NÉEL INSTITUTE Grenoble

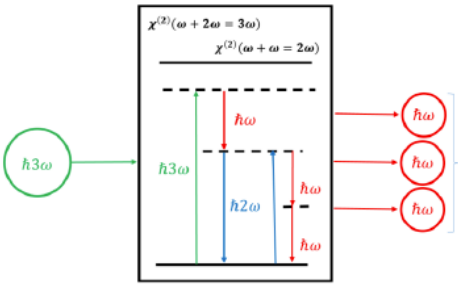
Topic for Master 2 internship – Academic year 2024-2025

Title: Second-order parametric cascading in PPKTP quasi-periodic photonic crystals for spontaneous triple photons generation

General Scope: This position concerns Triple Photons Generation (TPG). It is based on a third order nonlinear optical interaction is the most direct way to produce pure quantum states of light, called three-photons states. These states exhibit three-body quantum entanglement and their statistics go beyond the usual Gaussian statistics relevant to coherent sources and optical parametric twin-photon generators, offering thus outstanding potential applications in the field of quantum information. Undoubtedly, three-photons states are new quantum tools to study the non-intuitive properties of quantum mechanics [*K. Bencheikh, M.F.B. Cenni, E. Oudot, V. Boutou, C. Félix, J.C. Prades, A. Vernay, J. Bertrand, F. Bassignot, M. Chauvet, F. Bussières, H. Zbinden, A. Levenson, and B. Boulanger, Demonstrating quantum properties of triple photons generated by $\chi^{(3)}$ processes, European Physical Journal D - Topical Issue on "Quantum Optics of Light and Matter: honoring Alain Aspect", 2022, **76**:186, https://doi.org/10.1140/epjd/s10053-022-00514-3*].

Research topic and facilities available: This work is in the line of a previous study on cascaded third-harmonic generation (CTHG: $\omega + \omega \rightarrow 2\omega$ / $\omega + 2\omega \rightarrow 3\omega$) in a quasi-periodically poled KTP (QPPKTP) crystal [*A. Vernay, L. Bonnet-Gammard, V. Boutou, S. Trajtenberg-Mills, A. Arie, and B. Boulanger, High efficiency cascaded Third-Harmonic Generation in a quasi-periodically poled $KTiOPO_4$ crystal, OSA Continuum, 2020, **3**(6), 1536-1544*]. The first step ($\omega + \omega \rightarrow 2\omega$) was governed by the second-order nonlinear coefficient d_{33} while it was d_{24} for the second step ($\omega + 2\omega \rightarrow 3\omega$). The phase-matching was achieved at the fundamental wavelength $\lambda_\omega = 1587$ nm when the QPPKTP crystal was heated to 95°C. The energy conversion efficiency reached 40% in the picosecond regime for a fundamental energy of 20 µJ that corresponds to an intensity of 1.5 GW/cm^2. It was the highest value of THG efficiency ever reported to the best of our knowledge. The QPPKTP samples were fabricated in Tel Aviv and the optical experiments were performed in Grenoble.

The goal of the internship is to perform a cascaded spontaneous triple photon generation (CTPG) in a QPPKTP crystal, which is the exact reverse of CTHG, *i.e.*: $3\omega \rightarrow \omega + 2\omega$ / $2\omega \rightarrow \omega + \omega$. It means that for the generated triplet {ω, ω, ω}, one photon comes from the first step of the cascade and the two others from the second step, knowing that these three photons are quantumly correlated because arising from the same parent photon at 3ω. The achievement of CTPG would be an alternative to a direct TPG, *i.e.* ($3\omega \rightarrow \omega + \omega + \omega$), which is a third-order nonlinear process that has never been observed because of a too weak efficiency.



More precisely, the present project deals with the design and study of a bright CTPG emitting a triplet at $\lambda_\omega = 1596$ nm based on a QPPKTP crystal pumped at $\lambda_{3\omega} = 532$ nm, the intermediate photon is then at $\lambda_{2\omega} = 798$ nm. We developed the modeling of the CTPG and we expect the generation of about 4 x 10^4 triplets/s using a pump laser intensity of 10 GW/cm^2 with a pulse duration of 15 ps and a beam *radius* of 50 µm in a QPPKTP crystal with a length of 1 cm.

Possible collaboration and networking: Tel Aviv University (Tel Aviv).

Possible extension as a PhD: It is strongly expected.

Required skills: A background in laser optics, nonlinear optics, quantum mechanics or quantum optics will be useful for the purpose of the project.

Starting date: February or March 2025

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