[8] S. Fubini, Comm. on Nuclear and Particle Phys. 3, 22 (1969).
[9] C. Alff and D. Berley et al. Phys. Rev. Lett. 9, 325 (1962); S. M. Flatte and D. O. Huwe et al. Phys. Rev. 145, 1050 (1966).
[10] M. Gell-Mann, D. Sharp, and W. C. Wagner, Phys. Rev. Lett. 8, 261 (1962).
[11] H. Goldberg and Y. Srivastava, Phys. Rev. Lett. 22, 749 (1969).
[12] F. I. G. Gilman and H. Harari, Phys. Rev. Lett. 18, 1150 (1967).
[13] S. C. C. Ting, Electromagnetic Interactions, DESY Г31/4 (1968).
[14] G. Fidecaro and M. Fidecaro et al. Phys. Lett. 23, 163 (1966).

PHASING OF THE SPECTRUM AND SHORT LIGHT PULSES IN STIMULATED RAMAN SCATTERING

T. I. Kuznetsova
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 3 July 1969
ZhETF Pis. Red. 10, No. 3, 153 - 156 (5 August 1969)

We propose in this article a new method of obtaining short light pulses, based on the excitation of stimulated Raman scattering (SRS), of Stokes frequency, propagating along the pump direction. If the pump constitutes radiation from a multimode laser with unsynchronized modes, then Stokes radiation is produced, whose spectral components are partly phased, unlike the pump components. Under certain conditions it is possible to obtain complete phasing of the SRS spectrum; the time dependence of the intensity of the Stokes radiation then takes the form of a sequence of isolated short pulses.

The effect of phasing the spectrum is particularly clearly pronounced in the case of an SRS amplifier, for which the output signal at the Stokes frequency $I_s(t, \ell)$ is connected with the input signal $I_s(t, 0)$ and with the pump $I(t)$ by the relation

$$I_s(t, \ell) = I_s(t - \frac{\ell}{v}, 0) \exp\{g\ell I(t - \frac{\ell}{v})\} \qquad (1)$$

The envelope of the pump intensity $I(t)$ contains fluctuation spikes due to the interference of various modes, and is a quasiperiodic function having the period of the intermode beats. In the case of large gain, $g\ell I(t) \gg 1$, the irregularities in the time variation of $I(t)$ become manifest in the time dependence of the function $\exp[g\ell I(t)]$ to a much greater degree; in particular, it becomes possible to separate the most intense of the series of fluctuation spikes contained in one period of the function $I(t)$.

We note that the change of the temporal characteristics of the Stokes radiation compared with the pump profile was discussed in [1, 2], where the narrowing of Stokes pulses was considered. We wish to call attention here to the fact that in the case of multimode pumping there occurs also separation of the intense pulses (i.e. the phasing of the spectrum) in addition to the narrowing of the pulses. Owing to the narrowing effect, the ratio of the instantaneous radiation power to the average power increases by several times, in typical cases by a factor of 3 or 4. The phasing of the spectrum makes it possible to increase this ratio by m times (m is the number of the pump modes).

The effect of interest to us can be described by the simple formula (1) if the following conditions are satisfied.

It is necessary, first, that the sum of the spectral widths of the Stokes signal and of the pump be smaller than the width of the amplification band

$$(\Delta\omega_s + \Delta\omega)^2 \ll \gamma^2/g\ell I \ . \qquad (2)$$

Here γ is the width of the spontaneous Raman scattering line, ℓ is the length of the amplifier, and g is given by the known formula

$$g = \left(\frac{c}{\omega_s n_s}\right)^2 \frac{1}{\hbar\omega} \frac{d\sigma}{d\Omega} \frac{1}{\gamma} N 8\pi^2 , \qquad (3)$$

where n_s is the refractive index, $d\sigma/d\Omega$ is the differential cross section of the spontaneous Raman scattering, N is the density of the scattering molecules, and ω and ω_s are the frequencies of the pump and of the Stokes wave.

Further, the group velocities of the Stokes wave and of the pump should be close in magnitude and in direction:

$$\ell(1/v - 1/v_s) \ll 2\pi/\Delta\omega , \qquad (4)$$

$$(1 - \cos\phi)\ell/v \ll 2\pi/\Delta\omega , \qquad (5)$$

where ϕ is the angle between the propagation directions of the two waves.

In addition, the magnitude of the output signal should greatly exceed the level of the amplified noise of the spontaneous Raman scattering in the amplification solid angle $\Delta\Omega$, and there should likewise be no pump saturation

$$\frac{d\sigma}{d\Omega} \Delta\Omega N \ell \pi^{-1/2} \{g\ell I(t)\}^{-3/2} \exp\{g\ell I(t)\} I(t) \ll I_s(t,0) \exp\{g\ell I(t)\} , \qquad (6)$$

$$I_s(t,0) \exp\{g\ell I(t)\} \ll \frac{\omega_s}{\omega} I(t) . \qquad (7)$$

It should be noted that the absence of pump saturation is very important for the separation of a single pulse from a random temporal structure. This is connected with the fact that saturation weakens primarily just those most intense sections of the pump profile which are to be enhanced with the aid of the SRS.

Let us consider a concrete example. Let the period of the intermode pump beats be $T = 3 \times 10^{-9}$ sec, and let the number of modes be $m = 10$; the characteristic duration of the pump spikes is here $2\pi/\Delta\omega \cong T/m = 3 \times 10^{-10}$ sec. Let us take the following values of the SRS amplifier parameters: $\ell = 20$ cm, $N = 10^{-22}$ cm^{-3}, $\sigma = 10^{-28}$ cm^2, $\gamma = 2 \times 10^{11}$ sec^{-1}, $\omega = 3 \times 10^{15}$ sec^{-1}, and $n = 1.5$. The conditions (2) and (4) are then satisfied for ordinary liquids, and from (5) we obtain a limitation on the angle: $\phi < 0.2$; under real conditions one customarily uses angles $\phi \lesssim 0.1$. We assume in this connection, for estimating purposes, $\Delta\Omega = 10^{-2}$. We then obtain from conditions (6) and (7) the following limitations on the instantaneous pump power density and on the gain: $I(t) \lesssim I_{max} = 150$ MW/cm^2, and $g\ell I_{max} = 18$. We assume that the pump power averaged over the period is $(1/5)I_{max} = 30$ MW/cm^2. Let us find the probability W that the maximum Stokes pulse contains not less than half the total energy radiated in one period at the Stokes frequency. A calculation similar to that performed in [3] for another problem yields $W > 0.55$.

We have thus demonstrated the possibility of obtaining during the time evolution of the Stokes radiation one intense pulse per pump period. The parameter values assumed for the estimates are typical of SRS experiments, so that pulses of duration $\Delta t \sim 10^{-10}$ sec are readily obtainable. We note that the presence of an initiating signal of Stokes frequency is not obligatory, since a similar picture is apparently obtained when spontaneous Raman scattering is amplified.

The limiting SRS pulse duration that can be attained by the indicated method are determined by the Raman-scattering line width, $\Delta t \sim 1/\gamma \sim 10^{-11}$ sec. However, on going to lower values of $\Delta t/T$, the probability of separating one pulse per period decreases. For a more effective separation of the pulse, it is possible to introduce selective absorption for the Stokes wave, which leads to a decrease of the output intensity $I_s(t\ell)$ by a factor $\exp(\alpha\ell)$. Then the intensity ratio of the different sections of the pump profile I_1/I_2 will change, as in the absence of absorption, by a factor $\exp[g\ell(I_1 - I_2)]$ times. At the same time, conditions such as (6) and (7) will now limit the total gain $\exp(-\alpha\ell + g\ell I)$, and the value of $g\ell I$ can be increased, making it possible to obtain an appreciable probability of separating one pulse with a larger number of modes.

[1] W. G. Wagner, S. Yatsiv, and R. W. Hellwarth, In Physics of Quantum Electronics, ed. by P. L. Kelley et al. p. 159, New York 1966.

[2] V. A. Zubov, A. V. Kraiskii, K. A. Prokhorov, M. M. Sushchinskii, and I. K. Shuvalov, Zh. Eksp. Teor. Fiz. 55, 443 (1968) [Sov. Phys.-JETP 28, 231 (1969)].

[3] T. I. Kuznetsova, ibid. 57, No. 4 (1969) [30, No. 4 (1970)].