Temperature-tuned cascade third-harmonic generation of a Nd:YAG Laser in type II KTP/DKDP crystals

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The characteristic of unconverted fundamental elliptical polarized laser radiation in a KTP crystal are studied experimentally as a function of temperature when generating the second harmonic. Temperature-tuned cascade third-harmonic generation has been studied using a type II DKDP crystal.
Key words: cascade third-harmonic generation, nonlinear KTP, DKDP crystals.

The question about Nd:YAG laser cascade third-harmonic generation (THG) conversion efficiency has been studied in many works [1,2]. For plane waves maximal THG conversion efficiency is obtained when the number of photons with a frequency of ω is equal to the number of photons with a frequency of 2ω. In this case second-harmonic generation (SHG) conversion efficiency amounts to ~67% [2]. The crystal KTP is unique nonlinear optical material that is being widely used for SHG of Nd lasers emitting around 1μm. Possessing high nonlinearity ($d_{eff}=8,3 \cdot d_{36}$ (KDP)), this crystal has at the same time a high angular acceptance ~20mrad $\cdot$ cm^{-1} and a wide temperature bandwidth ~25°C $\cdot$ cm^{-1} for SHG at λ=1,06μm, which significantly exceeds analogous parameters of the KDP, DKDP, BBO, LBO and other crystals [1]. The KTP crystal is nonhygroscopic and has high damage threshold. SHG conversion efficiency in a 10-mm-long KTP crystal with type II phase matching in the xy-plane amounts to ~60 ÷70% with incident intensity ~25÷40MW/cm^2 [3]. However, at room temperature in a KTP crystals there appear colour centers and a grey-track reducing the crystal damage threshold. To eliminate the negative effects the KTP crystals are heated up to and beyond 70°C [2,3]. On the other side, the KTP crystal may be regarded as a wave plate for fundamental radiation , which is sensitive to a temperature change. For 1,064μm radiation a phase shift of π/2 is obtained with a change of 13,5°C per centimeter of crystal length in the region of 25°C [3]. Thus in a KTP crystal converting fundamental harmonic into second harmonic it is also possible to control the polarization of unconverted, fundamental radiation by means of a crystal temperature change, which is of practical interest in cascade harmonic generation.

This work explores peculiarities of a temperature-controlled cascade THG in the KTP/DKDP crystals with type II phase matching .

Experimental setup scheme is given in Fig.1. We use a multimode Q-switched Nd:YAG laser with pulse energy up to 330mJ, peak power density up to 250MW/cm^2 and pulse width ~5ns as a radiation source at 1,0642μm. The transverse intensity distribution profile in the beam with a diameter of ~5,7mm and a divergence of ~1mrad was uniform and nearly rectangular. Linearly polarized fundamental radiation is converted into circular-polarized with a quarter-wave plate 1. For SHG we use a 3-mm-long type II, anti-reflection coated KTP crystal (cutting angles φ= 23,5 ° and θ = 90 °) placed in an oven and oriented in such a way that second harmonic radiation was polarized in the horizontal plane (p-component in the plane of Fig.1). To compensate phase differences with unconverted, elliptically-polarized fundamental radiation we mount a dichroic-wave plate 3 behind the KTP crystal acting as a quarter-wave plate for the fundamental and a full-wave plate for the harmonic. For space division of the unconverted fundamental radiation and second harmonic beams mirrors 4 and 5 were used which have a high transmittance T_p=0,98 for λ_2 =0,5321μm and a high reflection R_s≈0,99 and R_p ≈0,98 for s- and p-components at λ_1 =1,0642μm respectively. By means of thin film polarizer 6 and dichroic-wave plate 3 we effected analysis of unconverted, elliptically-polarized fundamental radiation. To measure pulse energies of s- and p-component of unconverted, fundamental radiation and second harmonic power meter 7 was used.

The maximal SHG conversion efficiency is 55 % and maintained stable with a temperature change of the KTP crystal in the range from 30°C to 60°C by means of angular tuning in xy-plane. At that pulse width of second harmonic and unconverted, fundamental radiation were ~5ns and ~7ns respectively. Fig.2 shows a dependence of pulse energies of second-harmonic (1) and p-component (2) and s-component (3) of unconverted, elliptically-polarized fundamental radiation after dichroic-wave plate 3 from a KTP crystal temperature. The unconverted, fundamental radiation is linearly polarized under 45° with respect to the z-axis of KTP at crystal temperatures of 31,5°C, 49,5°C and 63,5°C and circularly polarized at temperatures of 40°C and 57°C. A temperature change from 40°C to 57 °C corresponds to a phase shift between e- and o-components of π. This means that rotation directions in the unconverted, fundamental radiation with circular polarization at a temperature of 40°C and 57°C are opposite. While passing through dichroic-wave plate 3, circular-polarized light is converted into linearly-polarized light and at temperatures 40°C and 57°C unconverted, fundamental radiation being polarized in the horizontal (p-component) and vertical (s-component) planes respectively. Thus the experiment demonstrates that at certain temperatures unconverted, fundamental radiation may be linearly-polarized in a plane perpendicular or parallel to the second harmonic polarization plane, which is of interest in cascade harmonic generation.

For cascade THG we use a 20-mm-long type II DKDP crystal (cutting angle θ =59°). The DKDP crystal was positioned behind the dichroic-wave plate 3 such that the phase matching plane is perpendicular to the polarization plane of the second harmonic. At temperature of 57°C the unconverted, fundamental radiation behind the dichroic-wave plate is polarized perpendicularly to the SHG wave, pulse energies then are ~125mJ (fundamental) and ~178mJ (SHG) respectively.

A pulse energy in the third harmonic of ~98mJ is achieved. In this case the temporal pulse width of unconverted, fundamental radiation was ~7ns, which was more than 40% broader than the incidence pulse width (~5ns). Detuning the KTP crystal over a small angle in the xy-plane away from the phase-matching angle decreases the SHG pulse energy to 150mJ, whereas the THG energy increases to 110mJ. In this case effects the temporal pulse broadening of unconverted, fundamental radiation is less significant. In this position of the KTP crystal we measure pulse energies of unconverted fundamental (s-component)-1 and second harmonic-2 before and third harmonic-3 after the DKDP crystal as a function of temperature in the range of 42°C to 57°C. The results of these measurements are shown in the Fig.3. Maximal THG conversion efficiency is obtained with a KTP crystal temperature of ~56°C, where the energies of the fundamental and second harmonic pulses are equal at~150mJ. Apart from that, with a temperature change in the range from 57°C to 42°C pulse energies of third harmonic decreases from maximal ~110mJ to minimal ~ 28mJ respectively.

This experimental data suggest that by changing the temperature of the KTP crystal it is possible to control polarization of unconverted fundamental radiation and, consequently, the efficiency of the subsequent third-harmonic generation process.

References:

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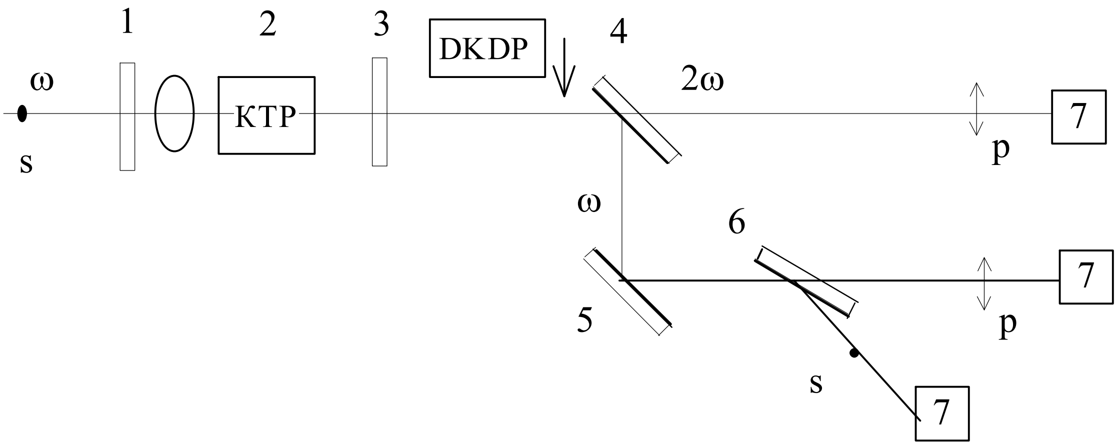

Fig. 1. Experimental setup scheme.

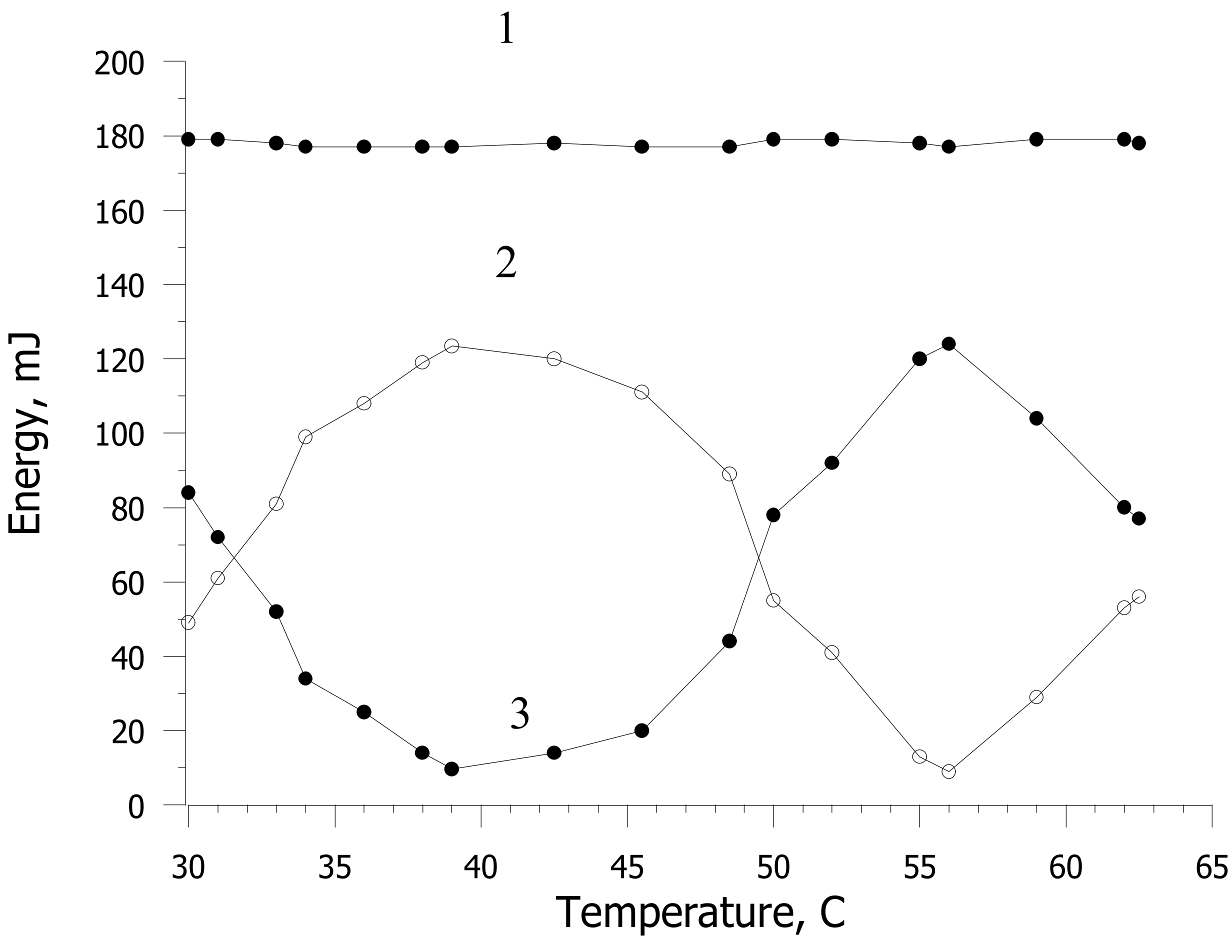

Fig. 2. Dependence of pulse energies of second harmonic (1) and p-component (2) and s-component (3) unconverted, elliptically-polarized fundamental radiation after dichroic-wave plate from KTP crystal temperature.

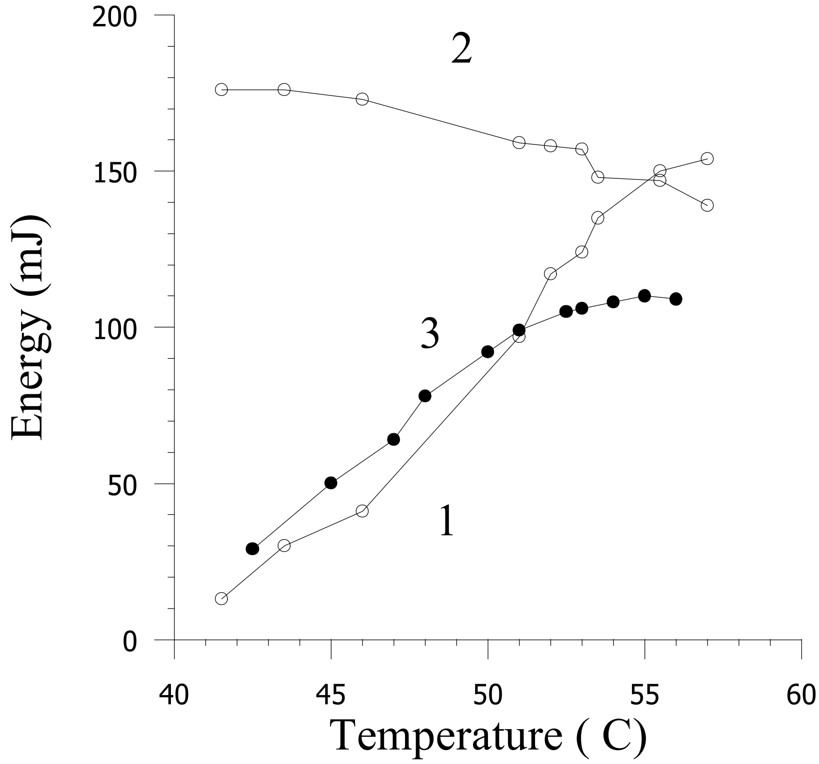

Fig. 3.Pulse energies of s-component (1) unconverted fundamental radiation and second harmonic (2) before and third harmonic (3) after the DKDP crystal versus a KTP crystal temperature.