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GENERATION OF COHERENT RADIATION AT λ = 2120 Å BY CASCADE FREQUENCY CONVERSION

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1. The purpose of the present paper is to report the results of an experimental investigation that has led to the development of a source of intense coherent radiation at a wavelength λ = 2120 Å. Ultraviolet (UV) radiation of $\sim$ 1 kW power was obtained by synchronous cascade generation of the fifth harmonic of the radiation of a neodymium laser in a KDP crystal. The strong frequency dispersion of the synchronism direction in the UV region causes the generation of the fifth harmonic to be accompanied by an appreciable narrowing of the spectrum $\Delta\lambda_5$. In our experiments $\Delta\lambda_5$ did not exceed $\Delta\lambda_5^{lim}$ = 1 Å, regardless of the width of the spectrum of the fundamental radiation (of course, provided $\Delta\lambda_1 > \Delta\lambda_5^{lim}$).

2. Up to now, the shortest wavelengths obtained by nonlinear-optics methods under contions of accumulating interactions with KDP and ADP crystals are λ = 2650 Å, the fourth harmonic of a neodymium laser (see [1 - 3]) and λ = 2573 Å, the second harmonic of an argon gas laser (see [4, 5]). These wavelengths are not the shortest possible, the edge of the absorption edge for the KDP and ADP crystals lies near λ = 2000 Å [10]. When it comes to powerful solid-state lasers, the most convenient scheme for advancing further in the UV region is admittedly the generation of the fifth harmonic of the emission of a neodymium laser; the total absorption of the KDP crystal used by us at λ_5 = 2120 Å was 60%. This is precisely

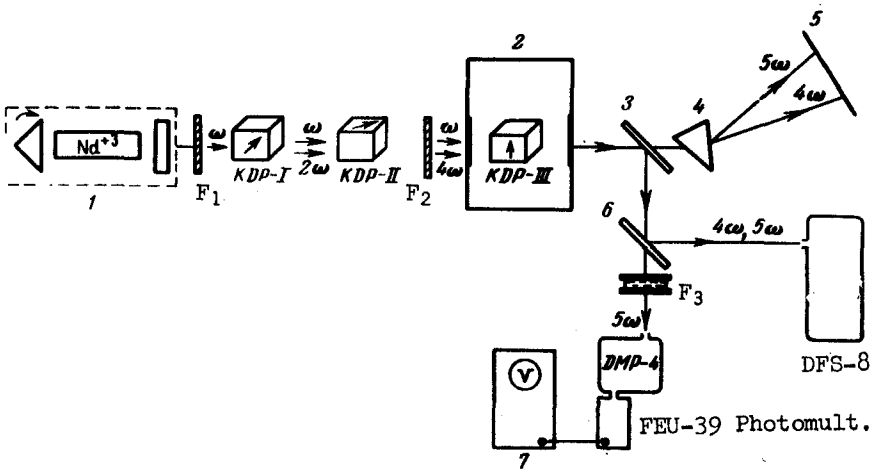

Fig. 1. Block diagram of experimental setup for the generation of the fifth harmonic of a neodymium laser.

the system first realized in our investigation.

3. A block diagram of the experimental setup is shown in Fig. 1. A giant pulse for a neodymium-glass laser ($\lambda_1 = 1.06\mu$) excites a cascade frequency converter consisting of three KDP crystal. The second ($\lambda_2 = 0.53\mu$) and fourth ($\lambda_4 = 0.265\mu$) harmonics are obtained in succession in the crystals KDP-I ($\ell = 4$ cm) and KDP-II ($\ell = 4$ cm) at room temperature. Synchronous OO → E interaction is used in both crystals. The third stage (KDP-III, $\ell = 2.5$ cm) is a mixer, in which the frequencies of the fundamental radiation end of the fourth harmonic was added ($\nu_5 = \nu_1 + \nu_4$). The conditions for synchronous addition of the frequencies ν_1 and ν_4 are not satisfied in KDP and ADP crystals at room temperature and at $\lambda_1 = 1.06\mu$. This difficulty can be circumvented in two ways: 1) by tuning the frequency of the laser to a longer wavelength (according to calculations, by approximately 130 Å) and 2) cooling the crystal. We used the latter variant and at a temperature $T_c = -70°C$ we obtained in the KDP-III crystal a synchronous interaction $K_1^0 + K_4^0 = k_5^e$ at 90° to the optical axis (to eliminate aperture effects).

On going through the synchronism temperature, we observed a sharp increase of the fifth-harmonic power, by a factor $10^3 - 10^4$, reaching 1 kW in the unifocused beam. The spectra of the second, fourth, and fifth harmonics, obtained with a DFS spectrograph, are shown in Fig. 2.

4. A distinguishing feature of the synchronous nonlinear interactions in the UV region is the exceedingly strong sensitivity of the synchronism directions to the frequencies of the interacting waves [11]. The permissible laser wavelength fluctuations from flash to flash should not exceed $\Delta\lambda_{fl} \approx 1$ Å in our cascade system.

Therefore, in the first experiments aimed at obtaining the fifth harmonic we used a multimode laser with a broad spectrum $\Delta\lambda_i \gg \Delta\lambda_f$; in this case the stability of the fourth-harmonic power is obtained at the cost of decreasing the efficiency. It is easy to perform the calculations by using the already developed nonstationary theory of frequency multiplication (see [6 - 9]), and using the specified values of the widths of the spectra and the

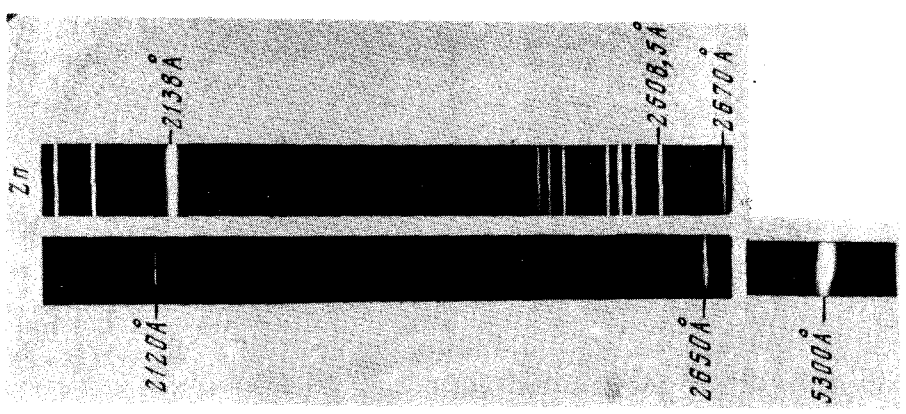

Fig. 2. Emission spectra of 2d, 4th, and 5th harmonics of neodymium laser, obtained in KDP crystals, $\Delta\lambda_2 \approx 30$ Å, $\Delta\lambda_4 < 1$ Å, $\Delta\lambda_5 < 1$ Å.

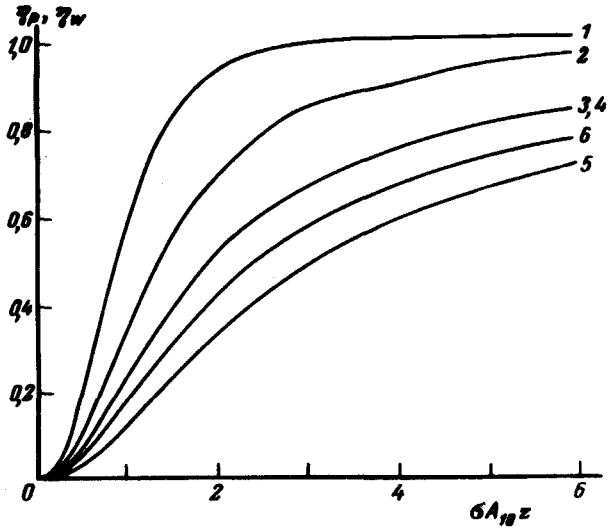

Fig. 3. Plots of the power efficiency of the doubler η_P with allowance for the spatial modulation (curves 1, 2, 3) and the energy efficiency η_W with allowance for spatial and temporal modulation of the main radiation (curves 4, 5, 6); 1 - rectangular distribution, 2 - Gaussian: $\exp[-r^2/a^2)]$, 3 - nearly Gaussian distribution: $[1-(r^2/a^2)]^{-1}$, 4, 5, 6 - spatial distribution in accord with the law $[1 + (r^2/a^2)]^{-1}$ and temporal distribution: 4 - rectangular, 5 - triangular with exponential fronts, 6 - intermediate between cases 4 and 5.

group detunings $\beta_{ij} = u_i^{-1} - u_j^{-1}$.

Using the results of [6, 8], we can calculate the width of the spectral fifth-harmonic line obtained in an essentially non-quasiastic regime, $\Delta\nu_5 = 1/|\beta_{5,1}|z$; substituting z = 2.5 cm and $\beta_{5,1} = 0.116 \times 10^{-10}$, we obtain $\Delta\nu_5 \approx 1.15$ cm^{-1}.

5. In conclusion it is of interest to estimate the limiting value of the conversion efficiency of the described generator. For a highly-stable single-mode laser, the energy efficiency of each of the first two stages can reach 50 - 60% if the diaphragm aperture effect is compensated for. The factors limiting the efficiency at this level are the Gaussian character of the beam and of the main radiation pulse, which causes the conversion in the "wings" to much less effective than in the center. The foregoing is explained by the diagrams of Fig. 3, which illustrate the relation between the power and energy efficiencies of the doubler.

Analysis shows that in the optimum mixer, the regime $P_1 \gg P_4, P_5$; this can be readily obtained in practice. In this case

$$P_5(z) = (\sigma_5/\sigma_4)\, P_{40} \sin^2 \sqrt{\sigma_4\sigma_5}\, A_{10} z$$

(A_{10} is the amplitude of the main-radiation field, and σ_4 and σ_5 are nonlinear coefficients), i.e., the maximum fifth-harmonic power is equal to that of the fourth harmonic at the mixer input when $z = \pi/2\sigma A_{10}$, where $\sigma = \sqrt{\sigma_4\sigma_5}$ (for a KDP crystal of length z = 2.5 cm, the maximum conversion occurs at $P_1 = 60$ MW/cm^2). The energy efficiency can be determined with the aid of curves of the type shown in Fig. 3. Thus, when $P_1 \approx 60$ MW/cm^2 the energy efficiency of the fifth-harmonic generator excited by a single-mode laser (once the diaphragm aperture effect is eliminated) can be of the order of 1 - 3%. A certain change in this figure is possible as the result of nonstationary thermal self focusing; this effect is presently under investigation by us.

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LOCAL OSCILLATIONS IN LiF CRYSTALS WITH HYDROGEN CENTERS

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A group of bands in the 4 - 6 μ region was observed in the infrared absorption spectra of LiF crystals exposed to radiation [1]. To explain the nature of the centers responsible for the bands observed in [1], we investigated spectra of crystals with different contents of the hydroxyl ions OH^- irradiated in a reactor and in γ source.

These investigations make it possible to propose the center models listed in the table.

We start the analysis with the 1900 cm^{-1} bands. Calculation based on the formula

$$\omega_L \approx \{[\epsilon/(1-\epsilon)](6r_0/\beta M)\}^{1/2}, \quad (1)$$

where r_0 is the distance between ions, β is the compressibility, $\varepsilon = 1 - (M'/M)$, M' is the mass of the impurity ion, M is the mass of the host lattice ion [2]), gives for the local frequency of a tritium U center in LiF a value ∿ 637 cm^{-1}. However, in view of the fact that the transmission limit of LiF, at a sample thickness 1 - 10 mm, lies above ∿ 100 cm^{-1} [3], the local frequency of the $[T^{-1}]$ center could not be registered by us.

Absorption band, cm^{-1}	Model of center
2200	H_i^0 - hydrogen atom in interstice (U_2-center)
2100	H_i^- - negative hydrogen ion in interstice (U_1-center)
2000	$(H_2^0)_i$ - hydrogen molecule in interstice
1900	$[T^-]$ - negative tritium ion in halide site (tritium U-center)