Tandem OPO Source Generating 1.5-10-μm Wavelengths

Y. Isyanova, G.A. Rines, D. Welford and P.F. Moulton

Schwartz Electro-Optics, Inc., Research Division
45 Winthrop Street, Concord, MA 01742

Phone: 508-371-2299
FAX: 508-371-1265
email: seord@seord.com
www: http://www.seord.com

Abstract

We have demonstrated the first, to our knowledge, "tandem" OPO system based on a CdSe OPO pumped by the idler output of a KTA OPO.

Key Words

Parametric oscillators, infrared

Introduction

The optical parametric oscillator (OPO) has always been considered as an attractive source of tunable coherent radiation extending well into the infrared. The emergence of new nonlinear materials with high optical damage thresholds, such as KTP and its isomorphs, has had a significant impact on OPO technology. However, the long-wavelength limit of OPOs based on the isomorphs is limited by crystal transparency to approximately 5 μm.

For OPO operation further into infrared, only a few crystals with high transparency at long wavelengths are available, with CdSe, $ZnGeP_2$ and $AgGaSe_2$ among them. These crystals are semiconductors and have high absorption in the near-infrared region, which precludes direct pumping by well-developed, Nd-doped, 1-μm lasers. One alternative to direct Nd-laser pumping is a two-stage, or tandem OPO design, where the output of one OPO serves as the pump for another [1-3]. In references [1] and [2], $AgGaSe_2$ was used as a second-stage OPO material, with $LiNbO_3$ [1] and $KNbO_3$ [2] used in the first-stage, Nd-laser-pumped OPOs. The spectral range covered in [1] was between 2.6 and 6 μm with a maximum conversion efficiency of 1.75%. A tandem OPO configuration was also employed in [3] where a KTA OPO produced a 30% efficient source of 4-μm radiation, with tunability from 3.4 to 4.4 μm obtained by tuning the 2 μm KTP OPO pump source.

In this paper we report, for the first time to our knowledge, a high-conversion- efficiency, tandem OPO source that can cover the spectral range from 1.5 to 10 μm. The first OPO, using KTA, is pumped by a 1.053-μm, Q-switched Nd:YLF laser, and the idler output is used to pump the second, CdSe-based OPO. The CdSe OPO, operating with non-critical phase-matching (NCPM), provides signal and idler wavelengths in the regions 3.5-5 and 8-10 μm, respectively, through tuning of the pump wavelength. We show in Figure 1 our calculated angle tuning curve for a Type II, x-cut KTA OPO pumped at 1.053 μm, where we limit the smallest angle to near the degenerate operating point. We also show in Figure 1 the calculated tuning of the CdSe OPO signal and idler, assuming the use of the KTA idler as the pump source.

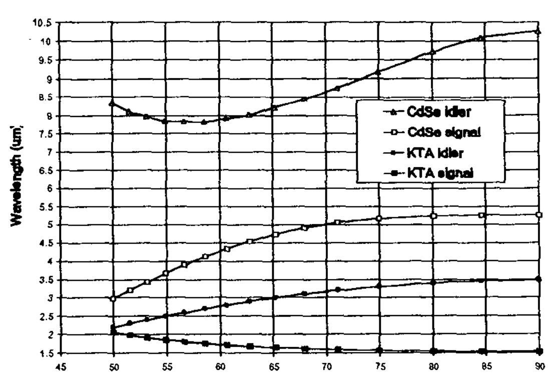

Figure 1. Composite angle-tuning for KTA-CdSe tandem OPO.

We chose KTA because the material has much lower absorption loss than KTP at the OPO idler wavelength. In terms of damage threshold and nonlinearity, the characteristics of KTA are similar to those of KTP, based on reported operation with a 1.06-μm pump laser [4] and our experiments with a Ti:sapphire pump laser [5].

Experimental Setup and Results

We show our experimental arrangement in Fig. 2. The Q-switched, flashlamp-pumped, Nd:YLF stable-resonator oscillator used a 5x100-mm rod and an intracavity telescope and was followed by a 5x100-mm rod, single-pass amplifier. The amplifier output had essentially the same beam quality and pulse width of the oscillator, which were 2 times the diffraction limit and 30 ns, respectively.

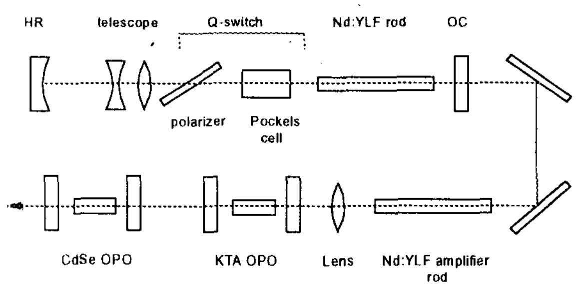

Figure 2. Experimental setup.

In our experiments the KTA crystal, provided by Crystal Associates, Inc. was x-cut, 15-mm long, with AR-coated (1.5 μm), 5x5 mm faces. We focused the pump beam with a 1.5-m lens to a diameter of approximately 3.5 mm. The singly-resonant first-stage OPO cavity design was a simple two-mirror, 3-cm-long, standing-wave resonator with pump feedback and 20% output coupling for the signal. In Figure 3 we plot our experimental data on total (signal and idler) output pulse energies for the KTA OPO with NCPM; the slope efficiency is 49%. The measured signal and idler wavelengths were 1.52 μm and 3.45 μm, respectively, in good agreement with the calculated data. To separate the signal and idler wavelengths from the KTA OPO we used a dielectric filter and the resultant available idler energy was 25% of the total output shown in Fig. 3.

The CdSe crystal used in the second-stage OPO has a relatively low surface-damage threshold, 60 MW/cm^2 for 50-ns pulses, but also a high nonlinear figure of merit, $d^2/n^3 = 2.4x10^{-23}$ $(m/V)^2$. The ability to operate with NCPM and use all the available crystal length for gain allows OPO operation at pump intensities well below the damage level. The ratio of nonlinear figure-of-merit to damage threshold is actually higher in CdSe than in the KTP-crystal family.

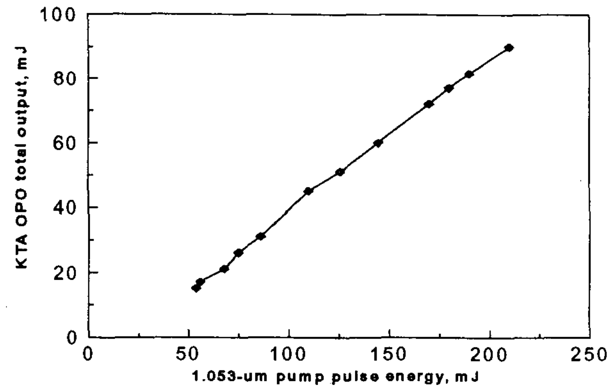

Figure 3. Input/output data for KTA OPO.

The CdSe crystal, provided by Cleveland Crystals, Inc., was cut for type II NCPM and was 35-mm in length, with a 10x10 mm cross section and AR coatings for the signal wavelength. The OPO cavity design was similar to that of the KTA OPO; the idler pump beam from the KTA OPO was directed into the cavity without any focusing. The input mirror was highly transmitting within the range from 3.2 to 3.6 μm and highly reflecting within the 4.7-5.3-μm range while the output mirror was highly reflecting for the pump wavelength and coated for ~70% reflectivity within the signal wavelength range. We show pump input/signal output energy data in Fig. 4, with a slope efficiency of 27%. The signal wavelength was measured to be 5.12 μm and the resultant idler wavelength was 10.58 μm.

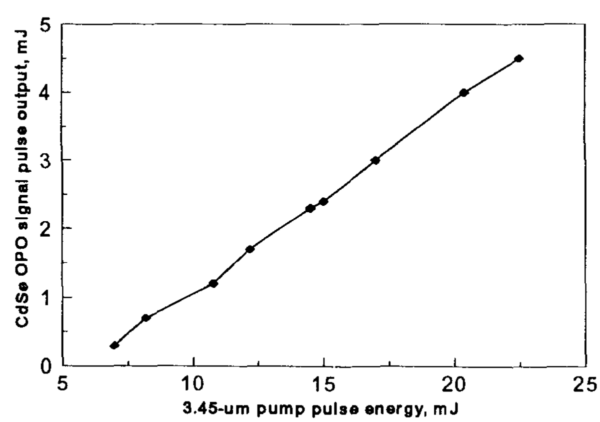

Figure 4. Input/output data for CdSe OPO.

Future Prospects

With the availability of larger-aperture KTA crystals we expect to be able to angle-tune the first-stage OPO and generate the range of wavelengths predicted in Figure 1. In our system, operation of the KTA OPO away from NCPM will not entail a substantial increase in threshold because the large pump spot size yields an aperture length much longer than that of the crystal. Optimization of output couplers and improved optics should yield even higher efficiencies. Since the absorption losses in all the nonlinear crystals are low, we anticipate that the limit to the pulse rate will reside in the pump laser, and not in the OPO stages. The gap in wavelength coverage for the tandem system, between approximately 5.5 and 7.5 μm, falls in a region of strong atmospheric water absorption. Thus this particular tandem design is well suited for atmospheric sensing applications such as DIAL, since the tuning gap includes wavelengths practically unusable for long-range sensing. Longer wavelengths than 10.6 μm can be generated by resorting to critical phase-matching in CdSe.

Acknowledgments

This work was supported by the Air Force Small Business Innovative Research Program, Contract No. FY71219503309.

References

1. J. Raffy, T. Debuisschert, J.-P. Pocholle, and M. Papuchon, Appl. Optics **33**, 985 (1994).
2. H. Komine, J.M. Fukumoto, W.H. Long, and E.A. Stappaerts, IEEE J. of Selected Topics in Quantum Electron. **1**, 44 (1995).
3. A. Kaz, R. Burnham, L.R. Marshall, and A. Pinto, OSA Proceeding on Advanced Solid-State Lasers (Optical Society of America, Washington, DC, 1994), v. 20, p. 443.
4. W.R. Bosenberg, L.K. Cheng, and J.D. Bierlein, Appl. Phys. Lett. **65**, 2765 (1994).
5. G.A. Rines, H.H. Zenzie, R.A. Schwarz, Y. Isyanova, and P.F. Moulton, IEEE J. of Selected Topics in Quantum Electron. **1**, 50 (1995).