# Tandem optical parametric oscillator mid-infrared laser source

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Mid-infrared laser sources in the 3.5 to 5 µm atmospheric transmission window have an important application in systems to protect aircraft against heat-seeking missiles. Portable missiles with infrared seekers (MANPADS) are a serious threat to military aircraft in peace-keeping operations and have also been used against civilian aircraft by terrorists. Laser sources with the needed specifications are not readily available and the best alternative is wavelength conversion of near-infrared lasers by nonlinear optics in optical parametric oscillators (OPO). For wavelengths longer than 4 µm most nonlinear optical crystals however absorb. The only available alternative for high average power applications is ZGP ($ZnGeP_2$). The drawback of this material is absorption in the near-IR, so that a pump source at >2 µm is needed. The best developed lasers are however the $Nd^{3+}$-lasers at 1.06 µm. This dilemma can be solved by using one near-degenerate OPO to convert from 1.06 to 2.1 µm and then use this radiation to pump the mid-IR ZGP OPO.

In the last ten years periodically poled (PP) crystals that use quasi phase-matching (QPM) have become increasingly popular. Compared to birefringent phase matching in bulk crystals this has several advantages, e.g. access to higher nonlinearity and lack of walk-off and type I operation that allows use of both signal and idler to pump the ZGP OPO. As OPO efficiency depends on the pump bandwidth the very broad gain spectrum near degeneracy is problematic.

We have developed an OPO setup where we limit the bandwidth of the radiation generated from the near degenerate PPKTP OPO by using a cavity with very narrowband feedback. The bandwidth limiting component is a volume Bragg grating (VBG) that in our setup replaces the traditional dichroic mirror output coupler. A VBG is created by recording a periodic refractive index modulation in a piece of photo-thermo-refractive (PTR) glass by UV exposure and subsequent thermal annealing. By controlling the modulation period, grating length and modulation strength it is possible to control central wavelength, diffraction efficiency (i.e. reflectivity) and bandwidth of the VBG. The gratings we use have 50 % peak reflectivity with 0.5 nm FWHM bandwidth at different wavelengths near 2.13 µm.

By using different VBG output couplers we limit the signal spectrum to 10 GHz (0.15 nm) FWHM with an accompanying idler of 20 GHz (0.3 nm) FWHM or to a common envelope of 40 GHz FWHM. This should be compared to the 200 nm wide spectrum of the mirror OPO shown in Figure 1. This is an extraordinarily narrow bandwidth from an OPO with only passive wavelength control.

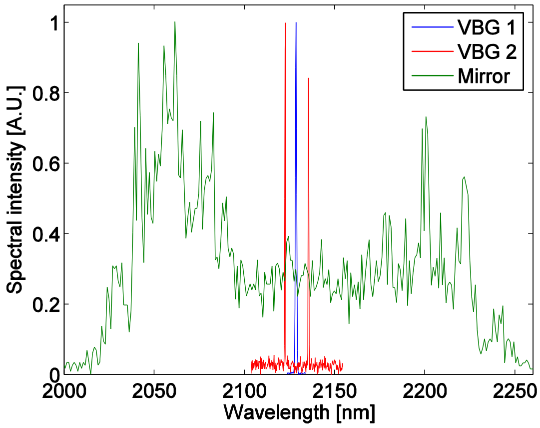


Figure 1. Spectra from the PPKTP OPO using three different outcouplers to illustrate the bandwidth narrowing achieved by using a VBG compared to a dichroic mirror.

When pumping a ZGP OPO with the output from the bandwidth narrowed PPKTP OPO we get an OPO that is tunable from degeneracy at 4.2 µm to signal wavelength of 2.9 µm with the corresponding idler at 8 µm[1]. Some examples of spectra are given in Figure 2.

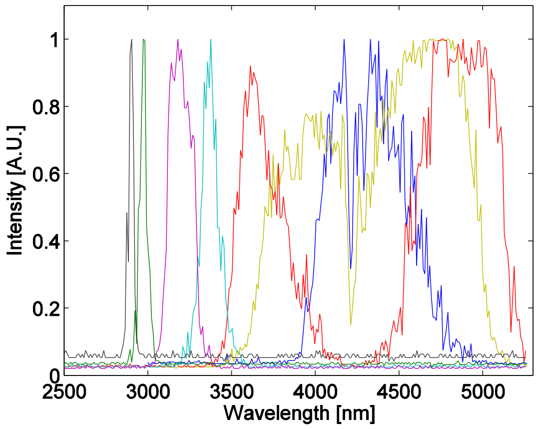


Figure 2. Spectra from the ZGP OPO for different crystal angles. The spectra are limited to 5.5 µm by spectrometer sensitivity, but energy conservation gives that the idler was tunable to 8 µm.

Using a commercial $Nd:YVO_4$ pump laser with 20 kHz pulse repetition frequency and a total pump power of 26 W we generate 8 W average power at 2.13 µm and 3.2 W in the 3.5 to 5 µm region[2]. This corresponds to a conversion efficiency of 12 %, which is among the highest conversion efficiencies reported for a two stage OPO setup.

1. M. Henriksson, M. Tiihonen, V. Pasiskevicius, F. Laurell, Appl. Phys. B. 88, 37-41 (2007).
2. M. Henriksson, L. Sjoqvist, V. Pasiskevicius and F. Laurell, Proc. SPIE **7115**, 71150O (2008).