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NONLINEAR OPTICAL PHENOMENA

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Features of the SRS dynamics at the intersection of pumping beams in an active medium

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Abstract. **The features of the dynamics of Raman scattering observed upon excitation of SRS in compressed hydrogen by two pumping beams intersecting at a small angle are studied. The Raman scattering was observed in a direction other than the directions of the pumping beams. A qualitative explanation is offered for the observed experimental results.**

Keywords: *SRS dynamics, dynamic grating, self-intersection of pumping beams*

Stimulated Raman scattering is usually observed by pumping an SRS-active medium by a single beam propagating along the optical axis of the system. For a number of practical applications, however, excitation of Raman scattering by two pumping beams interacting in the active medium also seems to be quite promising.

Such excitation of Raman scattering can be achieved in several ways. One of the methods involves the excitation of SRS by two pumping beams having different frequencies but propagating along the same axis (biharmonic pumping [1, 2]). The SRS excitation by injecting seed radiation at the frequency of the Stokes component in addition to the pumping radiation is another version of the same method [3, 4]. The second method consists in the excitation of Raman scattering upon self-intersection of a pumping beam or the use of two pumping beams having the same frequency and intersecting in the active volume at a small angle [5, 6].

The physical processes occurring in lasers with intersecting (or self-intersecting) pumping beams are quite complex. These processes have not been studied comprehensively because they involve, as a rule, several nonlinear phenomena (SRS, SBS, phase conjugation, the emergence of spatial dynamic gratings in the active medium, etc.), which proceed simultaneously. The present work is devoted to the experimental investigation of some features of the dynamics of radiation emitted by such lasers.

The experimental setup is shown schematically in Fig. 1. The linearly polarised radiation from a single-frequency, single-mode Q-switched ruby laser ($\tau = 50$ ns, $W_p = 0.2$ J) was split by a prism beamsplitter into two parallel beams of equal intensities.

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The pumping beams were directed with the help of a lens ($f = 220$ or 680 mm) into a chamber with compressed hydrogen ($p = 40$ atm), where they intersected at a small angle α which could be varied from 2° to 5.5°. A phase plate inserted into one of the pumping beams made it possible to rotate its polarisation by $\pi/2$. The chamber with compressed hydrogen was oriented in such a way that the normals to its windows formed an angle no smaller than 3 – 5° with the direction of the pumping beams and the bisector between them (the x axis, see Fig. 1).

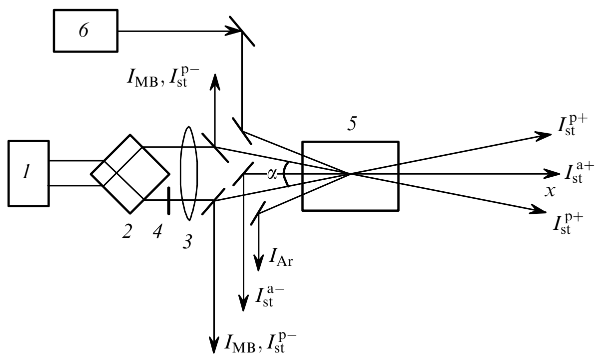

Figure 1. Schematic of the experimental setup: (*1*) ruby laser; (*2*) beamsplitter cube; (*3*) lens; (*4*) phase plate; (*5*) chamber with compressed hydrogen; (*6*) argon laser.

We recorded the temporal, energy and spectral parameters of radiation at the pumping frequency and the frequencies of Raman components both in forward and backward directions of the pumping beams, as well as along the x axis. It was found that stimulated emission produced in this case propagates not only along the pumping beams in the forward and backward directions, but also along an auxiliary channel whose axis coincides with the bisector of the plane angle α between the axes of the pumping beams.

The emergence of such radiation can apparently be explained by the fact that a dynamic grating (spatial modulation of the gain and the refractive index) is formed in the region of intersection of the pumping beams in the SRS-active medium. This grating causes the appearance of an additional Raman scattering channel along the x axis. The existence of such a grating was established by the reflection of the 0.51-μm radiation (reflectivity ~0.01 %) of an auxiliary probe laser from it.

As expected, components of counterpropagating Stokes ($I_{\rm st}^{\rm p-}$) and copropagating Stokes ($I_{\rm st}^{\rm p+}$) and anti-Stokes ($I_{\rm ast}^{\rm p+}$)

waves emerge along the directions of propagation of the pumping beams. Shutting down of one of the pumping beams leads to a considerable attenuation of the intensity of Raman components observed in the direction of the second pumping beam. In addition to the Stokes components, a quite intense SBS radiation also emerges in the backward direction. Fig. 2 shows the characteristic oscillograms illustrating the mutual temporal arrangement of the pumping pulses, SBS, various Stokes components and the probe laser signal reflected from the dynamic grating.

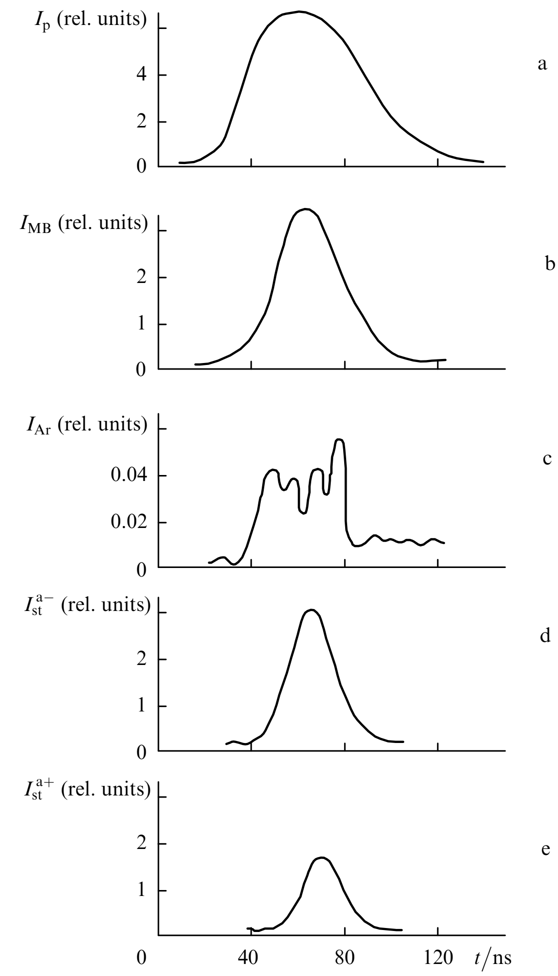

Figure 2. Oscillograms illustrating the mutual temporal arrangement of the pumping pulse I_p (a), the SBS pulse I_{MB} (b), the argon laser signal I_{Ar} reflected from the dynamic grating (c), and the Stokes waves propagating along the x-axis (I_{st}^{a+}, I_{st}^{a-}) (d, e).

An analysis of the obtained oscillograms shows that the dynamic grating is formed in the region of intersection of the pumping beams with a delay of about 10 ns relative to the onset of the pumping pulse (as indicated by the 10-ns delay in the probing laser signal), but simultaneously with the emergence of SBS. This grating is formed a few nanoseconds before the emergence of the copropagating Stokes pulse (I_{st}^{p+}).

The dynamics of radiation in the additional channel, where counterpropagating Stokes (I_{st}^{a-}, I_{st}^{a+}) and anti-Stokes (I_{ast}^{a-}, I_{ast}^{a+}) pulses were detected, was found to be most interesting. Note that Raman scattering emerges in the additional channel only when the pumping beams have the same polarisation. In this case, the intensity I_{st}^{a+} is about of 10 % – 20 % of the intensity I_{st}^{p+}.

When the direction of polarisation of one of the pumping beams is rotated by $\pi/2$, no dynamic grating is formed in the region of intersection of pumping beams (this is confirmed by the absence of the reflected probe laser radiation), and there is no radiation in the additional channel. A rather unexpected result was a significant time delay τ between the counterpropagating pulses of the Raman components in the additional lasing channel. It was found that the time delay τ between the Stokes pulses I_{st}^{a+} and I_{st}^{a-} depends on the pumping intensity I_p and achieves ~ 10 ns for the maximum value of I_p (Fig. 3).

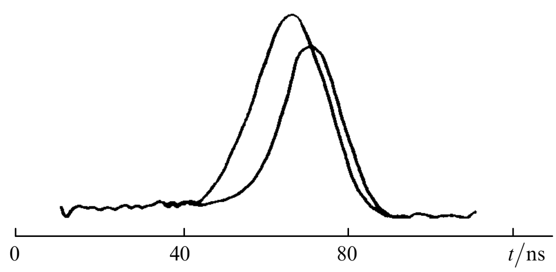

Figure 3. Oscillograms showing the presence of a time delay between the pulses I_{st}^{a+} and I_{st}^{a-}.

Note that if a reflector (e.g., a glass plate without antireflection coating) is placed in the path of radiation propagating along the additional channel, the time delay between the pulses I_{st}^{a+} and I_{st}^{a-} vanishes, and the intensities of these components increase to about 35 % – 40 % of the intensities I_{st}^{p+} and I_{st}^{p-}, respectively. The delay τ also depends on the angle α, and increases from zero to ~ 10 ns as α decreases from 5.5° to 2°. A similar delay is also observed between the radiation pulses I_{ast}^{a+} and I_{ast}^{a-}.

The peculiarities of the dynamics of radiation in the additional channel necessitated a more comprehensive analysis of the mechanisms of interaction of radiation with the dynamic grating. It was found that in the experimental setup shown in Fig. 1, radiation along the x axis emerges not only at the Raman frequencies, but also at the pumping freqquency ($\lambda = 0.6943$ μm). It was found that the duration of the 0.6943-μm radiation pulse, reflected from the dynamic grating in the direction of the x axis, is about half the duration of the output pulse of a ruby laser. The emission spectrum in the 0.6943-μm region contains several components displaced relative to one another by about 0.14 cm^{-1}, which coincides with the Mandel'shtam – Brillouin shift in hydrogen at a pressure $p = 40$ atm. Components identical to those for SBS also accompany the SRS radiation propagating in the additional channel.

Our investigations have confirmed once again the complexity of dynamics of stimulated emission upon the self-intersection of the pumping beams, which is a consequence of the mutual influence of various physical processes proceeding in a nonlinear medium. The observed features can be explained qualitatively as follows. The interference of two mutually coherent self-intersecting pumping beams in a nonlinearly active medium leads to the formation of an amplitude – phase grating in it as a result of the spatial modulation of the gains and the refractive index of the nonlinear medium, a considerable role in the formation of such a grating being played by SBS.

The formation of a dynamic grating in the active region results not only in the energy exchange between the intersecting waves, but also to their self-diffraction from this grating. Naturally, all this is possible only for coherent pumping beams with the same polarisation, which is consistent with the experimental results.

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