nonlinear Frequency Conversion
 - Ultrashort Pulses
 - Mid-and Long Wave Frequency Combs
 - X-Ray Imaging
 - Micromachining
- **Microplasma Arrays**
 - Specialized Lighting
 - Plasma chemistry
 - Plasma electronics



AFOSR Study of 6.1 Opportunities in High Energy and High Power Lasers



- Ceramic Solid-State Laser Materials
 - Spatially Varying Index and Doping Concentration
 - Non-Isotropic hosts
- Fiber Lasers
- Ultra-short, Ultra-Intense Pulses
 - Matter Interactions, Propagation, X-Ray Beams
- Integrate with HPL JTO Programs

**High Energy Solid-State, and Some Gas, Lasers Today
are an Exercise in Mode Conversion**



AGENDA



- Ceramic Solid-State Lasers
- Fiber Lasers
 - Photonic Bandgap Gas Lasers
- Mid-Infrared Semiconductor Lasers
- Quasi-Phasematching Materials

Technology Transfer Examples

- Broadband OPOs, Infrared Combs
- Infrared Countermeasures

Some Program History



Ceramic laser gain media offer a number of important advantages over single crystals and glasses



:

- Ceramic media can be fabricated with arbitrary shapes and size.
- Ceramics are well suited to produce composite gain media, consisting e.g. of parts with different doping levels, or even different dopants
- Spatially varying doping profiles are relatively easily possible. These aspects give additional freedom in laser design.
- Significantly higher doping concentration can be achieved without quenching effects degrading the laser efficiency.
- Some materials, e.g. sesquioxides are very difficult to grow into single crystals, and much easier to obtain in ceramic form.



Ceramic Solid-State Laser Materials Program Examples



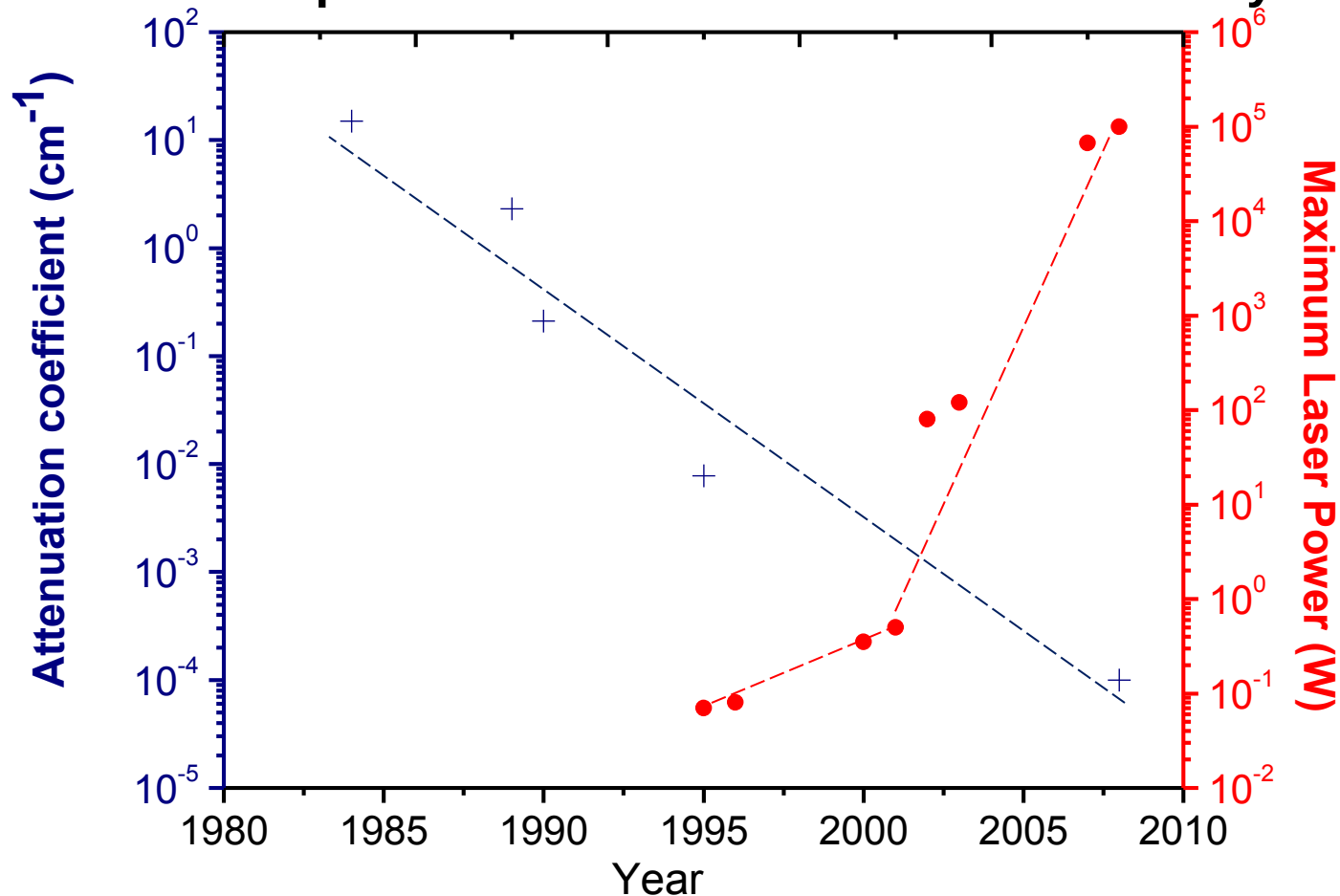
- Ballato - Clemson (JTO, Dr Sayir)
 - Sesquioxides
- Byer – Stanford (JTO, AFOSR)
 - Nd, Yb, Tm doped ceramics, Tm fibers
 - Works with U. Central Florida (Gaume)
- Wu – Alfred University (AFOSR YIP)
 - Yb doped $\text{Sr}_5(\text{PO}_4)_3\text{F}$ (Yb:S-FAP)
 - Excellent properties as laser host
 - Prototype uniaxial material
 - Study conversion from ceramic to single crystal
- Potential Topic for new BRI



Essential for Power Scaling: Low Loss Materials



Fabrication improvement of Nd:YAG ceramics over years



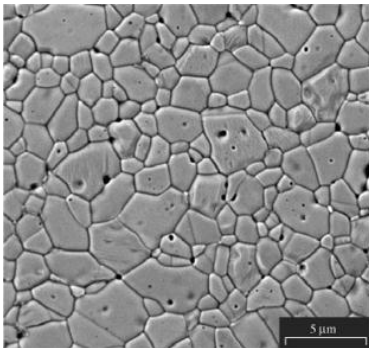


Low Optical loss Ceramics

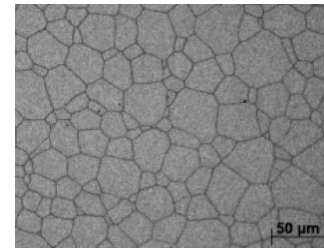


Attenuation = scattering + absorption

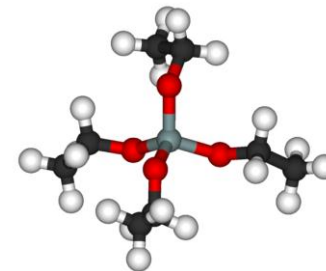
Non-Stoichiometry



Pores



Inclusions

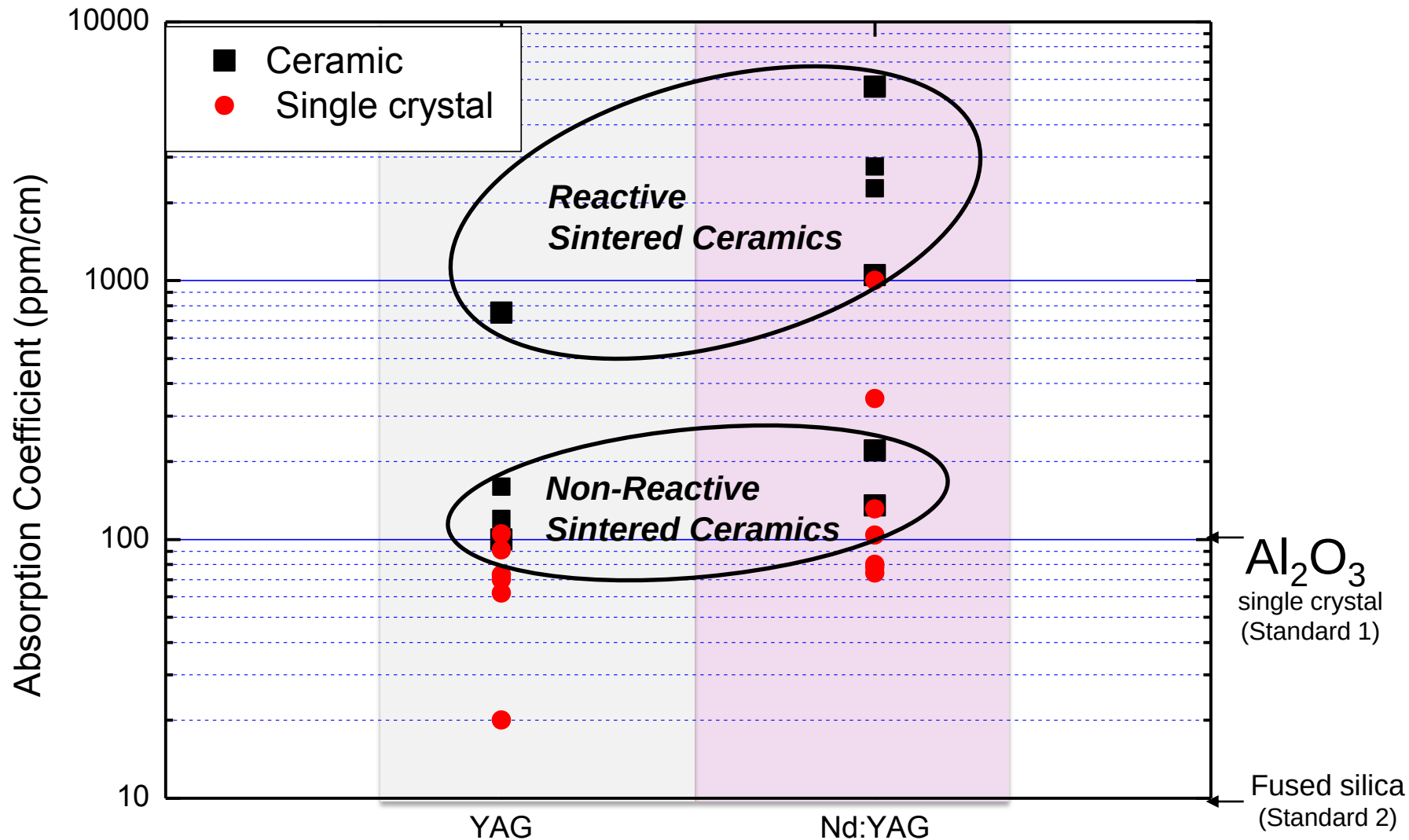


Impurities

Robert Byer - Stanford
Romain Gaume – U.C.F.



PCI Measurements in YAG

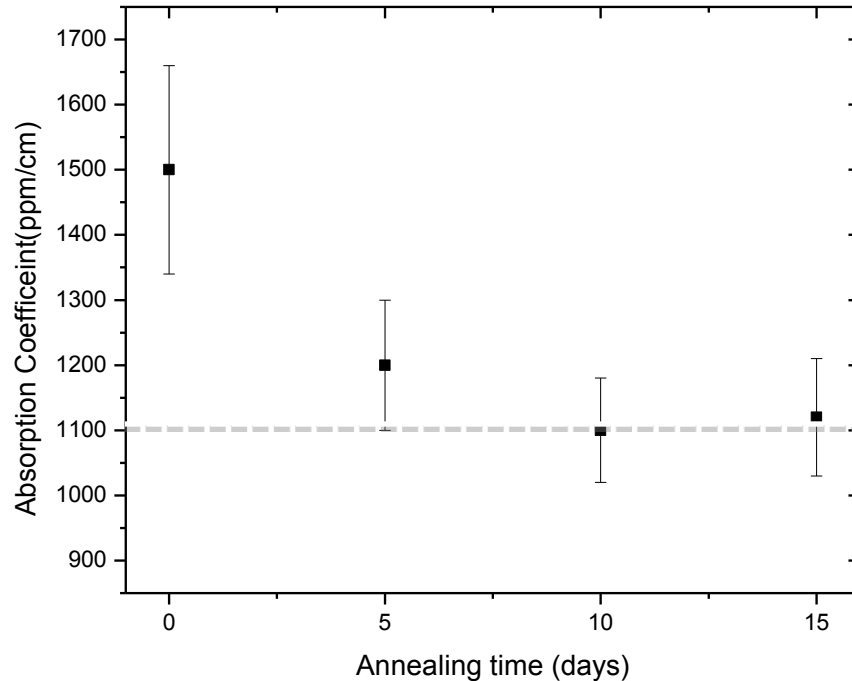




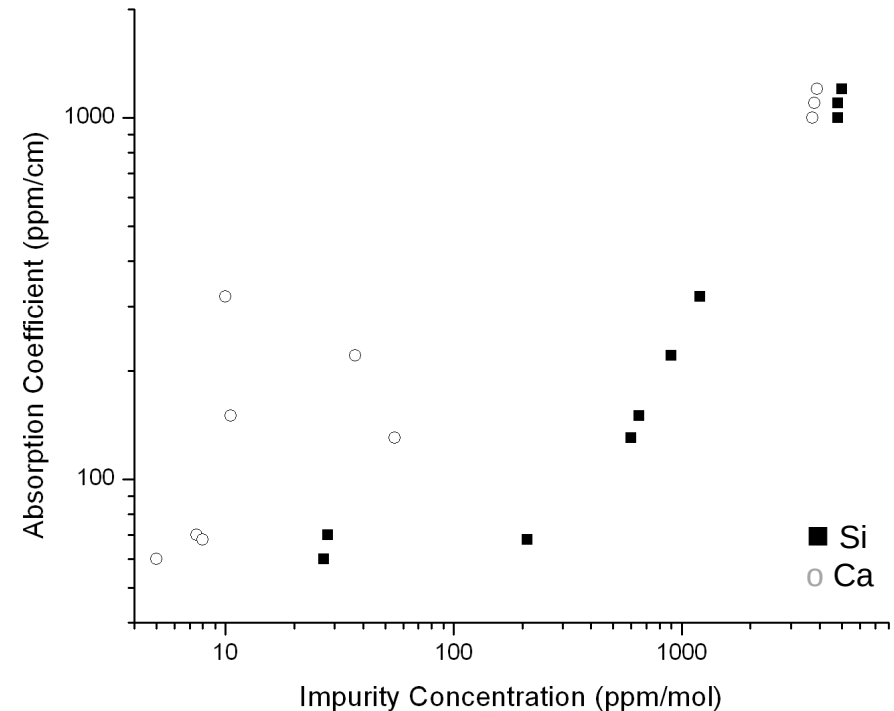
Photothermal Common-path Interferometry at 1064nm



Effect of air-annealing on Absorption



Effect of impurities on Absorption

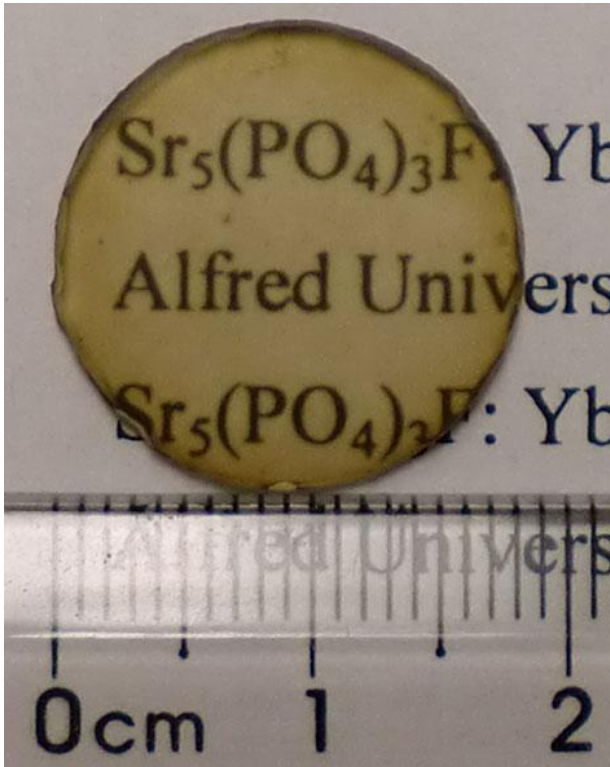


Thermalized Absorption does not vanish at long annealing times.

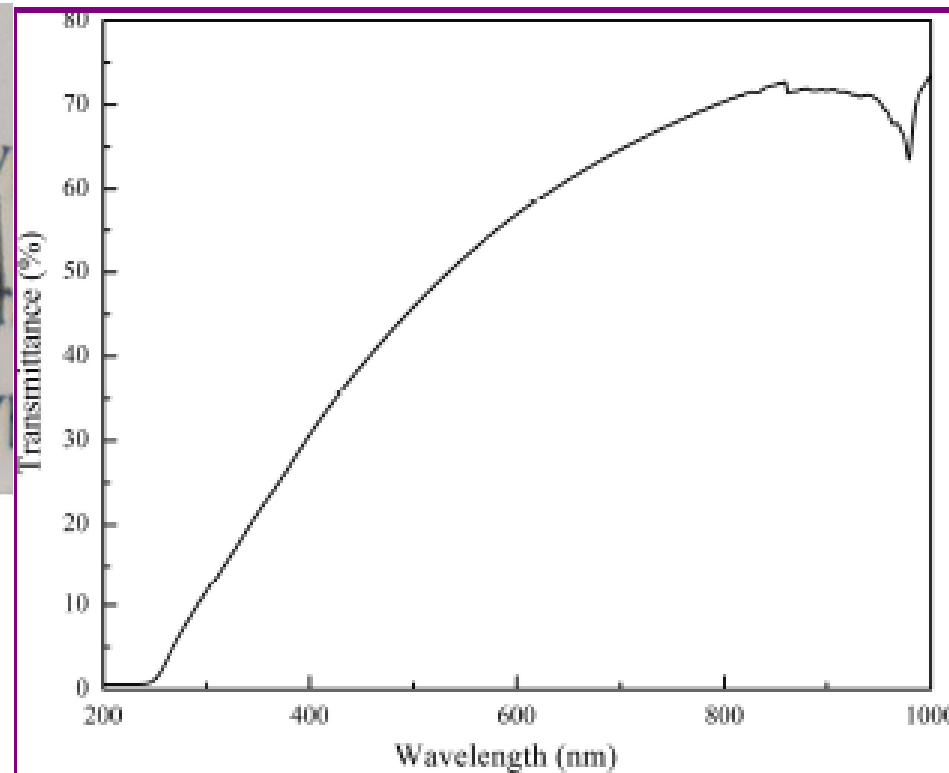
Thermalized Absorption scales with Silicon and Calcium impurity contents.



Yb:S-FAP Ceramic



Sr-FAP: Yb
1.6 mm thick



Yiquan Wu
Alfred University



AGENDA



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 - Photonic Bandgap Gas Lasers
- Mid-Infrared Semiconductor Lasers
- Quasi-Phasematching Materials

Technology Transfer Examples

- Broadband OPOs, Infrared Combs
- Infrared Countermeasures

Some Program History



Fiber Lasers



Research Areas

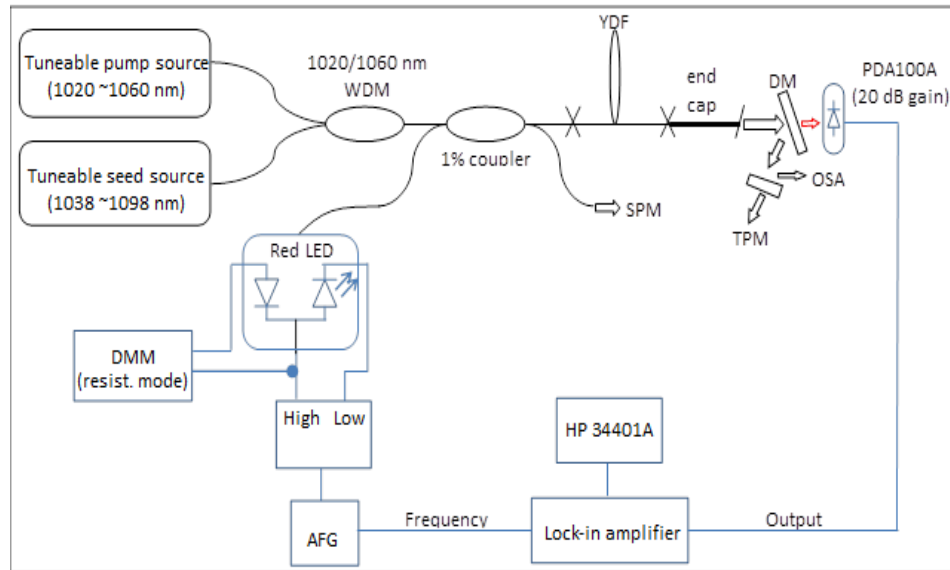
- Beam Combining
- Tandem High Power Fibers
- High Power Pulsed Lasers
- Photonic Bandgap Fiber Gas Lasers
- Mode Locked Infrared Fiber Lasers
- Applications

BRI Topic

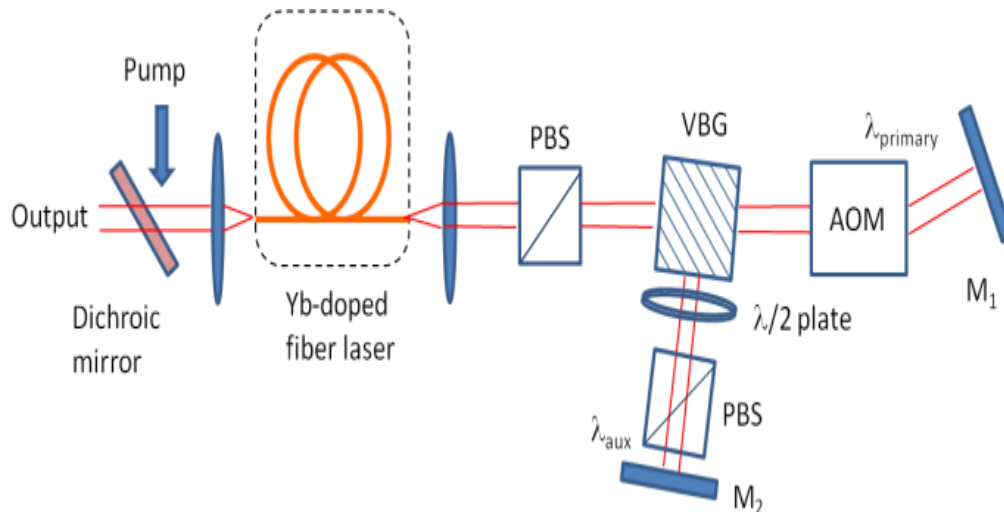
- High Power from Single Fibers
 - Large Area
- University Source of Specialty Fibers for Collaborative Research



Fiber Laser Experiments



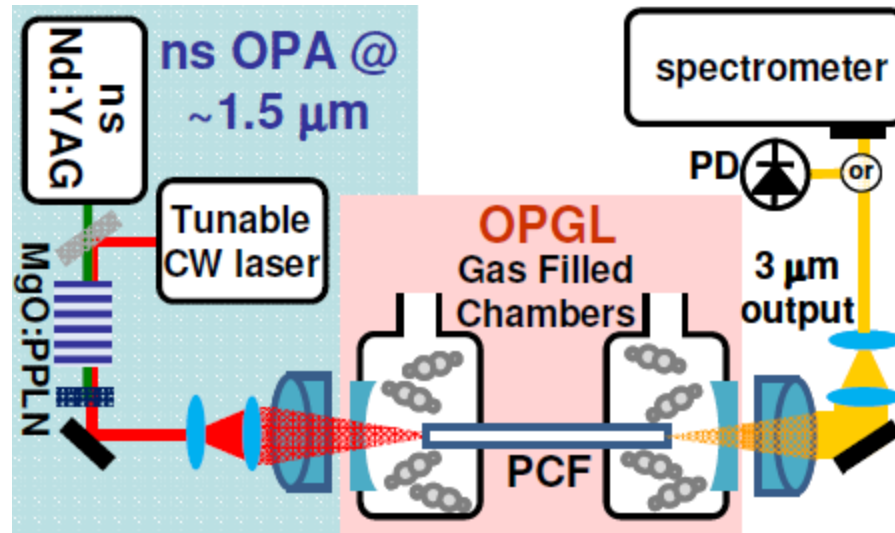
Tandem
Pumping



Catastrophic
Q-Switching



PHOTONIC BANDGAP GAS LASERS

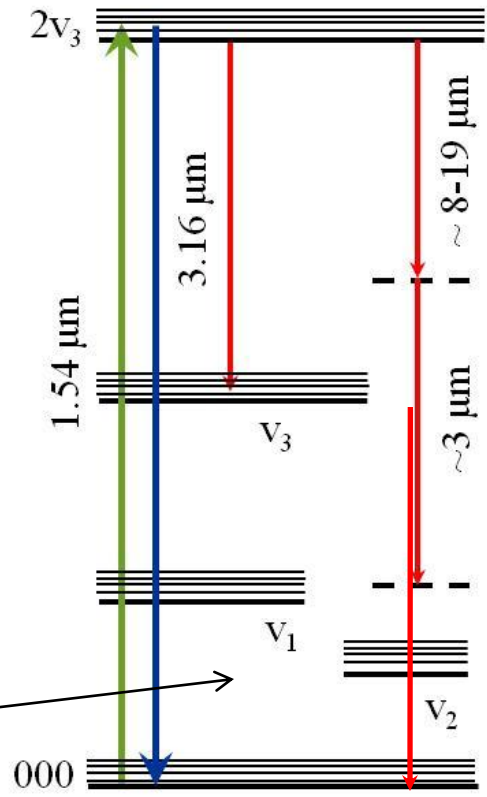
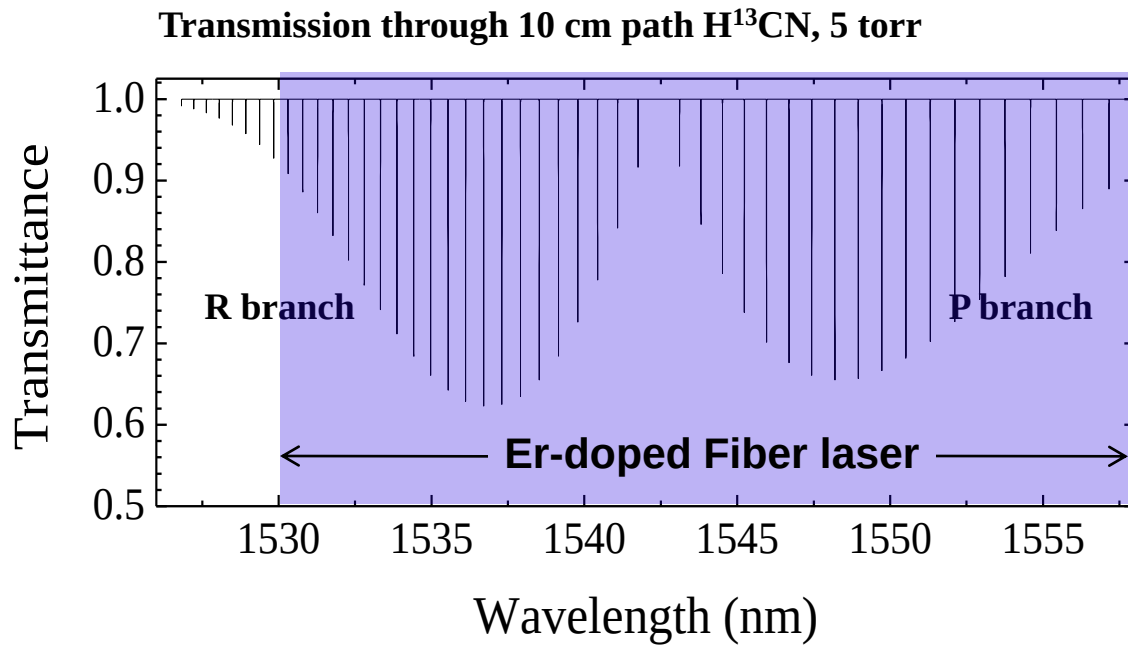
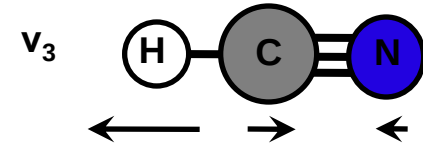
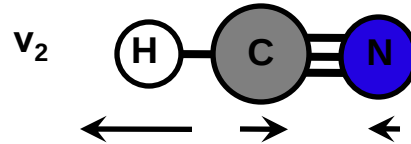
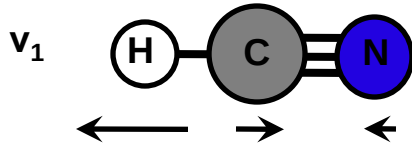


- Diode-pumped gas laser
- Long interaction length allows small absorption
- Enhanced efficiency possible through V-V collisions
- Large mode area or coherent coupling possible

- Corwin - Kansas State U
- U. New Mexico
- University of Bath



H¹³CN Energy States and Transitions



Potential for CW
small QD laser



Optically pumped gas lasers in capillary wave guides and exploring cw lasing in gas filled hollow fibers

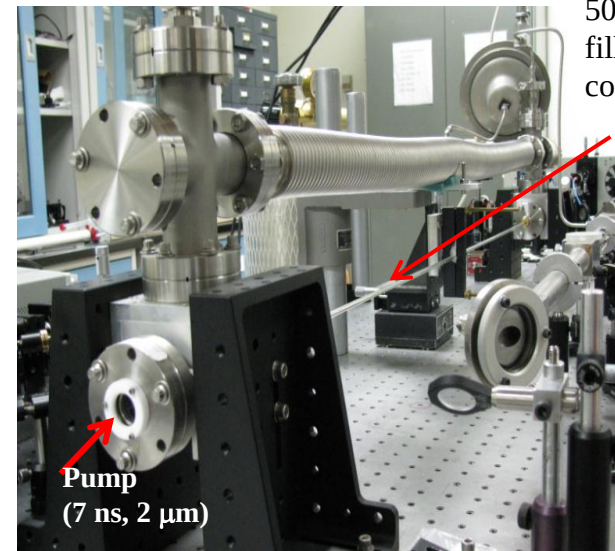


Major Goals:

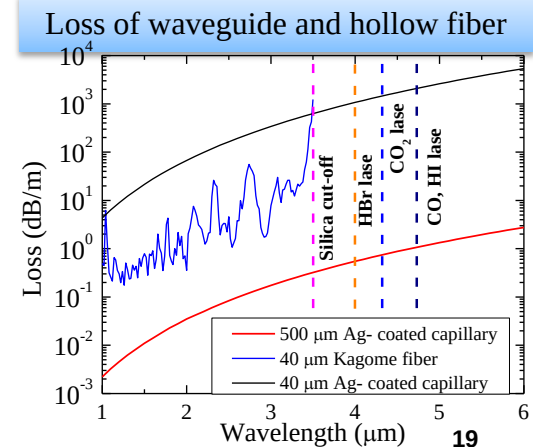
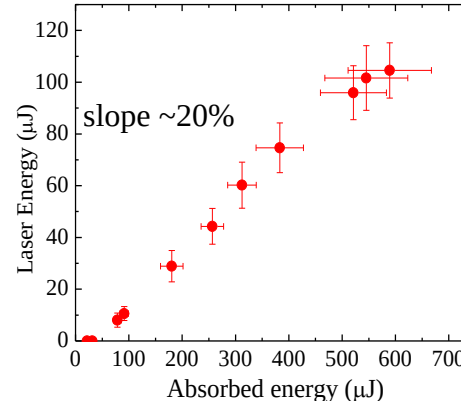
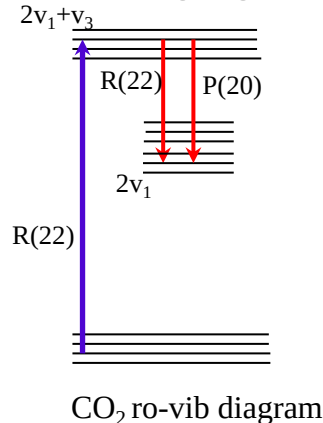
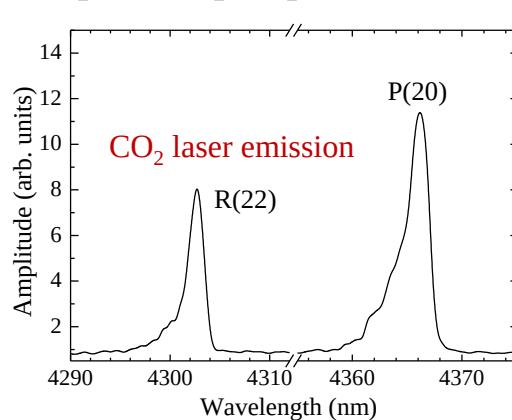
1. Use capillary waveguides to extend the emission of optically pumped gas lasers to mid-infrared where hollow core fiber technology is not yet developed.
2. Identify and characterize gas candidates for scalable CW pumped hollow fiber and capillary systems. Previous simulations by us [1] indicated promise of this approach.

Results:

1. Demonstration of pulsed mid IR (~ 4 micron) optically pumped CO_2 and CO lasers using capillary waveguides with slope efficiency of $\sim 20\%$.
2. Explored the feasibility of CW optical pumping of I_2 in a hollow core photonic crystal fiber - identified possible pump source and spectral lasing region



500 μm CO/CO_2 filled capillary coated with Ag





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Some Program History



AFOSR is funding research at AFRL/RDLT to:



- Develop in-house Quantum Cascade Laser technology at 4-5 μ m wavelength range**
- Generate high power from broad-area QCL devices**
- Explore novel novel schemes to produce high brightness**
- Advance beam-combining strategies in QCLs**
- Transition high brightness QCL technology to AF and DoD users**



Quantum Cascade Laser Research at AFRL/RD



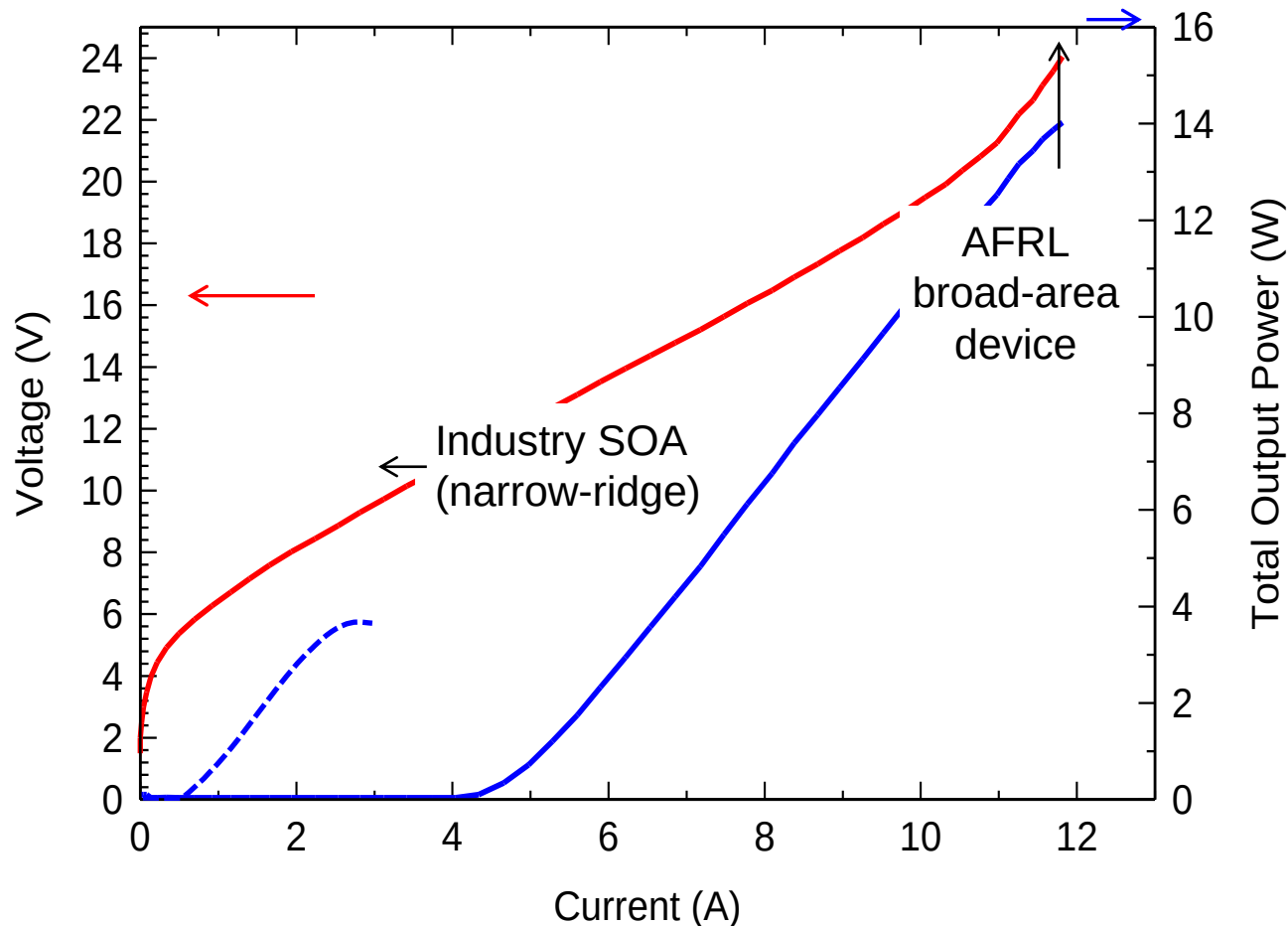
- Quantum Cascade Laser (QCL) technology can produce compact laser sources that emit at the mid-infrared wavelengths, with a promise of high brightness at room temperature.
- Broad-area devices that produce high power suffer from lateral beam filamentation and loss of coherence.
- Narrow ridge devices are required to maintain single lateral mode.
- Long cavity length devices are necessary for high power.
- Narrow ridge ($\sim 5\text{-}10\mu\text{m}$) and long cavity (6-10mm) devices suffer from low yield, high cost, facet damage, high beam divergence etc...
- Researchers at AFRL/RDL have developed a novel technique to produce a laterally coherent beam from broad-area QCLs to produce high brightness from a single device.



Quantum Cascade Laser Research at AFRL/RD



5.0 μm QCL, 45 μm x 3mm uncoated broad-area device
(epi from Northwestern University, processed at AFRL)
 $T=20^\circ\text{C}$, Pulse width=500 ns, Duty Cycle=0.5%





Optically pumped semiconductor laser (OPSL)

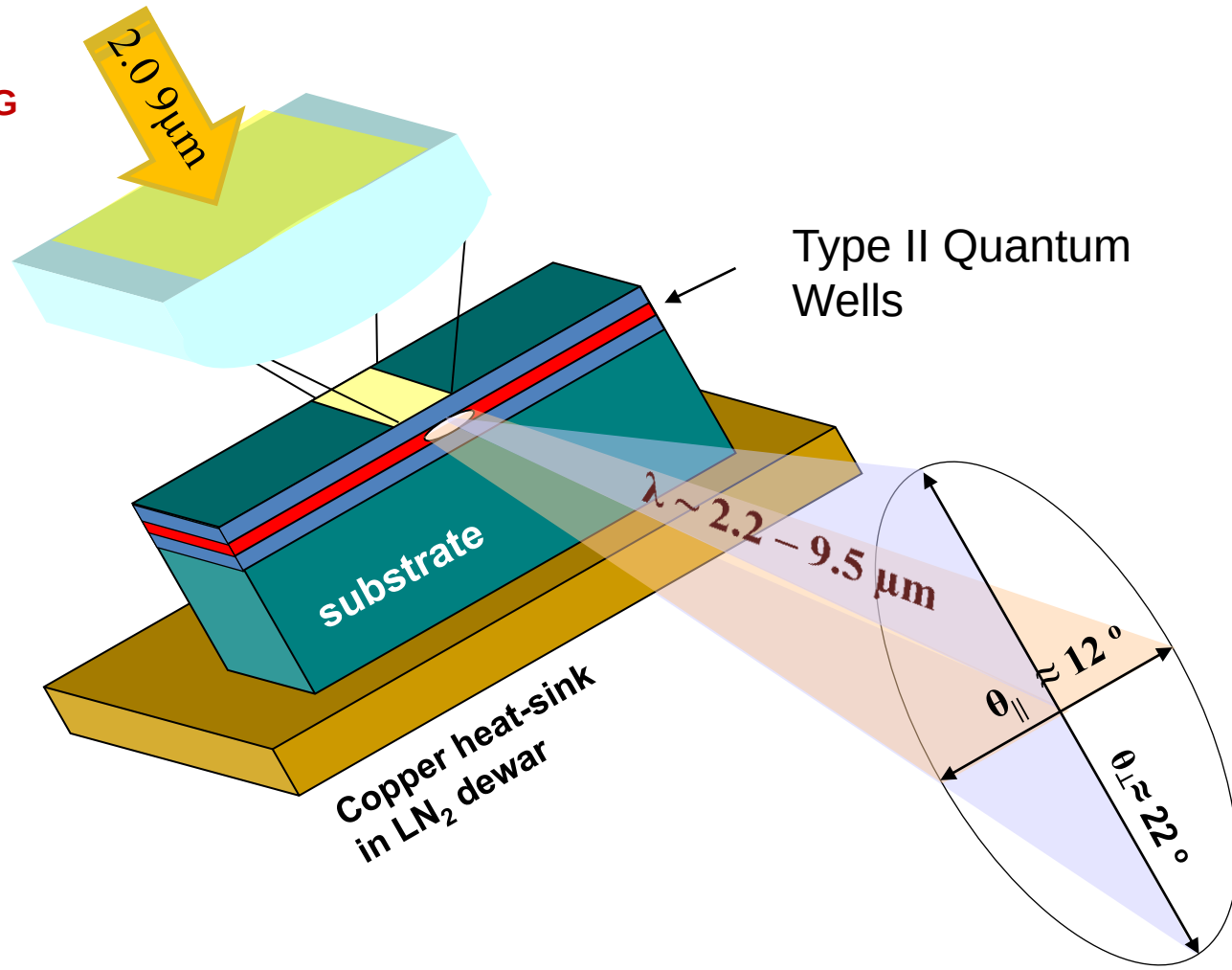
Converts 2 μm pump radiation to 2.2 – 9.5 μm mid-IR radiation



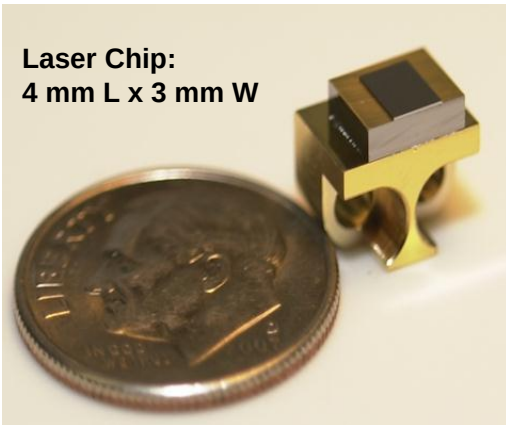
U.S. AIR FORCE

Passively Q-switched Ho:YAG Pump:

- 1.4 mm beam diameter
- Peak Power ~ **90 kW**
- Rep Rate 0.7 – 3 kHz
- Pulse duration ~ **16 ns**
- Linearly polarized



Laser Chip:
4 mm L x 3 mm W

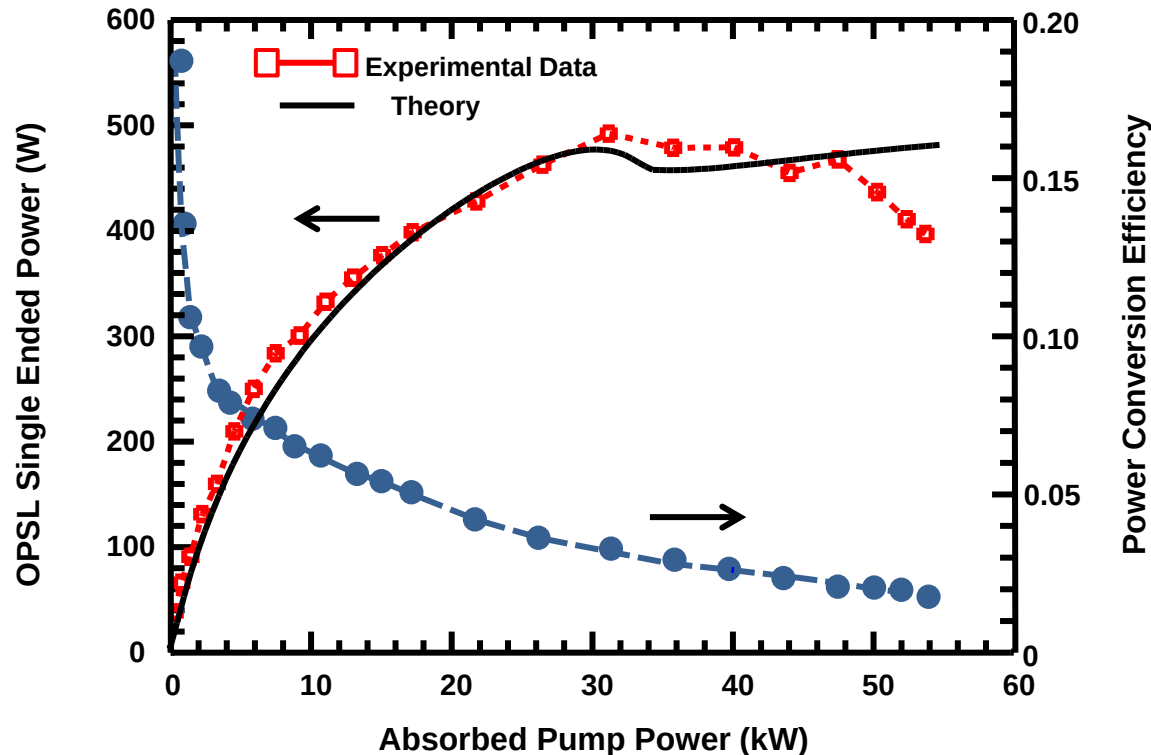




U.S. AIR FORCE

Power Results

Highest reported peak-power from a mid-IR SCL

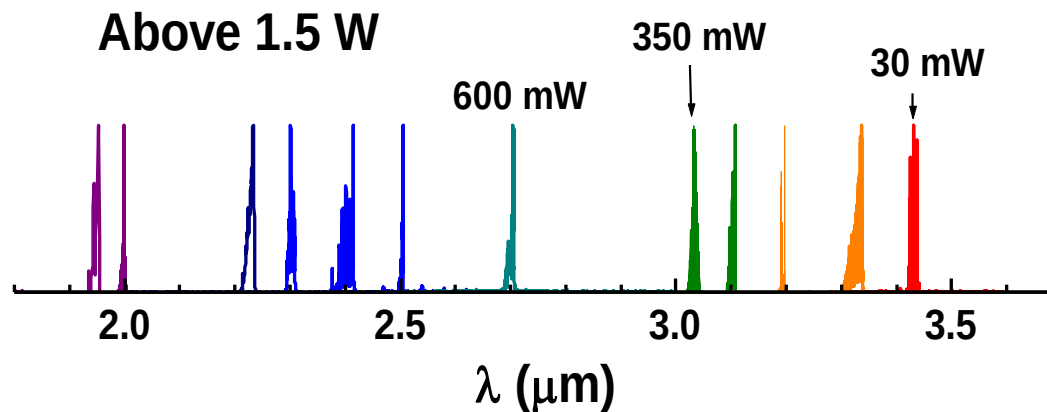


- Maximum single output power of **490 W**
- At low pump power the efficiency is $\approx 20\%$ (agrees with low-power data)
- The decreasing laser efficiency is not due to thermal effects
- A three rate equation model gives good agreement with the data



Room Temperature Diode lasers from 1.9 to 3.5 μm

Type-I QW GaSb-based diode lasers operate in CW regime at Room Temperature in spectral range from 1.9 to 3.5 μm



Narrow ridge waveguide lasers with diffraction limited beam do not suffer from extra optical loss.

The current state-of-the-art thresholds and efficiencies are not fundamentally limited yet and will be improved.

Belenky. SUNY SB



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PERIODICALLY ORIENTED QUASI-PHASEMATCHING



1. Develop affordable, simple techniques for preparation of OP templates
2. Perform thick HVPE growth on OP templates
3. Convert frequency to obtain high power IR radiation

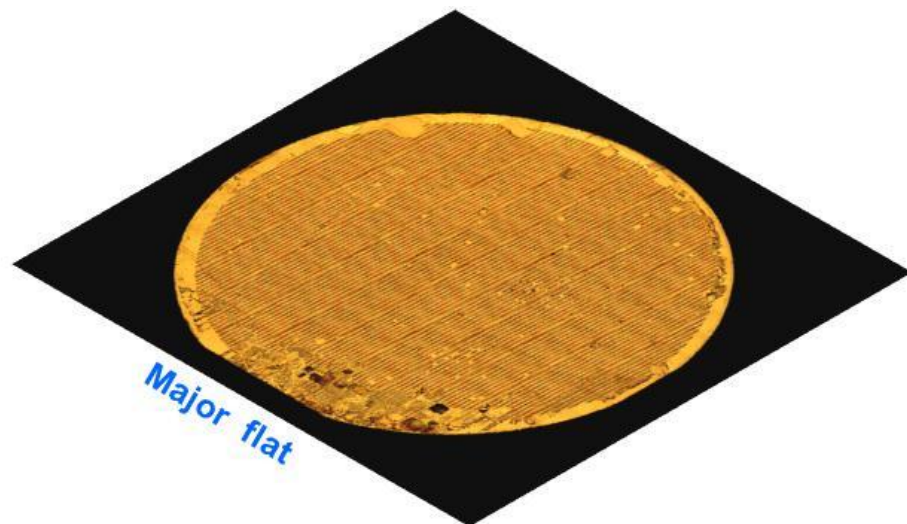
AFRL/RV

Builds on Pioneering AFOSR Funded Research
on PPLN and OPGaAs

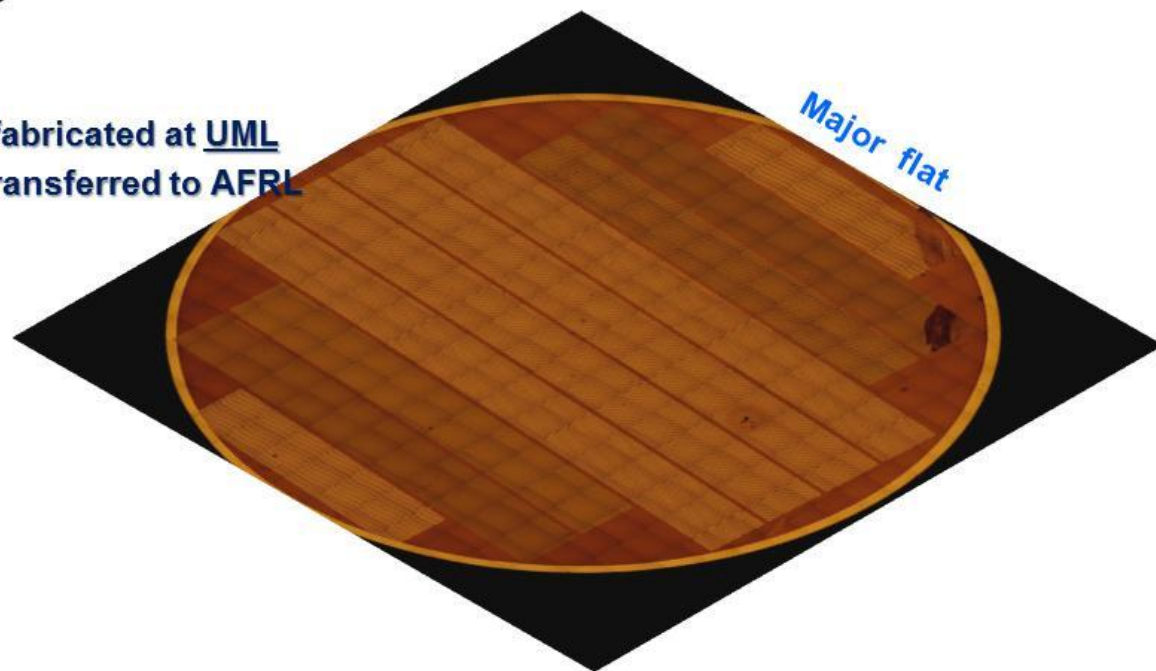


8. Fabrication of OP Templates: continues

(MBE inversion and wafer fused bonding techniques adopted)



2 inch OP (wafer bonded) template fabricated at UML
This bonding technology has been transferred to AFRL



3 inch OP (MBE inverted) template fabricated at BAE Systems



12. Summary of FY12 Progress and Forecast for the Future Research



Summary of FY2012 Progress

- Further optimization of the growth conditions allowed equalizing the growth rate of the oppositely oriented domains, restricting their lateral growth.
- Growths conducted on half-patterned templates helped to find the optimal orientation of the substrate and the pattern. 500 μm thick layer with vertically propagating domain walls were grown on such templates. The results were used as a feedback to improve the template preparation process.
- Growth experiments performed on both wafer fusion bonded and MBE assisted process OP-GaP templates resulted in the first 350 μm thick device quality OPGaP.
- The three HVPE reactors were transported during the BRAC move from Hanscom to Wright-Patterson. The reactors were installed at the EpiLab and the Bulk Growth Lab and hooked up to the facility gas, water and electrical lines.
- Some of the reactors were upgraded with new computer controllable furnaces. New gas lines were added to others to allow the usage of more or alternative precursors/dopands. This aimed to widen the diversity of chemical paths, involving new promising materials and approaches.
- A new cleaning station was installed between the GaAs and GaP reactor, which increased the safety of the reactor operation.
- These funds with other sources were used to increase the capability of the crystal growth facility.
- The critical wafer bonding technique for preparation of OP templates were transferred from UML for in-house research to AFRL. A wafer bonding station was equipped and a contractor was hired.



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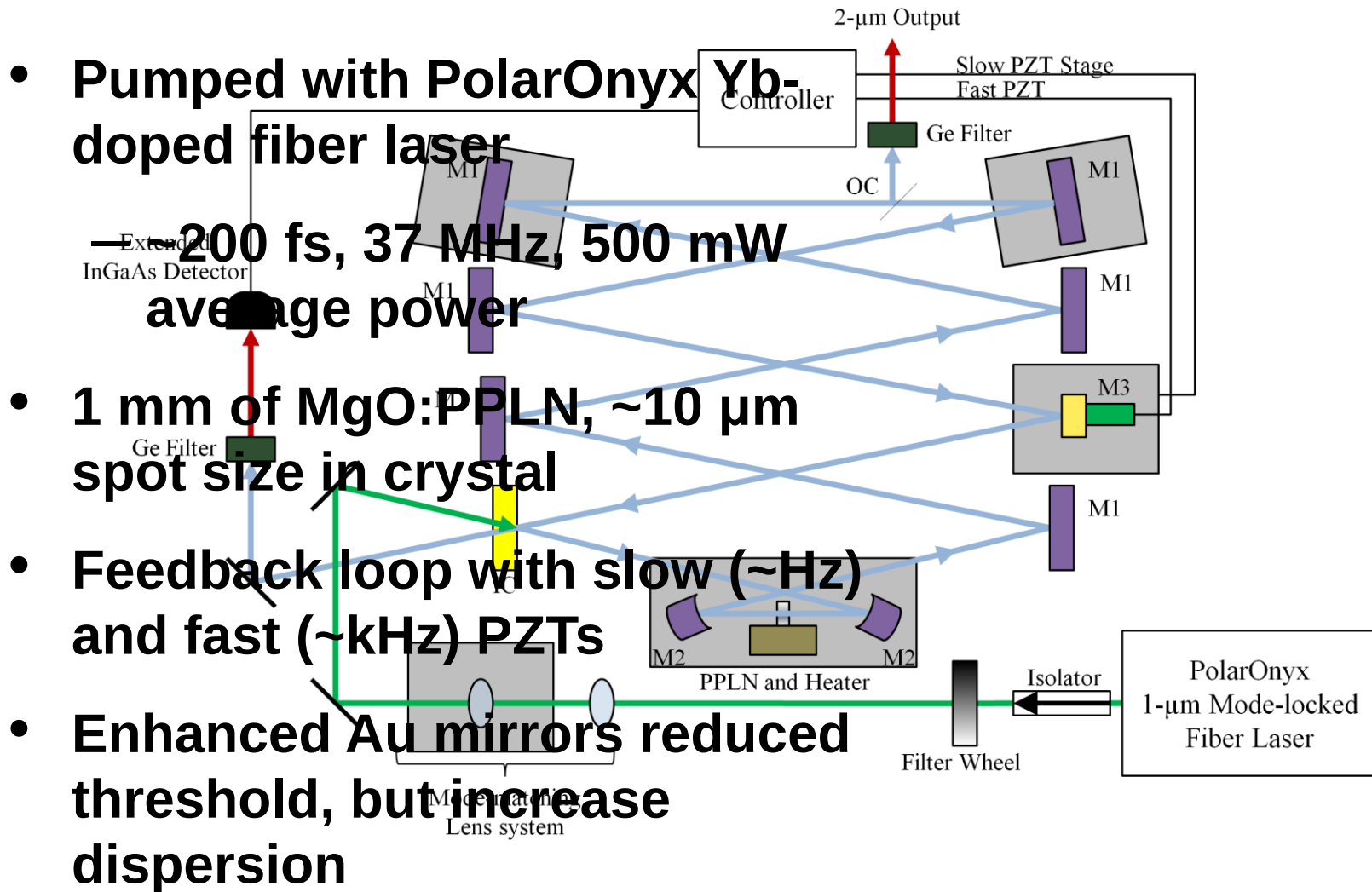
Technology Transfer Examples

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Some Program History



Synch Pumped Degenerate OPO Broad Band Mid-IR Combs



Wang – Polaronyx
Vodopyanov – Stanford, U.C.F. 32



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Some Program History



IRCM



This quarterly exception SAR is being submitted to terminate reporting for the LAIRCM program. As of September 2011, the LAIRCM program is greater than 90 percent expended, therefore; pursuant to section 2432 of title 10, United State Code, this is the final SAR.

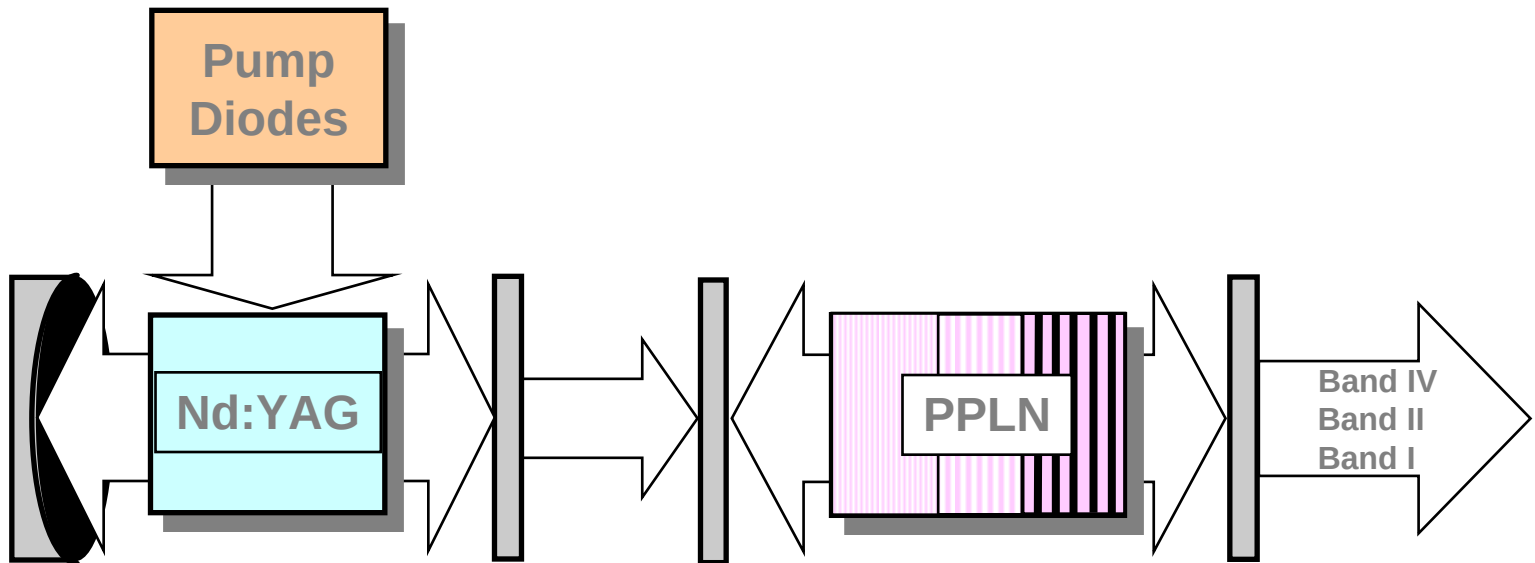
The LAIRCM system is installed on 279 Mobility Air Force (MAF) and Air Force Special Operations Command (AFSOC) aircraft.

Final development efforts are planned for the LAIRCM integration on AFSOC EC-130J and AC-130U aircraft. The aircraft are the last two in the development effort due to their high demand in theater and non-availability for integration efforts.

LAIRCM production cost will be managed under Air Force oversight as Acquisition Category II and III programs for the C-130, C-130J, C-17, C-5, and HC/MC-130J aircraft.



IRCM





AFOSR Contributions

- **Fundamental Advances in Optical Parametric Oscillators**
- **Fundamental Contributions to Diode Pumped Solid-State Lasers**
- **Quasi-Phasematched Nonlinear Optical Materials (PPLN)**
- **Test Devices at AFRL/Sensors**



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New Program Spinoffs



- **Combustion Diagnostics**
- **Cold Ions and Atoms**
- **Ultrashort Pulses, Extreme Light**
 - **High Harmonic Generation**
- **Adaptive Telescopes**



Nobel Prize Winners



- **David Wineland**
- **Steven Chu**
- **Arthur Shawlow**
- **John Hall**

Future Ones?

- **Stephan Harris**
- **Lene Hau**
- **James Fujimoto**



Thank You