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Diode-pumped Nd:YAG eye-safe laser

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Nd:YAG laser is pumped with two-dimensional side pumping diode-laser array. The wavelength from the Nd:YAG is 1064 nm, which is not safe for the eye. Here this eye hazardous laser is converted into the eye safe region using a singly resonant extra cavity KTP OPO. The output energy is an eye safe radiation at 1525 nm, with 8 mJ, corresponding to an energy conversion efficiency of 21 % at phase matching angle 21^0, in a type-II, NCPM *x*-cut KTP crystal (15 × 10 × 10 mm) placed in a plane-parallel resonator.

Keywords: Eye safe laser, Phase matching, Optical parametric oscillation (OPO)

Introduction

Laser application have proliferate in recent years and, as to be expected, their presence is no longer confined to the laboratory or places where access to their radiation can be controlled. Military operations are obvious applications where various devices such as laser range finders, target designators, and secure communications equipment elevate the risk of exposure, specifically eye exposure, to unacceptable levels. It is found that laser with operating wavelengths in the region of approximately 0.4 µm to 1.4 µm (i.e. visible and near infrared) is the eye hazardous portion of optical spectrum, because in this region it is transmitted by the cornea and the lens serves to focus the laser beam on the retina. Thus, the actual laser power density entering the eye can be increased by some 10^5 by the time the light gets to the retina, and burn it without any time lag. This hazardous wavelength region often called ocular focus region[1]. Whereas wavelengths beyond this region are absorbed in the cornea, lens, and vitreous humor of eye, and therefore laser cannot make direct impact on the retina. In this region our eye is relatively safe, and there is only thermal injury to eye.

Optical Parametric Oscillation

Optical parametric oscillation (OPO) is one type of second harmonic process. In this process, a nonlinear material having nonzero value of its second order susceptibility (χ^2), is placed within an optical cavity made by two reflective mirrors and a intense input laser beam at frequency ω_p is known as the *pump* frequency, when passes through it, generates the desired frequencies ω_s (signal) and the frequency ω_i (idler), while conserving the total energy and momentum. The mirrors are specifically made reflective at either one of these two frequencies, or for both. Thus the intensity at those frequencies will amplified within the cavity, by Fabry-Perot interferometer. Such an amplification process is known as an optical parametric oscillator (OPO)[1,2]. This process is used most often in the infrared frequency range, where tunable lasers are not as readily available as in the visible portion of the frequency spectrum.

The output of an optical parametric oscillator (OPO) is similar to that of a laser. The energy conservation requires that[3,4].

$$\omega_p = \omega_s + \omega_i$$

For a given ω_p, there can be a continuous range of choices of ω_s and ω_i. This, in fact, is the origin of the tunability of the optical parametric oscillator. The specific pair of frequencies that will be emitted is dictated by the momentum conservation condition, or phase matching condition: $k_p = k_s + k_i$, that must also be satisfied in order to ensure that the signal waves generated in different parts of the nonlinear crystal are in phase and add coherently. Tunability of the signal-idler pair is usually achieved by changing the crystal birefringence through its angular dependence of the

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*Corresponding author (E-mail: kireetsemwal@gmail.com) extraordinary index of the crystal. The pump signal is usually provided by a laser and, therefore ω_p is fixed[5-7].

The requirements of nonlinear crystals for optical parametric oscillation are essentially the same as that for SHG. In other words, the nonlinear materials must be non-centrosymmetrical crystals, highly transparent for pump, signal, and idler beams, able to fulfill the phase matching by using angle-tuning or temperature-tuning. In principle, all commonly used SHG crystals used for OPO purpose. A possible simple implementation of the optical parametric oscillator is shown schematically in Fig.1. It is consist of a suitably oriented nonlinear optical crystal in a Fabry-Perot cavity. The cavity mirrors are coated to transmit the pump wave and reflect either the signal wave only or both the signal and idler waves. In the former case, the oscillator is known as the singly resonant oscillator, and, in the latter case, it is known as the doubly resonant oscillator. After passing through the output-coupling mirror the transmitted pump beam is blocked by a filter. The further separation between the signal beam and idler beam can be done by using appropriate spectral filters or optical dispersive elements. Various optical cavity designs, including stable, unstable, or metastable cavity configurations, can be employed for OPO purpose. The criteria of selection of cavity designs are same as that for laser cavity devices[8-11].

Experimental Details

The active laser medium consists of an antireflection-coated Nd:YAG laser rod transverse pumped by laser diode arrays, the schematic diagram is shown in Fig. 2. Two diode laser bars of total power 12 W transversely pumps, a 40 mm long, 5 mm diameter Nd:YAG laser rod. The diode-laser array has a total input of 120 mJ at 808 nm from the two transverse laser diodes. Up to, 40 mJ TEM_{00} mode energy is obtained by Nd:YAG at 1064 nm. The 42 cm long laser cavity is formed by two Plano concave confocal mirrors, with 5 m radius of curvature. The rear mirror M_1 is 100 % reflective dielectric coated for wavelength at 1064 nm whereas output coupler M_2 is having 70 % reflective coating at 1064 nm. The bandwidth of laser spectra is 0.2 nm. The TEM_{00}, mode is obtained by keeping an aperture in front of mirror M_2. The OPO consists of a 15 × 10 × 10 mm KTP crystal, placed within the 4.5 cm OPO resonator consisting plane mirrors M_3 and M_4. Mirror M_3 is highly reflective (100 %) for the signal wavelength, while mirror M_4 is 85 % reflective for the signal wavelength and highly reflective for pump and idler wavelengths. The KTP OPO is pumped by this 1064 nm, diode-pumped Nd:YAG laser with a TEM_{00} transverse mode. The laser beam is set normal to the z-axis (*c*-axis), which indicates $\theta = 90^0$. The KTP crystal is cut so as to achieve type-II non-critical phase matching *x*-cut ($\theta = 90^0$ and $\phi = 0^0$) as it maximizes effective non-linear coefficient and has large angular acceptance angles, for a pump wavelength of 1064 nm (Nd:YAG). The input pump energy is fixed at 40 ± 0.6 mJ. The largest signal energy is obtained at the point of normal incidence, at phase matching angle of $\theta = 90^0$ and $\phi = 21^0$. For this configuration, the direction of propagation is along *x*-axis. The polarization of the pump wave and signal wave is along y-axis (o-wave) whereas idler wave is polarized in the x-z plane (e-wave). The output energy at 1525 nm is 8 mJ (Figs.3 & 4), and Fig.5 shows the corresponding to an energy conversion efficiency of 21 %. Figure 6 shows the calculated signal wavelength as a function of phase-matching angle θ for $\phi = 0$ in type-II KTP OPO pumped at 1064 nm. In the non-critically phase-matched configuration the refractive indices are $n_s = 1.73$, $n_p = 1.73$, and $n_i = 1.82$. For pump wavelength of 1064 nm, it

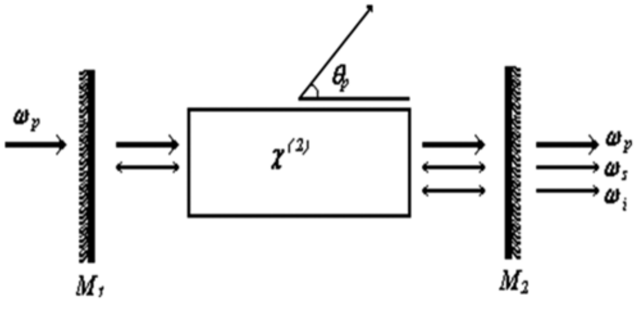

Fig. 1 — Singly-resonant optical parametric oscillator.

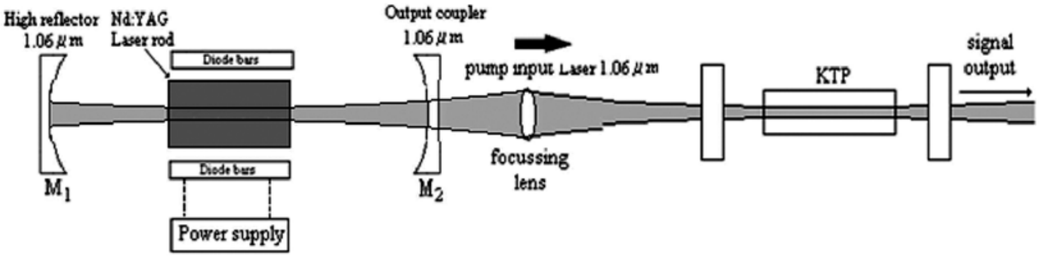

Fig. 2 — Schematic diagram for the Nd:YAG eye safe laser system.

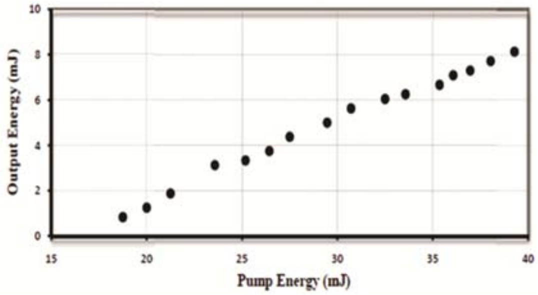

Fig. 3 — OPO energy as a function of pump energy.

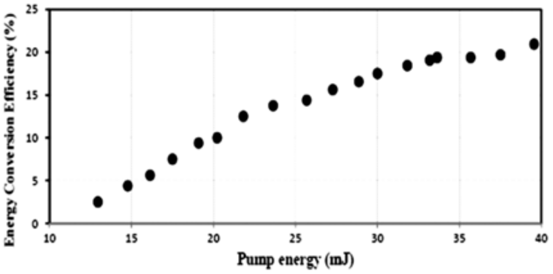

Fig. 5 — OPO conversion efficiency as function of pump energy.

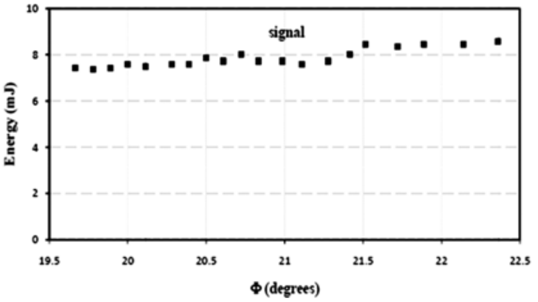

Fig. 4 — Signal energy at a polarization angle.

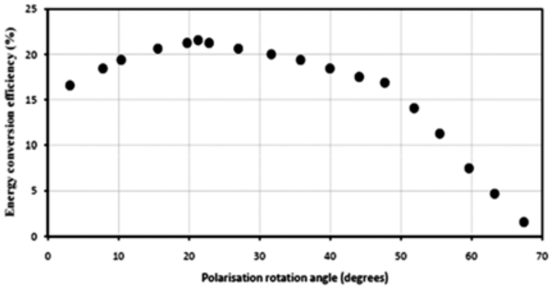

Fig. 6 — Conversion efficiency with the variation of angle of crystal.

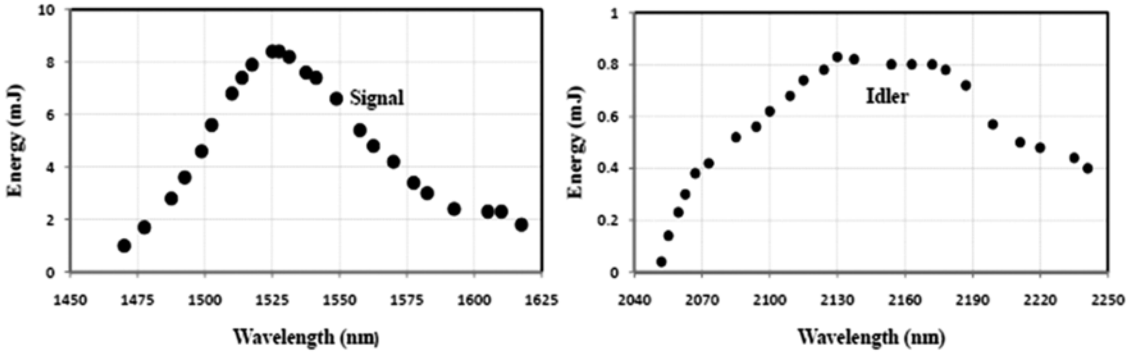

Fig. 7 — Variation of signal & idler energy with wavelengths.

generates a signal wave at 1525 nm and idler beam at 2130 nm shown in Fig.7. For focusing the pump laser beam (1064 nm) inside the crystal a convex lens of focal length 100 cm is employed. The focused pump beam spot size within the crystal is measured to be 2 ± 0.1 mm. This wavelength is beyond the ocular region, thus the output laser is safe for eye.

Conclusions

In summary, we have demonstrated the operation of Nd:YAG eye-safe laser, pumped by two-dimensional side pumping diode-laser array at 50 Hz of power 12 W, and energy 120 mJ, which pumpes the Nd:YAG laser and generate laser pulse of wavelength 1064 nm of power 40 mJ, which is not safe for eye. A singly resonant extracavity KTP OPO pumped by this pulsed Nd:YAG laser. The output energy is an eye safe radiation at 1525 nm, with 8 mJ, corresponding to an energy conversion efficiency of 21 %.

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