High-power Frequency Doubling for the Production of 780 nm Light

Steven Peil, Scott Crane, Christopher R. Ekstrom

U. S. Naval Observatory, Washington, D.C. 20392

http://tycho.usno.navy.mil/clockdev/CDpapers/

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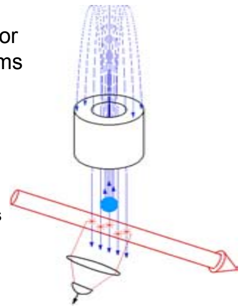
We are developing a source of 780 nm light by frequency doubling the amplified output of a telecom laser for use in rubidium atomic clocks. A doubling efficiency of 70% and generated power of 100 mW have been demonstrated.

Motivation

- atomic fountain clocks require hundreds of mWs of laser light for cooling and manipulation of atoms

- available 780 nm sources for rubidium systems:

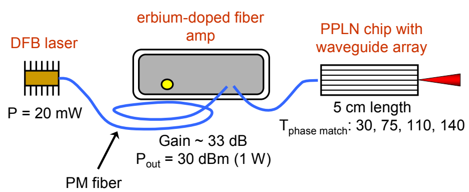


1) diode lasers
   - good low-power (~10 mW) sources
   - high-power (~100 mW) diodes and tapered amplifier chips becoming scarce (and less reliable?)

2) Ti:sapphire laser
   - 1-2 W output
   - Price >$200k
   - ~1 year service interval for pump laser
   - water-cooled
   - mode control servo (birefringent filter)

Telecom Laser-based 780 nm Source

- frequency double 1560.48 nm light from telecom laser



- achieve high doubling efficiency with PPLN waveguide

- technology is likely to be available (even improved) in the future

- long life, rugged components

- easy to integrate, mostly fiber

Current 1560 nm Source

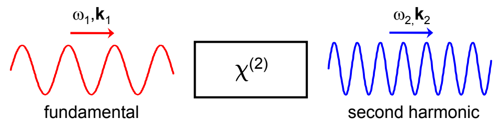
- DFB laser: no external cavity – grating etched into gain medium

- λ=1560.61 nm (1560.48 nm is between values in C-band of ITU grid)

- temperature coefficient = 0.1 nm /°C ⟶ 0.5 mK temp. regulation required for 5 MHz frequency stability

- fiber laser possible alternative to diode laser

Frequency Doubling



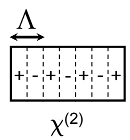
- fundamental at ω_1 and second harmonic at ω_2 get out of phase due to dispersion, $n(\omega_1) \neq n(\omega_2)$

- need to phase match: $2\mathbf{k}_1 - \mathbf{k}_2 = 0$ inside the doubling medium

- can be achieved with birefringence (angle tuning) or temperature tuning

Quasi-phase Matching

- reverse phase lag at certain intervals by changing sign of $\chi^{(2)}$



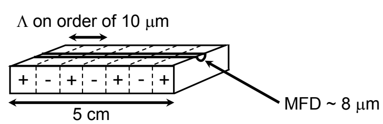
- quasi-phase match: $2\mathbf{k}_1-\mathbf{k}_2+\mathbf{K}=0$, where $|\mathbf{K}|=2\pi/\Lambda$ and Λ is the poling period … enables doubling in more situations

- optimal when Λ is twice the *coherence length* (length ℓ for which $(2\mathbf{k}_1-\mathbf{k}_2+\mathbf{K})\ell = \pi$) ...

$$\Lambda = 2\lambda/(4(n_2-n_1))$$

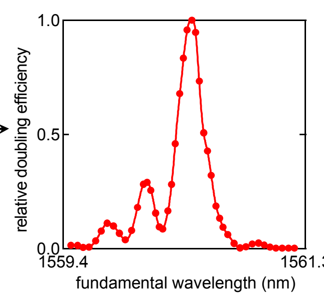
PPLN Waveguide

- we use a waveguide fabricated in a periodically poled lithium niobate (PPLN) crystal to increase the interaction length for doubling while keeping the beam waist small and the intensity high

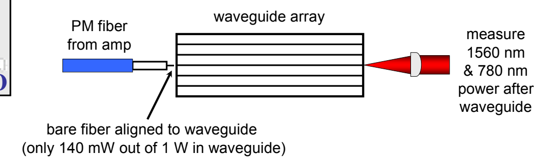


- we have waveguides that phase match at temps. of 30, 75, 110, and 140 C

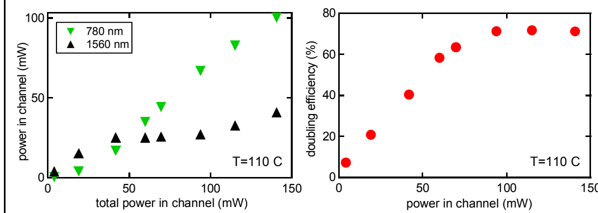
- example wavelength tuning curve for 110 C



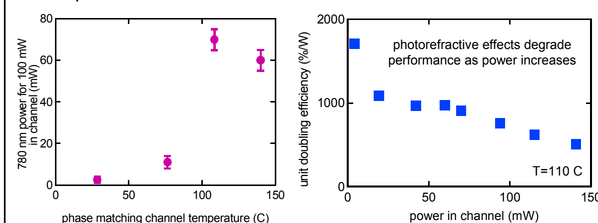
Generation of 780 nm Light



- demonstrate 100 mW of 780 nm light, 70% doubling efficiency



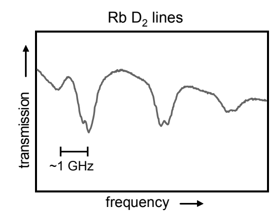
- observe decrease in photorefractive effects with increasing temperature



- preliminary rubidium spectrum – frequency stability can be improved to resolve individual 6 MHz peaks:

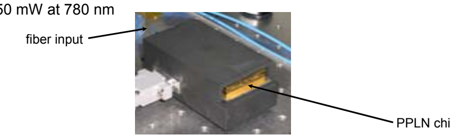
  1) improved temp. regulation

  2) fiber laser



Future Work

- increasing 780 nm power
  1) coupling
     - fiber pigtailed waveguide
       ⟶ 35-40% coupling efficiency … flat 70% doubling rate would give ~ 250 mW at 780 nm



     - taper waveguide output to couple into 780 nm fiber

  2) photorefractive effects
     - higher crystal temperatures
     - MgO doping of PPLN
     - carry out splitting, AOM shifting at 1560 nm … then double several lower power beams

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