Action of broadband pumping in excitation of SRS near resonance

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An investigation of SRS near resonance has revealed the existence of a critical spectral pump density which is independent of the detuning and above which the pumping efficiency is independent of the width of the pump spectrum.

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Research on resonant nonlinear processes in rarefied media has gained in importance of late. In view of the narrowness of the energy levels of such media, the spectral width of the pump can greatly exceed the transition line width of the medium (broadband pumping). The excitation of SRS by broadband pumping was investigated in the nonresonant case theoretically and experimentally in a number of studies. [1,2] The purpose of the present work was to study the action of broadband pumping in the excitation of SRS near resonance. The SRS was excited in rubidium vapor, using two tunable organic-dye lasers excited by a single ruby-laser pulse. The light beams of the dye lasers were combined and directed into a cell of length $l = 18$ cm filled with Rb vapor. The diameter of the light beam in the cell was ~ 1.8 mm. We investigated the radiation emerging from the cell in the direction of the exciting beam. The frequency ω_A of one laser (laser *A*) was tuned to the resonant transition 1—2, $\lambda = 794.8$ nm (we use from now on the level numbering shown in Fig. 1), thus ensuring effective population of level 2 (Fig. 1a). The second laser *B* excited SRS from this level (Fig. 1b). Its frequency ω_B was varied near the resonant transition 1—3 ($\lambda = 780.0$ nm, frequency ω_{31}). The power and the line width of laser *A* were $P_A = 300$ kW and $\Delta\omega_A/2\pi c = 0.2$ cm^{-1}. The spectral width of the emission of laser *B* ranged from 0.2 to 20 cm^{-1}. The temperature of the Rb vapor was 220 °C (atom concentration 2×10^{15} cm^{-3}). Owing to the relatively large detuning from the resonant intermediate level 1, the power of laser *A* was insufficient to excite SRS at the frequency ω_s' (Fig. 1c) when the laser *B* was turned off. There was no self-focusing or self-defocusing of the beam of laser *A*, in view of the deep saturation of the resonant transition 1—2 in the beam cross section. The induced-transparency channel produced in the medium by this laser prevented defocusing of the beam of laser *B*, for which it served as an optical waveguide. This made it possible to determine with good accuracy the power

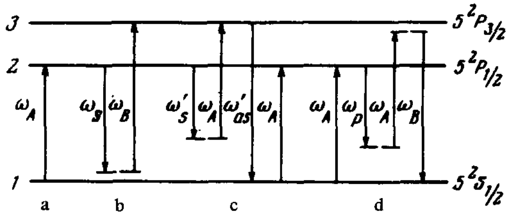

FIG. 1. Level scheme of the processes observed near resonant transitions of Rb.

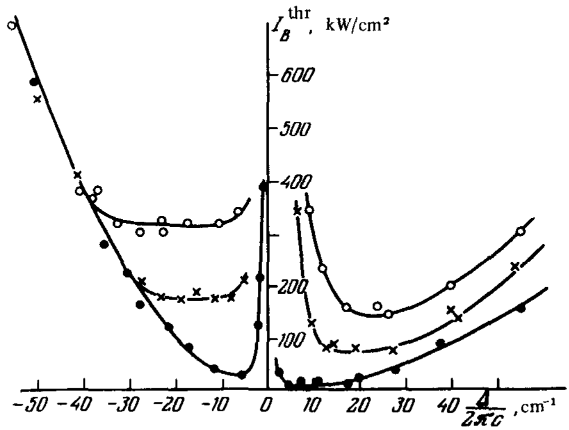

FIG. 2. Frequency dependence of the SRS at various widths of the pump spectrum: dark circles—0.2 cm^{-1}, crosses—10 cm^{-1}, light circles—20 cm^{-1}.

density (intensity) of the radiation of the exciting laser B in the case of long-wave detunings $\Delta=\omega_B-\omega_{31}<0$. Self-focusing of the laser B was observed for short-wave detunings. The SRS excitation threshold was taken to be the appearance of a signal at the Stokes frequency ω_s with energy $\sim 10^{-6}$ J.

The dependence of the threshold intensity I_B^{thr} of the exciting laser on the detuning Δ at different values of its spectral width $\Delta\omega_B$ is shown in Fig. 2. The horizontal sections seen on the long-wave detuning side of the threshold curves at pump-spectrum widths 10 and 20 cm^{-1} demonstrate that the SRS is produced here only after certain critical values I_B^{cr} of the intensity are reached, equal to ~ 170 and 320 kW/cm^2 respectively and independent of the detuning. Within the limits of experimental error, these values of I_B^{cr} yield for the critical spectral pump density $J_B^{cr}=I_B^{cr}/\Delta\omega_B=2\pi c\tilde{J}_B^{cr}$ one and the same value $\tilde{J}_B^{cr}=16.5$ kW/cm. Starting from this value of $\tilde{J}_B^{cr}$ we find that at a pump line width 0.2 cm^{-1} we have $I_B^{cr}=3.3$ kW/cm^2. As seen from Fig. 2, the corresponding threshold curve lies entirely in the region $I_B^{thr}>I_B^{cr}$. In the immediate vicinity of the resonance, experiment yields a sharp increase of I_B^{thr} at all values of $\Delta\omega_B$. With the exception of this region, all the experimental points on the long-wave detuning side fit well, a common parabola at $I_B^{thr}>I_B^{cr}$. From this parabola, assuming in accordance with the experimental conditions that the gain per pass in the cell is $I_B^{thr}l\sim 18$, we find that the SRS gain above the critical spectral pump density is $b=4.4(2\pi c/\Delta)^2$ kW^{-1}cm. The behavior of the threshold curves at short-wave detunings was undoubtedly influenced by self-focusing of the radiation of laser B.

The critical spectral pump density given in[2] can be used in the resonant case provided that the detuning greatly exceeds the widths of the levels and of the pump line. When saturation of the transition 1—2 is taken into account, calculation for resonant SRS yields

$$J_B^{cr}=\frac{c^2\hbar^2\omega_{31}\Delta\Omega}{\pi^2\omega_s\mu_{21}^2}. \quad (1)$$

where μ_{21} is the matrix element of the dipole moment for the 1—2 transition and $\Delta\Omega$ is the spontaneous-scattering line width. Expression (1) shows that J_B^{cr} does not depend on the density of the atoms or on the detuning Δ. The value of $\Delta\Omega$ is determined mainly by the broadening of the level 2 in the field of the intense radiation of the laser A. As an approximate estimate, we can put $\Delta\Omega \sim \Delta\omega_A$. Then $\tilde{J}_B^{cr} = 19$ kW/cm, which agrees well with the experimental value. At the same value of $\Delta\Omega$, calculation yields for the SRS gain in monochromatic pumping a value $b = 3.4(2\pi c/\Delta)^2$ kW^{-1} cm, which is close to the experimental value obtained above for broadband pumping under the condition that the critical spectral density is exceeded.

Near resonance, two four-photon parametric processes were effectively excited (Figs. 1c, 1d)

$$2\hbar\omega_A \to \hbar\omega_s' + \hbar\omega_{as}', \tag{2}$$

$$2\hbar\omega_A \to \hbar\omega_B + \hbar\omega_p. \tag{3}$$

Although the frequency ω_B does not take direct part in the process (2), this process does not occur in the absence of the radiation from laser B. In the presence of this radiation, modulation of the medium at the frequency $\omega_B - \omega_A$, by ensuring the occurrence of the process (3), seems to initiate also excitation of the process (2). As resonance is approached, the power that laser B must deliver to excite these processes decreases rapidly, and their experimental thresholds turn out to be lower than the threshold of SRS at the frequency ω_s.

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[2]S. A. Akhmanov, Izv. Vyssh. Uchebn. Zaved. Radiofiz. 17, 541 (1974).