The Usage of MgO:PPLN Crystal in f-to-2f Interferometry

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ABSTRACT
MgO:PPLN crystals encounter limitations in the feed-forward carrier-envelope phase (CEP) stabilization for f-to-2f interferometry due to phase mismatch, and temperature and photorefractive effects that can compromise the accuracy of second harmonic generation (SHG).

INTRODUCTION
In the field of ultrafast laser technology, the accurate measurement and control of the CEP of laser pulses play a crucial role in applications such as high resolution spectroscopy, optical parametric oscillators, and high-precision metrology [1, 2]. In order to achieve CEP stabilization, changes in f_{ceo} need to be detected, which is completed in feed-forward f-to-2f interferometry. Periodically Poled Lithium Niobate (PPLN) crystals are often used in f-to-2f interferometry because of their unique nonlinear properties. PPLNs' quasi-phase matching capability allows efficient second harmonic generation (SHG) frequency components from laser pulses [1].

The material of lithium niobate in the PPLN is a highly ferroelectric material. This means that the atoms in the crystal each have a dipole unit, and if an electric field of about 22 kV/mm is applied for a few milliseconds, the electric field can invert the crystal structure [3]. This electric field creates an inversion, ultimately flipping the orientation of the dipole. The period of the crystal, denoted with Λ, is determined by the wavelength of light being absorbed, which is 1.55 μm commonly for telecommunication [1]. MgO:PPLNs also have common uses in blue-green laser sources. Doping with magnesium alters the nonlinear coefficient from that of an undoped PPLN, which determines the strength of the material's nonlinear optical response. MgO:PPLNs uses the largest nonlinear value of the material's tensor of d_{33} = 27 pm/V. The introduction of magnesium can enhance the effectiveness of the poling process and enable efficient quasi phase matching for nonlinear frequency conversion applications [3].

Quasi phase matching (QPM) allows for efficient generation of the second harmonic by ensuring that the phases of the fundamental and second harmonic waves align properly within the nonlinear crystal [4]. When phase matching is achieved, the waves propagate with the same phase velocity, which enables constructive interference and efficient energy transfer from the fundamental frequency to the second harmonic frequency. The key idea behind QPM is that by periodically reversing the sign of the nonlinear coefficient, the effective phase mismatch can be canceled out or significantly reduced. This periodic variation allows for more flexible tuning of the phase-matching condition, enabling efficient SHG over a broader range of wavelengths. When a high-intensity laser beam at the fundamental frequency is incident on the MgO:PPLN crystal, the periodic poling structure interacts with the fundamental wave. As the wave propagates through the crystal, the alternating regions with different signs of the nonlinear coefficient ensure that, over a certain distance, the accumulated phase mismatch is compensated [4]. QPM allowing for constructive interference is shown in Figure 1 compared to a nonlinear crystal. The PPLN creates a stronger beam of generated photons than simpler, nonlinear crystals. The up and down arrows in the periodic structure of the PPLN represent the different inverted charges of the crystal.

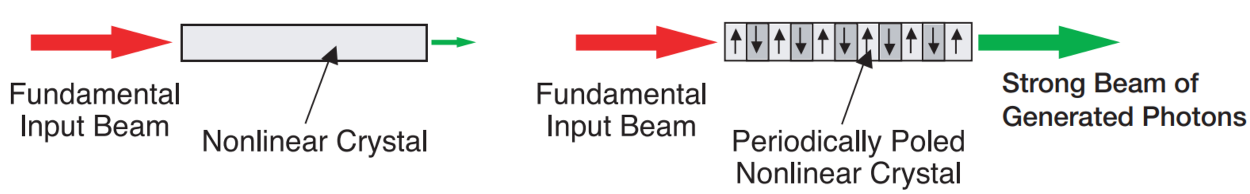

Figure 1: Comparing the generated photons of a nonlinear crystal versus a periodically poled nonlinear crystal [3]

METHODS
Most recently, the CEP of an Er:Yb:glass laser was phase stabilized with a feed-forward technique at 1.55 μm with a low timing jitter of 2.9 as in the range of 1-3 MHz, with long term stability for 8 hours [5]. In this experimental setup, there is both an in and out of loop f-to-2f interferometer to convert optical signals into RF signals to find f_{ceo}

[6]. The method of SHG is used with a magnesium doped PPLN at 1024 nm. It is stated that spectrally broadened pulses from a highly nonlinear fiber from 1000 nm to 2080 nm with 250 mW of power are coupled to a magnesium doped PPLN tuned at SHG at 1024 nm [5]. There is no information on the aperture dimensions of the crystal, which would be necessary to know to recreate these results. There is also no mention of how much magnesium is doped in the PPLN, typically it is 5%, but it is not stated in the paper [3].

RESULTS AND INTERPRETATION

Using a MgO:PPLN allows for efficient second harmonic generation due to its nonlinear coefficients and periodic poling, but its index of refraction is still vulnerable to changes in temperature. The Sellmeier equation shown below demonstrates how the index of refraction is dependent on both wavelength and temperature [1]. Due to the nonlinear nature of PPLNs, coefficients that are dependent on temperature and the wavelength cannot be ignored.

$$n^2(\lambda, T) = a_1 + b_1 f + \frac{a_2 + b_2 f}{\lambda^2 - (a_3 + b_3 f)^2} + \frac{a_4 + b_4 f}{\lambda^2 - (a_5)^2} - a_6 \lambda^2$$

Here, the temperature dependent factor is $f = (T - 24.5°C)(T + 570.82)$

After careful plotting of this data, implementing the experimental setup at room temperature 20℃ (room temperature) displays weak or negligible temperature dependence, but it is unclear if the f-to-2f interferometer in the setup occurs at room temperature. It is unknown if there are any thermal effects from the laser that is being coupled to the super continuum generator that are leaking into a nearby area of the MgO:PPLN crystal. If these thermal effects are significant, it may alter the index of refraction, causing potential mismatch in phase matching with the second harmonic waves. MgO:PPLN crystals can be very sensitive to changes in temperature, and it is unclear how the experimental setup accounts for these potential effects or works around them.

While temperature can alter the index of refraction of the crystal, the photorefractive effect can also benefit or harm the nonlinear effects of the MgO:PPLN. The photorefractive effect refers to the phenomenon where the refractive index of the crystal is modulated by light, resulting in changes in the crystal's optical properties [7]. Photogenerated carriers in the crystal affect the space-charge field and ultimately the refractive index. It is known that with a pump of higher power, the PPLN will exhibit more of a measurable photorefractive effect, resulting in beam distortion. These distortions can result in permanent damage to the crystal. Under milliwatt level illumination, there are still measurable photorefractive induced QPM wavelength shifts [8]. However, it is recommended that the PPLN operates at a temperature between 150-200℃ to allow all the charge carriers to re-diffuse. Again, it is unclear what temperature the experimental setup in [5,6] are operating in, and if the temperature or photorefractive effects to the MgO:PPLN crystal are considered.

Although there can be temperature and photorefractive effects that compromise accuracy, the experimental setup implemented for SHG demonstrates excellent control and adherence to low power levels. The output of the supercontinuum generator stays around 250 mW of power [5]. Careful consideration has been given to maintain power levels within the safe operating range of the crystal to ensure optimal performance and avoid entering the damage threshold of the PPLN. It is not stated directly what precise power monitoring and regulation systems are employed to maintain power stability and prevent any power spikes or fluctuations that could surpass the recommended limits. However, even at around 250 mW power levels, photorefractive effects and beam distortions may still be noticeable, and it is unclear if the authors in [5, 6] work around or account for this.

CONCLUSIONS

MgO:PPLN crystals have emerged as a valuable tool in this field, offering efficient second harmonic generation (SHG) and enabling low timing jitter of the CEP. However, their utilization comes with certain limitations. Temperature sensitivity poses a challenge as changes in temperature can affect the phase matching condition required for efficient SHG. Moreover, the photorefractive effect inherent in these crystals can cause undesired refractive index changes, impacting their performance.

Typically, PPLN crystals are used in the form of bulk optics off-chip, where a crystal is employed for frequency conversion. Recent research has focused on developing waveguides as an alternative platform. By utilizing materials like aluminum nitride and silicon nitride, researchers have been able to create on-chip waveguides that offer compactness, enhanced light-matter interaction, and potentially better control over temperature effects and photorefractive issues [9]. These advancements in waveguide technology hold promise for more integrated and efficient CEP stabilization systems, high-resolution spectroscopy and attosecond science [2].

REFERENCES

1. Material Properties of Lithium Niobate. 12 Nov 2020 [cited 19 May 2023]. In: Covesion [Internet]. Available: https://covesion.com/en/resource/material-properties-of-lithium-niobate/
2. Yu T, Nam C. Carrier-envelope phase stabilization of femtosecond lasers by the direct locking method. Prog Quantum Electron. 2012;36: 541–565.
3. Periodically Poled Lithium Niobate (PPLN) Tutorial. [cited 31 May 2023]. Available: https://www.thorlabs.com/catalogpages/693.pdf
4. MgO:PPLN Bulk Crystals. 27 Aug 2020 [cited 19 May 2023]. In: Covesion [Internet]. Available: https://covesion.com/en/products/mgoppln-crystals-and-chips/
5. Lemons R, Liu W, de Fuentes IF, Droste S, Steinmeyer G, Durfee CG, et al. Carrier-envelope phase stabilization of an Er:Yb:glass laser via a feed-forward technique. Opt Lett. 2019;44: 5610–5613.
6. Hirschman J, Lemons R, Chansky E, Steinmeyer G, Carbajo S. Long-term hybrid stabilization of the carrier-envelope phase. Opt Express. 2020;28: 34093–34103
7. Taya M, Bashaw MC, Fejer MM. Photorefractive effects in periodically poled ferroelectrics. Opt Lett. 1996;21: 857–859.
8. Li G, Cui Y, Wang J. Photorefractive inhibition of second harmonic generation in periodically poled MgO doped $LiNbO_3$ waveguide. Opt Express. 2013;21: 21790–21799.
9. Okawachi Y, Yu M, Cardenas J, Ji X, Lipson M, Gaeta AL. Silicon-Chip-Based f-2f Interferometer. Conference on Lasers and Electro-Optics. Optica Publishing Group; 2019. p. SF3H.4