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Conversion of the 'Iskra-5' iodine laser to second-harmonic operating mode

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***Abstract*. The conversion of the 'Iskra-5' iodine laser to the regime of fusion target irradiation by second harmonic radiation at 657.5 nm is reported. The laser upgrading enabled obtaining from 12 channels a total second-harmonic energy yield of 2.5 kJ, which corresponds to an output power of 5 TW. The conversion efficiency was equal to $\sim$50 % in experiments with DKDP crystals with an aperture of 35 cm. A series of 12-channel experiments was conducted involving second-harmonic irradiation of microtargets.**

Keywords: *iodine laser, second harmonic generation, 'Iskra' facility, interaction of high-power radiation with matter.*

1. Introduction

The interaction of high-power laser radiation with matter at intensities $I_{\rm las}\lambda^2 \geqslant 10^{14}$ μm^2 W cm^{-2} ($I_{\rm las}$ is the laser radiation intensity and λ is the wavelength) is a fundamentally nonlinear process. Fast electron and ion generation (see, for instance, Ref. [1]) as well as the low efficiency of classical inverse bremsstrahlung are responsible for a decrease in the laser energy input into a laser microtarget. This is the reason why the target irradiation in high-power laser facilities intended for the investigation of laser fusion physics is effected by the second or third harmonic of the fundamental radiation.

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The high-power 12-channel 'Iskra-5' laser facility [2], which is primarily employed for indirect-irradiation target research [3], was initially designed for investigations at the first iodine laser harmonic ($\lambda_1 = 1315$ nm). However, the necessity of elaborating the technique for the investigation of the processes in laser fusion targets in the interests of the 'Iskra-6' facility, which now is under construction in the Russian Federal Nuclear Centre, called for the conversion of the 'Iskra-5' facility to an operating regime involving target exposure by the second harmonic radiation ($\lambda_2 =$ 657.5 nm).

The problem of high-efficiency conversion of high-power laser radiation to the second harmonic (2ω) has been adequately studied, both theoretically and experimentally. A wealth of publications are concerned with the conversion of high-power neodymium and iodine laser radiation to the second harmonic (see, for instance, [4 – 7]). In particular, it was shown for the 'Iskra-4' iodine laser [7] that DKDP crystals should be used to convert the radiation to the second harmonic: these crystals are transparent for the 1315-nm operating wavelength, they have a high damage threshold and may be grown to large sizes.

At the same time, the practical realisation of second harmonic operating regime involves special features of its own for every specific laser facility. That is why in the conversion of the 'Iskra-5' laser to this operating regime ($\lambda = 657.5$ nm) investigations were made of the parameters of the real output laser radiation to select the optimal optical configuration for the conversion to the second harmonic [8, 9]. These works were concerned with the investigation of the conditions for high-efficiency oee-type radiation conversion with the use of large-aperture DKDP crystals produced by the fast growth technique [10].

DKDP crystals (Fig. 1) with an aperture of 35 cm were grown at the Institute of Applied Physics, RAS (Nizhnii Novgorod). The crystals are 2 cm thick, with a 'Rozakor' coating deposited on both faces to protect them against humidity. The damage threshold of the coating at the fundamental frequency is equal to $\sim$3 J cm^{-2} for a pulse duration $\tau_{0.5} \sim 0.5$ ns.

To match the apertures of the DKDP crystals in use with the aperture of the output A4 amplification stage, the latter was decreased from 70 to 35 cm. The optical configuration of the channel upon its modernisation is depicted in Fig. 2. Compared to Ref. [2], the arrangement of electric-discharge

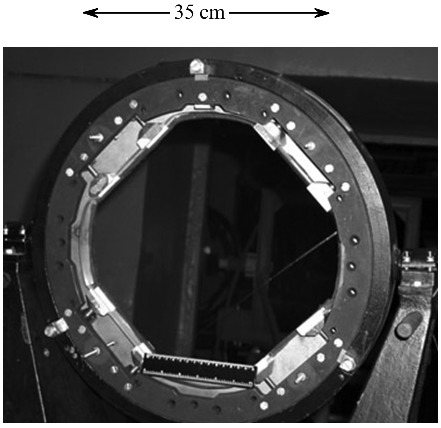

Figure 1. Large-aperture DKDP crystal in an adjustable mount.

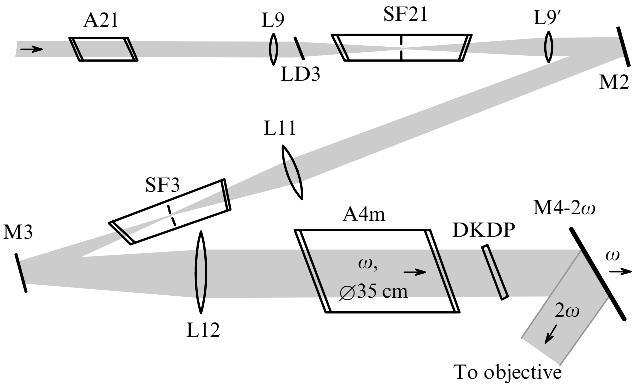

Figure 2. Fragment of the optical arrangement of one channel of the 'Iskra-5' facility upon conversion to the second harmonic operating mode: A21, A4m – amplification stages; LD3 – liquid dye (saturated absorber); SF21, SF3 – spatial filters; L9, L9′, L11, and L12 – lenses; M2, M3 – fold mirrors; M4-2ω – selective mirror; DKDP – nonlinear conversion crystal.

A4m-amplifier pump sources was changed so that to obtain a 'clean' rectangular aperture with a $\sim 30 \times 30$-cm size matched with the DKDP crystal aperture. The output aperture was decreased by changing the telescope made up of lenses L9 – L9′. Furthermore, in comparison with Ref. [2] the amplification channel A3, which had been located between mirror M2 and lens L11, was removed from the channel. Upon laser modernisation, every channel permits obtaining from a 35-cm aperture a single pulse with an energy up to 1 kJ, a duration of 0.3 – 0.8 ns, a divergence of 0.1 mrad, and a beam-integrated degree of fundamental radiation depolarisation of $\sim 5\,\%$. The DKDP crystal intended for the radiation conversion to the second harmonic is located at the channel output. The crystal tilt angles required to ensure the phase matching were set with the aid of an autocollimation 2T2A theodolite with an uncertainty below 0.1 mrad.

After upgrading the laser, we carried out the investigations of the efficiency of radiation conversion to the second harmonic [8, 9], the results of which are given in Fig. 3. One can see that the highest efficiency for the DKDP crystals in use is reached at a radiation intensity of 1 – 2 GW cm^{-2} and is equal to about 60 %. With increase in the average pump intensity to ~ 3 GW cm^{-2}, the conversion efficiency lowers to $\sim 35\,\%$ due to radiation depolarisation.

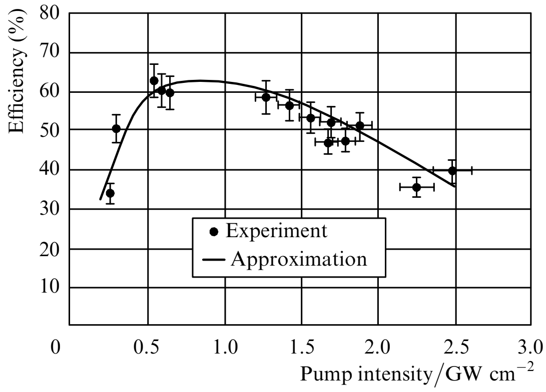

Figure 3. Second harmonic conversion efficiencies as functions of time-averaged pump intensity obtained on the 'Iskra-5' iodine laser.

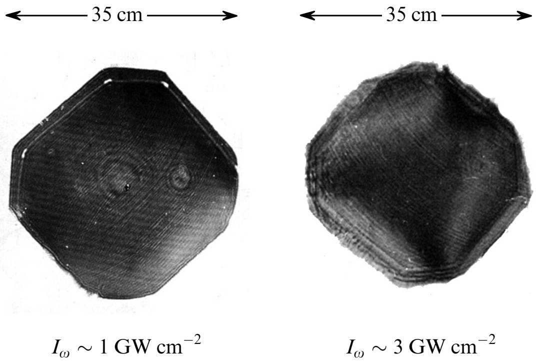

Figure 4. Typical near-field intensity distributions for the radiation with a frequency 2ω at the channel output for different pump intensities.

This is accompanied with a change in the near-field 2ω-frequency radiation distribution: it becomes nonuniform (see Fig. 4, which shows the typical near-field distributions of radiation at the 2ω frequency for different pump intensities).

In the subsequent investigations we employed the operating mode of A4m power stages with an energy (at the ω frequency) of ~ 500 J per channel, which in turn enabled obtaining from every channel a second-harmonic pulse with an energy of 200 – 250 J approximately 0.5 ns in duration (with a time diversity of ± 0.1 ns with which pulses from different channels arrive at the target).

To introduce the second harmonic radiation into the interaction chamber, we employ selective mirrors M4-2ω (Fig. 2), which reflect primarily the radiation with the frequency 2ω ($R_\omega < 5\,\%$, $R_{2\omega} > 95\,\%$). This design makes it possible, on the one hand, to significantly decrease the pump radiation intensity on the target and on the other hand to prevent the possible self-excitation of the A4m amplifier. The damage threshold of the coatings is about 3 J cm^{-2}, which is quite sufficient for their employment in the configuration involved.

Using the above configuration, a series of 4-channel experiments involving injection of the second harmonic radiation into the interaction chamber were conducted on the 'Iskra-5' facility. In this case, it was determined that the reflection coatings of the focusing mirrors in standard catadioptric objectives located in the interaction chamber were damaged by the 2ω radiation. That is why a new triplet lens with a focal distance $F = 1.6$ m was calculated and fabricated. It consists of a lens L13 of the previous objective and two additional lenses 30 cm in diameter. The new objective provides a focal spot ~ 150 μm in diameter for the 2ω-frequency radiation and possesses an antirefletion coating with a radiation damage threshold of ~ 2 J cm^{-2}.

Upon replacement of all 12 objectives, a series of experiments were carried out on the 'Iskra-5' facility involving microtarget irradiation by the second harmonic radiation of all 12 channels with a total energy of 2.6 kJ. In these experiments, the average energy per channel was equal to 220 ± 40 J, the radiation pulse duration was equal to 0.55 ± 0.10 ns, and the divergence did not exceed 0.1 mrad. The time diversity of laser pulse arrival at the target was ~ 50 ps. A more comprehensive result of these experiments will be published in the near future.

The experiments performed in our work allow the following conclusions.

– Improvement of the optical configuration of the 'Iskra-5' facility for the purpose of converting it to the second-harmonic operating mode allowed us to obtain in every channel a fundamental-frequency radiation beam with an energy up to 1 kJ, a divergence of 0.1 mrad, a depolarisation degree of 5 %, and an aperture of 35 cm matched with the aperture of the DKDP crystals in use. The fundamental-to-second harmonic conversion efficiency maximum possible in the context of the 'Iskra-5' facility for 2-cm thick DKDP crystals was achieved for a pump intensity of about 1 GW cm^{-2} and was equal to ~ 60 %. The highest energy output at the second harmonic obtained from one channel is equal to 350 J for a pulse duration of ~ 0.3 ns and 500 J for a pulse duration of ~ 0.8 ns.

– Modernisation of the focusing lenses in the interaction chamber permitted us to carry out a series of 12-channel experiments involving injection of the second-harmonic radiation with a total 2ω-energy of about 2.5 kJ and an integral duration of ~ 0.6 ns for a fundamental-to-second harmonic conversion efficiency of ~ 50 %.

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