High-Power CW Optical Parametric Oscillator Design for gap-free Wavelength Tuning across the Visible

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Abstract: A tunable laser light source based on continuous-wave optical parametric oscillator technology is demonstrated to achieve output powers at the Watt-level while providing a tuning range of more than 260 nm across the visible spectrum.

1. Introduction

Tunable continuous-wave optical parametric oscillators (CW OPOs) are appealing sources of widely tunable laser light, as their wavelength coverage is - at least in principle - not limited. Due to technical challenges, practical CW OPO devices so far have been mainly operated in the near infrared [1]. Only relatively recently, tunable CW OPOs covering visible spectral ranges have matured into commercially available systems also, offering up to a few hundreds of mW of output power [2]. However, tailoring wavelength coverage and tuning protocols to fundamental research applications remains a challenge, as is the notorious demand for higher output powers in the realm of industry-oriented studies [3-5]. Here, we present a novel tunable CW OPO design delivering unprecedented output powers across a gap-free tuning range of 500 nm to 765 nm in the visible.

2. Conceptual Layout

The availability of high-power (and preferentially single-mode) pump lasers as well as the absorption properties of suitable non-linear materials impose major challenges for the design of CW OPO devices sought to operate in the visible spectrum. Despite the appealing conceptual simplicity that pumping such CW OPOs at ultraviolet wavelengths would offer, so far only two-stage implementations have been proven practical, combining longer wavelength pumping with second-harmonic conversion (SHG) of the primary OPO output [2]. Accordingly, the novel scheme presented in Fig. 1a employs a fiber-laser based pump source delivering 7 Watt at 780 nm to drive the primary OPO process efficiently up to multi-Watt output levels, generating signal (idler) wavelengths in the range 1000 - 1540 nm (1580 - 3540 nm). In essence, the resonator layout for both OPO and SHG is designed to match optimum OPO pump threshold (cf. Fig. 1b) and to maximize SHG conversion rates up to more than 60% in a resonant enhancement cavity [6].

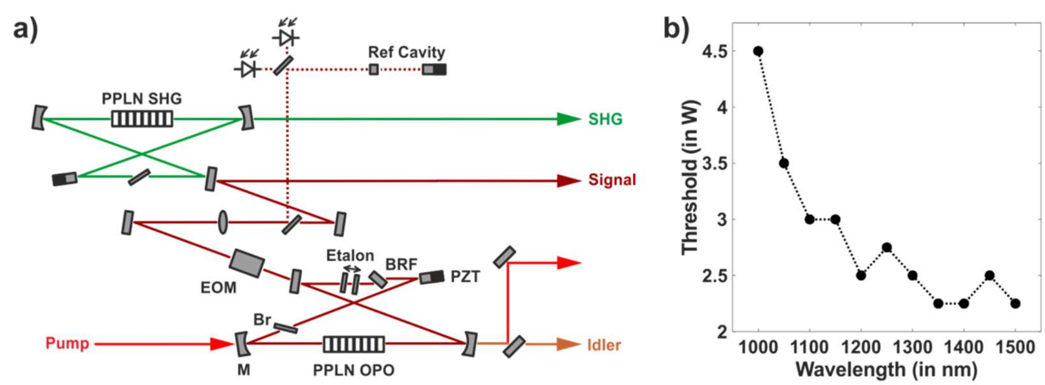

Figure 1. (a) Schematic beam path of the tunable CW OPO pumped by a 780 nm single-frequency fiber laser and with cascaded SHG of the primary OPO output; red arrow depicts the pump laser beam, dark-red and brown arrows depict the signal and the idler beam respectively. Green arrow depicts the SHG beam originating from frequency-doubling of the signal. (b) OPO pump power threshold as a function of OPO signal wavelength. Optimization is crucial to gain highest efficiency from the OPO process [6].

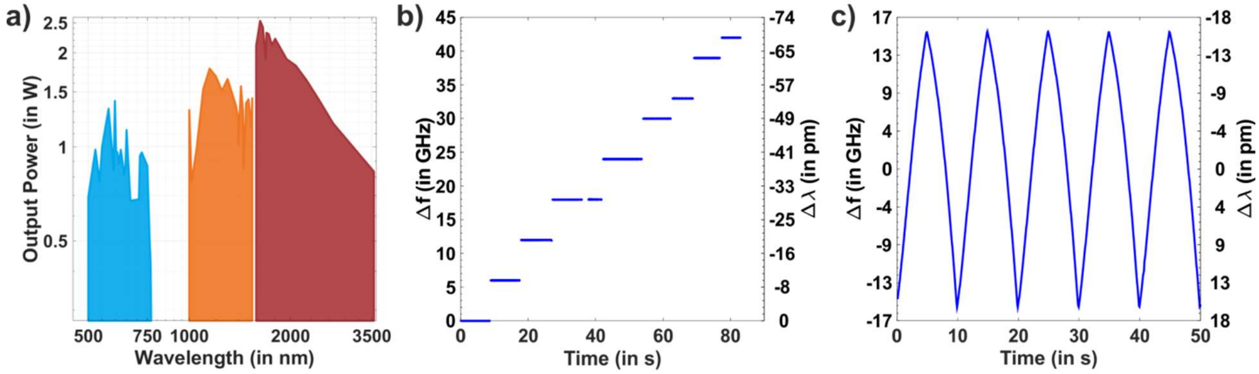

Figure 2. (a) Output power versus wavelength of the tunable CW OPO operating in the visible and near-infrared spectral range. Orange and dark-red indicate the fundamental OPO output (signal/idler), blue indicates SHG output. (b) Frequency tuning by intracavity etalon stepping at a central wavelength of 700 nm. The laser light frequency can be changed discretely with step sizes down to 3 GHz in the visible spectral range. (c) Truly continuous (mode-hop-free) scan at a central wavelength of 550 nm, providing a scan range greater than 30 GHz.

3. Performance Characteristics

As shown in Fig. 2a, key characteristic of the tunable CW OPO platform presented here is to provide convenient coverage of the visible wavelength range of 500 to 765 nm at a typical output power level of 1 W. The main three wavelength tuning mechanisms accessible are temperature tuning of the non-linear crystal (referred to as coarse tuning), intra-cavity Etalon scanning (quasi-continuous stepwise tuning), and scanning the cavity length by a piezo-element (continuous mode-hop free tuning). These mechanisms can be combined and fully automated for truly continuous wavelength coverage. For illustration, an exemplary quasi-continuous and a mode-hop free scan are shown in Figure 2b and 2c, respectively. Throughout all wavelength ranges (SHG, signal, idler), the system delivers high quality CW output with linewidths well below 1 MHz (translating into coherence lengths well above 100 m) and an output beam quality factor of typically $M^2 < 1.2$. Thereby, a long-term frequency stability of < 150 MHz over hours is routinely achieved at typical lab conditions. For applications with highest demands, the performance can be further improved by operating the system in closed-loop mode (in conjunction with an external wavelength measurement device), to achieve a long-term stability as good as on the order of a few MHz.

4. Outlook

The presented tunable CW OPO design provides unprecedented performance with regard to the combined wavelength coverage and output power. We point out that the system layout is general enough to be further adaptable, e.g. by power up-scaling or wavelength shifting of the employed pump laser. Not least, the scheme discussed here has been developed keeping an eye on operational practicability, to pave the way for commercialization into turnkey systems.

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