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Interplay of light and collisions in photon echo formation

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Abstract. Situations when a set of resonant radiation pulses can not create photon echo (PE) or stimulated photon echo (SPE) at relatively simple optically allowed transition in a gas are investigated. Some cases when dilution by atomic buffer can imply PE or SPE generation are analyzed. Discovered experimentally mechanisms, amplitudes, and polarization properties of these collision induced PE and collision induced SPE are in agreement with theoretical predictions. Dynamic Stark suppression of photon echo is also studied.

1. Introduction

The most common way to generate photon echo is to apply a sequence of at least two light pulses to resonant non-homogeneously broadened (in the case of gaseous media — due to Doppler effect) quantum transition. In the frames of the model which represents a matter as a gas of two-level atoms, a definite set of optimal conditions for an echo generation appears [1]. The first condition comes from evident requirement of low gas pressure: collision relaxation time should be considerably less than time delay between exciting light pulses. Besides, exciting pulses area should be optimal; this requirement is connected with the nature of interaction between quantum transition and resonant light, i.e. with Rabi oscillations.

In realistic atomic or molecular transitions, the levels degeneracy implies new phenomena. In particular, polarizations of exciting pulses acquire great importance [2]. Depending on the angular momenta of the resonant working levels, photon echo polarization and even its power become strongly dependent on the polarizations of exciting pulses.

The goal of this article is to highlight the conditions which imply apparently strange (from the viewpoint of photon echo formation) results which origin is related to specific features of light and collisions.

2. Experimental technique

The experimental scheme in Fig. 1 shows the excimer XeCl laser (wavelength is 308 nm, pulse duration is 5–6 ns, average pulse energy is of about 20 mJ) used as a pump source for the dye laser operating on a solution of Rhodamine 110 and the external optical scheme.

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Figure 1. Experimental scheme for investigation of photon echo polarization.

The dye laser consisted of master oscillator (10 cm cavity shown in Fig. 1 by broken line box) and two sequential amplification stages. A slow circulation of alcohol dye solution was ensured for master oscillator and both amplifiers. The master oscillator cavity was formed by 1800 grooves/mm grating, operating in the second diffraction order in the auto-collimation regime and an output dielectric mirror. The grating placed inside a chamber with a controllable dry nitrogen pressure allowed us to make a fine tuning of the master oscillator frequency. An additional 1200 grooves/mm diffraction grating placed at the output of the master oscillator served as spectral selector for the rejection of spontaneous emission of the dye cell. Spatial-angular selectors consisted of two positive lenses with a diaphragm between them were placed between the master oscillator and the first amplification stage as well as between the amplification stages. The central part of the beam emerging from the final amplification stage was extracted through the diaphragm of 1.5 mm diameter and expanded by a Kepler telescope up to 10 mm diameter to be delivered to the external optical scheme. The application of spatial-angular selectors and a telescopic beam expander allowed us to reduce the background related to the superluminescence of dye and to prepare a radiation beam with a sufficiently uniform transverse intensity distribution and with a divergence close to the diffraction limit. The resulting power of dye laser pulse after passing through two amplifiers was 250 μ J, the pulse duration was 2.5– 5 ns. A neutral optical filter was placed at dye laser output to control the areas of exciting pulses. The filter transmission of 10 percent was applied for echo formation in our experimental condition — in such a case the pulses areas were close to the optimal values of $\pi/2$ and π for the first and second pulses correspondingly. Spectral properties of our dye laser were improved as compared to the previous work [3] by Fabry-Pérot interferometer inserted into the master oscillator between the grating and the dye cell. Now dye laser pulse spectrum contains only one strong mode with the spectral width less than 100 MHz in 90 cases out of 100. Other 10 percent of radiation pulses contain two modes with the spectral separation of 1.5 GHz. Optical responses from medium for these 10 percent of pulses were rejected at a stage of computer processing of registered data.

External optical scheme (see Fig. 1) included beam splitter BS and optical delay line ODL used to create the pair of coherent exciting pulses and two Glan-Taylor prisms P1 and P2 as independent polarizing elements for each of two exciting pulses. Quarter-wavelength plate (denoted as " $\lambda/4$ " in Fig. 1) inserted between the output beam and the beam splitter BS gave

the possibility of choosing the necessary orientation for the polarization plane of each beam by the corresponding orientation of Glan-Taylor prisms. If necessary, linear polarization of any exciting beam (or even both) could be converted into circular polarization using another quarter-wavelength plate (marked by symbol " $\lambda/4$ " and drawn as broken line plate inserted into the second exciting beam in Fig. 1). The film polarizer A placed after the working cell (Cell in Fig. 1) provided the polarization analysis of photon echo detected by high sensitive short time response photomultiplier PMT. An additional photomultiplier (not shown in Fig. 1) was used to control the power of both exciting pulses. All the signals were converted into digital form by the analogue-to-digital converter (ADC in Fig. 1) triggered by the first exciting pulse. Data acquisition, averaging and treatment were provided by personal computer PC.

The scheme of angled photon echo was used for reliable photon echo detection. Part of the beam delayed by an optical delay line ODL (second pulse of exciting radiation) was directed to the working cell under the angle of about 2×10^{-3} rad to the first pulse. Such a scheme allowed us to detect a signal of photon echo without considerable losses of its amplitude and, simultaneously, without photomultiplier bleaching by the radiation of exciting pulses — due to spatial separation between echo and exciting pulses. The photon echo signal was focused onto the fiber end (Fiber in Fig. 1) and delivered to photomultiplier PMT for detection.

The state of polarization for exciting pulses and for the photon echo were analyzed by the detection of polarization diagrams obtained using the analyzer A (see Fig. 1) in front of photomultiplier PMT.

To suppress the influence of power and spatial distribution instabilities of excimer laser on the data, several technical solutions were undertaken, including the above-mentioned design of dye laser and external optical scheme, investigation of dye laser radiation properties and special technique of data acquisition and treatment (see for details [3, 4]).

In this experiment, a special attention was paid to the absence of any external stray fields, especially the magnetic ones, in the area of the working cell filled with ytterbium vapours. The magnetic field was measured inside the cold cell without vacuum and its value was not higher than 20 mG. The evaporation of ytterbium was induced by double heating wires passing along the cylindrical cell. This construction allowed us to minimize the stray longitudinal magnetic field from the heater. The absence of any stray magnetic field was finally controlled via the absence of non-Faraday rotation for the photon echo polarization plane. This could be done with accuracy of polarizer angle measurement of about one degree; above-mentioned upper limit for stray magnetic field (if this field was directed strongly along the cell axis) could imply the non-Faraday rotation by an angle of about 1.4 degree according to our measurements in [3]. Hence, both methods to estimate the stray magnetic field agree.

The temperature of the working cell with ytterbium vapour was kept between 800 and 840 K, which corresponds to Yb pressure 3.9–12.9 mTorr. In order to avoid the undesirable collision effects on the polarization properties of photon echo, the temperature in a working cell was maintained as low as possible; so most of experiments were made at 800 K. The working cell heater was driven by a special autonomic electronic scheme which warranted the temperature stability not worse than ± 2 K.

The sample with a natural content of ytterbium isotopes was used. The exciting radiation wavelength was thoroughly controlled by an electronic wavelength meter in order to get the operation spectral region coinciding with the Doppler center of ¹⁷⁴Yb isotope. The precision of wavelength meter was 10^{-4} nm which (for the wavelength of ¹⁷⁴Yb inter-combination transition under investigation) corresponds to 100 MHz in the frequency scale. Isotopic shifts for natural ytterbium were measured in [5]. The neighbouring isotopic lines for ¹⁷⁴Yb are ¹⁷⁶Yb and ¹⁷²Yb, which are shifted by -954 MHz and +1 GHz, correspondingly. All these even isotopes do not have a hyperfine structure, too. Ytterbium odd isotopes have higher isotopic shifts and do not overlap with the Doppler width of ¹⁷⁴Yb absorption line in our experimental conditions.



Figure 2. Exciting optical beams, SPE beam spot and PE generated by the first and the third exciting pulses PE_{1-3} .

The deviation of exciting pulses polarization from the ideal linear one was not greater than 10^{-3} in power. The circular polarization of exciting pulses deviated from the ideal circularity at about three percent. The origin of this inaccuracy of measurements is related to some amplitude instability of dye laser (Rhodamine 110) pumped by the excimer laser.

For SPE investigations, corresponding modification of the set up was made. External optical scheme used in our early works on SPE at the transition $(6s^2)$ ${}^{1}S_0 \leftrightarrow (6s6p)$ ${}^{3}P_1$ in 174 Yb vapour was described in [6, 7]. The pulsed Rhodamine 110 dye laser was a source of three resonant radiation exciting pulses formed by two optical delay lines. Each of the beams passed through the Glan-Thompson polarizers; the beams were directed into the working cell with ytterbium vapour in a non-coplanar geometry making small ($\approx 2 \cdot 10^{-3}$ rad) angle between any pair of exciting pulses propagation vectors. As a result, the angled SPE could be spatially selected from the exciting pulses.

Fig. 2 shows picture detected by web-camera in the focal plane of lens L (Fig. 1 for the case of SPE generation. Three exciting beams, SPE beam spot, and PE generated by the first and by the third exciting pulses can be seen here.

In this work, unlike [6, 7], the dye laser was pumped by the second harmonic of Nd^{3+} :YAG laser, which provided much better amplitude stability for exciting pulses.

The parasite longitudinal magnetic field was minimized with residual value of 20 mG to ensure correct results on SPE polarization. Linear polarization of each exciting pulse was checked through polarization diagram, and the deviation of polarization from the "ideal" linear one was of about 10^{-3} in power.

The temperature of the working cell was kept at 820 K with accuracy of 2 K. The buffer gas pressure was measured with accuracy of $5 \cdot 10^{-3}$ Torr in the range of 0–3 Torr.

3. When resonant exciting radiation does not form coherent response in pure gas 3.1. No PE at $0 \leftrightarrow 1$ transition

Polarization properties of photon echo (PE), stimulated photon echo (SPE) and other coherent transients is the first source of seemly paradoxical situation: we have exciting pulses of radiation which are resonant to a chosen quantum transition, they have optimal pulse areas, but they can not create photon echo.

Really, let us consider relatively simple transition of type $0 \leftrightarrow 1$. Experimental realization of such a transition can be done at the inter-combination transition $(6s^2)$ ${}^{1}S_0 \leftrightarrow (6s6p)$ ${}^{3}P_1$ of 174 Yb vapour. It is worth to note that polarization properties of photon echo generated in a gas at the transitions of type $0 \leftrightarrow 1$ or $1 \leftrightarrow 1$ do not depend on the area of exciting radiation pulses. This property predicted in [8] make two above mentioned transitions very attractive for experimental research. Photon echo generated in a gas by two pulses of resonant radiation with linear polarizations at such transitions should have linear polarization, and its polarization vector should be located along the polarization vector of the second exciting pulse. So, photon echo generated at these two types of transitions by linearly polarized exciting pulses "follows" the polarization of the second pulse. If polarization vectors of exciting pulse make an angle ψ , PE amplitude is proportional to $\cos(\psi)$. For the angle $\psi = 90^{\circ}$ photon echo is absent [8]. Obvious explanation is that polarization created at the transition $0 \leftrightarrow 1$ by the first exciting pulse with linear polarization oriented, say, vertically can not be re-phased by the second exciting pulse with linear polarization oriented horizontally.

The combinations of circular and linear polarizations of exciting pulses were investigated for the transition $0 \leftrightarrow 1$ experimentally in ¹⁷⁴Yb vapour [9]. For all combinations of exciting pulses polarizations, for pure ytterbium vapour, the photon echo polarization "follows" the polarization of the second exciting pulse — in agreement with [8].

For exciting pulses with circular polarizations we meet another situation when PE can not be generated: that is for two exciting pulses with opposite circular polarizations. In this case, the first exciting pulse creates optical coherence between one definite pair of magnetic sub-levels (say, m = 0 of the lower and m = +1 of the upper levels). This optical coherence, in other words, circular polarization wave, can not by re-phased by the second exciting pulse which interacts with another pair of magnetic sub-levels (in this example, m = 0 of the lower and m = -1 of the upper levels).

3.2. No SPE at $0 \leftrightarrow 1$ transition



Figure 3. SPE polarization in a pure gas at $0 \leftrightarrow 1$ transition has linear polarization coinciding with exciting pulses polarization (upper graph, SPE $\uparrow\uparrow\uparrow$) or its linear polarization "follows" polarization of crossed exciting pulse(lower row SPE $\uparrow\rightarrow\uparrow$ and SPE $\uparrow\uparrow\rightarrow$).

Now, let us consider stimulated photon echo (SPE) at the transition $0 \leftrightarrow 1$ in a pure gas.

If all three pulses of exciting radiation have identical linear polarization, the SPE at the transition $0 \leftrightarrow 1$ is polarized in the same manner. This polarization diagram denoted as SPE^{†††} is shown in the upper part of the Fig.3.

In the case when one of the exciting pulses was polarized linearly and orthogonally to another two exciting pulses, SPE polarization at the transition $0 \leftrightarrow 1$ in the pure ytterbium vapour showed linear polarization oriented in parallel to this exciting pulse of "crossed" polarization.

This result is illustrated by two polarization diagrams in the lower row of the Fig.3. Left part of this row corresponds to case of the second pulse with crossed linear polarization denoted as $\text{SPE}\uparrow\rightarrow\uparrow$. Lower right part of the Fig.3 denoted as $\text{SPE}\uparrow\rightarrow\rightarrow$ corresponds to the case when the third exciting pulse has linear polarization crossed to another two pulses.

It was surprising to find that the situation when the second and the third pulses have "crossed" polarization relative to the first pulse is not equivalent to the case when the third pulse has the "crossed" linear polarization relative the first two exciting pulses. Evidently, the first exciting pulse plays a special role in the SPE formation. In a pure ytterbium vapour at the transition $0 \leftrightarrow 1$ stimulated echo of type SPE $\rightarrow\uparrow\uparrow$ does not appear.

4. Collision induced PE



Figure 4. Ordinary (upper insert) and collision induced PE dependence on buffer gas pressure (left bottom graph) and polarization diagram together with 1-st exciting pulse (right graph).

The left bottom part of the Fig. 4 shows the power (in arbitrary units) of collision-induced photon echo generated by two mutually orthogonal linearly polarized exciting pulses of laser radiation resonant to the transition $(6s^2)$ ${}^{1}S_0 \leftrightarrow (6s6p)$ ${}^{3}P_1$ of 174 Yb in a mixture of Yb+Xe as a function of Xe pressure. Collision-induced echo is absent at zero buffer gas pressure. As buffer gas pressure grows, collision-induced photon echo power increases, then reaches its maximum value and starts to decay exponentially in a high pressure limit of buffer gas.

This non-monotonic behaviour of collision-induced echo power as a function of buffer gas pressure is in contrast to ordinary (generated in the same gas mixture by pulses of resonant radiation with linear parallel polarizations) echo behaviour. The error bars for echoes power shown in both parts of Fig. 4 arose from the statistics of power storage and averaging; the origin of these errors lies in fluctuations of pulse laser power. The buffer pressure was measured with high accuracy; these errors are less than experimental points size; that is why the error bars for pressure are not indicated in Fig. 4.

The maximum value of collision-induced echo is reached at Xe pressure of about 200 mTorr, and its value is several orders of magnitude lower than ordinary echo power at the same value of buffer gas pressure.

For comparison, the upper insert of Fig. 4 shows buffer gas behaviour for the "ordinary" photon echo generated at the same conditions but by application of exciting pulses with parallel linear polarizations. Here, the monotonous decay of PE power can be seen.

Polarization of collision-induced photon echo generated by two mutually orthogonal linearly polarized exciting pulses of laser radiation resonant to transition $(6s^2)$ ¹S₀ \leftrightarrow (6s6p) ³P₁ of ¹⁷⁴Yb

in a mixture of Yb+Xe was investigated using analyzer A (see Fig.1). In the right part of Fig. 4, the power of collision induced echo (gray circles) is plotted as a function of rotation angle of analyzer A. The distances from the center of the picture are proportional to the radiation power transmitted by analyzer A at a given rotation angle. Both these polarization diagrams — for collision induced photon echo and for the first exciting pulse (black squares) — are represented in Fig. 4 for comparison. The error bars for echo and exciting pulse power are indicated in both curves. As it was already discussed, the polarizer angle measurement accuracy was about one degree; this value is less than experimental points size; so, the angle error bars are not shown in Fig. 4.

Unlike ordinary photon echo, which "follows" the polarization of the second exciting pulse, the collision-induced echo polarization coincides with the polarization of the first exciting pulse. This result well agrees both with the earlier prediction [10], and with the analytical calculation in the previous section.

As it was predicted in [8] and experimentally verified in [9], there is another combination of exciting pulses polarizations which gives zero power of ordinary photon echo, that is opposite circular polarizations. The calculations [11] predict that the collision-induced echo can not be generated at transition $0 \leftrightarrow 1$ even if we take into account depolarizing collisions anisotropy.



Figure 5. Collision induced PE appears for linear crossed polarization but does not exist for opposite circular polarizations.

The sensitivity of collision-induced echo detection was improved the following way. From the signal detected by PMT at the conditions of resonant excitation at wavelength $\lambda = 555.802$ nm (as measured by λ -meter at the atmospheric pressure), which corresponded to the center of Doppler contour of ¹⁷⁴Yb, the signal at non-resonant wavelength of $\lambda = 555.815$ nm was subtracted. This technique permitted the suppression by at least one order of magnitude of a residual stray signal arising from the wings of spatial distribution of exciting pulses. This differential signal is shown in Fig. 5 for two experimental cases: one corresponds to mutually orthogonal linear polarizations of exciting pulses (black curve, right vertical axis), and another one (grey curve, left vertical axis) — to the opposite circular polarizations. For the sake of clarity, the black curve and its axis are shifted up.

In Fig. 5, the following signals appear from the left to the right. Two peaks directed down were interpreted as absorption of exciting pulses in a mixture of Yb+Xe; the time delay between them corresponds to 42 ns, which equals to the time delay between exciting pulses provided by the optical delay line. At the tail of the second peak the signal changes its sign to the opposite

one. This can be interpreted as the appearance of a free polarization decay signal. All these signals appeared both for linear orthogonal and opposite circular polarizations of exciting pulses. As for the photon echo signal, it appeared only for linear orthogonal polarizations of exciting pulses. It is worth emphasizing that other experimental conditions (pressure of Yb and Xe in a mixture, powers and radial distributions of exciting pulses, time delay between them, a small angle between wave vectors) were identical. The only one difference consisted in the quarter wave plate inserted in both exciting beams in order to convert linear polarizations into circular ones. As it is clear from Fig. 5, the collision echo is detected only for linear orthogonal polarizations of exciting pulses.

So, in the same Yb+Xe mixture at identical intensities of exciting pulses of resonant radiation, only pulses with linear perpendicular polarizations can generate collision induced photon echo. Pulses with opposite circular polarizations can not do that. In our experiments [11] this was shown with accuracy of about 10^{-2} of collision induced PE power for crossed linear polarizations.

5. Collision induced SPE

All above described cases of SPE generated in a pure ytterbium vapour at the transition $0 \leftrightarrow 1$ are in complete agreement with the theory [12] considered with an account of elastic depolarizing collisions. It was shown in [12] that with the polarization of the first pulse orthogonal to that of the second and third pulses, the appearance of the echo signal will be entirely determined by the action of collisions. The existence of this echo is determined by the difference of collision induced decay rates of two polarization moments of the upper working level — the alignment and the orientation.

As it was found experimentally, collision induced SPE can really appear for the case SPE $\rightarrow\uparrow\uparrow$ at the huge dilution of active atoms by buffer atoms Xe. The right graph of Fig.6 shows collision induced SPE power versus buffer gas pressure. SPE $\rightarrow\uparrow\uparrow\uparrow$ is practically zero in the absence of buffer, its amplitude increases sharply as buffer gas pressure raises from zero. Then collision induced SPE $\rightarrow\uparrow\uparrow\uparrow$ reaches its maximum value approximately at xenon pressure of about 200·10⁻³ Torr. Let's remind that active atoms pressure was kept at $\approx 7.5 \cdot 10^{-3}$ Torr, so, Xe pressure was more than an order of magnitude higher. As Xe pressure overcomes value of 200 $\cdot 10^{-3}$ Torr, collision SPE power starts decreasing, as is clear from the right graph of Fig.6.



Figure 6. Polarization diagram (left graph) for collision induced SPE of type SPE $\rightarrow\uparrow\uparrow$ and collision induced SPE amplitude dependence on the buffer gas pressure (right graph).

The left graph of Fig.6 shows polarization diagram of SPE induced by collisions with buffer gas Xe at the transition $0 \leftrightarrow 1$ in ytterbium vapour. The diagram was registered at buffer gas Xe pressure $200 \cdot 10^{-3}$ Torr which is optimal for collision induced SPE formation. The collision induced SPE polarization is linear and it coincides with the polarization of the first exciting pulse "crossed" with another two exciting pulses.

6. When resonant radiation blocks PE generation

Intense resonant CW electromagnetic radiation in the presence of weak irreversible relaxation changes the behaviour of a quantum system due to its dynamic interaction with the field. In the stationary case, quasi-energy levels appear which correspond to the so-called dressed states of an atom or a molecule: the initial levels are split into two sub-levels spaced by a distance determined by the Rabi frequency. The absorption spectrum usually detected by the probe field [13, 14] is significantly changed. The dynamics of nonstationary optical phenomena including coherent transient processes also changes significantly in the presence of a strong field. The known experimental works in this area for purely rotational microwave transitions in OCS molecules [15], in a Yb atomic beam [16], for Cs atoms trapped in an optical lattice [17], and in a dense Sr atomic gas [18] were carried out in the presence of the homogeneous broadening of a spectral line.

The inhomogeneous broadening of the line in the rarefied gas, which is caused by the Doppler effect, complicates the effect of the intense radiation on the kinetics of the coherent transient processes as demonstrated theoretically [19] for the photon echo in a three-level system in the presence of a dressing-field pulse.

The possibility to control coherent transient processes by intense resonant CW radiation was demonstrated in our work [20] in the rarefied gas, i.e., when the Doppler effect is significant.

In [20] coherent transient processes were generated through the Stark switching of levels in the presence of CW laser radiation. Experiments were carried out at the vibrational rotational transition $R(4,3) \ 0 \leftrightarrow 1 \ \nu_3 \ ^{13}CH_3F$ in the radiation field of a CO₂ laser on the 9 P(32) generation line. The laser radiation was single mode with a line width of no more than 100 kHz and its frequency was tuned to the center of the absorption line of $^{13}CH_3F$.

Intense-field radiation was linearly polarized with polarization vector parallel to the Stark field strength, and its intensity was varied from 0.6 to 56 W/cm². The intensity of the weak field linearly polarized orthogonally to the strong field was equal to 0.2 W/cm². After the passage through a cell with the low-pressure ¹³CH₃F gas, the weak field was separated by means of the reflection from a plate placed at the Brewster angle for the strong field, and then it was detected. The Stark pulses were applied on the internal electrodes of the working cell. The transverse distribution of the beams of high- and low-intensity radiation was close to a Gaussian distribution whose radius was about 2 mm for high-intensity radiation and was somewhat larger for low-intensity radiation. The intensity of the weak field was sufficient for the formation of coherent transient processes; i.e., this radiation gave rise to the saturation of the working transition; the term weak is used here only as compared to more intense radiation.

Focusing of radiation beam made it possible to reach a higher intensity; from other side, owing to this narrow beam, the relaxation due to the transit effect prevails over collision relaxation rate, and gave relaxation rate of about $\Gamma = 1$ MHz. This value is much lower than the Doppler width of ≈ 80 MHz. Thus, all of our experiments were performed in the presence of a significantly inhomogeneous broadening of the spectral transition.

The photon echo in the ¹³CH₃F gas was formed and detected in low intensity, linearly polarized radiation. The molecular levels undergo a fast switching by two Stark voltage pulses with durations $T_1 = 0.1\mu$ s and $T_2 = 0.2\mu$ s spaced by the delay time $\tau = 1\mu$ s. The gas was simultaneously irradiated by intense resonant CW radiation linearly polarized along the Stark field and orthogonally to the weak field forming the photon echo. An echo signal appears in the form of a weak heterodyne beating signal at the time approximately equal to the double delay time between the Stark pulses.

Each photograph in Fig. 7 exhibits from the left to the right two intense signals corresponding to the gas response to the action of two forming Stark pulses (a sort of optical nutation signals), and weaker response appearing through the time interval approximately equal to the delay time between the Stark pulses after the second Stark pulse, which is just the photon echo signals.

The strong (control) field radiation power is marked by P_z and is indicated for each photograph in Fig. 7. As seen in the images Fig. 7, the behaviour of the photon echo amplitude is a nonmonotonic function of the strong field. At low control field an increase of PE amplitude was observed; at higher control field, PE signal decrease and complete suppression of the photon echo was detected. In addition, a change in the shape of the photon echo signal is seen in Fig. 7 (we recall that the heterodyne receipt occurs). The maximum of the photon echo signal or, for a more complex shape, the center of gravity of the photon echo signal also varies nonmonotonically with driving field power. These changes occur in the limits that do not exceed the duration of the forming pulses.

Observed photon echo variations as a function of dressing field (amplitude, PE-signal temporal shape and t_{min}) are non-monotonous functions of dressing field, in agreement with calculations.

As it can be seen in Fig. 7, photon echo can by suppressed by the intense radiation due to dynamic Stark effect.



Figure 7. Collision induced SPE.

7. Discussion

Because of the levels degeneracy, we meet situations when exciting pulses can not create PE or SPE at the relatively simple transition $0 \leftrightarrow 1$.

In some cases, collision relaxation can change this situation. In particular, collision induced PE at the transition $0 \leftrightarrow 1$ appears due to anisotropy of collisions (i.e. due to different relaxation

rates along and across velocity of active atoms) for the pair of exciting radiation pulses with crossed linear polarizations. Exciting pulses with opposite circular polarization can not create collision induced PE.

Explanation "at the finger tips" for the collision induced PE generated at the transition $0 \leftrightarrow 1$ looks as following. The first exciting pulse creates polarization for each active atom, and polarization vector for each atom is parallel to polarization vector of the first exciting pulse. The anisotropic collision relaxation "gives a turn" to dipole moments of individual atoms, depending on their velocity. As a result, medium polarization created by the first exciting pulse acquires orthogonal component; as a result, it can interact with the second pulse of resonant exciting radiation (which has crossed linear polarization) and obtains possibility for Doppler re-phasing. During the time interval after the second pulse and collision induced echo appearance, along with the Doppler rephrasing, the same kind of reverse atomic dipole "turns" due to collisions takes place, so that at the instance of echo appearance the atomic dipoles are aligned along the polarization vector of the first radiation pulse, and that is why collision induced photon echo has linear polarization along the first exciting pulse.

Collision induced SPE at the transition $0 \leftrightarrow 1$ appears under action of three linearly polarized exciting pulses with mutual orientation of type $\rightarrow\uparrow\uparrow$. Such a combination of polarizations can not create SPE in a pure gas. At the dilution of active atoms by great amount of heavy buffer atoms, SPE appears due to the difference in relaxation rates of polarization moments (orientation and alignment).

Both collision induced PE and collision induced SPE at the transition $0 \leftrightarrow 1$ have some similarity. Both have linear polarization coinciding with polarization of the first exciting pulse. Both reveal non-monotonous buffer gas pressure dependence. Both have small power, several orders of magnitude less that corresponding "ordinary" signal (created by two or three pulses of identical linear polarizations).

However, they have quite different nature. Mechanism of induced PE generation at the transition $0 \leftrightarrow 1$ is related to collision relaxation dependence on the *direction* of active atoms translational velocity. Collision induced SPE appears due to different collision relaxation rates for orientation and alignment of the upper working level.

There is possibility to suppress PE or other coherent response due to dynamic Stark effect produced by additional (driving) radiation.

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