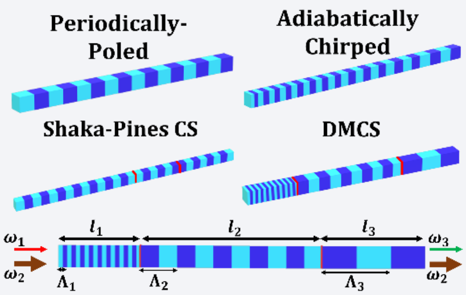
Detuning Modulated Composite Segments for robust optical frequency conversion

Yuval Reches , Elazar Elias, Haim Suchowski
Raymond and Beverly Sackler School of Physics and Astronomy,
Tel Aviv University, Ramat Aviv 6779801, Tel Aviv, Israel
TEL AVIV UNIVERSITY אוניברסיטת תל אביב

Introduction

- Sum Frequency Generation (SFG) is the process of creating an output beam with a frequency equal to the sum of two input beams' frequencies. Under certain approximations, SFG can be modeled as a 2-level system.
- A common method for creating an efficient SFG process is using a Quasi-Phase-Matching (QPM) crystal, with a sign-alternating polarization.
- Detuning Modulated Composite Segments (DMCS) is a 2-level system conversion scheme that enables efficient and robust broadband conversion.



- We show a proof of concept for implementing DMCS schemes in SFG QPM crystals and demonstrate its superiority over other common QPM schemes under length and power constraints.

Methods

- The unitary propagator, $U(z,0)$ that describes an SFG process in a QPM crystal segment is:

$$\begin{pmatrix} \cos\left(\frac{A}{2}\right)+i\frac{\Delta k}{2\Omega_R}\sin\left(\frac{A}{2}\right) & -i\frac{\kappa}{\Omega_R}\sin\left(\frac{A}{2}\right) \\ -i\frac{\kappa}{\Omega_R}\sin\frac{A}{2} & \cos\left(\frac{A}{2}\right)-i\frac{\Delta k}{2\Omega_R}\sin\left(\frac{A}{2}\right) \end{pmatrix}$$

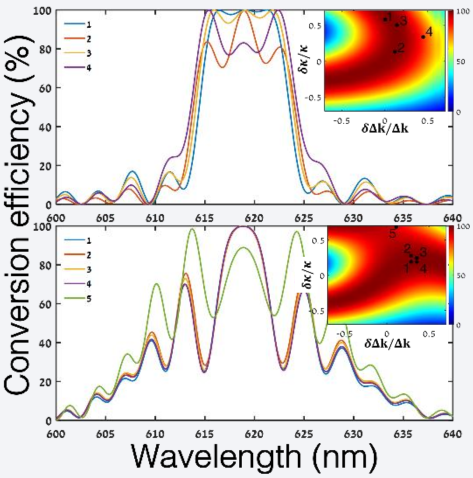
- In composite schemes:
  $U^{(N)}(z,0)=U_{\Delta k_N}(\delta z_N)\ldots U_{\Delta k_1}(\delta z_1)$.
- In DMCS we use the following constraints:

(i) $|U_{12}^{(N)}(z,0)|^2=1$.
(ii) $\frac{\partial^n}{\partial A^n}|U_{12}^{(N)}(z,0)|^2=0$.
(iii) 1st family ((ii) up to n=2):
$\Delta k_i=-\Delta k_{i+1}$.
2nd family ((ii) up to n=4):
$\Delta k_i=-\Delta k_{N+1-i}$ & $\Delta k_{mid}=0$.

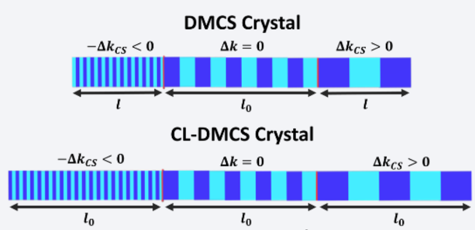
- We simulate an SFG process with quasi-continuous wave lasers and DMCS crystal design. Then insert errors in the setup parameters and explore the parameter-space to find efficient, broadband and robust crystal designs.

Results

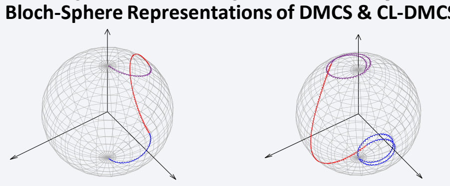
- We present the efficiency at the "phase matched" wavelength vs. partial errors in the phase-mismatch and coupling coefficient for the 1^{st} and 2^{nd} families of DMCS schemes, and conversion curves of several setup parameters.



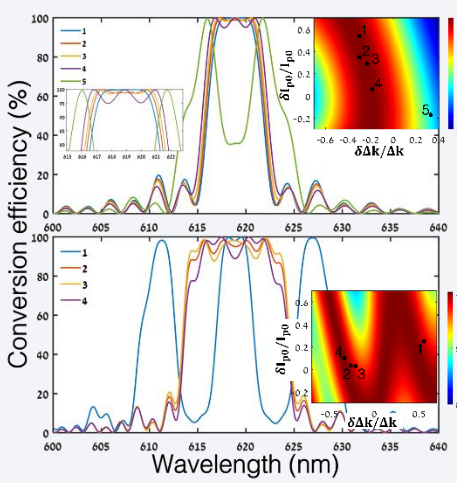
- We discovered the CL-DMCS scheme, where the lengths of the segments were all equal to that of a π-segment with 0 detuning.



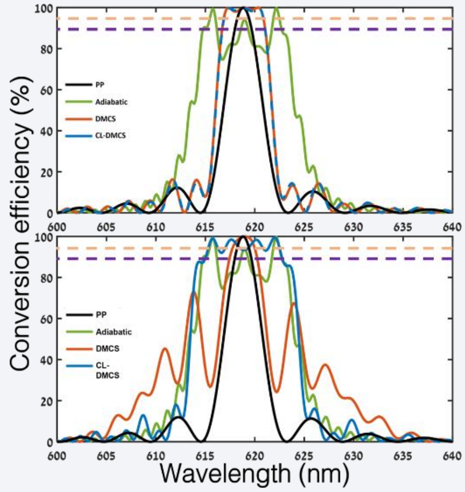
Bloch-Sphere Representations of DMCS & CL-DMCS



- The CL-DMCS scheme has highly broadband conversion curves.
- Some CL-DMCS designs show 3 separate efficient lobes.



- We compared selected designs of DMCS & CL-DMCS to commonly used QPM conversion schemes: Periodically Poled and Adiabatic Chirp.



Scheme	BW @90% [THz]	BW @95% [THz]
Periodically Poled 0.43[mm]	1.29 (0%, -34%)	0.92 (0%, 5%)
Adiabatic Chirp 2[mm]	1.94 (50%, 0%)	0.876 (-5%, 0%)
DMCS 2 segments 0.99[mm]	3.35 (160%, 73%)	3.118 (239%, 256%)
CL-DMCS 2 segments 1[mm]	3.35 (160%, 73%)	3.118 (239%, 256%)
DMCS 3 segments 0.88[mm]	2.154 (67%, 11%)	1.68 (83%, 92%)
CL-DMCS 3 segments 0.99[mm]	6.03 (367%, 211%)	3.469 (277%, 296%)

Conclusions & Future Research

- We showed the DMCS and CL-DMCS schemes could be applied as a QPM pattern which yields broadband and efficient conversion with relatively short crystals.
- We demonstrated the superiority of our DMCS designs over PP and adiabatic designs under length and power constraints.
- Performance should be verified experimentally.
- The simulations could be adjusted for DFG process and include temporal effects to better fit pulsed lasers.

References

[1] Reches Y, Elias E and Suchowski H 2022 J. Phys. B: At. Mol. Opt. Phys. **55** 194002.

[2] Kyoseva E, Greener H and Suchowski H 2019 Phys. Rev. A **100**(3) 032333.