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SENSING THE KINETICAL FEATURES OF ENERGY EXCHANGE IN MIXTURE CO_2-N_2-H_20 OF ATMOSPHERIC GASES UNDER INTERACTING WITH LASER RADIATION

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Abstract

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A kinetics of energy exchange in the mixture CO_2-N_2-H_20 gases in atmosphere under passing the powerful laser radiation pulses is studied and the features are detected on the basis of the three-mode model of kinetical processes for different laser pulse parameters.

Key words: kinetics of energy exchange, gases in atmosphere, laser radiation

Резюме

ДЕТЕКТУВАННЯ КІНЕТИЧНИХ ОСОБЛИВОСТЕЙ ЕНЕРГООБМІНУ У СУМІШІ CO_2-N_2-H_20 АТМОСФЕРНИХ ГАЗІВ ПРИ ВЗАЄМОДІЇ З ЛАЗЕРНИМ ВИПРОМІНЮВАННЯМ

М. Г. Сербов, О. В. Глушков, Ю. Я. Бунякова, Г. П. Препелица, А. А. Свинаренко

Розглянуто детектування кінетичних особливостей енергообміну у сумішу CO_2-N_2-H_20 атмосферних газів при проходженні скрізь атмосферу міцного лазерного випромінювання у межах уточненої 3-модової кінетичної моделі для різних параметрів лазерних імпульсів.

Ключові слова: кінетика енергообміну, атмосферні гази, випромінювання лазера

Резюме

ДЕТЕКТИРОВАНИЕ КИНЕТИЧЕСКИХ ОСОБЕННОСТЕЙ ЭНЕРГООБМЕНА В СМЕСИ CO_2-N_2-H_20 АТМОСФЕРНЫХ ГАЗОВ ПРИ ВЗАИМОДЕЙСТВИИ С ЛАЗЕРНЫМ ИЗЛУЧЕНЕМ

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Рассмотрено детектирование кинетических особенностей энергообмена в смеси CO_2-N_2-H_20 атмосферных газов при прохождении через атмосферу мощного лазерного излучения в рамках уточненной 3-модовой кинетической модели для разных параметров лазерных импульсов.

Ключевые слова: кинетика энергообмена, атмосферные газы, излучение лазера

Carrying out new, avanced sensors and microsystems technologies in the modern atmosphere and environmental physics is related to one of the most important problems (c.f.[1-4]). It is well known [1] that in the resonant absorption of IR laser radiation by the atmospheric molecular gases a redistribution of molecules on the energy levels of internal degree of freedom occurs. The change of level population

for gas composition leads to the disturbance of thermodynamic equilibrium between the oscillations of molecules and its translation. Then an effect of the kinetic cooling of environment may take a place, as it was at first predicted in ref. [4]. It should be noted that a new effect of kinetical cooling CO_2 in a process of absorption of the laser energy by gas was considered for the middle latitude atmosphere and for special form of a laser pulse. Besides, there were used approximate values for constants of collisional deactivation and resonant transfer in reaction CO_2-N_2. Using the more precise values for constants may lead to quantitative changing temporary dependence of the resonant absorption coefficient by CO_2. This is accompanied by additional effects. The formation of the excited molecules of nitrogen owing to the resonant transfer of excitation from the molecules CO_2 results in the change of environment polarizability. Perturbing the complex conductivity of environment, all these effects are able to transform significantly the impulse energetics of IR lasers in an atmosphere and realization of different non-linear laser-aerosol effects. An effective example is the pulsed enlightenment of artificial water aerosol by laser radiation [2]. In [5] more precise modelling kinetics of energy exchange in the mixture CO_2-N_2-H_20 atmosphere gases under passing the powerful laser radiation pulse was carried out for different atmosphere and laser pulse parameters. Here we present the results of sensing the kinetical features of energy exchange in the laser aerosol system for different form of laser pulse and make estimating the changes in temporary dependence of resonant absorption relative coefficient for CO_2.

A usually, to describe the energy exchange and relaxation processes in the CO_2. — N_2 — H_2O mixture interacting with laser radiation, we start from the modified three-mode model of kinetic processes [1,5]. We consider a kinetics of three levels: 10°0, 00°1 (CO_2) and v = 1 (N_2). Availability of atmospheric constituents O_2 and H_2O is allowed for the definition of the rate of vibrating-transitional relaxation of N_2. The system of balance equations for relative populations is written in a standard form as follows:

$$\frac{dx_1}{dt} = -\beta(\omega + 2gP_{10})x_1 + \beta\omega x_2 + 2\beta g P_{10})x_1^0,$$

$$\frac{dx_2}{dt} = \omega x_1 - (\omega + Q + P_{20})x_2 + Qx_3 + P_{20}x_2^0, \quad (1)$$

$$\frac{dx_3}{dt} = \delta Q x_2 - (\delta Q + P_{30})x_3 + P_{30}x_3^0.$$

Here, $x_1 = N_{100}/N_{CO_2}$, $x_2 = N_{001}/N_{CO_2}$, $x_3 = \delta N_{N_2}/N_{CO_2}$; N_{100}, N_{001} are the level populations 10°0, 00°1 (CO_2); N_{N_2} is the level population v=1(N_2); N_{CO_2} is concentration of CO_2 molecules; Δ is ratio of common concentrations of CO_2 and N_2 in atmosphere ($\Delta = 3.85\cdot10^{-4}$); x_1^0, x_2^0 and x_3^0 are the equilibrium relative values of populations under gas temperature T:

$$x_1^0 = \exp(-E_1/T),$$

$$x_2^0 = x_3^0 = \exp(E_2/T) \quad (2)$$

Values E_1 and E_2 in (1) are the energies (K) of levels 10°0, 00°1 (consider the energy of quantum N_2 equal to E_2); P_{10}, P_{20} and P_{30} are the probabilities (s^{-1}) of the collisional deactivation of levels 10°0, 00°1 (CO_2) and v = 1 (N_2), Q is the probability (s^{-1}) of resonant transfer in the reaction $CO_2 \rightarrow N_2$, ω is a probability (s^{-1}) of CO_2 light excitation, $g = 3$ is statistical weight of level 02°0, $\beta=(1+g)^{-1}= 1/4$.

The solution of system (1) allows defining a coefficient of absorption of the radiation by the CO_2 molecules according to the formula:

$$\alpha_{CO_2} = \sigma(x_1 - x_2)N_{CO_2}. \quad (3)$$

The σ in (3) is dependent upon the thermodynamical medium parameters according to [5]. It is well known that the absorption coefficient for carbon dioxide and water vapour is dependent upon the thermodynamical parameters of aerosol atmosphere. In particular, for radiation of CO_2-laser the coefficient of absorption by atmosphere $\alpha_g = \alpha_{CO_2} + \alpha_{H_2O}$ is equal in conditions, which are typical for summer mid-latitudes, $\alpha_g(H=0) = 2.4\cdot10^6$ cm^{-1}, from which $0.8\cdot10^6$ cm^{-1} accounts for CO_2 and the rest — for water vapour (data are from ref. [2]) . On the large heights the sharp decrease of air moisture occurs and absorption coefficient is mainly defined by the carbon dioxide. The physics of resonant absorption process is defined by changing the population of low level 10°0 (CO_2), population of level 00°1 and the vibrating-transitional relaxation (VT-relaxation) and inter modal vibrating-vibrating relaxation (VV'-relaxation). A threshold value, which corresponds to the decrease of absorption coefficient in two times, for the strength of saturation of absorption in vibrating-rotation conversion give $I_{sat}=(2\cdot5)10^5$ Wcm^{-2} for atmospheric CO_2. In this case the laser (λ=10,6μm) pulse duration t_i must satisfy the condition $t_R << t_i < t_{VT}$, where t_R and t_{VT} are the times of rotary and vibrating-transitional relaxation's. by The fast exchange of level

10°0 with basic state, and by the relatively slow relaxation of high level 00°1define a renewal process of thermodynamic equilibrium is characterized. This can results in an energy outflow from the transitional degree of freedom to vibrating ones and in the cooling of environment. In table 1 we present data for the relative coefficient of absorption $\bar{\alpha}_{CO_2}$, which is normalized on linear coefficient of absorption, calculated using (1) on corresponding height H. All data for $\bar{\alpha}_{CO_2}$ are obtained for the height distribution of pressure and temperature according to the mid-latitude atmospheric model [2].

It is clear that the temporary dependence of resonant absorption relative coefficient $\bar{\alpha}_{CO_2}$ of laser radiation by CO_2 molecules for different laser pulses differs. A significant aspect of modelling is connected with the correct choice of probabilities P_{10}, P_{20} and P_{30} of the collisional deactivation of levels 10°0, 00°1 (CO_2) and v = 1 (N_2), probability Q of resonant transfer in the reaction $CO_2 \rightarrow N_2$, probability ω of CO_2 light excitation and other constants. A quality of choice of the molecular constants may be significant under modelling an effect of kinetic cooling of the CO_2 under propagation of the laser radiation in atmosphere.. The effect of kinetic cooling of the CO_2 is defined by the condition [1]:

$$\alpha^0_{H_2O} < (E_1/(E_2 - E_1))\alpha^0_{CO_2} = 1.44\alpha^0_{CO_2} \qquad (5)$$

Table 1

Temporary dependence of resonant absorption relative coefficient $\bar{\alpha}_{CO_2}$ (sm^{-1}) for rectangular (R), gaussian (G) and soliton-like (S) laser pulses (intensity I, 10^5 W/sm^2) on the height H=10km : A- data of modelling [2]; B — data of modelling [5]; C- present data.

T μs	A I; R	A 10·I;R	B I; R	B 10·I; R	B I; G	B 10·I; G	C I; S	C 10·I; S
0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
1	0,48	0,12	0,45	0,11	0,40	0,10	0,42	0,10
2	0,34	0,08	0,31	0,05	0,25	0,03	0,28	0,04
3	0,41	0,27	0,36	0,19	0,30	0,17	0,33	0,18
4	0,48	0,35	0,43	0,28	0,36	0,25	0,39	0,26

Taking into account the data of the table 1 one can wait for the changing CO_2 kinetic cooling effect realization in dependence upon the atmospheric model conditions and parameters of laser radiation. The cited effect vanishes for some critical intensity. Under large intensities of radiation the energy flux from transnational degrees of freedom to the vibrating ones reaches the maximal magnitude and not depends on intensity of incident radiation [1]. The energy flux, which results in the heating of gas, onto transnational degrees of freedom due to the absorption of radiation by the water vapor remains proportional to the intensity of radiation. Consequently, starting with some critical intensity, the gas heating prevails over its cooling for any time instant. It is natural to conclude that the correspondent values may change for different atmospheric conditions, laser radiation and molecular parameters.

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