INVESTIGATION OF INFRARED RADIATION IN RUBIDIUM VAPOR UPON TWO-PHOTON AND STEP-BY-STEP EXCITATIONS OF THE INITIAL LEVEL

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Stimulated infrared (IR) 5.231-μm line radiation is obtained upon two-photon and step-by-step excitations of the initial level. Dependences of the line power on the concentration of atoms and laser frequency are investigated. The mechanism of initial level occupation is explained.

Keywords: stimulated radiation, intensity, laser, power, resonance, occupation, rubidium, infrared radiation, concentration, process of optical collisions.

INTRODUCTION

Nonresonant occupation of atomic levels has been investigated both theoretically and experimentally in a number of works (for example, see [1–5]). The luminescence of lines of atomic Rb and Cs vapors with concentration of \(10^{16}\) cm\(^{-3}\) excited by neodymium and ruby laser radiation was investigated in [1]. In that case, laser frequency detuning from resonant levels was in the range 1000–2000 cm\(^{-1}\). The occupation of the resonant level is explained by the process of optical collisions (OC), that is, the change of the interaction potential of atoms at the moment of quantum absorption. Generation of coherent radiation (with population density inversion) on the 5\(P\)–5\(S\) resonant transition of the rubidium atom [2] and the 3\(P\)–3\(S\) transition of the sodium atom [3] upon resonant excitation was investigated in the presence of a buffer gas. Generation was excited in a wide range of laser radiation detuning from the resonant line (up to 250 cm\(^{-1}\)) depending on the buffer gas pressure; moreover, generation was excited only for positive frequency detuning.

In [4], the interaction of ruby laser radiation with potassium vapor was investigated, and stimulated IR-radiation was registered on the 5\(^2\)\(P\)\(_{3/2}\)–3\(^2\)\(D\)\(_{5/2}\) (3.14 μm) and 5\(^2\)\(P\)\(_{1/2}\)–3\(^2\)\(D\)\(_{3/2}\) (3.16 μm) transitions. In that case, detuning of the ruby laser frequency from the frequency of the resonant transition was 1360 cm\(^{-1}\), and its detuning from the 6\(^2\)\(S\)\(_{1/2}\) level was 8 cm\(^{-1}\). Generation was interpreted as a result of two-photon excitation of potassium molecules and their subsequent dissociation into atoms in the 5\(^2\)\(P\)\(_{3/2}\) and 5\(^2\)\(P\)\(_{1/2}\) states. However, in [5] IR-radiation was excited at frequencies corresponding to transitions from higher levels of the potassium atom (including 6\(^2\)\(S\)\(_{1/2}\)–5\(^2\)\(P\)\(_{1/2}\) (3.64 μm), 6\(^2\)\(S\)\(_{1/2}\)–5\(^2\)\(P\)\(_{3/2}\) (3.66 μm), 4\(^2\)\(D\)\(_{3/2}\)–5\(^2\)\(P\)\(_{1/2}\) (3.71 μm), and 4\(^2\)\(D\)\(_{5/2}\)–5\(^2\)\(P\)\(_{3/2}\) (3.74 μm) transitions) together with IR stimulated Raman scattering on the 4\(^2\)\(P\)\(_{3/2}\)–5\(^2\)\(P\)\(_{3/2}\) transition. This effect cannot be explained by dissociation of molecules into atoms in the 6\(^2\)\(S\)\(_{1/2}\) states, because the energy at \(2\omega_L - \omega_{6S} = 28818.4\) cm\(^{-1}\) – 27466.6 cm\(^{-1}\) = 1351.8 cm\(^{-1}\) was smaller than the dissociation energy of the molecule which exceeded 4000 cm\(^{-1}\). Generation of these lines can be explained by step-by-step occupation of the 6\(^2\)\(S\)\(_{1/2}\) level in the process of optical collisions, that is, the 4\(^2\)\(P\)\(_{3/2}\) resonant level is first occupied and then the 6\(^2\)\(S\)\(_{1/2}\) level is occupied. However, the ruby laser used as a pump source did not allow a frequency dependence of the IR-line to be investigated. Therefore, it is convenient to use rubidium or cesium vapor, because the energy of their resonant levels is smaller than that of potassium, which allows a dye laser with ruby laser
pumping to be used. Almost equidistant location of the $5^2S_{1/2}$, $5^2P_{3/2}$, and $5^2D_{5/2}$ levels in the Rb atom allows the $5^2D_{5/2}$ level to be excited by two methods: 1) two-photon excitation from the ground state and 2) step-by-step occupation using one laser. We note that the two-photon excitation of the IR-line at $5.231 \mu m$ on the $6^2P_{3/2} - 5^2D_{5/2}$ transition has been investigated in [6].

To confirm the above-discussed mechanism of IR-radiation generation, dependences of the 5.231-µm line radiation power on the concentration of atoms and laser frequency are investigated in the present work.

**DESCRIPTION OF AN EXPERIMENTAL SETUP**

A dye laser with tunable frequency excited by a ruby laser pulse was used as a source of pump radiation. The ruby laser operated in the Q-switched mode with a brightening filter. The dye laser frequency was tuned with the help of diffraction gratings. A standard tilted Fabry–Perot resonator with different base thicknesses was placed into the cell. The dye radiation power was measured by a calorimeter on which pump radiation reflected from one surface of a glass substrate was incident. The light beam of the dye laser was incident on the cell filled with alkaline metal vapors. A telescopic system that decreased the light beam diameter inside of the cell down to 1 mm was used to increase the exciting radiation intensity.

Infrared radiation leaving the cell in the direction of the exciting beam was focused onto the slit of an IR-monochromator by means of a spherical silver mirror. A specially prepared grating with linear dispersion of 5.6 cm$^{-1}$/mm was used for a dispersion unit. An additional spherical mirror with a focal length of 25 cm was placed behind the output monochromator slit. Focused radiation was incident on the sensitive area of an IR receiver the signal from which was applied to the input of an oscillograph. The signal with energy of $3\times10^{-8}$ J was set to be the experimental excitation threshold. The width of the instrumental function of the monochromator was 0.5 cm$^{-1}$.

Visible radiation leaving the cell was directed to the slit of a diffraction spectrograph with the help of a dielectric mirror. An LG-52/3 helium-neon laser was used for alignment of the experimental setup.

**INVESTIGATION OF THE DEPENDENCE OF THE 5.231-µm LINE POWER ON THE CONCENTRATION OF ATOMS UPON TWO-PHOTON AND STEP-BY-STEP EXCITATIONS OF THE $5^2D_{5/2}$ INITIAL LEVEL**

The work was performed with the dye laser having the output power $P_\lambda = 200$ kW, tunable frequency, and line width of 0.2 cm$^{-1}$. The atom concentration $N$ changed in a wide range from $10^{21}$ to $30\times10^{21}$ m$^{-3}$, while the output laser power remained constant. Figure 1 shows the energy level diagram for the 5.231 µm line upon two-photon and step-by-step excitations of the $5^2D_{5/2}$ level. In the first case, the $5^2D_{5/2}$ level is excited by the two-photon absorption, and in the second case, the $5^2P_{3/2}$ level and then the $5^2D_{5/2}$ are occupied. The wavy line indicates a portion of light quantum energy transferred to the kinetic energy of the atom.

As can be seen from Fig. 2, the IR-line power for two-photon excitation is greater than for step-by-step excitation, and with increasing concentration, the IR-line power for step-by-step excitation becomes higher.

The dependence of the IR-line power on the concentration of atoms for two-photon excitation was linear, and it was quadratic for step-by-step excitation. The linear dependence is explained by the fact that the $5^2D_{5/2}$ level is occupied from the $5^2S_{1/2}$ ground state of atoms, whereas the quadratic dependence is due to binary collisions of atoms on the $5^2P_{3/2}$ level. The quadratic dependence also explains the 5.231-µm line arising upon step-by-step excitation for high concentrations of atoms.

With further increase in the concentration of atoms, IR-radiation decreases in both cases. The decrease of the IR-radiation power for two-photon excitation was explained by Bimagambetov et al. [2] by collisional ionization. We note that the decrease of the IR-line power can be due to the absorption of pump radiation, since in these cases, the laser frequency is close to that of the $5^2S_{3/2} - 5^2P_{3/2}$ resonant transition, and the number of atoms having concentration of $10^{23}$ m$^{-3}$ becomes comparable with the number of exciting radiation quanta.