Widely tunable CW Optical Parametric Oscillators: Mastering the challenges posed in quantum technology research

HÜBNER Photonics

Korbinian Hens[1)], Jaroslaw Sperling[1)], Niklas Waasem[1)], Ronja Gärtner[1)], Gunnar Elgcrona[2)]

Introduction

Widely tunable continuous wave optical parametric oscillators (cw OPOs) are gaining popularity as novel sources of tunable laser light, not least due to the unprecedented wavelength coverage in the visible and the near infrared spectral range. While the technology is becoming increasingly recognized to offer a number of potential advantages in particular to the quantum research community, the experimental requirements are often challenging the device performance. In this context, we discuss the characteristics of state-of-the-art tunable cw OPO designs and describe several tuning schemes tailored to meet various experimental needs.

In an illustrative fashion, we compare recently published experimental data from several photoluminescence excitation (PLE) studies, which have been carried out on ensembles as well as on individual quantum emitters.

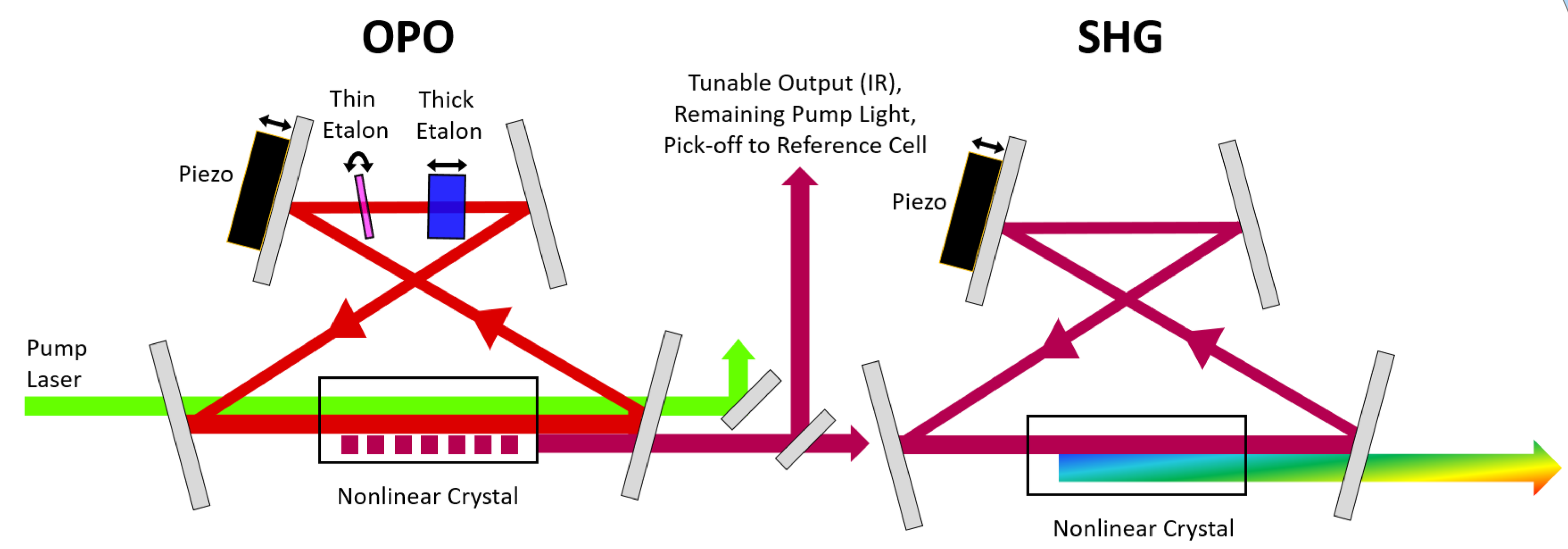
OPO Characteristics

The huge potential of OPOs, compared to conventional sources of laser light, derives from their exceptional wavelength versatility, as they are in principle not limited by the wavelength coverage of suitable laser gain media[1]. Only relatively recently, advances in the design of nonlinear crystals and the availability of high performance solid-state pump laser sources enabled the practical realization of cw OPOs with game-changing characteristics.

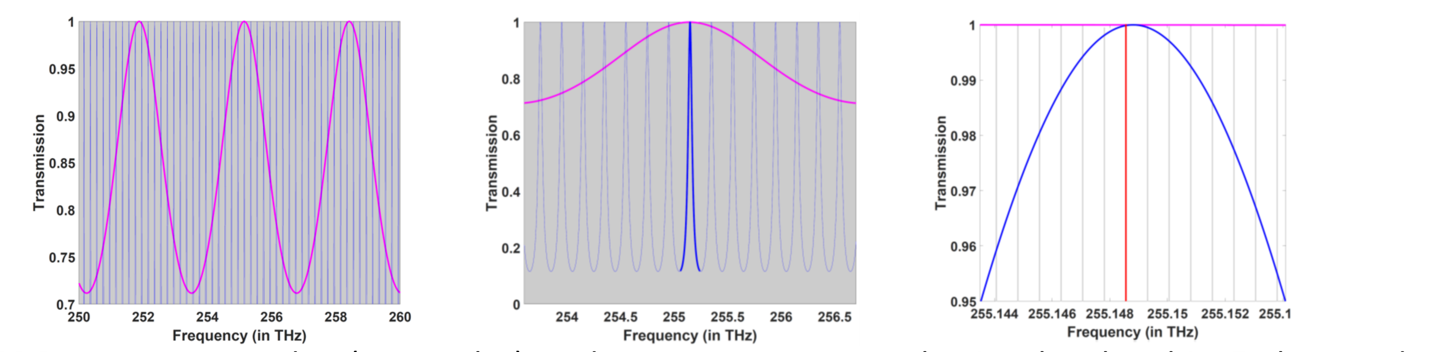
C-WAVE | The tunable laser light source

- **Broad tuning range**
  - **IR (900 – 1300 nm)**
  - **VIS (450 – 650 nm)**
- **High output power**
  - **IR: 400 mW, typ. max. > 1.2 W**
  - **VIS: 200 mW, typ. max. > 600 mW**
- **Single-frequency operation**
- **Linewidth < 1 MHz (typ. < 500 kHz)**
- **Fast mode-hop-free tuning: > 20 GHz , > 15 GHz / s (VIS)**
- **All solid state – no consumables**

Operational Principle

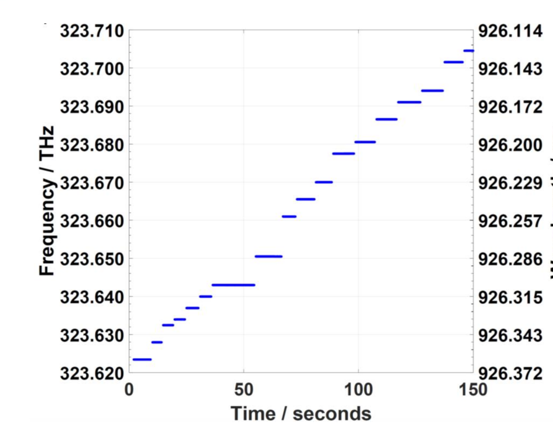


The operational principle of C-WAVE is based on two subsequent nonlinear processes. In a first step (OPO), a 532 nm laser pumps a nonlinear crystal to generate signal and idler photons in the near infrared spectral range (900 - 1300 nm). Wavelength selection using a two-stage etalon process and subsequent second harmonic generation (SHG) converts either signal or idler photons into the visible range of the spectrum (450 - 650 nm).

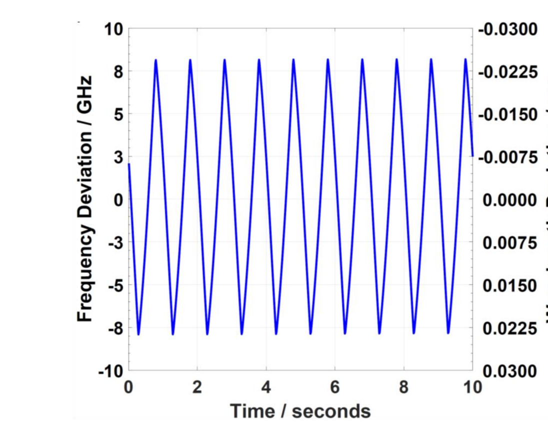


The OPO resonator modes (grey color) undergo a coarse pre-selection by the thin Etalon modes (magenta color). In combination with the thick Etalon mode (blue color) only a single OPO resonator mode (red color) is supported for resonant oscillation contributing to the laser light output.

Tuning Performance

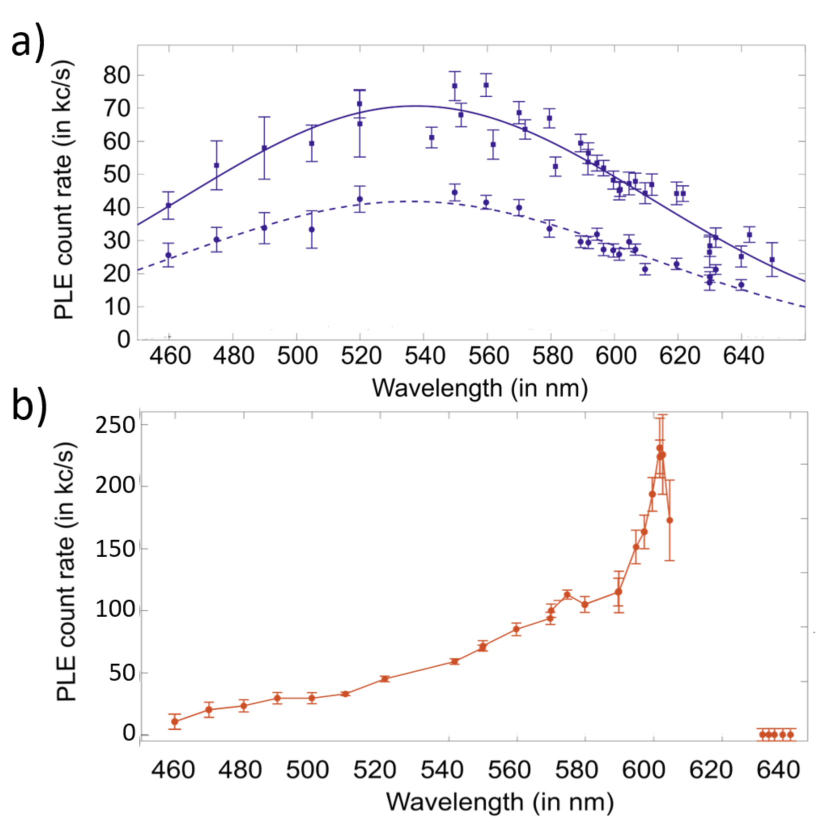


The frequency of the laser light output can be changed in discrete steps down to 2 GHz (in the IR range) by stepping the Thick Etalon.

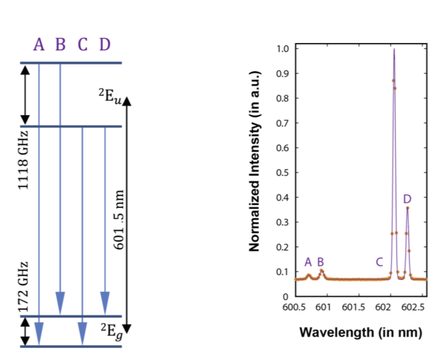


Truly continuous mode-hop free scans (presented at a central wavelength of 940 nm) can be achieved by cavity length tuning. The scan range in the IR is >10 GHz and can reach up to more than 20 GHz, depending on the central wavelength. After frequency conversion, this results in mode-hop free scans over more than 40 GHz in the visible wavelength range.

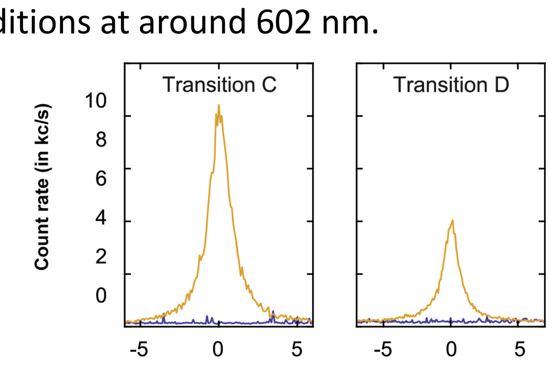
PHOTOLUMINESCENCE EXCITATON STUDIES OF SINGLE-PHOTON EMITTERS



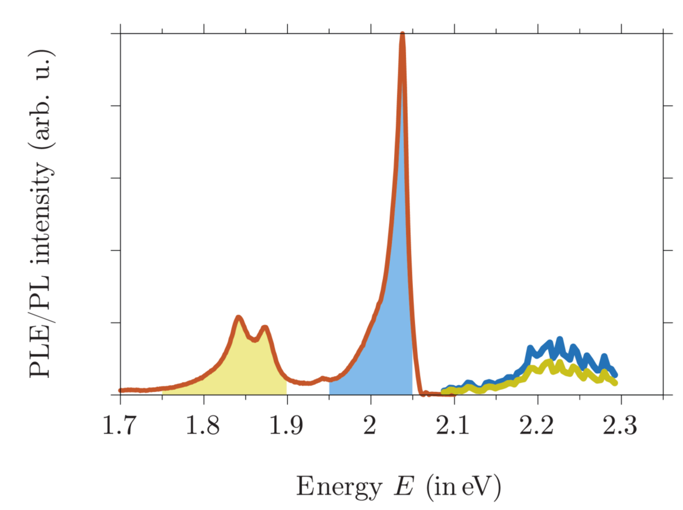
Photoluminescence excitation spectra of an ensemble of Si-V centers recorded at two excitation powers (a) and of an ensemble of Ge-V centers (b) are recorded at room temperature. The data has been recorded by exploiting the full coarse tuning range of the C-WAVE OPO with a step-size of approx. 10 nm, straight-forward accessible by automated crystal selection and temperature tuning. Adapted with permission from reference 2.



A further refined electronic level structure of Ge-V can be investigated at cryogenic temperature conditions at around 602 nm.



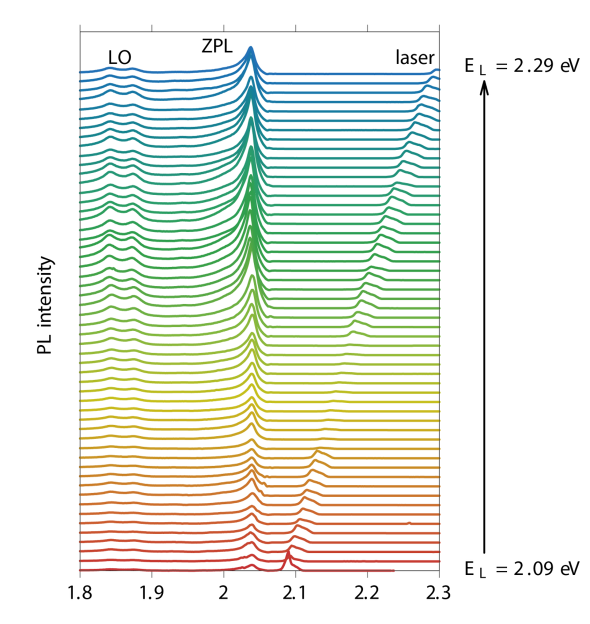
PLE spectra of transition C (left) and D (right) are recorded under tuning resonant excitation using the truly continuous (mode-hop-free) tuning mechanism of C-WAVE. Zero detuning corresponds to 602.2903 nm and 602.4828 nm respectively. Orange lines represent the signal when an additional 532 nm gating laser is switched on, blue lines represent the signal when the gating laser is off. Adapted with permission from reference 3.



A very recent study[4] on defect centers in hexagonal boron nitride (hBN) uses the tuning capabilities of C-WAVE for characterization at room temperature. The figure shows a photoluminescence spectrum of a single defect center in hBN.

Blue shaded area: integration interval over zero phonon line (ZPL) for PLE spectrum, yellow shaded area: integration interval over longitudinal optical (LO) sideband for PLE spectrum,
blue line and yellow line: corresponding PLE spectra.

Photoluminescence spectra of the single defect center in hBN are recorded under laser excitation energy tuning from 2.09 eV (593.30 nm) to 2.29 eV (541.48 nm) by employing a suitable crystal temperature tuning protocol of the cw OPO that is used for the emitter excitation. The shown data is corrected for background and Raman-lines. Adapted with permission from reference 4.



Summary

- **OPO technology provides an unprecedented wavelength coverage**
- **The tuning capabilities of C-WAVE cover the relevant frequency scales for quantum technology research**
- **The concept presented is quite general and thus, it allows for continuous adaption to new experimental requirements respectively novel types of single-photon emitters and systems alike**
- **Overall, cw OPO technology is about to mature into a recognized choice among laser light sources that advance the rapidly evolving field of quantum research**

References

[1] Ebrahim-Zadeh, M., [Optical Parametric Oscillators], Handbook of Optics 2nd Ed. Chap. 22, McGraw-Hill, 22.1-22.72 (2001)

[2] Häußler, S., Thiering, G., Dietrich, A., Waasem, N., Teraji, T., Isoya, J., Iwasaki, T., Hatano, M., Jelezko, F., Gali, A. and Kubanek, A., "Photoluminescence excitation spectroscopy of SiV- and GeV- color center in diamond", New J. Phys. 19(6), 063036 (2017).

[3] Chen, D., Mu, Z., Zhou, Y., Fröch, J. E., Rasmit, A., Diederichs, C., Zheludev, N., Aharonovich, I. and Gao, W., "Optical gating of resonance fluorescence from a single germanium vacancy color center in diamond", Phys. Rev. Lett. 123(3), 033602 (2019)

[4] Wigger, D., Schmidt, R., Del Pozo-Zamudio, O., Preuß, J. A., Tonndorf, P., Scheider, R., Steeger, P., Kern, J., Khodei, Y., Sperling, J., de Vasconcellos, S. M., Bratschitsch, R. and Kuhn, T., "Phonon-assisted emission and absorption of individual color centers I n hexagonal boron nitride", 2D Mat. 6(3), 035006 (2019)

Acknowledgement

The authors gratefully acknowledge the support and fruitful discussions with Alexander Kubanek and his group, Wei-bo Gao and his group, and Rudolf Bratschitsch and his group.

[1] Division Hübner Photonics, HÜBNER GmbH & Co. KG, Heinrich-Hertz-Str. 2, 34123 Kassel, Germany
[2] Division Hübner Photonics, Cobolt AB, Vretenvägen 13, 17154 Stockholm, Sweden

Corresponding author: Dr. Korbinian Hens, Product Manager – Korbinian.Hens@hubner-germany.com