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Mid-Infrared Generation in an Uncoated Wedge ZGP OPO

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Abstract: Novel uncoated wedge ZGP OPO configuration was demonstrated, generating 3.8mJ of MIR pulses operating at 100Hz. The nature of the wedge configuration allows a highly stable OPO cavity from any misalignment on the cavity mirror.

OCIS codes: (140.3613) Lasers, upconversion; (190.4410) Nonlinear optics, parametric processes; (190.4970) Parametric oscillators and amplifiers

1. Introduction

Conventional linear OPO configuration requires the optical surfaces of the nonlinear crystal to be applied with multi-layer AR coating for the pump, signal and idler wavelengths. For MIR upconversion using ZGP crystals, AR coating covering 2.1 μ m pump wavelength and 3-5 μ m MIR wavelength is essential. Due to the immaturity in the development of such dual-band AR coating for the ZGP crystal surfaces, these coatings often suffered from laser induced damage by high energy pump laser pulses. Damage threshold of the AR coating can be increased by expanding the pump beam size to a larger area to reduce the energy fluence experienced by the AR coating. However, this increases the pump threshold and also decreases the OPO output beam quality.

To overcome this issue, a novel uncoated wedge ZGP OPO configuration was examined. Typical well-polished ZGP crystal surfaces are able to withstand a laser damage threshold of >1J/cm². The damage threshold can further improved to 2J/cm² with improved polishing techniques [1]. As compared to the well-polished ZGP crystal surfaces, typical dual-band multi-layer AR coating for the MIR wavelength lies below 0.5J/cm². This provides a strong motivation to investigate a potential OPO configuration which makes use of the higher intrinsic damage threshold of ZGP crystal. Uncoated ZGP crystal surface has a Fresnel reflection of ~27% for an incoming laser beam at normal incidence. This introduces a significant interface reflection loss in contrast to the AR coating surfaces. Instead of treating the Fresnel reflection as an optical loss, we make use of it as a fixed output coupling with reflectivity of ~27% in an OPO cavity.

2. Experimental Setup

The schematic design of the uncoated wedge ZGP OPO is shown in Fig. 1(a). The ZGP crystal was designed in a wedge configuration with two optically polished surfaces. The designed optical axis of the ZGP crystal fulfilled the phase matching condition for a Type I nonlinear optics interaction with pump wavelength of 2.09 μ m at the degenerate point. The fundamental concept of the wedge design relies on the Brewster angle of the ZGP crystal for the polarization of the generated MIR wavelength. The linearly polarized 2.09 μ m pump laser is the ordinary wave with respect to the optics axis of the ZGP crystal while the generated MIR signal and idler wavelengths were the extraordinary waves. As shown in Fig. 1(a), the extraordinary MIR wavelengths were p-polarized with respect to the wedge interface. By designing the cutting angle of the ZGP crystals, the p-polarized MIR wavelengths incident on the wedge interface at the Brewster angle. This leads to the high transmission of the MIR wavelengths through the crystal/air interface without suffering from reflection losses.

Fig. 1 (a) Schematic of the desired design of uncoated wedge ZGP crystal OPO configuration. (b) Actual Wedge ZGP cutting angle used in the experiment.

The OPO cavity is formed by a HR mirror at MIR wavelength and the flat input surface of the wedge ZGP crystals. This uncoated ZGP crystal surface acts as an output coupler for the MIR radiation with $R \sim 27\%$. The $2.09\mu\text{m}$ pumped beam is s-polarized and the generated MIR signal and idler are p-polarized. The second surface of the uncoated ZGP crystal is cut at an angle where the MIR radiation will be incidental on that surface at the Brewster angle. Due to Fresnel reflection from the uncoated ZGP surface, $\sim 27\%$ of the $2.1\mu\text{m}$ pump will be reflected. In order to prevent back-reflection into the laser, the pump beam is tilted slightly in the vertical plane by an angle of $<3^\circ$. With the large refractive index of ZGP, the internal angle mismatch introduced by the tilt will be $<1^\circ$. We tailor this tilt in the non-critical plane so that it does not impose an issue to the phase-matching condition. A commercial high energy $2.09\mu\text{m}$ Ho:YAG MOPA laser [2] is used as the pump source of the uncoated wedge OPO. The pump diameter is $\sim 5.5\text{mm}$. A 45° dichroic mirror, HR for the s-polarized $2.1\mu\text{m}$ pump beam and HT for the p-polarized MIR signal and idler, is used to separate the pump and MIR beam. The actual optics axis angle and the ZGP wedge angle used in the experiment is shown in Fig. 1(b). The cut wedge angle is $\sim 17.6^\circ$, slightly small than the desired internal Brewster angle of 17.64° for $4.18\mu\text{m}$ in the ZGP crystal. The optics axis of the ZGP crystal is at 54.74° , which also defer slightly from the desired angle at 55.3° . There is a great challenge to achieve the desired angle parameters while ensuring the input surfaces are well polished.

3. Results and Discussion

The preliminary result of the uncoated wedge ZGP OPO MIR generation is shown in Fig. 2. The pump energy shown was calculated, taking into the consideration of the 27% Fresnel reflection loss by the uncoated ZGP surface. A maximum pump energy of $\sim 29\text{mJ}$ was used for the nonlinear conversion. 3.8mJ of MIR pulses were generated, operating at 100Hz . As the feedback from the output coupler was only $R=27\%$, the threshold was relatively high. The resultant optical-to-optical conversion efficiency was 13%, with the OPO pumped at two times above threshold. The slope efficiency was $\sim 26\%$. Although the efficiency of this wedge OPO configuration was not impressive high, the OPO cavity was extremely robust. Any slight misalignment from the optimised position of the rear HR mirror only corresponds to a very minor deviation of the MIR beam within the ZGP crystal, due to the high refractive index of the crystal. By simple calculation using Snell's law, a misalignment of 1° external to the ZGP crystal correspond to an internal misalignment of only $\sim 0.25^\circ$.

Fig. 2 Experimental data of the uncoated wedge ZGP OPO MIR generation.

4. Conclusion

A novel uncoated wedge ZGP OPO configuration was demonstrated. Immature development of dual-band AR coating on the ZGP crystal surfaces suffered from laser induced damage by the high energy pump laser pulses. The novel uncoated wedge ZGP OPO configuration, with a laser damage threshold of $>1\text{J}/\text{cm}^2$, was examined to overcome the coating damage issue. 3.8mJ of MIR pulses were generated with $2.09\mu\text{m}$ pump energy of 29mJ , operating at 100Hz . Due to the nature of the wedge configuration, the OPO cavity was highly stable from any slight misalignment on the rear HR mirror. Thus the uncoated wedge ZGP OPO cavity can potentially implemented as a highly robust and compact setup for high energy MIR pulse generation.

5. References

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