Acta Universitaria
DIRECCIÓN DE APOYO A LA INVESTIGACIÓN Y AL POSGRADO

Pattern based optical memory in rubidium vapor

Memoria óptica basada en patrones de vapor de rubidio

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ABSTRACT

We investigated the optical transverse pattern produced by counterpropagating two waves through a rubidium vapor cell in presence of a longitudinal magnetic field. A bistable behavior is observed. The optical switching process between two of these patterns is carried out using three different mechanisms: mechanical closing of a pump beam, modulation of a pump beam intensity and modulation of additional beam intensity. A rapid switching of less than 10 s between patterns can be carried out with a 2 w power beam.

RESUMEN

Investigamos los patrones ópticos transversales producidos cuando se contrapropagan dos ondas a través de una celda de vapor de rubidio en presencia de un campo magnético longitudinal. El proceso de conmutación óptica entre dos de estos estados se realiza utilizando tres mecanismos: interrupción mecánica de uno de los haces, modulación en intensidad del haz de bombeo y modulación en intensidad de un haz adicional. El proceso de conmutación alcanzado tiene una duración menor a 10 s y puede ser realizado con potencias de 2 w.

Recibido: 11 de noviembre del 2012
Aceptado: 13 de junio 2013

Keywords:
Rubidium vapor; transverse optical pattern.

Palabras clave:
Vapor de rubidio; patrones ópticos transversales.

INTRODUCTION

Transverse optical patterns are observed when light whose frequency corresponds to the frequency of one of the possible atomic transitions is propagated on alkali vapors (Ackemann & Lange, 2001; Chang, Firth, Indik, Moloney & Wright, 1992; Grynberg, Maître & Petrossian, 2001; Yariv & Pepper, 1977; Zerom & Boyd, 2009). The mechanisms responsible for the appearance of these patterns have been associated with nonlinear effects resulting from a four wave mixing process in Kerr type media (Firth, Fitzgerald & Paré, 1990; Grynberg, 1988; Grynberg & Paye, 1989; Silberberg & Bar-Joseph, 1984). The amplification has a vector character and leads to the generation of additional beams whose polarization is orthogonal to what is called initial pumping beam. In reference (Maître, Petrossian, Blouin, Pinard & Grynberg, 1995) some of the complex dynamic behaviors present in these patterns are studied. In reference (Petrossian, Pinard, Maître, Courtois & Grynberg, 1992), it is shown that such a system can provide a hysteresis process in the transition from one pattern to another, if the pump beam is varied in intensity. In more recent work switching between transverse optical patterns in rubidium vapor using very low powers has been documented (Dawes, Illing, Clark & Gauthier, 2005). The switching mechanism used in this case, is to implement an additional low intensity beam in rubidium vapor, with a frequency corresponding to the transition of ^{87}Rb with Fg = 1 for a pumping beam whose polarization is linear and in the absence of additional electromagnetic fields. In this case, the generated pattern returns to its initial position when the additional beam is off. In this work, we propose an optically switchable memory element based on the generated cross-sectional pattern bistability in rubidium vapor. Under appropriate handling of the disturbance

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signal, the generated pattern can switch between two possible configurations and remains stable until the next switching event. One of the most attractive features of this mechanism is the possibility of inducing fast switching events between patterns less than 10 s, using an extra beam in the experimental arrangement of a few microwatts of power.

Experimental results

A diagram of the experiment setup is shown in figure 1. A tunable semiconductor laser with a wavelength of 780 nm and output 50 mW is used. The beam splitter generates two pumping beams that propagate in opposite directions inside the cell of rubidium. The cross section of the two beams is elliptical with a horizontal axis of 0.5 mm and a vertical of 2.1 mm (FWHM). In order to make the bistability more stable, one beam is rotated 60° on its longitudinal axis using a Dove prism. The Rubidium cell is within a solenoid producing a longitudinal magnetic field B of 0-0.3 mT and is heated to a temperature of about 80 °C. The acousto-optic modulator (AOM) shown is used to modulate beam intensity.

When the laser frequency corresponds to the transition Fg = 2, Fe = 2, 87 Rb, additional beams are generated in the observation plane. The generation is observed for a frequency range of approximately 20 MHz. The generation is possible with linear polarization pumping beams or even ones slightly elliptical, with a small angle between their axes. The optical pattern observed in the far field is composed of symmetrical pairs of points or segments of a ring as shown in figure 2. The number of points and their position depend on the value of system parameters such as the angle between the beams within the cell, frequency, the initial polarization and magnetic field. The appearance of these patterns can be explained as a result of a modulation process and instability of positive feedback of the beams within the cell. The theory of this generation nonlinear Kerr half can be found in (Agrawal, 1990; Firth & Paré, 1988). In this case, the interaction is a vectorial mechanism (generated beams have orthogonal polarization with respect to the pump beam). This type of interaction vector is stronger than the conventional Kerr-type nonlinearity (Korneev, 2011). However, from a formal point of view, and considering a lossless pump beam, these two approaches are similar. The calculations and experiments indicate that the nonlinearity in this case is not strongly dependent on the local and flight time, with a maximum for a certain optimum value of the intensity. For the transition to Fg = 1, the optimal value of intensity is lower than the transition to Fg = 2, but for the latter, the transition provides higher values of nonlinearity. Additionally, the nonlinear effect can be increased or decreased using magnetic fields with values below 0.2 mT and elliptical polarizations.

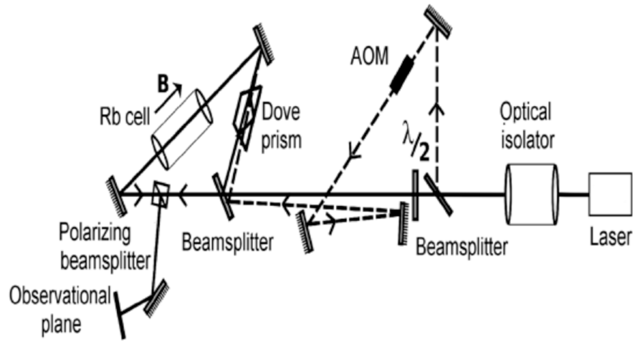


Figure 1. Experimental setup.
Source: Authors own elaboration.

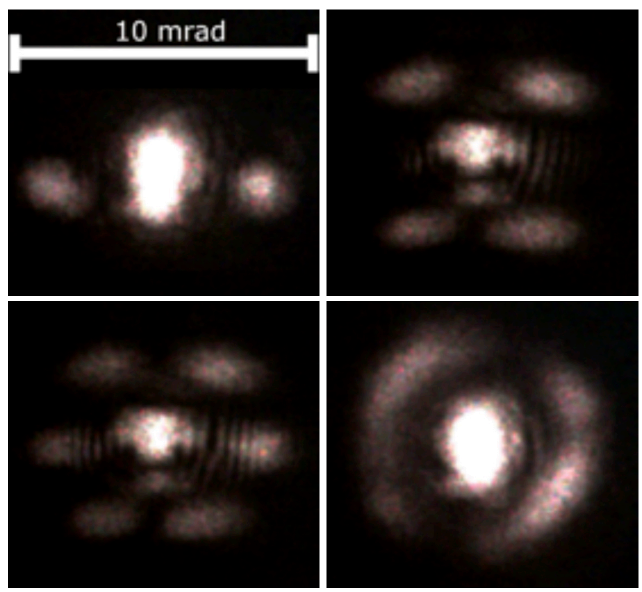


Figure 2. Optical transverse patterns generated in the far field.
Source: Authors own elaboration.

Bistability

Varying the system parameters, one bistable state is obtained as 1 and 2 of figure 3 (above). The effect of the variable magnetic field is observed on the signal generated in one point on pattern 1. The pattern observed depends on the magnetic field and/or illumination history. In a first experimental arrangement, without the presence of the Dove prism, a process of hysteresis due to the magnetic field is obtained, as is shown in figure 3 (below). In this case, the pattern is shifted abruptly from one position to another when it reaches a certain value in the magnetic field. This process takes 5 s - 10 s. Depending on whether the magnetic field increases or decreases, the values for which the configuration is generated 1 or 2 are generally different. When the Dove prism is added, a more pronounced difference between the values of the magnetic field in the hysteresis is obtained.

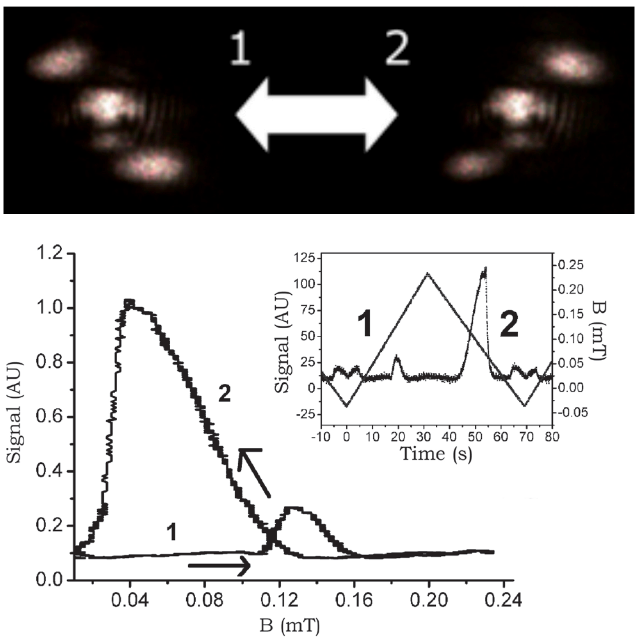


Figure 3. Hysteresis generated by the longitudinal magnetic field.
Source: Authors own elaborations.

Optical switching

▫ Mechanical interruption

This is performed by a rotating disc. The beam is off twice on each rotation period. Once the beam is closed it starts at the upper end and the second time it begins at the opposite end. This asymmetry occurs in the pattern forming process. The generation disappears at the time in which the beam is fully closed. When the beam is opened, the pattern is induced in one of its two possible states, for example state 1 in figure 3 (above) and remains in this state until the next switching event (figure 4).

▫ Modulation of a pump beam intensity

The bistable behavior of the system can also be induced by modulating the pump beam intensity using an AOM in the beam pumping. In this case, we observed again a phenomenon of hysteresis (figure 5) due to the difference between the intensity values generated by each setting. Thus, the system be switched temporarily varying the pumping beam intensity in the order of mW.

▫ Modulation of additional beam intensity

A considerable reduction in the value of the power required to switch the generated patterns can be achieved by adding a low power beam within rubidium cell with a polarization perpendicular to that of the pumping beam. The intensity modulation is performed using an arrangement of two acousto-optic modulators that produce a beam with appropriate frequency for interacting with the beam in the patterns produced. The beam has an exponential amplification within the cell, so that can influence the behavior pattern generated even if its power is low in comparison with the pumping beams generated. The phenomenon of hysteresis due to this additional beam is shown on figure 6.

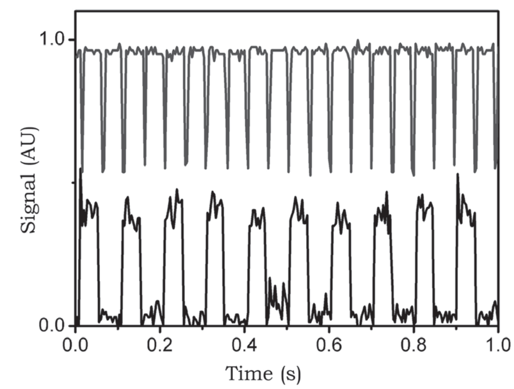


Figure 4. Mechanical switching. Upper trace: Interruption pulse. Lower trace: Generated spot intensity.
Source: Authors own elaboration.

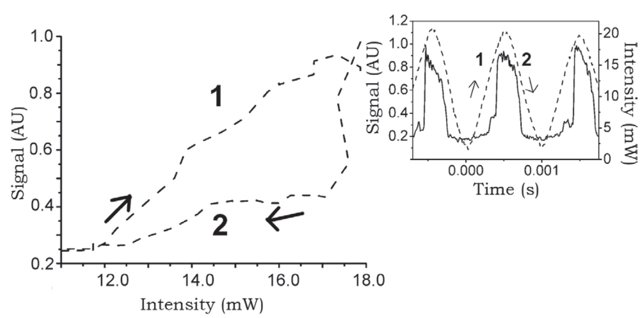
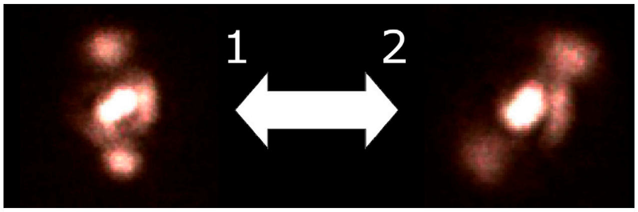


Figure 5. Hysteresis due to modulation intensity pump beam.
Source: Authors own elaboration.



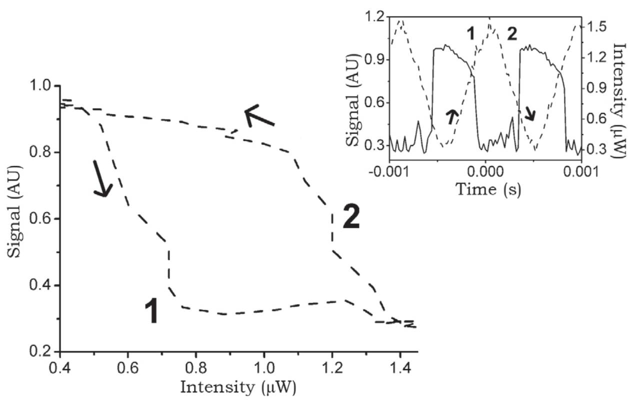


Figure 6. Hysteresis generated in the signal due to an additional
Source: Authors own elaborations.

DISCUSSION AND CONCLUSIONS

The study of the spatial behavior of the transverse optical patterns generated for the transition of 87 Rb Fg = 2 in the presence of a weak magnetic field shows a bistable laser for power of 10 mW. The results obtained indicate that the rubidium vapor cell can be used as an optical memory element, with a switching time below 10 s for additional low beam intensities (about 2 w). The switching mechanism between states can be a variable magnetic field or direct modulation of the incident beam. The experimental arrangement is sensitive to changes in control parameters. In particular, the main source of perturbation of the system is the instability of the laser frequency. Due to this instability, the beam patterns induced by low intensity, are observed for periods of less than one second, which is the time at which the laser frequency stabilizes. For higher intensities, the shift may be observed up to minutes. It is likely that the frequency stabilization of the laser allows the use of switching power still lower than those reported here.

ACKNOWLEDGMENTS

The work was performed in the framework of *Consejo Nacional de Ciencia y Tecnología* (Conacyt) project 156891. We also acknowledge the *Secretaría de Educación Pública-Subsecretaría de Educación Superior-Dirección General de Educación Superior Universitaria* project 2012-01-21-002-205 and Conacyt project 000000000189688 for supporting the LAOP Workshop 2012, where this work was presented.

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