MIRSURG

Mid-Infrared Solid-State Laser Systems for Minimally Invasive Surgery

Grant agreement no.: 224042

Specific Targeted Research
Theme 3: **Information and Communication Technologies (ICT)**

D3.5: High-power 1st stage ns OPO

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Start date of project:	01/06/2008
Duration:	3 years
Organisation name of lead contractor for this deliverable:	KTH Royal Institute of Technology

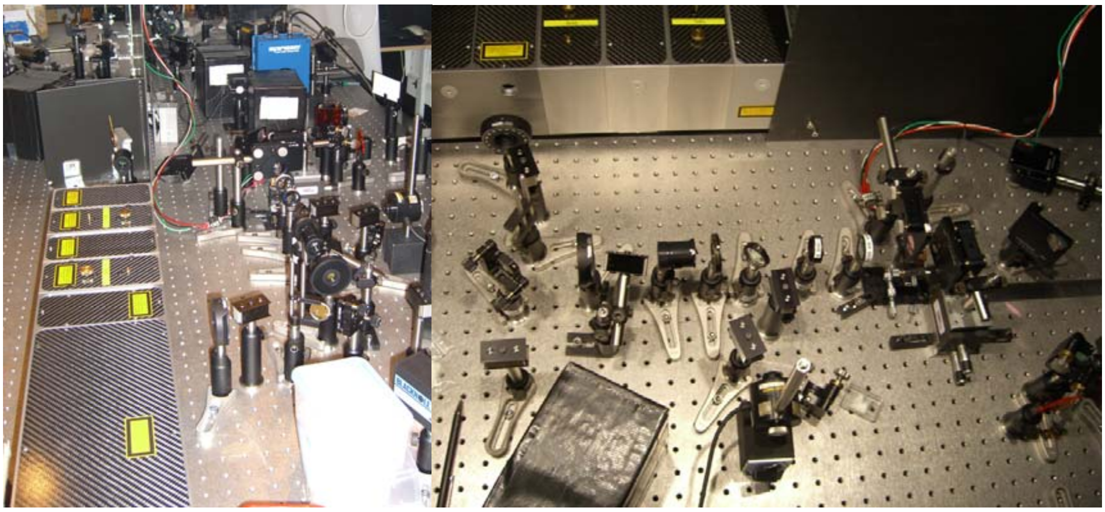
Project co-funded by the European Commission within the Seventh Framework Programme (2008-2011)		
Dissemination Level		
PU	Public	PU
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

1. Purpose of deliverable

The purpose of the deliverable is to provide a pump source for the second stage in the cascaded OPO setup presented in the first annual report. As direct pumping with 1 µm radiation is not suitable for ZGP the 1 µm pump light is converted to 2 µm radiation first and then in a second step used to pump a ZGP based OPO. This deliverable describes the OPO converting 1 µm radiation to 2 µm radiation. The primary goals at this stage were testing large-area periodically poled KTP isomorphs, which were previously fabricated in this project (Deliverable D1.7) as well as to assess the efficiency of spectral narrowing of the close-to degenerate OPO with volume Bragg grating (VBG) outcoupling and pumped with high-energy laser at 1064 nm.

2. Setup

The basic setup of the OPO consists of a linear cavity with a flat dielectric mirror as input coupler, a periodically poled crystal as gain medium, and a flat dielectric mirror or volume Bragg grating (VBG) as output coupler. A VBG is a Bragg grating written into photo-thermo-refractive glass by exposing it to UV radiation. VBGs offer a convenient way to spectrally narrow the output generated by quasi-phase-matched (QPM) OPOs, as it is normally quite broadband. The periodically poled KTP (PPKTP) crystal used as gain medium was described in Deliverable D1.7. The commercial pump laser was as described in the first year annual report and a waveplate-polarizer arrangement was used to control the pump power delivered to the OPO. The pump beam was collimated by a Galilean telescope and had a spot size of ~1 mm inside the cavity. The crystal was placed on a temperature controlled copper holder and was orientated such that the crystallographic c-axis was parallel to the pump beam polarization. General setup with pump laser is shown in Fig.1(a) and the OPO setup is detailed in Fig.1(b).



(a) **(b)**

Fig. 1 General setup of the pump laser and first stage OPO (a). OPO setup with pump control arrangement (b)

3. Results

First the OPO was used with a dielectric mirror as output coupler. The mirror had a reflectivity of 30% at 2.1 µm while the reflectivities of VBGs were about 50% for the signal wavelength. Thus the OPO with dielectric mirror outcoupling was doubly-resonant, while the OPO with VBG output coupling was singly-resonant. Figure 2 compares the output spectra obtained in the dielectric mirror and VBG outcoupled OPOs. Spectral width of the doubly-resonant OPO with the dielectric mirror output coupler is about 13 THz. The spectra recorded with better resolution for the VBG OPO are shown in Fig. 3. Here the signal and idler are separated by 269 GHz, and the spectral width of the parametric waves is 33 GHz, limited by the resolution of the spectrometer. The power at the idler wavelength is larger due to the fact that the OPO is singly resonant and the idler output power is completely dumped from the cavity at each roundtrip.

Numerical simulation has been performed in order to assess the efficiency of subsequent pumping ZGP OPO with 2 µm pump having different bandwidths. Although sometimes one can find references to so called pump acceptance bandwidth, this parameter is not well defined if the output wavelength of the second OPO in the tandem is not strictly fixed. On the other hand broad pump spectrum and associated increased influence of dispersion and phase-mismatch among different longitudinal modes will reduce the efficiency of the tandem OPO. The result of the simulation can be seen in Fig. 4. The efficiency indeed decreases and the ZGP OPO threshold increases quite strongly as the pump bandwidth is increased above 500 GHz.

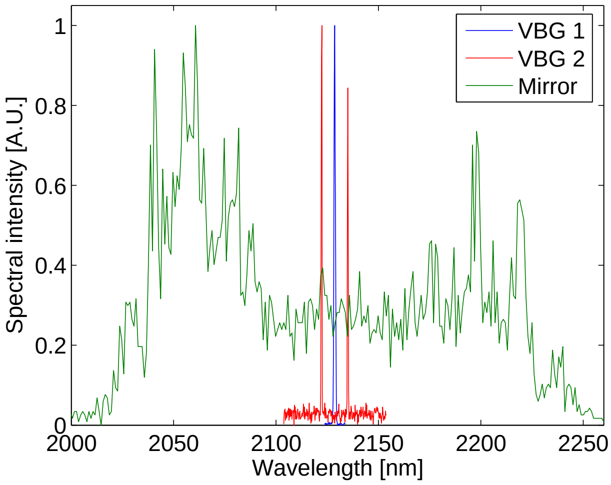


Fig. 2. Comparison of the output spectra of the PPKTP OPO with the dielectric mirror and VBG output couplers

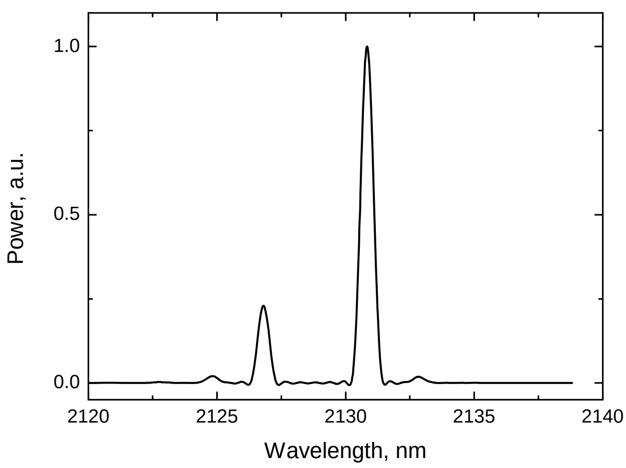


Fig. 3. Signal and idler of near-degenerate PPKTP OPO with VBG output coupler

The measured PPKTP OPO output energy at 2.1 µm together with the depletion and efficiency as a function of the pump pulse energy are shown in Fig. 5. Here we used 3 mm x 5 mm x 10 mm PPKTP crystals from Deliverable D1.7 of this project. The output energy reaches 32 mJ out of 70 mJ pump energy. The pump laser was operated at maximum repetition rate of 100 Hz and at the maximum energy used here the PPKTP OPO generated 3.2 W of average power at 2.1 µm. The pump depletion and efficiency reach 54% and 47%, respectively for a pump energy of 58 mJ. The energy provided by the OPO with the VBG output coupler was slightly lower than the archived energies with the 30% reflective dielectric mirror. This is attributed to the lower output coupling ratio provided by the VBG and to the internal losses caused by the rotation of the crystal. The crystal was rotated to prevent parasitic oscillations on the surface that would have caused broadband output. The losses induced by the crystal surfaces could be minimized by a coating or by polishing the surfaces in Brewster angle. Still a combination of the two OPOs in a master oscillator amplifier system can provide high energy output in a spectrally narrow output beam suitable for pumping the second stage OPO. Further increase in pump utilization would be possible by employing pump retroreflection. The peak pump power in the PPKTP reached 223 MW/cm^2 without optical damage. The OPO output energy and average power can be further increased if needed by increasing beam size by about 1.5 times for the same OPO efficiency. At the moment the output power is not limited by the aperture of the PPKTP crystal but by the considerations of beam quality.

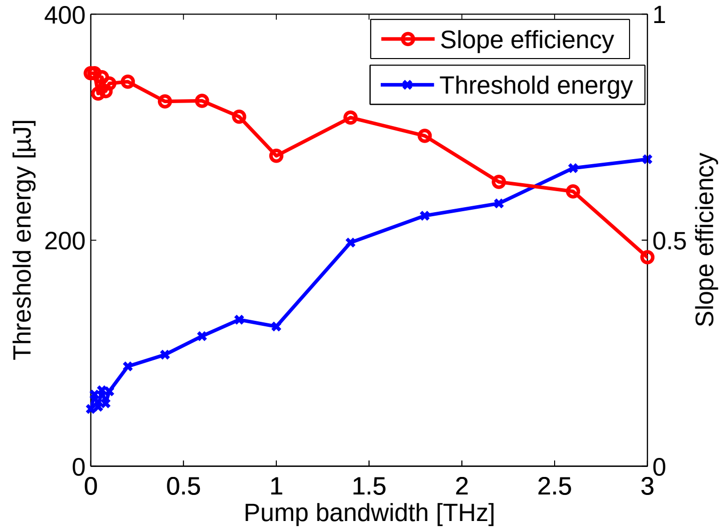


Fig. 4. Tandem ZGP OPO threshold and efficiency as a function of pump bandwidth in the first OPO stage

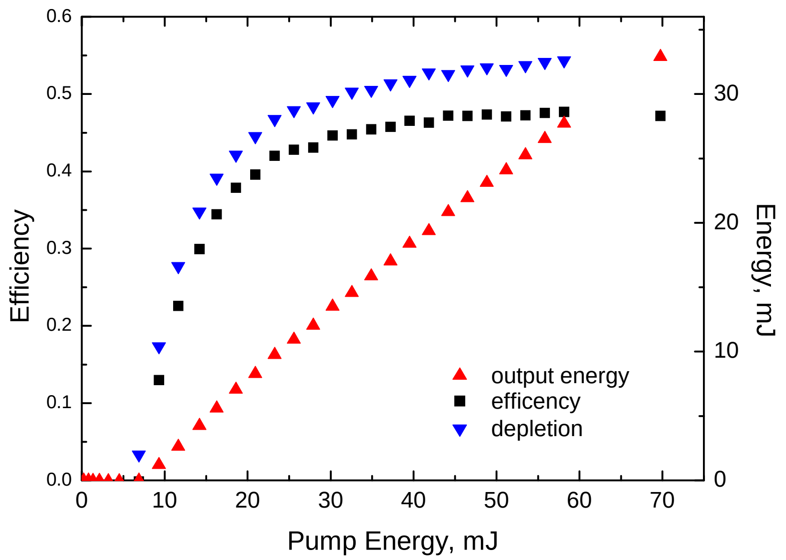


Fig. 5 Output power, depletion and efficiency for a 2.1 µm PPKTP OPO.

The beam profile of near degenerate PPKTP OPO at 2.1 µm was investigated by employing a pyroelectric camera (Spiricon). The pyroelectric bolometer chip had 124*124 pixels and a pixel spacing of 100 µm. Figure 6 shows the beam profile of the 2.1 µm beam. The beam shows a smooth beam profile and has a beam radius (1/e^2) of 3.4 mm and 2.6 mm. Increasing the pump beam size in the OPO would lead to undesired multi-transversal mode operation. However this is not a problem because due to available pump energy margin we will employ master-oscillator-power amplifier arrangement in order to preserve spectral and spatial quality of the 2.1 µm beam, as was previously described in original design (Deliverable D5.3).

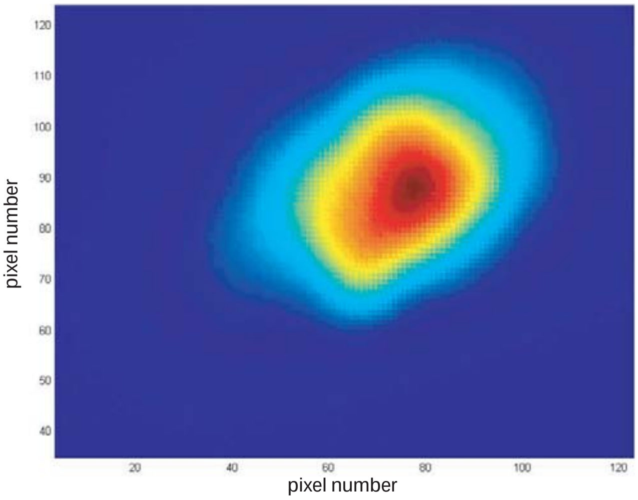


Fig.6 The 2.1 µm beam recorded on a pyroelectric camera.