OBSERVATION OF GENERATION AT THE SUM FREQUENCY IN ELECTRO-OPTIC NONLINEAR CRYSTALS

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Nonlinear electro-optic crystals make it possible to observe various nonlinear effects - generation of harmonics or of difference and sum frequencies, parametric amplification and parameteric generation, optic detection, and others (see [1,2]). The incomplete list of references [3-14] demonstrates the interest shown by various investigators to the process of addition of frequencies from different generators in nonlinear media, for example of two ruby lasers [3], a laser and an incoherent source [6], a ruby laser and a $CaWO_4:Nd^{3+}$ laser, and others (see [6-13]).

We present below the results of experiments aimed at observing the generation of the sum frequency of two lasers, ruby (λ = 0.6943 μ) and Nd^{3+} glass (λ = 1.058 μ); the sum frequency falls in this case in the blue-violet band (λ = 0.4192 μ). The frequencies are added in a nonlinear electro-optic KDP crystal cut in the synchronism direction (for interactions of the type $k_1^o + k_2^o = k_3^e$ and $k_1^o + k_2^e = k_3^e$, where k_1 is the ruby-laser wave vector, the calculated synchronism angles in KDP are 43°21' and 57°10', respectively; interactions of the type $k_1^e + k_2^o = k_3^e$ are not allowed by the dispersion characteristics of the KDP crystal). We used the data of [16] for the calculations.

The main difficulty in observing the radiation at the sum frequency of two different generators lies in combining their pulses in time and in space; this pertains in particular to lasers operating in the giant-pulse mode, where it is necessary to synchronize two laser pulses with accuracy of the order of 5 nsec. The usual (spike) mode was used in [5]; the difficulty of synchronizing the spikes in time was circumvented in that experiment by using confocal geometry for the cavity of the $CaWO_4:Nd^{3+}$ laser, thus ensuring quasicontinuous radiation at a wavelength λ_2 = 1.06 μ. The radiation power at the sum frequency amounted in [5] to 10^{-7} - 10^{-8} W.

We used ruby and neodymium-glass lasers operating in the Q-switched mode. The pulses of the two lasers were synchronized in time and in space by using a common resonator consisting of a rotating total-internal-reflection prism and an output mirror; the latter was a stack of two plane-parallel plates (see Fig. 1); a somewhat different scheme with common resonator was used in [14]. The prism rotated at 30 000 - 60 000 rpm. In our experimental setup the radiation at wavelengths λ_1 = 0.69 μ and λ_2 = 1.06 μ passes through both active elements; this, naturally, increases somewhat the threshold pump energies of the two lasers.

Under ideal pulse synchronization and spatial alignment, the power radiated at the sum frequency is proportional to the product of the power of the main-radiation generators;

for this case we can write the analogy of the Kleinman formula [15] for propagation of waves with identical phase velocities:

$$S^{\omega_1+\omega_2} = \frac{2(4\pi)^3 k_3^2 \chi^2 n_3^{(e)} \sin^2(\theta_s + \beta)}{\overset{o}{n}_1 \overset{o}{n}_2 c}$$

where χ is the nonlinearity coefficient ($\chi = 10^{-11}$ cm/V for KDP), l the length of the crystal, θ_s and β the synchronism and anisotropy angles, respectively, n the refractive index, and S the amplitude of the Poynting vector at the corresponding frequency.

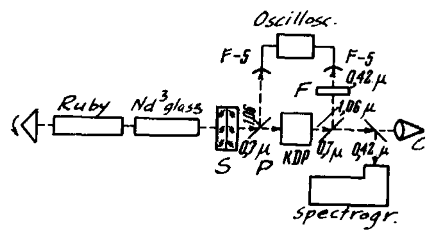

Fig. 1. Block diagram of experimental setup. S - stack of two plane-parallel plates, F - SZS-21 or FS-6 filter, C - calorimeter, P - plane-parallel plate.

It must be noted that when the power at frequencies ω_1 and ω_2 is increased, a definite role can be played by the effects of two-photon absorption in the active elements themselves, since ruby has an absorption band at the second harmonic of the neodymium-laser emission and neodymium glass contains an absorption band at the second harmonic of the ruby laser.

The radiation parameters of the employed lasers and of the output radiation were as follows:

Ruby laser: $\lambda_1 = 0.6943\ \mu$, $E_{pump} = 800$ J, $E_{out} = 0.1$ J, $\tau_p = 40$ nsec, $S(\omega_1) = 2.5$ mW/cm^2.

Neodymium-glass laser: $\lambda_2 = 1.058\ \mu$, $E_{pump} = 800$ J, $E_{out} = 0.4$ J, $\tau_p = 40$ nsec, $S(\omega_2) = 10$ mW/cm^2.

Output radiation parameters: ($\overset{o}{k}_1 + \overset{o}{k}_2 = \overset{o}{k}_3$, $\theta_s^{exp} = 43°40' \pm 30'$), $\lambda_3 = 4.192\ \mu$, $E_{out} = 10^{-3}$ J, $\tau_p = 10$ nsec, $S^{\omega_1+\omega_2} \approx 0.1$ mW/cm^2.

The coefficient of transformation in the radiation at the sum frequency was, by the same token, $\eta \sim 1\%$.

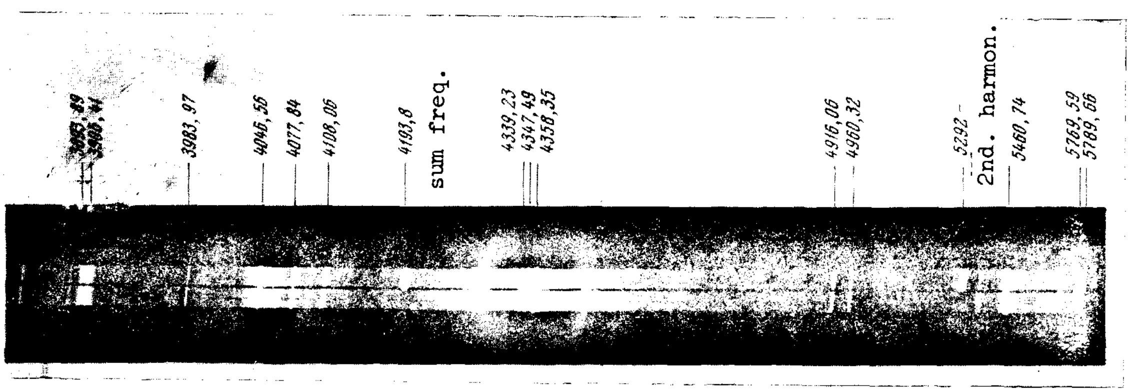

Fig. 2. Emission spectrum at the sum frequency ($\lambda_3 = 4192$ Å) and at the second harmonic ($\lambda = 5290$ Å); the spectrum of the PRK mercury lamp is shown for comparison

The spectrum of the sum-frequency radiation (blue line $\lambda_3 = 0.4192\ \mu$) is shown in

Fig. 2, which shows also for comparison the spectrum of mercury and the green line of the second harmonic of the neodymium laser ($\lambda = 0.529\ \mu$).

Generation at the difference frequency ($\lambda_4 = 2.02\ \mu$) is also of definite interest; such a subtraction of the neodymium laser frequency from the ruby laser frequency can be realized in a nonlinear $LiNbO_3$ crystal. The calculated synchronism angle (see [17]) for the interaction $k_1 - k_2 = k_4$ is $\theta_s = 50°40'$. It must be noted that owing to the Manley-Rowe relation the maximum coefficient of energy-into-radiation transformation at the difference frequency does not exceed $\eta = \omega_4/\omega_1 = 30\%$.

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SINGULARITIES OF THE FARADAY EFFECT IN n-InSb IN THE MILLIMETER BAND

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We investigated the Faraday effect in n-type InSb at 77.8°K as a function of the magnetic field $\vec{B}$ and of the sample thickness.