23nd ATF Users' Meeting
December 7, 2020

308053 - Development of wavelength conversion techniques for generation of coherent radiation at the mid to long-wave infrared

R. Kupfer[1], J. Wishart[1], T. Rao[1], M. Babzien[1], M. Polyanskiy[1], I Pogorzelski[1], M. Fedurin[1], K. Kusche[1] and M. Palmer [1]

[1]Brookhaven National Laboratory
*BNL-LDRD grant #20-001

The Accelerator Test Facility

BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

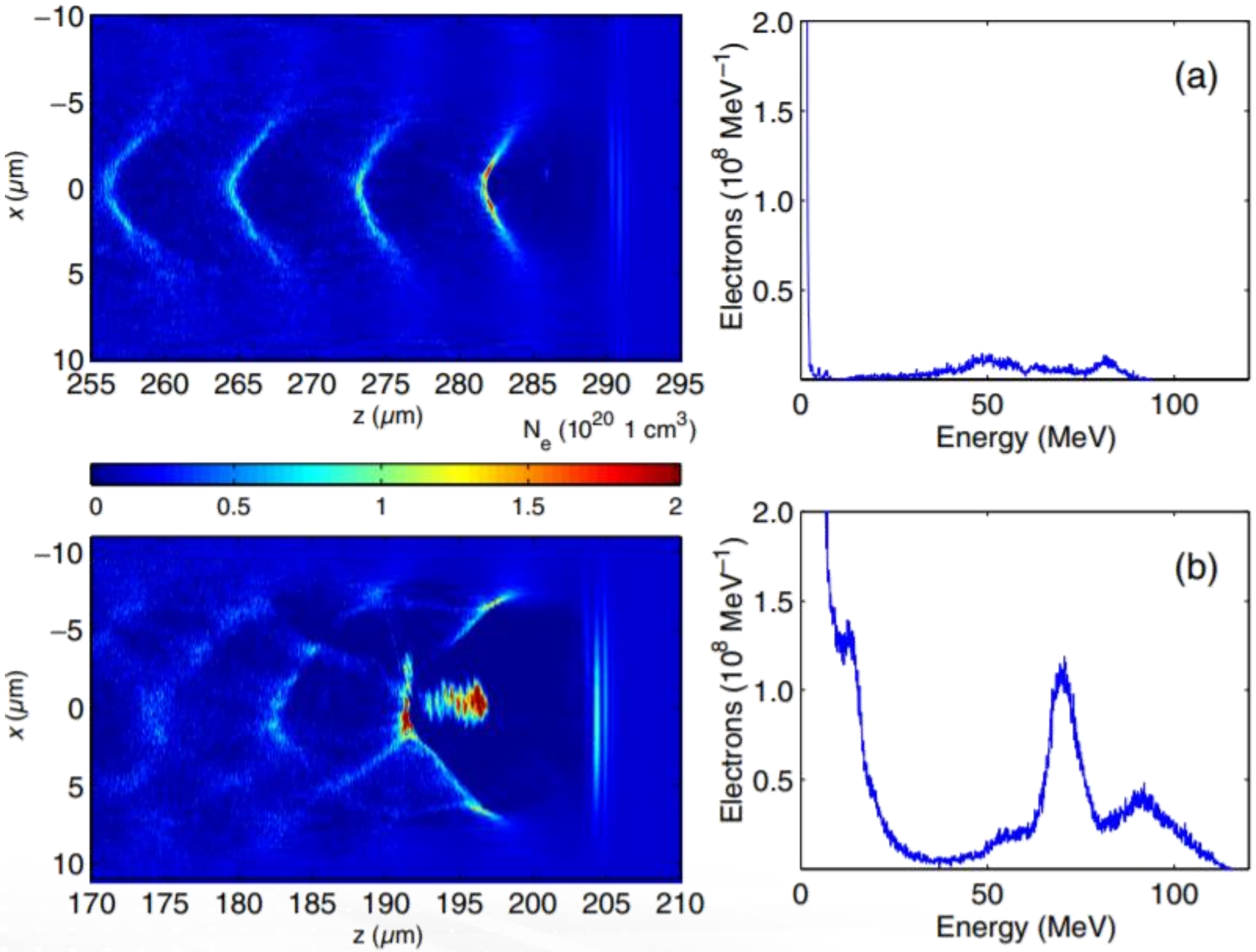
Wave breaking regime

Fastest
Cost-effective
Route

Blowout (bubble) regime

$$T_p = \frac{\omega_p \tau_{laser}}{2\pi {a_0}^{1/2}} < \frac{1}{2}$$

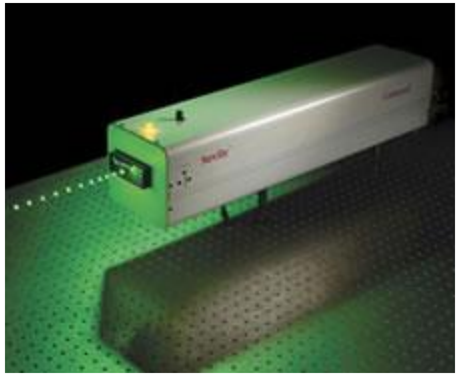
Game changer
Optical injection

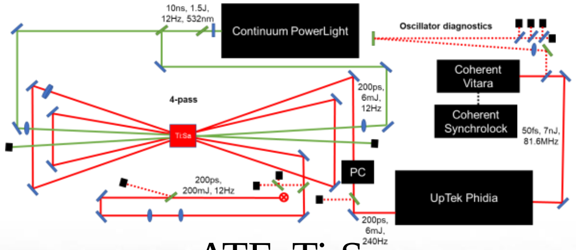


NJP 8 (2006) 186

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Cost effective, mature & currently available sources

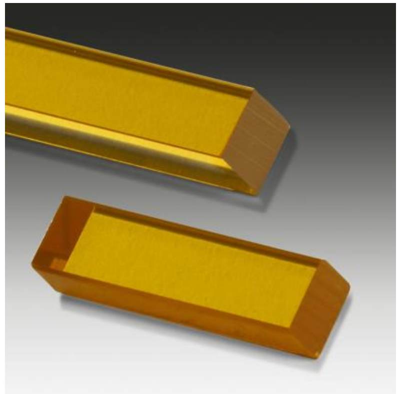




ATF Ti:Sa

Raman converters

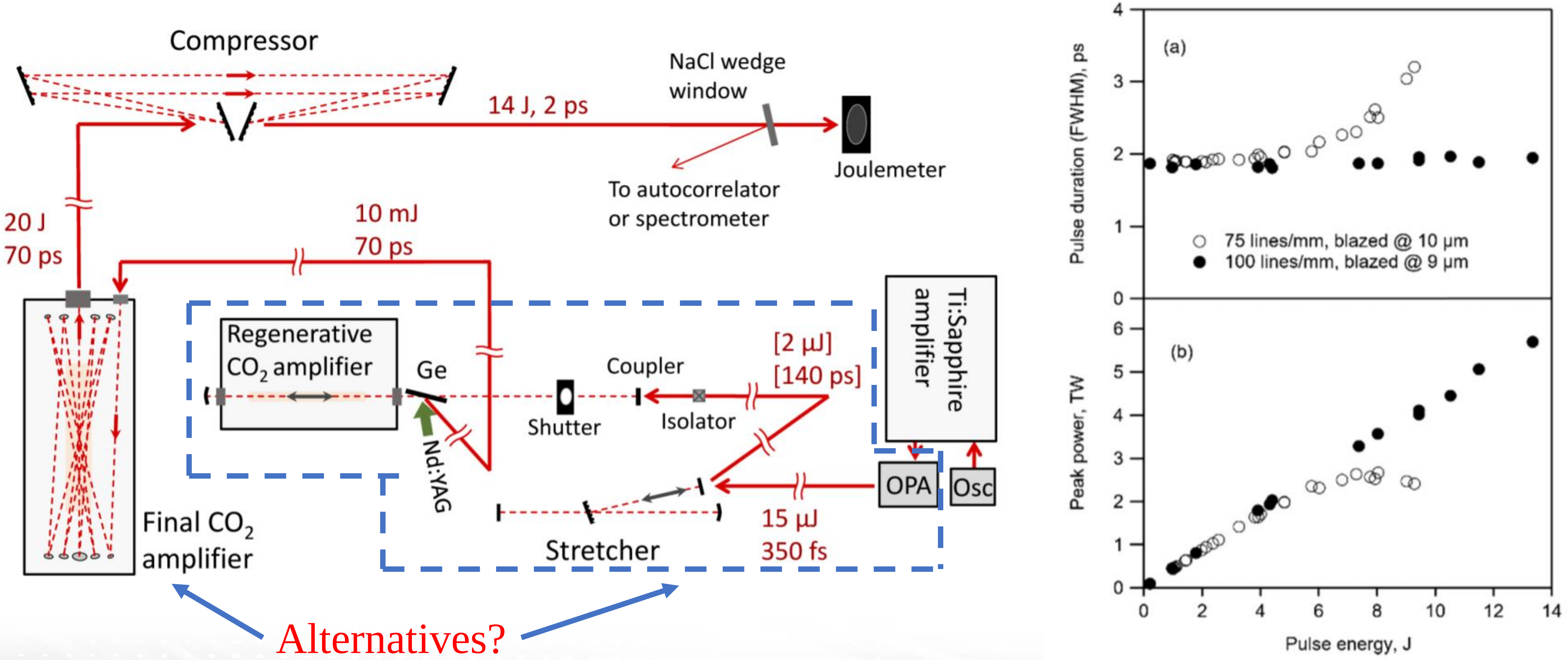
Wide bandgap nonlinear crystal



→ mJ level, broadband , chirped LWIR seed for direct amplification in the current final amplifier

→ High energy, ns, mid-IR pulses for optical pumping of CO_2 amplifier

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR



Alternatives?

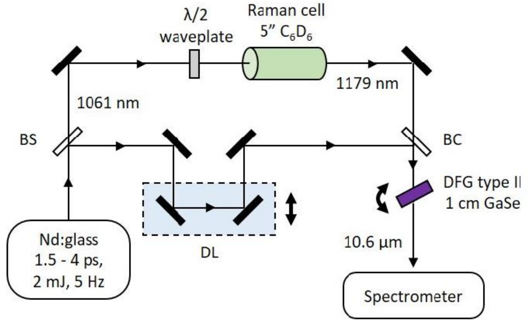
Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

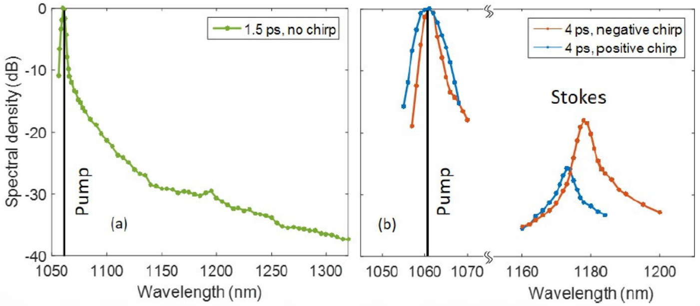
Research Article Vol. 26, No. 5 | 5 Mar 2018 | OPTICS EXPRESS 5154
Optics EXPRESS

Long-wave infrared picosecond parametric amplifier based on Raman shifter technology

E. C. WELCH,* S. YA. TOCHITSKY, J. J. PIGEON, AND C. JOSHI

Neptune Laboratory, Department of Electrical Engineering, University of California Los Angeles, 405 Hilgard Ave, Los Angeles, California 90095
*ewelch@ucla.edu





10 μm Fresnel losses. With this setup, we generated 3 μJ of 10 μm light—an external energy conversion efficiency of 0.15% from the Nd:glass pump. A phase-matching curve for the internal

Development of a dual-wavelength Ti:sapphire multi-pass amplifier and its application to intense mid-infrared generation

J.F. Xia*, J. Song, D. Strickland

Physics Department, Guelph-Waterloo Physics Institute, University of Waterloo, Ont., Canada N2L 3G1

Received 21 December 2001; accepted 28 February 2002

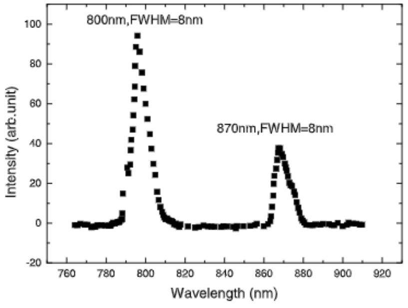


Fig. 4. Two colour spectra from the multi-pass amplifier.

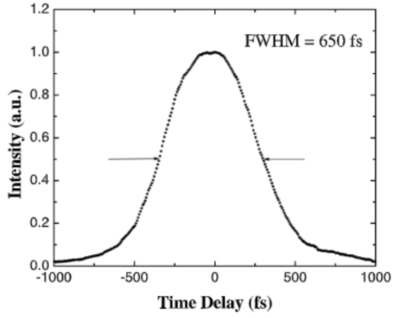


Fig. 8. Single shot cross correlation of mid-infrared radiation and 800 nm radiation.

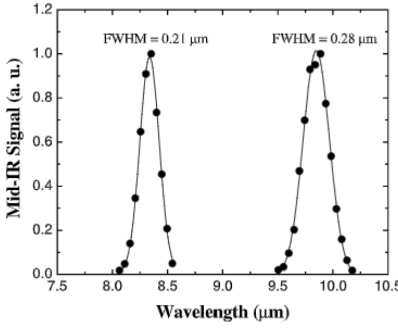


Fig. 7. Mid-infrared spectra generated by the difference frequency mixing of 800 nm short wavelength radiation and 870 or 885 nm long wavelength radiation.

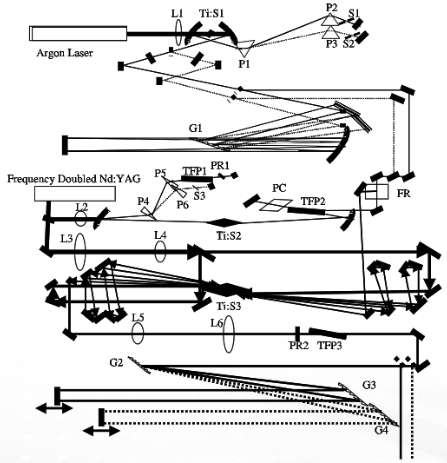
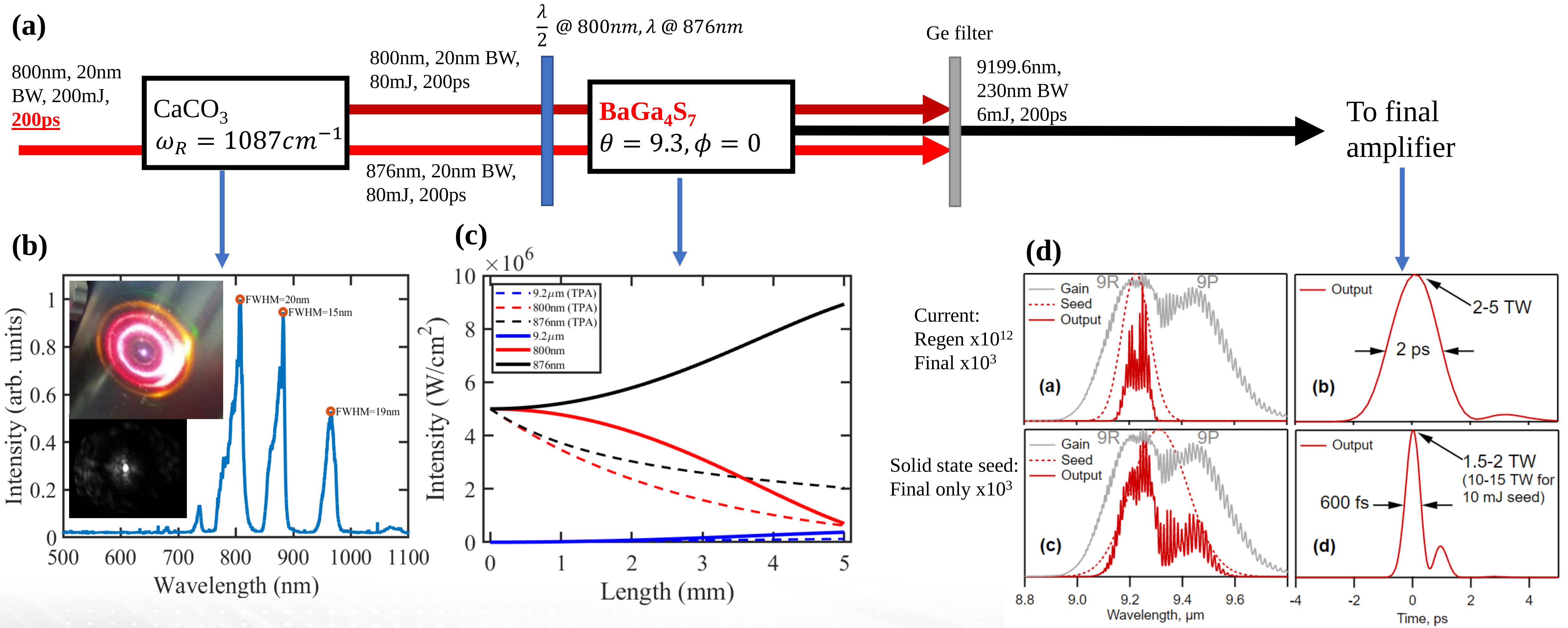


Fig. 1. Dual-wavelength multi-pass amplifier setup. Ti:S1–3, Ti:sapphire laser crystals; L1–6, lenses; P1–6, prisms; S1–3, slits; G1–4, gratings, 1200g/mm; TFP1–3, thin film polarizers; PR1–2, polarization rotators; FR, Faraday rotator; PC, Pockels cell.

at 800 nm and 885 nm. A 6.6 μJ mid-infrared output was achieved at this wavelength with 3.0 mJ total pump energy, corresponding to a total photon conversion efficiency of 2.1%.

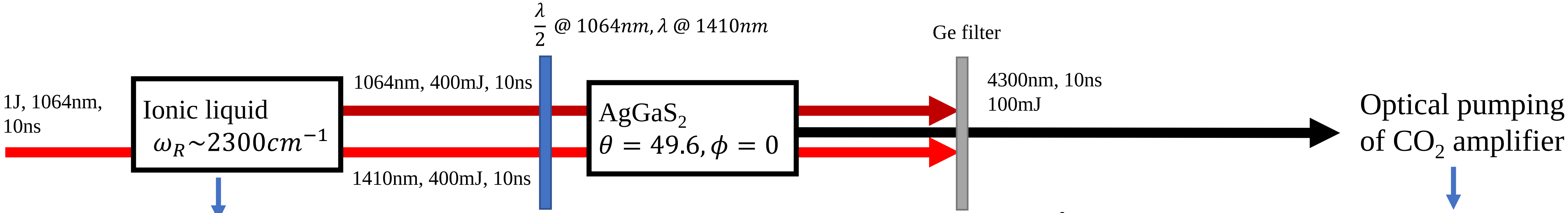
As previously reported, two photon absorption effect caused ~47% absorption of the intensity transmitted into the crystal, which limits the power scaling ability of the mid-infrared generation. That

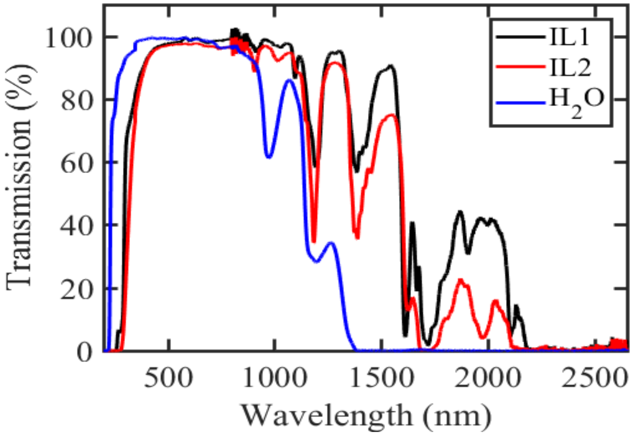
Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

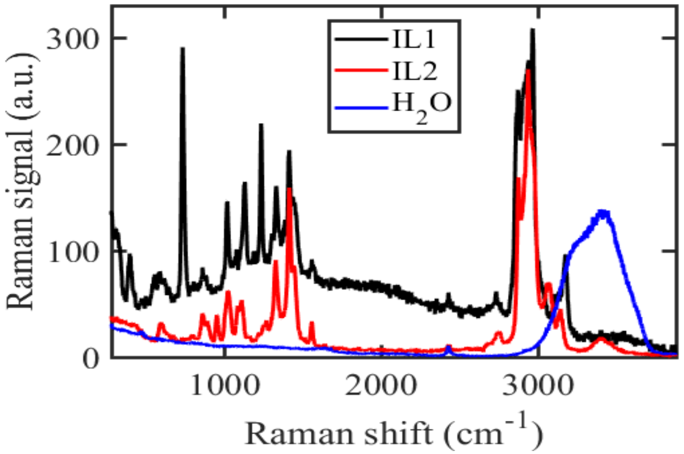


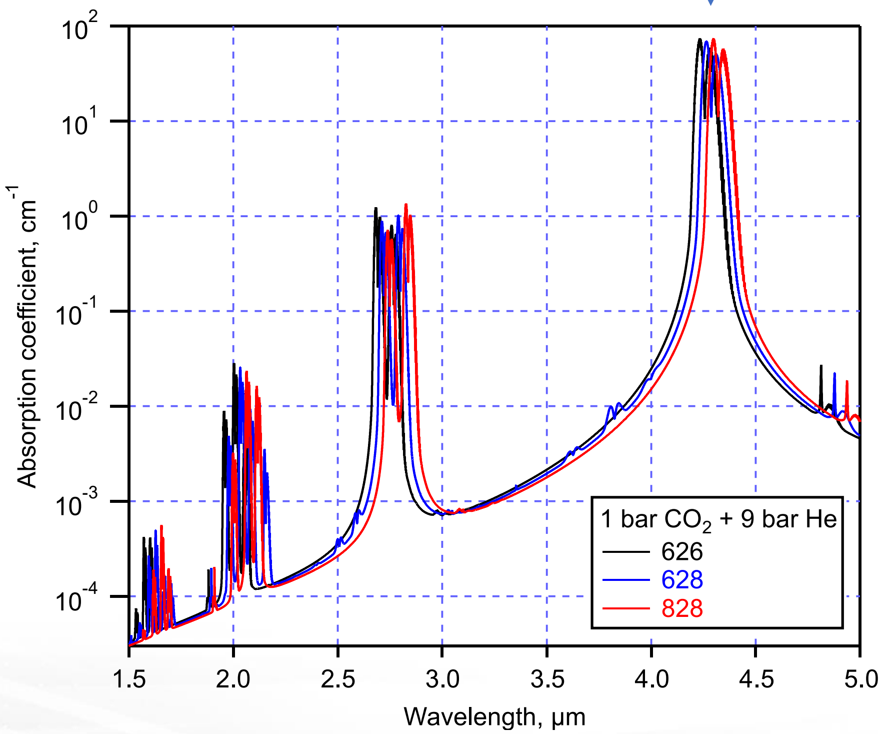
Higher peak power can be achieved by reducing pulse duration while maintaining the same energy

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR





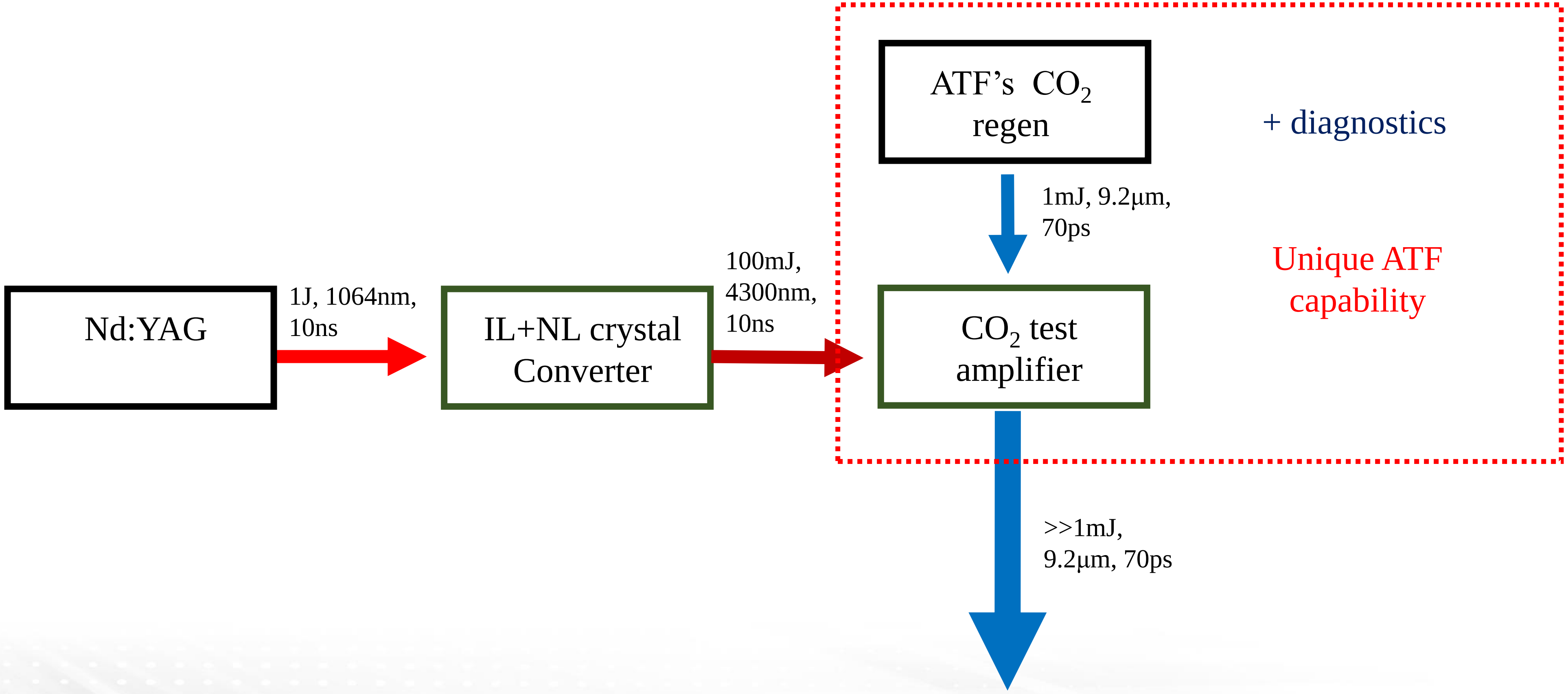




- High Raman cross-section, large Raman shift, wider optical transmission window, high viscosity (suppresses backward Brillouin scattering), favorable physical properties

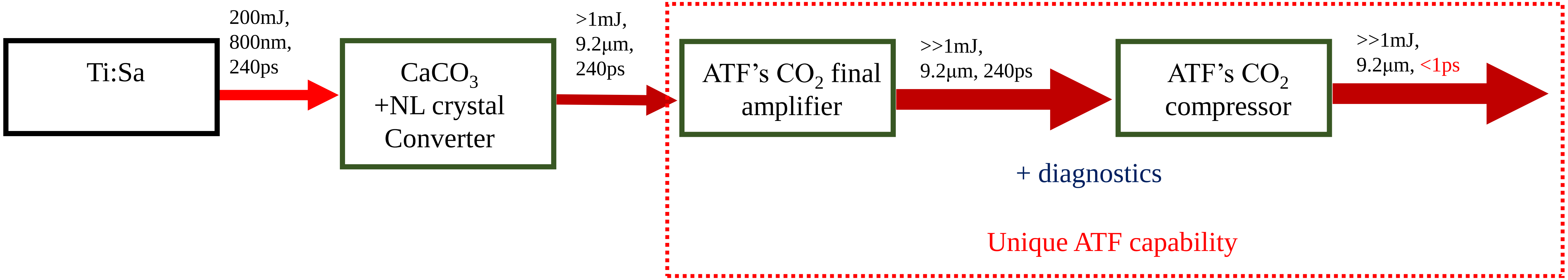
Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Beam time request #1: Optical pumping of CO_2



Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Beam time request #2: Solid-state, broadband LWIR source



Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Work in progress:

- Detailed and systematic study of the optical properties of ionic liquids with different functional groups
- Growth and fabrication of large, laser grade, single crystal BGS
- Initial testing & construction of prototypes will be performed off-line
- Beam time is needed to test seeding of CO_2 final amplifier and optical pumping of CO_2

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Electron Beam Requirements

Parameter	Units	Typical Values	Comments	Requested Values
Beam Energy	MeV	50-65	*Full range is ~15-75 MeV with highest beam quality at nominal values*	*N/A*
Bunch Charge	nC	0.1-2.0	*Bunch length & emittance vary with charge*	*N/A*
Compression	fs	Down to 100 fs (up to 1 kA peak current)	*A magnetic bunch compressor available to compress bunch down to ~100 fs. Beam quality is variable depending on charge and amount of compression required.* *NOTE: Further compression options are being developed to provide bunch lengths down to the ~10 fs level*	*N/A*
Transverse size at IP (σ)	μm	30 – 100 (dependent on IP position)	*It is possible to achieve transverse sizes below 10 um with special permanent magnet optics.*	*N/A*
Normalized Emittance	μm	1 (at 0.3 nC)	*Variable with bunch charge*	*N/A*
Rep. Rate (Hz)	Hz	1.5	*3 Hz also available if needed*	*N/A*
Trains mode	---	Single bunch	*Multi-bunch mode available. Trains of 24 or 48 ns spaced bunches.*	*N/A*

CO_2 Laser Requirements

Configuration	Parameter	Units	Typical Values	Comments	Requested Values
CO_2 Regenerative Amplifier Beam	Wavelength	µm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
	Peak Power	GW	~3		
	Pulse Mode	---	Single		
	Pulse Length	ps	2		*Chirped*
	Pulse Energy	mJ	6		*>1mJ*
	M^2	---	~1.5		
	Repetition Rate	Hz	1.5	*3 Hz also available if needed*	*1.5*
	Polarization	---	Linear	*Circular polarization available at slightly reduced power*	
CO_2 CPA Beam	Wavelength	µm	9.2	*Wavelength determined by mixed isotope gain media*	*9.2*
Note that delivery of full power pulses to the Experimental Hall is presently limited to Beamline #1 only.	Peak Power	TW	2	*~5 TW operation is planned for FY21 (requires further in-vacuum transport upgrade). A 3-year development effort to achieve >10 TW and deliver to users is in progress.*	*N/A*
	Pulse Mode	---	Single		
	Pulse Length	ps	2		
	Pulse Energy	J	~5	*Maximum pulse energies of >10 J will become available in FY20*	
	M^2	---	~2		
	Repetition Rate	Hz	0.05		
	Polarization		Linear	*Adjustable linear polarization along with circular polarization will become available in FY20*	

Near IR Experimental Laser Requirements

Ti:Sapphire Laser System	Units	Stage I Values	Stage II Values	Comments	Requested Values
Central Wavelength	nm	800	800	*Stage I parameters have been delivered, while Stage II parameters will be available for user experiments once our vacuum transport installation is complete (now planned for FY21 after COVID-19 delays)*	*800*
FWHM Bandwidth	nm	20	13		*15*
Compressed FWHM Pulse Width	fs	<55	<75	*Transport of compressed pulses will initially include a very limited number of experimental interaction points. Please consult with the ATF Team if you need this capability.*	*chirped*
Chirped FWHM Pulse Width	ps	≥50	≥50		
Chirped Energy	mJ	>30	200		*200*
Compressed Energy	mJ	>14	100		*N/A*
Energy to Experiments	mJ	>10	>80		
Power to Experiments	GW	>250	>1067		

Nd:YAG Laser System	Units	Typical Values	2021 Modifications	Comments	Requested Values
Wavelength	nm	1064	1064	*Single pulse*	
Energy	mJ	5	100		
Pulse Width	ps	14	<20		
Wavelength	nm	532		*Frequency doubled*	
Energy	mJ	0.5			
Pulse Width	ps	10			

Special Equipment Requirements and Hazards

- Electron Beam
  - N/A
- CO_2 Laser
  - Regen only / final amp only
- Ti:Sapphire and Nd:YAG Lasers
  - Chirped pulses
- Hazards & Special Installation Requirements
  - Generation of new wavelengths

Experimental Time Request

CY2021 Time Request

Capability	Setup Hours	Running Hours
Electron Beam Only	N/A	N/A
Laser* Only (in Laser Rooms)	N/A	40Hr in CO_2 room
Laser(s)* + Electron Beam		

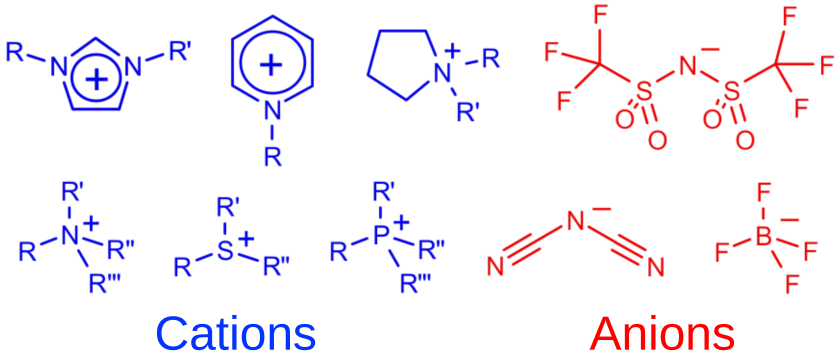
Time Estimate for Remaining Years of Experiment (including CY2021)

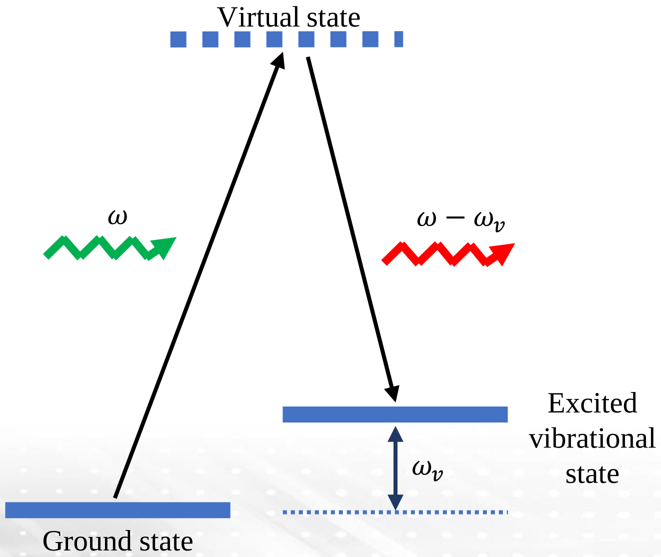
Capability	Setup Hours	Running Hours
Electron Beam Only	N/A	N/A
Laser* Only (in FEL Room)	N/A	120
Laser(s)* + Electron Beam		

* Laser = Near-IR or LWIR (CO_2) Laser

Development of wavelength conversion techniques for generation of coherent radiation at the M/LWIR

Ionic liquids have desirable properties and should be tunable for a specific shift.*





- ✓ Longer Raman shifts compared to solids.
- ✓ * Tunability: Ions can be selected for their Raman properties.
- ✓ Aromatics, double and triple bonds have high Raman cross sections.
- ✓ Higher IL viscosities reduce Brillouin scattering (scales inversely with viscosity)
- ✓ Viscosity can be controlled independently by changing R groups without affecting the vibrational spectroscopy.
- ✓ Many ILs have wide optical transmission windows.
- ✓ Many ILs have thermal stabilities above 300 ˚C in closed systems.

- ➢ This research addresses the core interests of the BES Condensed Phase and Interfacial Molecular Science (CPIMS) Program: "basic research at the boundary of chemistry and physics, pursuing a molecular-level understanding of chemical, physical, and electron- and photon-driven processes in liquids."