CONVERSION OF BROAD IR SPECTRA INTO THE VISIBLE BAND UNDER CRITICAL VECTOR PHASE MATCHING CONDITIONS

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1. If an infrared (IR) wave interacts in a nonlinear medium with a pump wave, and the respective spectral distributions are $E_{ir}(\omega)$ and $E_p(\omega)$, then the spectral distribution of the field at the sum frequency is given by [1]

$$E_s(\omega) = R(\omega) P_s(\omega), \tag{1}$$

where $R(\omega)$ is a function that depends on the geometry of the interaction scheme and $P_s(\omega)$ is the nonlinear polarization of the medium:

$$P_s(\omega) = \int_{-\infty}^{\infty} \chi(\omega') E_{ir}(\omega') E(\omega - \omega') d\omega'. \tag{2}$$

We average (1) over an ensemble of radiating atoms, assuming that the pump and IR sources are statistically independent. Then, neglecting the dispersion of the nonlinear polarizability χ, we obtain the following expression for the spectral distribution of the intensity of the converted radiation:

$$I_s(\omega) = (4\pi\chi^2/c)|R(\omega)|^2 \int_{-\infty}^{\infty} I_{ir}(\omega') I(\omega - \omega') d\omega'. \tag{3}$$

Expression (3) is valid in the given-field approximation for the pump and at small conversion coefficients. Knowing the spectral distribution of the pump and of the converted radiation, we can determine the spectrum of the IR radiation:

$$I_{ir}(\omega) = (c/4\pi\chi^2) \int_{-\infty}^{\infty} [(\widetilde{I_s/R})/I_p] \exp i\omega x \, dx, \tag{4}$$

where the superior tilde denotes the Fourier transform of the corresponding function.

2. The "critical" vector phase-matching scheme [2, 3] turns out to be applicable for simultaneous conversion of broad IR spectra into the visible. Indeed, phase-matched conversion of each spectral component ω_{ir} of the IR radiation occurs in this scheme at a definite orientation of the pump wave vector K_p relative to the wave vector $K_{ir}(\omega)$ of the given spectral component of the IR radiation, as follows from the phase-matching condition $K_p + K_{ir} = K_s$. Consequently, to convert a broad IR spectrum into the visible band it suffices to focus one of the two radiations (IR or pump). Obviously, the spectral components of the IR radiation will be converted with equal weights in the case of a uniform angular distribution of the focused radiation. However, for a uniform distribution of each component of the converted radiation it is necessary to focus[1)] into the receiving angular aperture of the spectrograph both light beams

[1)] The focusing can be spherical or cylindrical, unlike the case of image conversion, where one of the focusings must be cylindrical [2].

incident on the crystal. This makes it possible to register correctly the spectrum of the converted radiation. Since the proposed scheme makes it possible to convert all the spectral components of the broad IR spectrum with equal weights, the function $R(\omega)$ in (4) is a constant in our case. Consequently, in the case of monochromatic pumping the spectrum of the converted radiation duplicates exactly the IR spectrum. We then have

$$\Delta\omega_{ir} = \Delta\omega_s \qquad \text{or} \qquad \Delta\lambda_s = (\lambda_s/\lambda_{ir})^2 \Delta\lambda_{ir}, \tag{5}$$

where $\Delta\omega_{ir}$ is the width of the corresponding spectral interval. At a finite but small spectral width of the pump, the converted and the IR spectra coincide accurate to within the width of the pump spectrum. The IR spectral interval converted into the visible band is determined by the tuning curve of the critical vector phase matching and by the degree of focusing. Thus, for example, for an $LiIO_3$ crystal ($\lambda_p = 0.69$ μ) at $\sim 40°$ focusing it is possible to convert simultaneously into the visible region the IR radiation in the entire transparency band of the crystal. For proustite, the corresponding focusing angle is $\sim 60°$.

3. We have experimented with the conversion of the IR spectrum of a neodymium-glass laser ($\lambda_{av} = 1.06$ μ) into the visible band ($\lambda_{av} = 0.42$ μ) by pumping with a ruby laser in an $LiIO_3$ crystal. The experimental setup is shown in Fig. 1. Both lasers were Q-switched and their beams synchronized. The pump power was 1 MW at a spectral width $\sim 10^{-2}$ cm^{-1}. The IR power was 20 kW, and the spectrum width ~5 Å. The interacting beams were focused into the nonlinear crystal by cylindrical lenses. The focusing planes coincided with the XY plane of the crystal. The interaction was of the OOE phase-matching type. The IR spectrum was registered with an image converter and a PGS-2 spectrograph with linear dispersion 7 Å/mm in the 1.06 μ region. The sum-frequency spectrum was registered with an STE-1 spectrograph with linear dispersion 6.9 Å/mm in the 0.42 μ region and with an optical system having a linear magnification 4.5×.

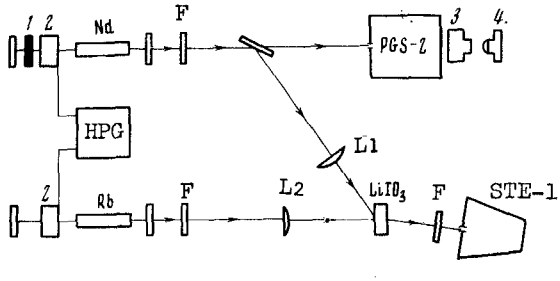

Fig. 1

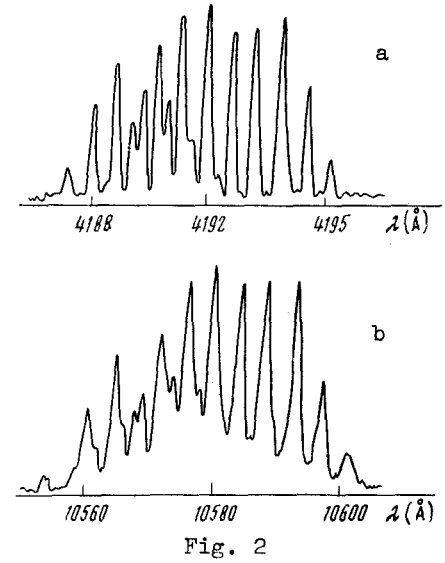

Fig. 2

Fig. 1. 1 - CdSe plate [3], 2 - Pockels cell, 3 - electron-optical converter, 4 - photographic camera, F - filters, L_1, L_2 - lenses, HPG - high-voltage pulse generator.

Fig. 2. Spectrograms: a) of converted radiation ($\lambda_s = 0.42$ μ); b) of IR radiation ($\lambda_{ir} = 1.60$ μ).

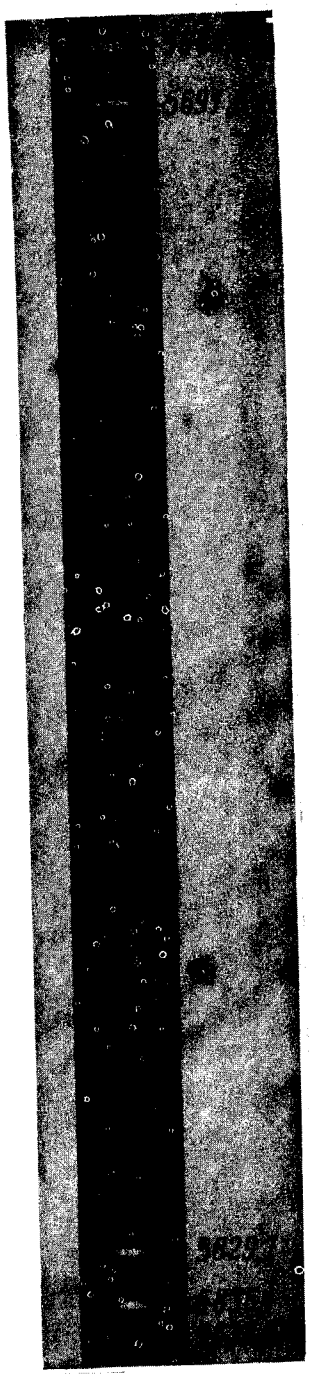

Fig. 3. Spectrum of the IR lines 3.66 μ (triplet) and 3.14 μ (doublet) converted into the visible band. The converted 2.7-μ line is not shown in the figure (λ_p = 0.69 μ).

The converted and IR spectra were registered simultaneously and compared (see Figs. 2a and 2b).

Certain distortions of the IR spectra are due to the insufficient rssolution of the electron-optical converter. We have also experimented with the conversion of an IR spectrum consisting of several spectral lines in the region 3.66, 3.14, and 2.7 μ, excited in potassium vapor by radiation from a ruby laser and by its Stokes component in nitrobenzene.[2] The corresponding spectrogram is shown in Fig. 3. Thus, an IR spectrum of approximate width 1 μ was converted into the visible region within one laser flash.

It should be noted in conclusion that the proposed method may be effective in the registration of broad IR spectra of fast processes.

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[1] V.L. Strizhevskii, Opt. Spektr. 20, No. 3 (1966).
[2] A.V. Gainer, S.V. Kruglov, G.V. Krivoshchekov, V.V. Lebedev, and S.I. Marennikov, ibid. 31, 772 (1971).
[3] A.V. Gainer, S.V. Kruglov, G.V. Krivoshchekov, V.V. Lebedev, and S.I. Marennikov, in: Kvantovaya elektronika No. 6, 122 (1971) [Sov. J. Quant. Electr. 1, 670 (1972)].

[2] In collaboration with Yu.M. Kirin, V.P. Safonov, and V.A. Orlov.