Parametric non-degenerate four wave mixing in hot potassium vapor

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ABSTRACT

In this study we show the results for parametric non-degenerate four wave mixing (FWM) obtained using double lambda scheme at D1 line in hot potassium vapor. We have investigated the influence of one-photon detuning and two-photon detuning on the FWM gain. The laser frequency is locked at approximately 1GHz from the resonance $4S_{1/2}$ F_g=1 -> $4P_{1/2}$, using external reference cavity. The probe beam passes through acoustooptic modulator that enables controllable detuning around 460 MHz (ground state hyperfine splitting) in respect to the pump beam. The vacuum glass cell containing the potassium vapor was heated by hot air in order to achieve necessary concentration of atoms. The efficiency of FWM process is studied by measuring the gains of the conjugate beam the probe beam, simultaneously. The maximal gain was achieved for nonzero two photon detuning.

Keywords: four wave mixing, potassium, copropagating beams

1. INTRODUCTION

Four wave mixing in atomic vapors is a non-linear interaction between atoms and light that allows exchange of energy between four different modes of light in a nonlinear medium. It has been investigated in inhomogeneously broadened hot atomic vapor[1], and in cold atomic samples[2], using different atomic level schemes. FWM in alkali atoms have shown success in generating high gain of twin beams, probe and conjugate photons, and efficient amount of relative intensity squeezing[3, 4]. Although there is a number of studies exploring FWM in Rb and Cs[5] to our knowledge this is the first investigation of FWM in double-Λ schemes in K.

We study FWM in ^{39}K, using double-Λ scheme, driven by far detuned (compared to Doppler width), and nearly co-propagating pump and probe laser beams. The pump and the probe are in near two-photon resonance between ground state hyperfine levels. Such FWM relies on coherence among two hyperfine levels[6] in the ground state of K, and elimination of resonant absorption due to electromagnetically induced transparency[3].The goal is to investigate ability of this scheme in K for efficient FWM and large gains of both pump and conjugate beam. Potassium hyperfine splitting in the ground state is 460 MHz[7], narrower that the Doppler broadened width. Therefore, detuning of the probe photons from the exited state hyperfine levels, in the outer Λ branch, is much smaller than in other alkalis and this could lead to very efficient FWM process and high gains. Besides atomic scheme, laser intensity and a single photon detuning, i.e., saturation intensity, together with atomic density and two-photon detuning play major roles in efficiency of FWM. In this work we investigate gains of the probe and the conjugate beams as a function of two-photon detuning, for various values of a single photon detuning. The pump laser power, atomic density, angle between the pump and the probe beams and diameters of the pump and the probe are kept fixed.

FWM in the atomic scheme of this experiment is suggested to efficiently generate non-classical beams and relative intensity squeezed light[8]. Our aim in this work is to maximize the gain of the FWM process since the degree of relative intensity squeezing depends on this gain. Interactions like FWM offer many promising applications due to unique properties of the conjugate beam and high entanglement between probe and conjugate[9].

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18th International School on Quantum Electronics: Laser Physics and Applications, edited by Tanja Dreischuh, Sanka Gateva, Alexandros Serafetinides, Proc. of SPIE Vol. 9447, 944706 · © 2015 SPIE
CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2177885

2. EXPERIMENTAL SETUP

We have used the D_1 line of potassium for the realization of the double-Λ system. The lower levels of the Λ scheme are two hyperfine sublevels of K ground level $^2S_{1/2}$, F=1 and $^2S_{1/2}$, F=2 (figure 1). For the upper level we neglect the hyperfine splitting since it is small compared to detuning. The hyperfine splitting between two lower levels is 461.7 MHz[7].

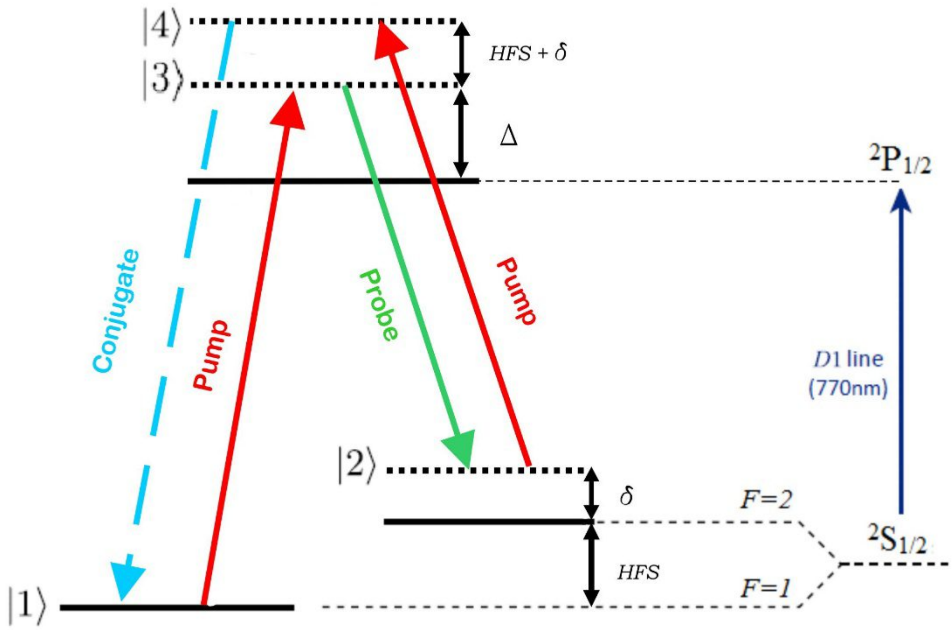


Figure 1. Double-Λ scheme on the D_1 line of ^{39}K. *HFS* – hyperfine splitting of the ground state, Δ- one photon detuning, δ- two photon detuning.

The experimental scheme is presented in Figure 2. Ti:Sapphire ring laser (MBR 110, Coherent Inc) is used as a light source. The pump and the probe beams are obtained by dividing the same laser beam with an asymmetric (90:10) beam splitter. Main part of the laser power is used as a pump beam, driving the D_1 line of ^{39}K at 770 nm and it is detuned for approximately 1GHz. The probe beam passes an acousto optic (AOM) modulator which operates on 230 MHz in double-pass configuration. The pump and the probe beams are focused with two pairs of lenses in order to achieve 1mm and 0.8 mm diameters respectively. They are perpendicularly polarized and combined on polarization beam splitter at the small angle of 1.5 mrad. Two beams intersect in the center of a 50 mm long natural-abundance potassium vapor cell. The temperature of the cell is kept at 100^{o}C. Concentration of potassium atoms on this temperature is $7.6*10^{17}$ atoms/m^3. In order to heat up the cell we have put it in an aluminum cylinder with drilled holes along its axis through which the hot air was blown. The windows of the cell are Brewster's angled and the position of the cell is optimized for maximal pump transmission (~90%). Since the probe is polarized perpendicularly to the pump transmission of the probe is much lower (~50%). Optical powers of the pump and the probe inside the cell are estimated to 400 mW and 0.2 mW respectively upon direct measurements in front of the cell and windows transmissivity. The four wave mixing process occurs in the intersection volume creating probe and conjugate photons. The amplified probe and the conjugate beams leave the cell and hit two photodiodes while the pump beam is reflected away by another polarizing beam splitter after the cell.

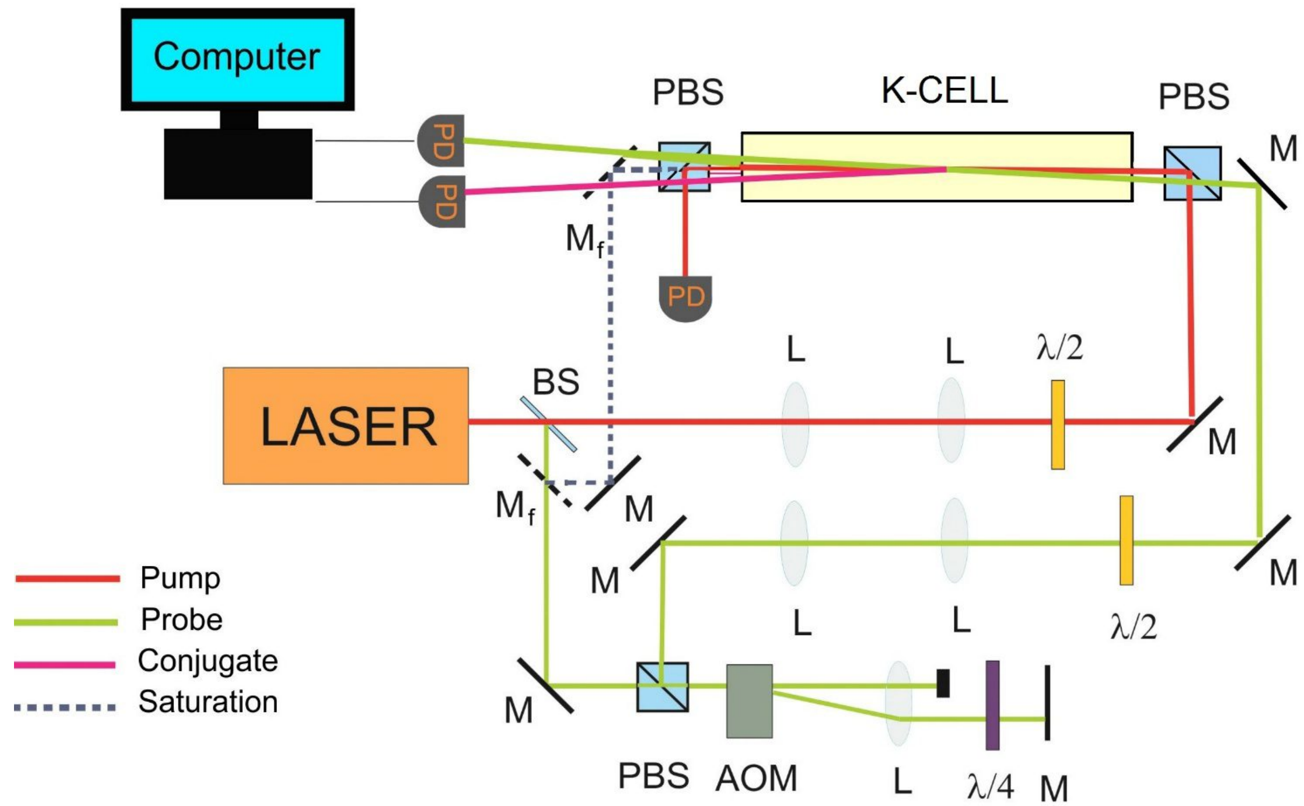


Figure 2. Experimental setup. BS - beam splitter, M - mirrors, M_f - flip mirrors, PBS - polarizing beam splitter, AOM - acousto optic modulator, L - lenses, $\lambda/4$ - lambda-quarter wave plate, $\lambda/2$ - lambda-half wave plates, PD - photodiodes.

The probe beam frequency i.e. the two photon detuning δ is scanned by changing the AOM frequency. The double-pass configuration of the AOM allows us to scan this frequency without the change of the probe beam direction. The frequency of the laser was locked by the internal locking system of the laser. Internal locking system of the laser has two stages. Firstly the single mode oscillation is achieved with an intracavity etalon and secondly the frequency was locked to the external reference cavity using Pound-Hall-Drever method. In order to determine the long term frequency stability of the laser and to measure one photon detuning we have incorporated the saturation spectroscopy (SS) setup into our experiment. To this end we have added two flip mirrors which divert the probe beam before the AOM making it the saturation beam in SS configuration which counter propagates the pump in the vapor cell. Initial pump is highly attenuated and used like probe beam in SS configuration. Spectrum with hyperfine resolved features are given in Figure 3.The temperature of the vapor was 67^{o}C.This spectra is obtained by subtracting Doppler profile from the SS signal. We can distinguish three groups of lines corresponding to different sublevels of ground state. Within these three groups there are three peaks (except for $F_g=2$ group) which correspond to different hyperfine transitions. We have used the $F_g=1$ -> CO transitions as our reference for one-photon detuning.

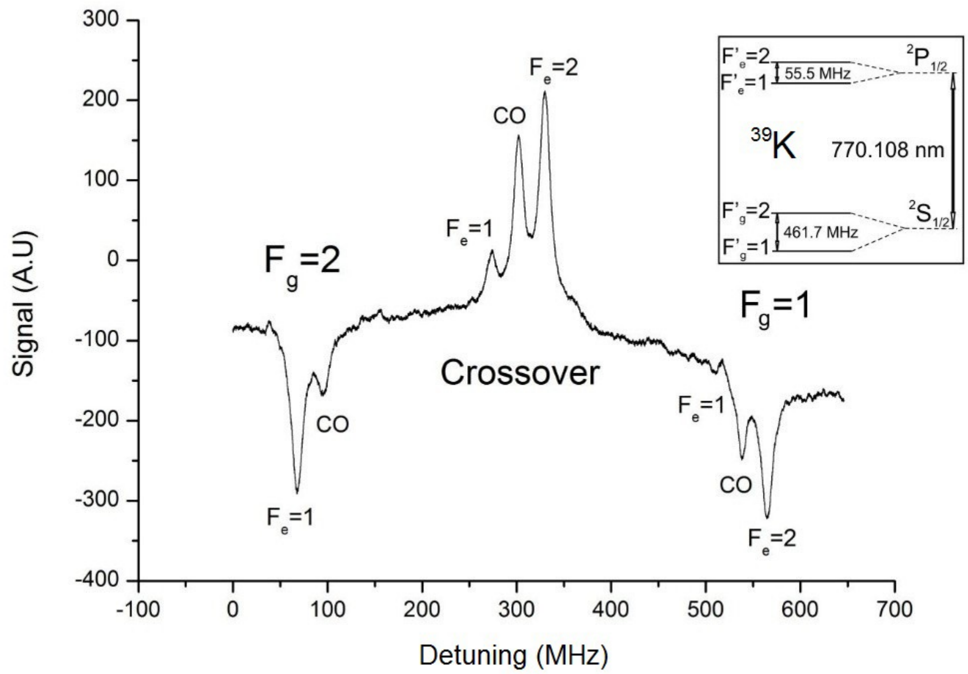


Figure 3. Measured saturation spectra of the D_1 line of ^{39}K (Scheme of levels is given in the inset[1]).

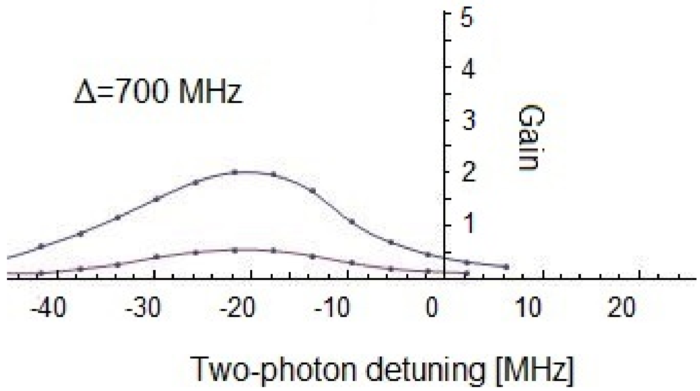
3. EXPERIMENTAL RESULTS

In our experiment we have measured the gain of the probe and conjugate as a function of two-photon detuning for three different values of one-photon detuning. The gain of the pump and the conjugate is defined as $G_p=P_p/P_{in}$ and $G_c=P_c/P_{in}$ respectively where P_p and P_c are measured powers of the probe and the conjugate respectively and P_{in} is initial power of the probe inside the vapor cell. The losses of the probe and the conjugate due to the output window of the vapor cell (∼30%) are not taken in count. Two-photon detuning (δ) is swept over 60 MHz around the two-photon resonance in 4 MHz steps. The values of one-photon detuning (Δ) in the experiment are chosen to be 700 MHz, 1000 MHz and 1300 MHz. The results are given in figure 4a, b, and c respectively. For Δ=700 MHz maximal gains of the conjugate and the probe beam are 2 and 0.55 respectively. They are located at $\delta\approx$-20 MHz. For this particular set of the parameters maximal gain for the conjugate is rather small while the probe amplification is negligible. The gain region spans about MHz of two-photon detuning determined as full width at half maximum (FWHM)

For Δ=1000 MHz maximal gains of the conjugate and the probe beam are significantly higher, and reach 8.2 and 2.2 respectively. These maximal gains occur at $\delta\approx$- 9 MHz. The gain region is a bit narrower and spans around 16 MHz, also measured as FWHM.

For Δ= 1300 MHz maximal gain of the conjugate and the probe is 5.9 and 1.7 respectively which is lower than for the Δ=1000 MHz case. They are placed around $\delta\approx$-5 MHz. Gain region is even narrower and spans about 12 MHz.

Regarding to the measurements, the highest gains are achieved for Δ=1000 MHz. Possible reason for that is the competition between the resonant absorption and the FWM process. The probe and the conjugate photons which are created in the FWM process are subjected to the resonant absorption on the D_1 line. Increasing the detuning of the pump and with it the detuning of the probe and the conjugate decreases the probability for resonant absorption, but decreases the probability for FWM process as well. The optimum is found at the wing of the Doppler profile (the width of the Doppler profile for ^{39}K vapor at t=100°C is 860 MHz[10]) which is in our case about 1000 MHz. The conjugate is detuned about 920 MHz (two hyperfine splitting of ground states plus δ) more from the D_1 line than the probe which may explain its larger gain.



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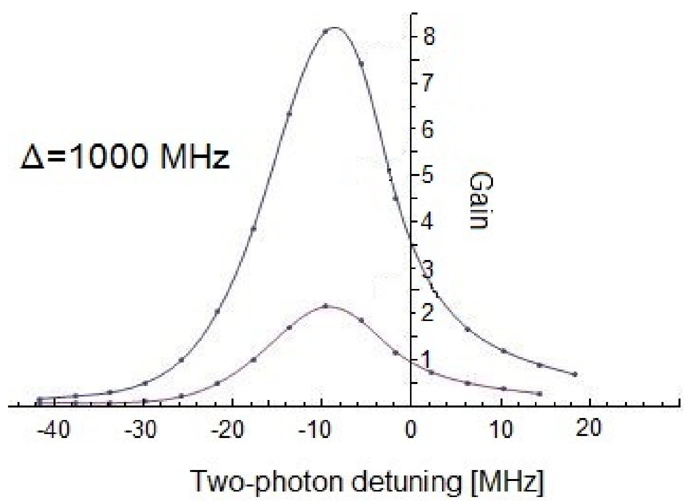

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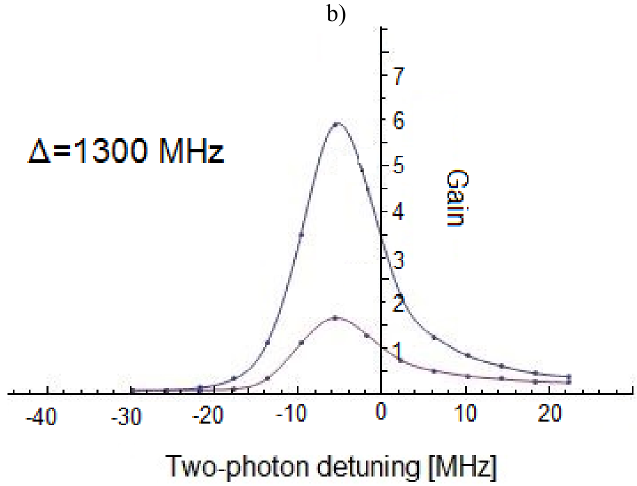

c)

Figure 4. Gain of the conjugate (blue) and probe (purple) versus two-photon detuning for a) Δ=700 MHz, b) Δ=1000 MHz, c) Δ=1300 MHz

4. CONCLUSION

We have demonstrated non-degenerate four wave mixing in hot potassium vapor based on coherent population trapping. The experiments of this type and generated twin beams are mostly used further for relative intensity squeezing and sub shot noise measurements. Unlike of ours, most of the experiments with similar problematic are performed in rubidium or cesium vapor. FWM process in potassium vapor is predicted to yield lager gain due to smaller ground state hyperfine splitting and thus smaller mutual detuning of the two lambda schemes.

The achieved effect is examined for maximum gain regarding to two most important parameters, one and two photon detuning. Counter intuitively we found out that maximum gain is achieved for non zero two photon detuning. This finding is in accordance with results of Turnbull *et al*[1]. Also, one photon detuning for the maximum gain is determined. Other parameters, such as vapor temperature, mutual pump-probe angle and intensities were fixed in the experiment, and the dependence of the FWM process on those parameters is not examined in details in this study.

These parameters will be investigated in the future studies, aiming to characterize relative intensity squeezing, and achieve noise below standard quantum limit.

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