Design and Performance of 1762 nm Tm-doped Fiber Amplifiers for Manipulation and Control of Optical Qubits in 133Ba+ Ions

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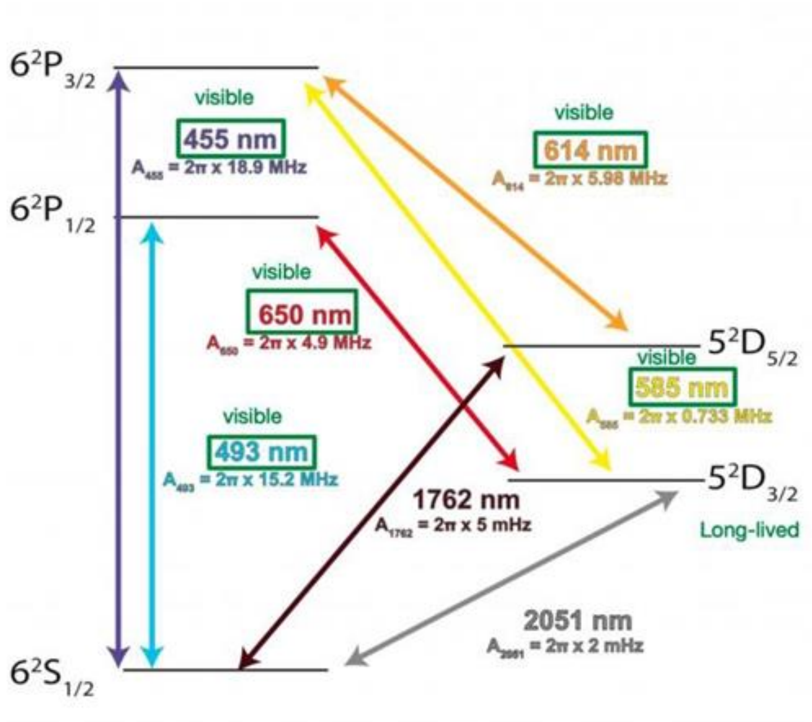
Outline

- Motivation and Objectives
- Architecture and Design of 1762 nm TDFAs
- Experimental and Simulated Performance of 1762 nm TDFAs
- Applications of 1762 nm TDFAs in a Representative Quantum Computing Experiment
- Discussion of Potential Experimental Applications
- Summary and Conclusions

Motivation



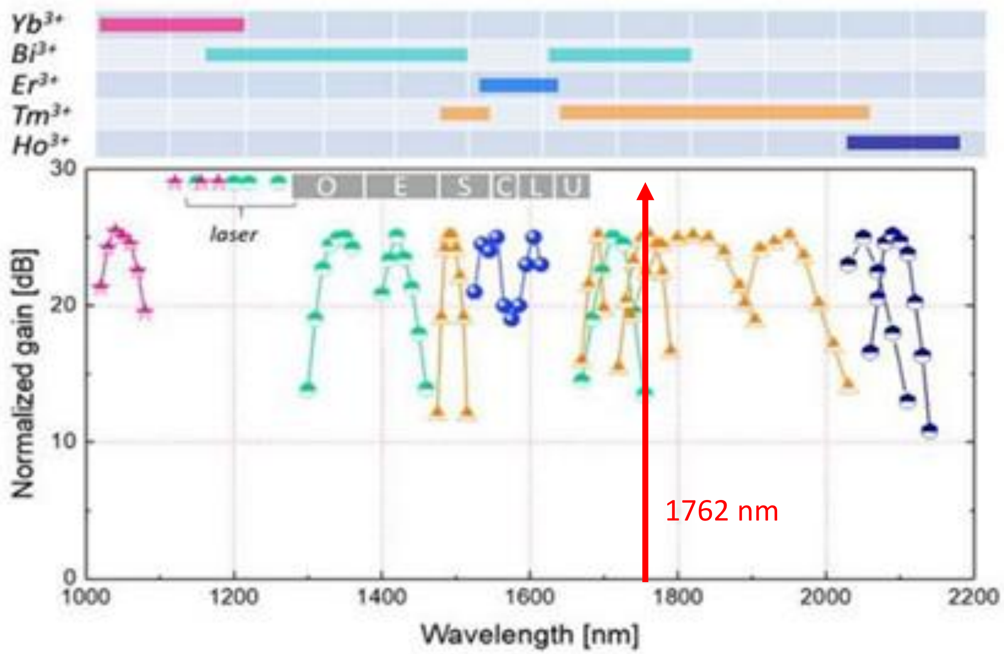
Gross 133Ba+ energy level diagram with transition wavelengths and level lifetimes.

Justin Christensen, "High-fidelity operation of a radioactive trapped-ion qubit," Ph.D Thesis, University of California at Los Angeles (2020). https://escholarship.org/uc/item/1975f05v.

Amara A. Graps, "From Perfect Qubit to Goldilocks Qubit for Ion Traps," https://www.insidequantumtechnology.com/news-archive/from-perfect- qubit-to-goldilocks-qubit-for-ion-traps/

- **Existing narrow linewidth single frequency sources at 1762 nm have typical 3-100 mW optical power with maximum demonstrated so far of 500 mW**
- **In quantum computing experiments as in spectroscopy, higher output power is always better**

Objectives

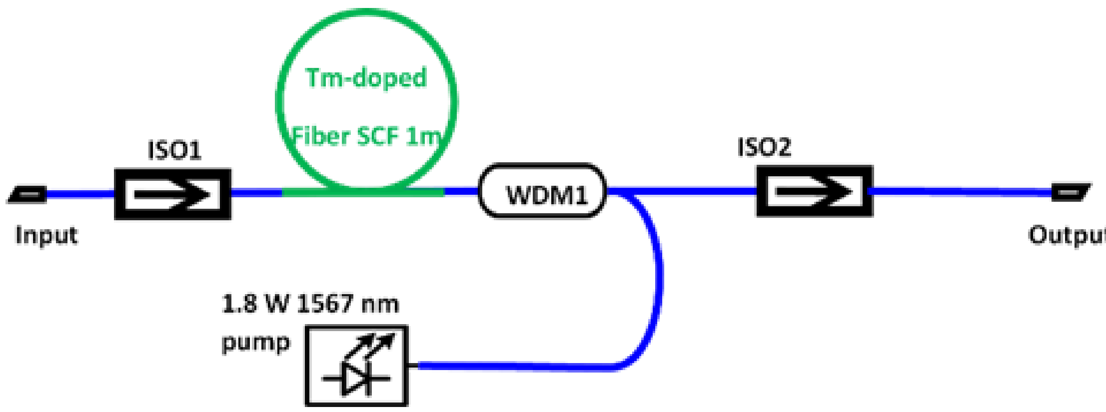


Graphical summary of the infrared wavelength bands covered by single clad doped fiber amplifiers in 2024.

D. Richardson, Tutorial W4E.1, OFC 2022

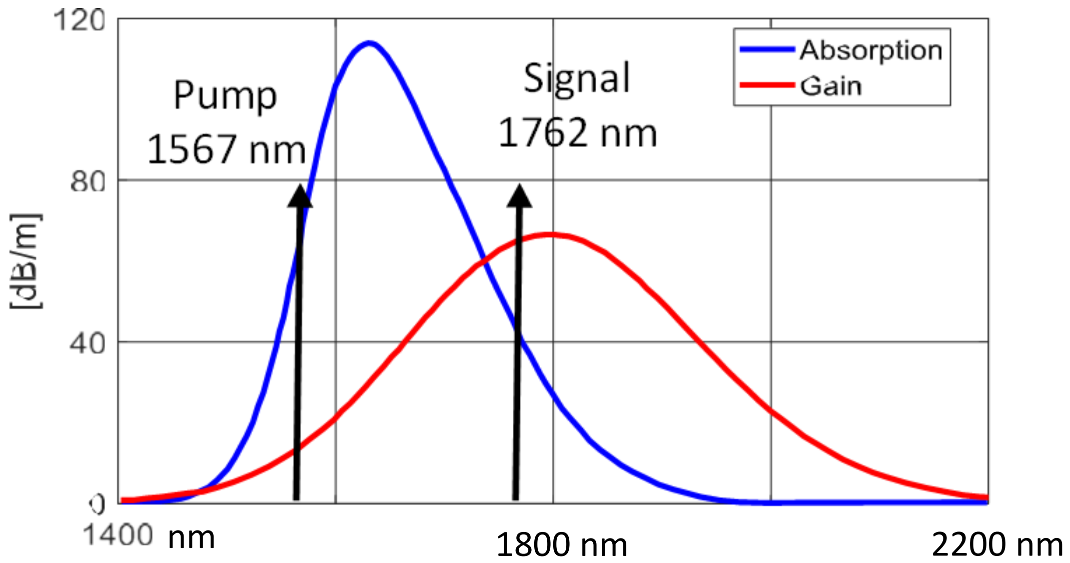
- **Thulium-doped fiber amplifiers can readily generate multi-Watt CW and pulsed output powers from 1750—2100 nm**

Basic Elements of a Tm-doped Fiber Amplifier



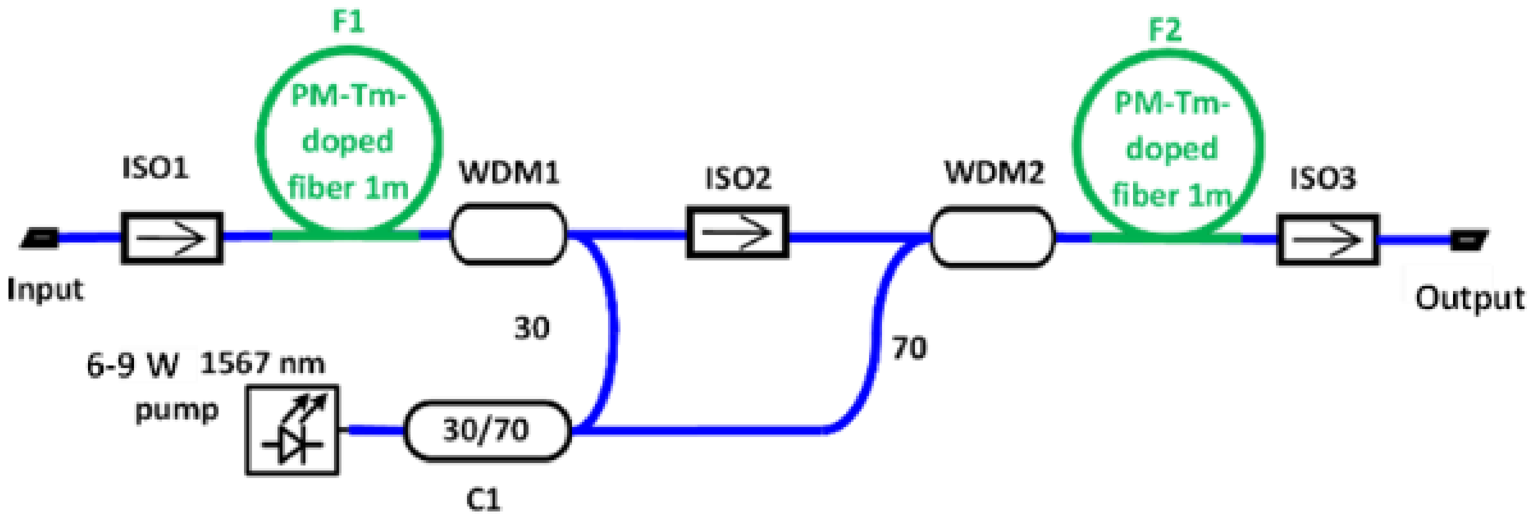
- A length of **single mode silica fiber doped with Tm3+ ions** diffused in the core
- A source of **pump light**, absorbed at an appropriate low wavelength, that generates optical gain in a band of higher wavelengths through the process of stimulated emission
- A means of **multiplexing** the pump light and signal light together in the Tm-doped fiber
- **Optical isolators** to couple the input signal into the TDF, couple the output signal out of the TDF after amplification, establish unidirectional amplification, and minimize the effects of external reflections
- **Input and output fiber pigtails** to interface the TDFA with the outside world

Gain and Absorption Coefficients for a Representative Tm-doped Fiber



- Pump wavelength is 1567 nm
- Effective signal amplification can occur from 1750 nm up to >2100 nm

Design and Architecture of a Two-Stage TDFA



- Short Tm-doped fiber lengths optimize performance at low signal wavelength of 1762 nm
- Two stage architecture achieves high gain and high power conversion efficiency for 1762 nm signal

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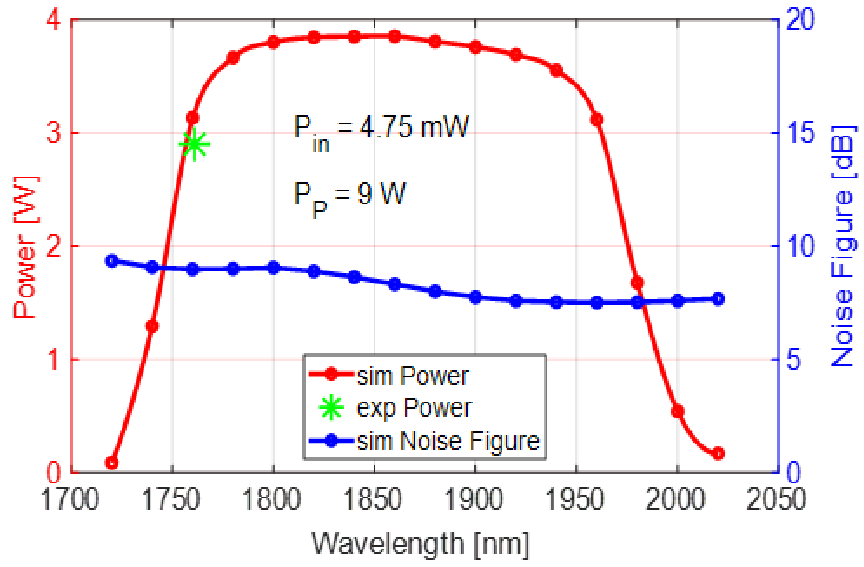
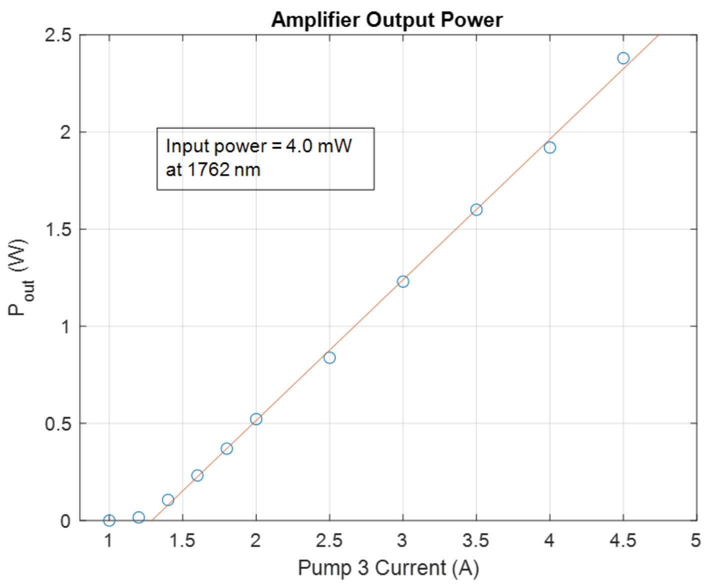
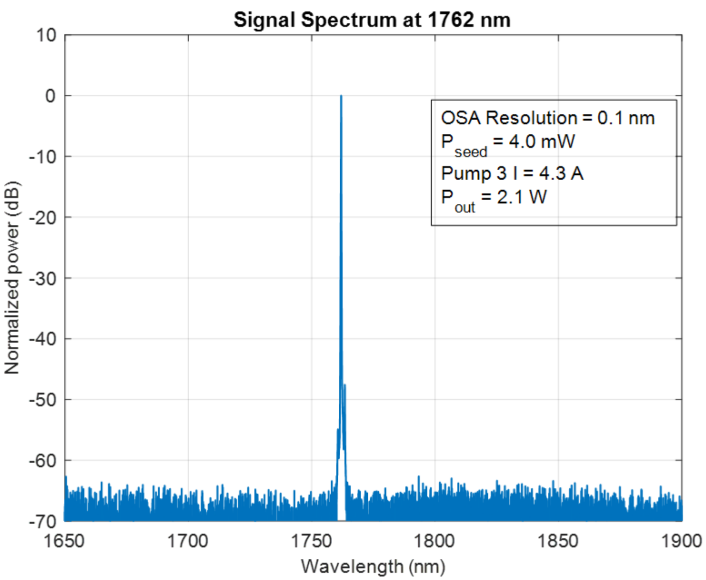
Experimental and Simulated Performance of a Two-Stage Polarization-Maintaining TDFA



- Experimental output power = 2.95 W at 1760 nm
- Experimental results agree well with simulations

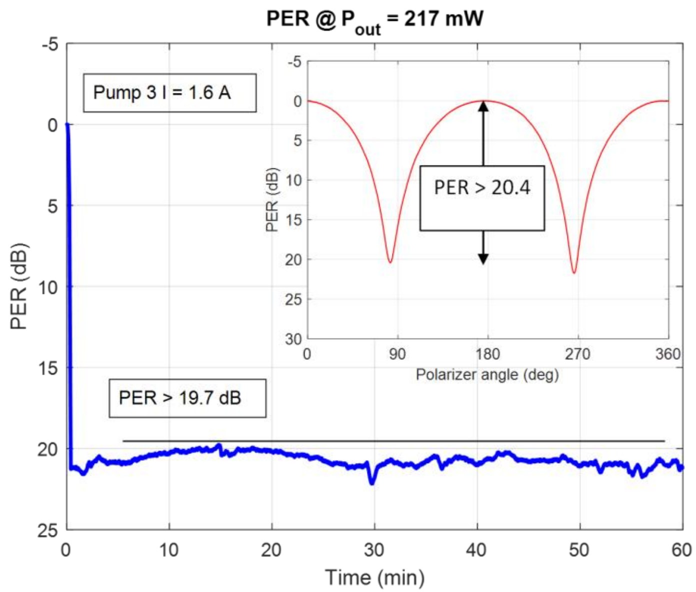
Experimental Performance of a Two-Stage Polarization-Maintaining TDFA With an Internal Bandpass Filter at 1762 nm

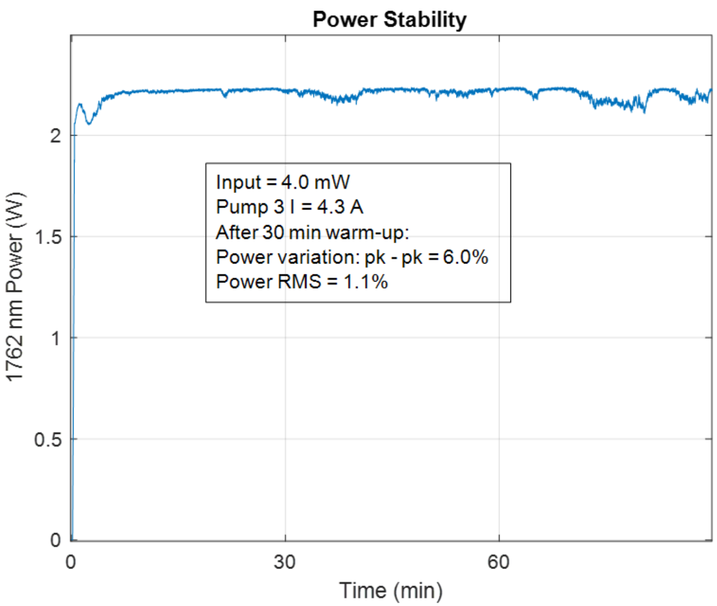




- Experimental output power = 2.4 W at 1762 nm
- Output OSNR > 60 dB/0.1 nm

Experimental Performance of a Two-Stage Polarization-Maintaining TDFA With an Internal Bandpass Filter at 1762 nm



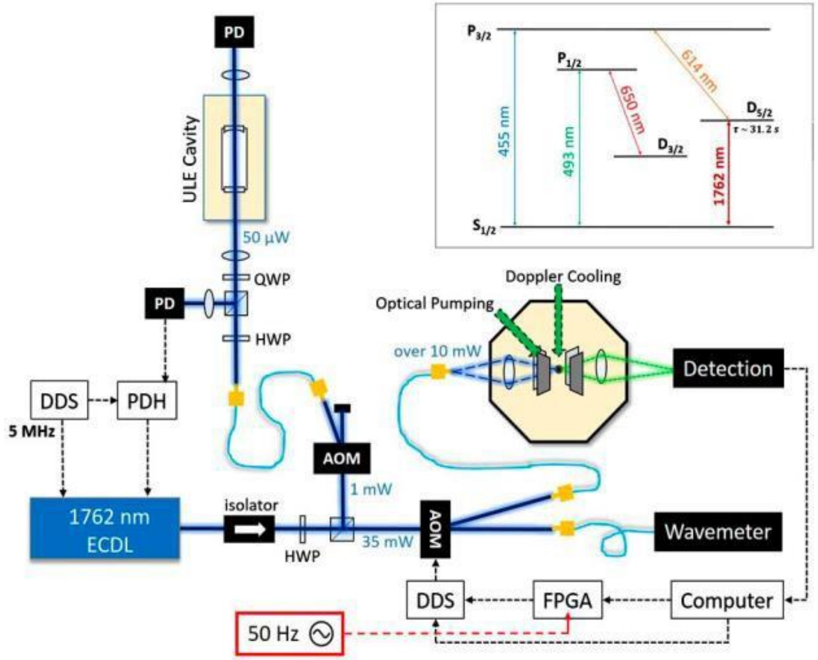


- Experimental PER > 19 dB
- Output Power Stability 1.1% RMS

Practical Advantages of the 1762 nm PM TDFA Design

- Up to 3 W CW Output Power at 1762 nm (6x greater than other sources)
- Highly Stable Output Power with Time
- Linearly Polarized Output with PER > 19 dB
- All-Fiber Design Means that No Bulk Optical Alignment is Required
- Input and Output Modes Determined by the PM Fibers: Gaussian Beams with $M^2 < 1.1$
- Immediate and Simple Integration into Laboratory Setups

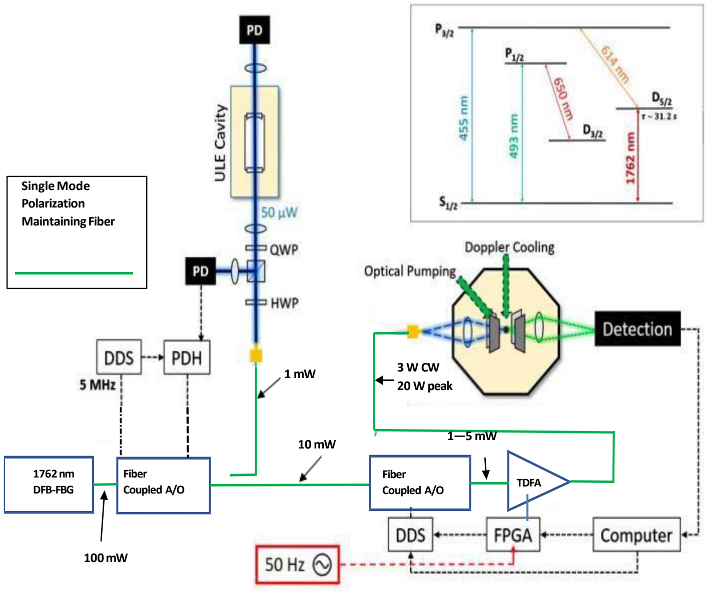
Existing Experimental Setup for Qubit Manipulation and Control



Dahyun Yum, Debashis De Munshi, Tarun Dutta, and Manas Mukherjee, "Optical barium ion qubit," J. Opt. Soc. Am. B 34, 1632-1636 (2017)
https://doi.org/10.1364/JOSAB.34.001632

- **Setup Based Largely on Free Space Optics with Minimal Use of Optical Fibers**
- **~10 mW of CW Output Power at 1762 nm Available at the Ion Trap**

Proposed Experimental Setup for Qubit Manipulation and Control Using a 3 W 1762 nm PM TDFA



- Setup Based Largely on Fiber Optics and TDFAs with Minimal Use of Bulk Optics
- ~3 W of CW Output Power at 1762 nm Available at the Ion Trap (300x increase over the existing experimental setup)

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Summary and Conclusions

- **We Have Reported and Demonstrated 3W PM TDFAs Operating at 1762 nm**
- **We Observe Good Agreement Between Experimental Results and Simulations**
- **With This TDFA Design, Up to 300 x Increase of CW Optical Power at 1762 nm is Available in a Typical Quantum Experimental Setup**
- **The Increased Power is Important for Future Quantum Computing Applications Using Hundreds/Thousands of Physical Ions to Implement Error Correction Algorithms**
- **Expected PM TDFA Output Power Progression:**
  - ✓ **2-3 W CW Today**
  - ✓ **5-7 W CW Tomorrow**
  - ✓ **>25 W CW Day After Tomorrow**
- **We Expect Our 1762 nm PM TDFA to Contribute Significantly to the Next Generation of Quantum Computing Experiments using 133 Ba+ Ions**

Thank You For Your Attention!