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Generation of 629 nm Pulsed Laser Using an Optical Parametric Amplifier

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Abstract: The main purpose of this work is the construction of an optical parametric amplifier (OPA) to generate a 629 nm pulsed laser. KTP nonlinear crystals were used for both parametric oscillation and amplification. A singly resonant parametric oscillator (OPO) is constructed to generate a signal of 1.54 µm and idler of 3.4 µm when the OPO system is pumped by 1.064 µm Q – switched Nd: YAG laser. The signal was then mixed with the pumping beam in OPA system to form the wanted wavelength. The obtained optical conversion efficiency was 60%.

Introduction

Optical parametric amplifier (OPA) is an example of second- order nonlinear process. It requires two pumping beams one of them must be higher than the other in its frequency. These two waves mixed inside a nonlinear crystal to form a new one with the sum frequency of that of the two input waves. The new wave should satisfy the laws of conservation of energy and momentum [1]. The gain of an OPA depends on the pumping power density (I_p) and it is given by [2]

$$G = (K \times I_{p\,(min)})^{1/2} \qquad (1)$$

where $I_{p\,(min)}$ is the minimum power density gives OPA output and K is the coupling constant. In order to achieve significant gain the parametric device, the three waves must be propagate inside the crystal with the same velocity and hence phase matched, i.e., the phase matching parameter Δk is zero [3]. This means that orienting the crystal in a particular manner relative to the incident beams. The external efficiency has the following relationship with effective nonlinear coefficient (d_{eff}), crystal length (l), input power density (I_p) and Δk [1].

$$\eta \propto I_p\, l^2\, d^2_{eff}\, \mathrm{sinc}^2(\Delta k l/2) \qquad (2)$$

In general, higher power density, longer crystal length (l) and smaller phase mismatching will result higher conversion efficiency [4].

In parametric amplifier, the high frequency wave tacks from lasers directly, while the other one tacks from another nonlinear process known as parametric oscillator (OPO) [5]. In OPO, one high frequency pumping photon is converted into two low frequency photons (signal and idler) [6]. To form an OPO, resonance is provided by feedback at cavity mirrors for either the signal or idler frequency (singly resonant) or both (double resonant) [3].

Boyd and Ashkin [7] produced cw parametric oscillation and amplification. The experiment involved the pumping of a $LiNbO_3$ crystal by a 0.5147 µm argon ion laser in an OPO process to produce an idler wave of λi= 0.93 µm and a signal wave of λ_s= 1.1526 µm. The signal wave was mixed with pumping wave of λp= 1.1526 µm from He: Ne laser in another $LiNbo_3$ crystal in an OPA process to produce a new wave at λn= 0.576 µm. The phase matching angle was achieved by adjusting the temperature.

The most attractive materials for OPA were KTP and BBO because of the possibility of non-critical phase-matching and relatively low damage thresholds [8]. Al-Dergazely [9] carried out a computational investigation on construction of doubly resonant OPO system pumped by different lasers (Nd:YAG, Er:YAG and diode lasers) to generate different wavelengths in IR spectral region.

A theoretical test has been done by Felippa [10]. Shultz Research Group [11] demonstrated a triplex nonlinear system (OPO, OPA and SFG). They used Q- switched Nd:YAG laser as a pumping beam and it was split into two parts; 40% of the Nd:YAG laser was frequency doubled in KTP crystal. This newly created light (532 nm) was split so that about 40% was sent to the sample for sum frequency generation (SFG), and 60% was directed to OPO to generate an idler wave of λ_i= (1.3– 1.7) µm and a signal wave of λ_s= (730– 860) nm. The idler was mixed then in a KTP crystal with 60% of the pumping beam (Nd: YAG) to produce the visible light in OPA process.

Osvay et al. [12] constructed femtosecond OPA in the UV region. They didn't use OPO to generate the signal wave but instead they used Astra laser of λp= 800 nm as a pump wave. Part of this beam was frequency doubled by BBO crystal to use as a signal wave. The pump and the signal waves were mixed in 12 mm long BBO crystal to produce λn= 266 nm in OPA process. The trace of the output pulse was photographed by CCD camera.

Recently, Central Laser Facility Department [13] produced ultra-short laser pulses OPA. A 5% of titanium sapphire laser pulse was converted into white light spectrum in a sapphire crystal by optical Kerr- effect and used as a signal wave. The remainder (95% of 800 nm) was frequency doubled in BBO crystal and used as pump wave. These two waves were mixed in two stage OPA process to generate a beam of λn= 450nm.

The conversion efficiency and the optical gain parameters of the constructed OPA system, which affect the generation of 629 nm powerful pulsed laser, have been studied in the present work.

Experimental Setup

Figure (1) shows the main components of the nonlinear system. A home-made Q-switch Nd:YAG laser was used to pump the parametric oscillator and amplifier systems. The maximum pulse energy is 76 mJ at 1.064 µm and pulse duration of 30 ns. The beam is divided by a partial reflective glass beam splitter with transmitted to reflected ratio of 60%- 40%. A singly resonant oscillator is fed by the transmitted fraction of the Nd:YAG laser to form a signal wave at 1.54 µm and idler wave at 3.4 µm wavelength. The incident pumping beam passes through a coated high reflection mirror (HR). A mirror with partial reflectivity at 1.54 µm is used as an output coupler. The reflectivity is 95.2% at the signal wavelength.

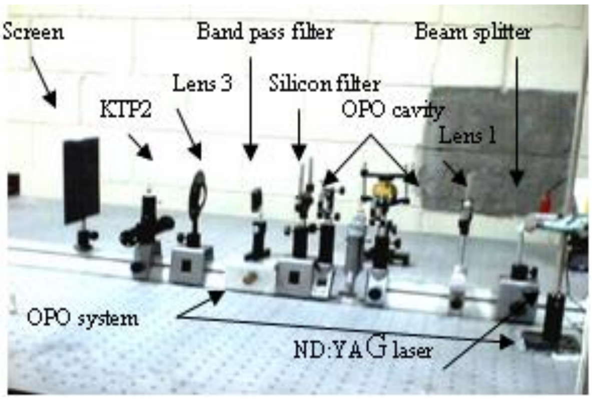

Fig. 1: Experimental setup for the nonlinear system.

The nonlinear crystal that employed in parametric oscillation is KTP. Its dimensions are 3 × 3 × 5 mm and it is an anti-reflection coated at 1.064 µm. The undepleted pumping beam out of OPO cavity blocked by silicon filter and for further separation between the signal and idler, the idler wave is rejected using band pass filter. The reflected fraction of input Nd:YAG laser is reflected by a gold mirror and mixed with the signal inside another KTP crystal for forming a new wave at 0.629 µm. This crystal has the same characteristic as that of the first one but it is cut in non-critical phase matching angle (θ_{pm}= 90^o), that insure no walk–off accord and hence optimum conversion efficiency will obtain.

Results and Discussion

Figure (2) illustrates the OPO output (total, signal and idler) energies as a function of pumping Nd:YAG energies (E_{p2}). Most of the pumping energy is depleted and the depleted energy goes into the signal and idler beams [1], therefore the energy of the signal increases as the pumping energy increasing.

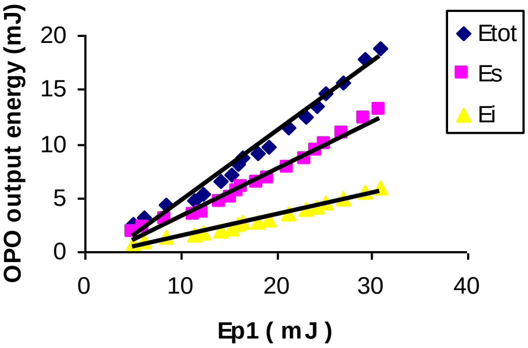

Fig. (2): OPO output energies as a Function of pumping energies.

The energy conversion efficiency from the input pumping beam to the output signal beam is measured from the slope of the straight line shown by Fig. (2). It has a value of 47%. Figure (3) shows the OPA output energies (En) as a function of the input pumping energies (E_{p2}+ E_s). The energy of the generated wave (E_n) increases as a result of increasing the energies of the two input waves (E_{p2} and E_s) where both of them contribute in part of its energy to form the new one [14].

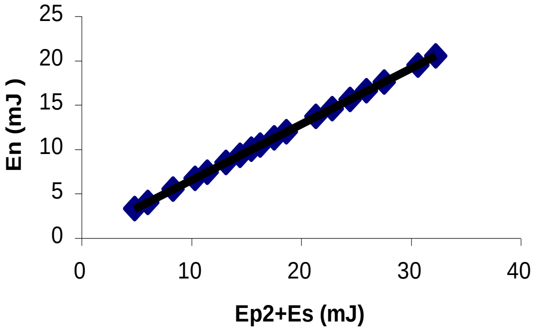

Fig. (3): The OPA output energies versus pumping energies

From the slope of straight line of Fig. (3), the conversion efficiency of OPA system was measured to be 60%. The output pulse of OPA is shown in Fig. (4).

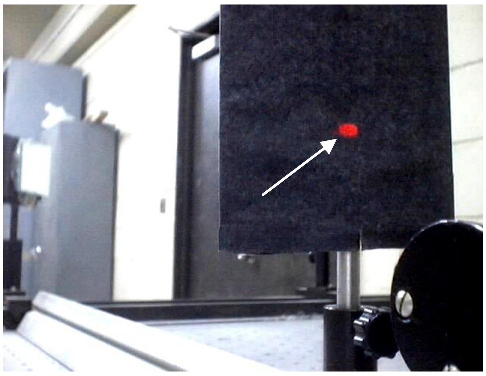

Fig. (4): The output beam spot of OPA.

Kahraman [15] constructed a nonlinear system that pumped by Nd:YAG laser. They used quasi phase matching in KTP crystals. The short length cavity and the decrease in the pumping power density (to avoid crystal damage) were due to the small- dimension crystal. The conversion efficiency of their system was 30% and it is relatively low comparing with what have been reached in this research, in which tilting the crystals until optimum phase matching is obtained and increasing the pumping power density lead to grow in the conversion efficiency. The optical gain of OPA system is measured using Eq. (1). The gain was 0.58 in 0.5 cm crystal long and 28.07 MW/cm^2 minimum pumping power density. Increasing the power density upon its minimum value plays an essential role in increasing the optical gain [13].

Conclusion

Using an OPA system gives the possibility of generation a powerful pulsed laser at 629 nm. Conversion efficiency of 60% can be reached when the nonlinear system is pumped by Q-switch Nd:YAG laser and a signal resulted from OPO.

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توليد ليزر نبضي بطول موجي 629 نانومتر بأستخدام منظومة تضخيم المعلم البصري

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الخلاصة

الهدف الرئيسي من هذا البحث هو بناء منظومة تضخيم المعلم البصري لتوليد ليزر نبضي بطول موجي 629 نانومتر. أستخدمت في البحث بلورة لاخطية نوع KTP في عمليتي التضخيم والاهتزاز. لقد تم بناء منظومة أهتزاز المعلم البصري (OPO) لتوليد طولين موجيين 1,54 و 3,4 مايكرومتر عندما يضخ بليزر النديميوم- ياك 1,064 مايكرومتر. ولتوليد الطول الموجي المطلوب تم خلط موجة الأشارة مع حزمة الضخ في منظومة تضخيم المعلم البصري ، وتم الحصول على كفاءة تحويل قدرها 60% لنبضة الليزر المتولدة .