

# Non-linear effect and patterns in the scattered beam of close resonance laser in a Rubidium vapor cell

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Nonlinear optics is an important branch of optics which studies the behavior of light in a nonlinear media in which the polarization is not a linear function of the electric field. The nonlinear effect in the media can cause interaction between light and an external field or even between two light beams for higher order nonlinear effects. These interactions give rise to the optical information processing that can possibly make computing faster using less energy. However, for classical nonlinear media, there is a compromise between nonlinearity and reaction speed. Recently, people have been hoping on using quantum effect to design a fast and efficient non-linear media. Several ways have been proposed including using optical crystal and atomic energy levels. In our experiment, we studied the non-linear effect and pattern formation in a Rubidium vapor cell and partially reproduced one possible way of making an all-optics switch.

## Introduction

Optical information processing, which uses light instead of electricity (like a modern computer), is thought to be one of candidates of next generation computing. It can be faster and also more energy efficient. The realization of such processing requires nonlinear media where the relation between polarization and electric field is no longer linear. In such media, the effective index of refraction as well as other properties can be affected by an external field or even another light beam which can be used to make electric-optics switches and even all-optics switches. These effects have been studied thoroughly in around 1980s and a lot of possible applications had been proposed. However, when using classical nonlinear media, there is a compromise between the reaction time and nonlinear coefficients. Materials like liquid crystal have really big nonlinear effect but they also have a reaction time in the order of 1ms. Other media usually have a really small nonlinear effect and will require high light power to work. These properties are really limiting the advantage of optical information processing and making it impossible to use classical nonlinear media.

Recently, people have been trying to solve the problem using quantum physics and the control of energy levels. One possible way is using an optical crystal in which one can introduce and control the nonlinear effects by designing certain band structures. Another way is using a close resonance beam of certain atomic line. Using the strong interaction between light and atom close to resonance, a pattern forming effect had been observed in both experiment[1] and simulation[2] and the possible application of making all-optics switch has also been studied experimentally[3].

In our experiment, we have used a similar setup with that used in the all-optics switch[3] and studied the light

generated when two counterpropagating beams are close to resonance with the Rubidium atom in the cell. We were able to see several patterns appear in the generated light and partially reproduce some effect for the all-optics switch.

## 1. THEORY

### 1.1. Saturated absorption and non-linear effect.

When a close resonance laser beam is interacting with atoms, part of the beam will be absorbed and scattered by the atoms. At the same time, if the intensity of the laser is strong enough, the stimulated emission will be comparable or stronger than the spontaneous emission, atoms will be pumped to the excited state, there will be almost equal number of atoms in the excited and ground states and the scattering will also reach a maximum. This effect is called saturated absorption and the intensity is called saturation intensity ( $I_{set}$ ). Since the stimulated emission is important in this regime, the reaction to light of the atoms is not linear anymore and there can be interaction between multiple beams. Since the scattering is already saturated, the close resonance light will no longer be strongly absorbed which makes it possible to do observations.

### 1.2. Scattering in a standing wave and interference rings.

By using a mirror to retroreflect the laser beam, we can create a standing wave in the cell. The distance between each wave crest where the constructive interference happens is half the incident wave length. Therefore, the phase of the light at each wave crest is alternating between 0 and  $\pi$  and the light scattered at each point will have the same phase relation. If the incident beam is red detuned the distance between wave crests will be

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larger than the wavelength of the wavelength scattered by the atoms and a interference ring can appear when the constructive interference condition is satisfied, i.e.,

$$\lambda \cos \theta = \lambda_0$$

where  $\lambda$  and  $\lambda_0$  are the wavelength of the incident beam and the atomic line respectively and  $\theta$  is the angle between the incident beam and the ring. In the small detuning limit (also in the small angle limit because rings with a larger angle will get out of the region of the beam and therefore absorbed by the non-pumped atoms), this can be rewrite as,

$$\theta = \sqrt{\frac{2\delta}{\nu_0}}$$

where  $\delta$  is the detuning and  $\nu_0$  is the frequency of the laser.

### 1.3. Flower like patterns from four wave mixing.

The strong nonlinear effect in the rubidium vapor at resonance can create a four wave mixing effect in the standing wave which will generate and amplify beams at an angle with the original ones. According to previous experiment and simulation result [1–3], for a perfectly symmetric setup, the generated light will form both forward and backward cones with a polarization orthogonal

to that of the linearly polarized original beams. However, when the symmetry of the system is slightly broken and when the atom density, therefore nonlinearity is above certain threshold, the cone can turn into several separated spots, which can also be disturbed by another weak beam (6500 times weaker[3]) and changes into another mode.

## 2. APPARATUS

### 2.1. Beam path setup.

### 2.2. Heater design.

### 2.3. Imaging system.

## 3. MEASUREMENTS AND RESULTS

### 3.1. Generated light in the orthogonal polarization.

### 3.2. Interference rings for red detuned light.

### 3.3. Flower like patterns

## 4. CONCLUSION

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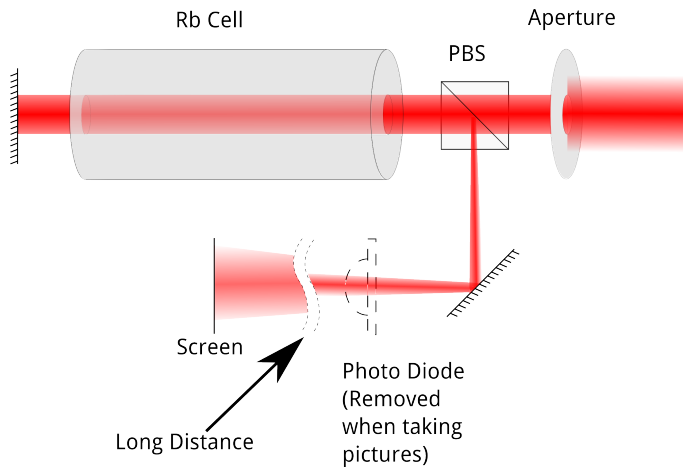


FIG. 1: Beam path setup of the experiment. The aperture is used to make the elliptical beam coming out of the diode laser more circular. The polarization beam splitter (PBS) is used to split the weak generated light with an orthogonal polarization from the main beam. A photo diode can be put in the beam path to measure the power helping to find the resonance frequency.

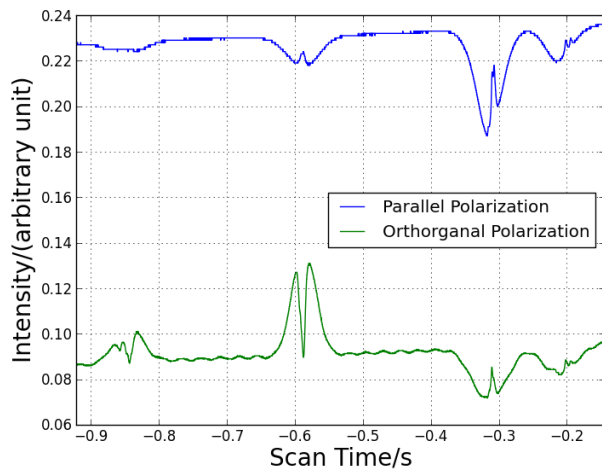


FIG. 2:

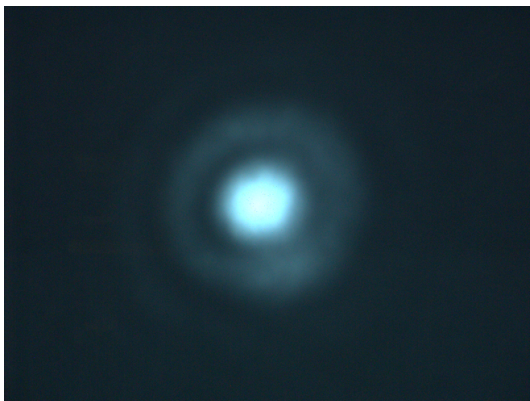


FIG. 3:

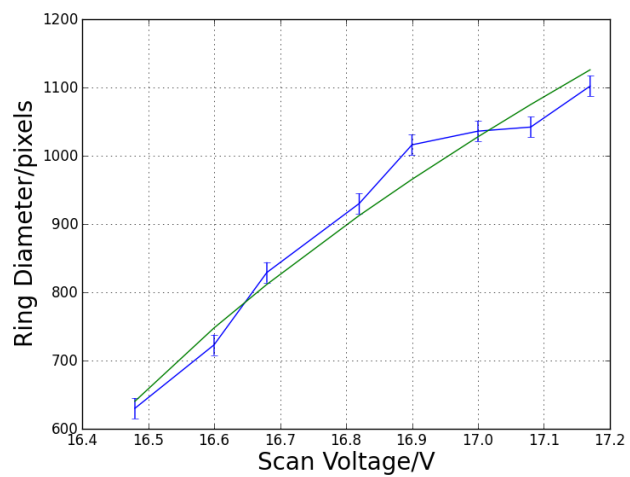


FIG. 4:



FIG. 5:

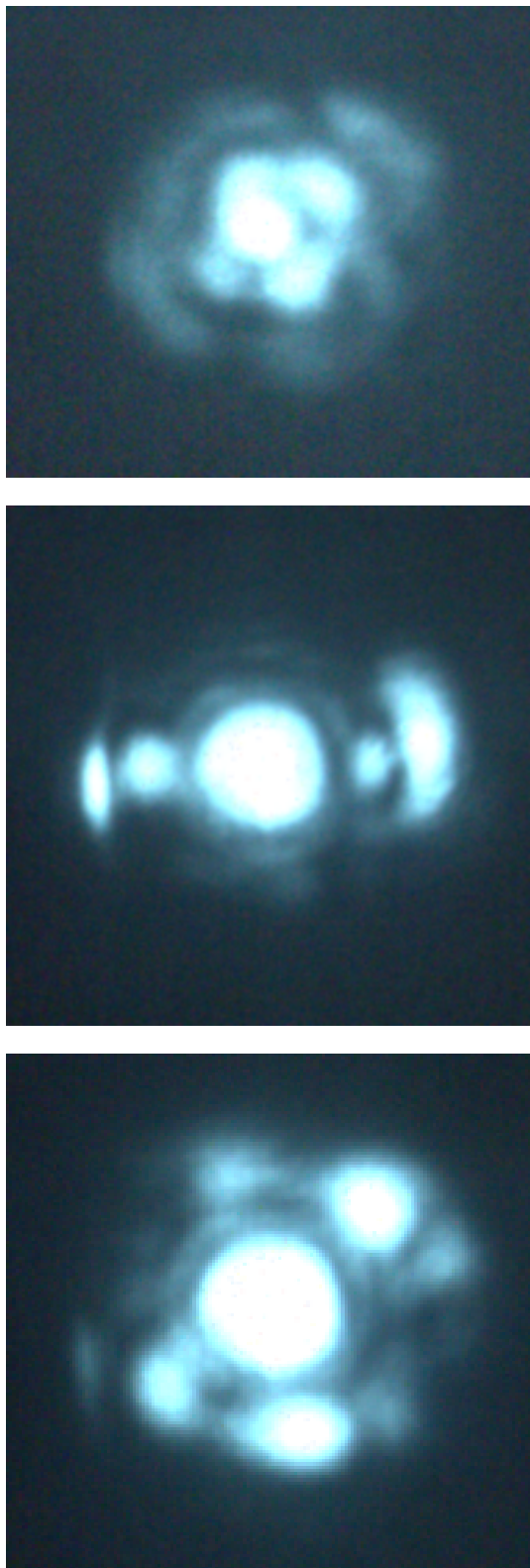


FIG. 6: