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To cite this version:

Nicolas Marsal, Delphine Wolfersberger, Marc Sciamanna, Germano Montemezzani. Noise-sustained dynamics of drifting patterns in a tilted nonlinear feedback system. ACOFT/ACOLS 2009, Sub Conference Dissipative Soliton (DS.2009), Nov 2009, Adelaide, Australia. hal-00445381

HAL Id: hal-00445381

https://hal-centralesupelec.archives-ouvertes.fr/hal-00445381

Submitted on 8 Jan 2010

Noise-sustained dynamics of drifting patterns in a tilted nonlinear feedback system

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Abstract

We investigate experimentally the dynamics of pattern excitation in presence of an advection-like effect in a nonlinear optical system. This advection effect, created when the angle of incidence of the pump beam is not zero, causes the existence of: (i) a transition from convective to absolute instabilities, (ii) the formation of new pattern geometries, (iii) the seeding of noise-sustained structures. All these phenomena, previously observed in nonlinear Kerr-type systems, are demonstrated in our setup composed by a photorefractive nonlinear medium in a tilted feedback configuration.

Keywords: Advection; Convective; Absolute; Photorefractive; Feedback; Noise

Introduction

The concepts of convective (CI) and absolute (AI) instability were first developed in the context of plasma physics [1], later theoretically investigated in optics using a Kerr nonlinearity [2]. In the convective regime, an initial local disturbance exponentially grows but is simultaneously advected away so that the system returns locally to the initial homogeneous solution. Thus no pattern can arise in this regime. In contrast, in the absolute regime, a disturbance growing locally competes with the drift so that the system reaches a pattern state [2].

The convective regime, where no pattern is expected, can, however, show structures or patterns if noise is present in the system. Then, macroscopic noise-sustained structures can be formed resulting from the amplification in preferential direction of the perturbations produced by the microscopic noise [2].

Despite the large theoretical interest, and recent experimental demonstrations using a Kerr-type nonlinearity [3,4], however, an experimental evidence of an advection effect on the dynamics of the pattern formation process in a photorefractive system is, to the best of our knowledge, still lacking.

Materials and Methods

In our experiments we employ the setup shown in Figure 1. It contains a standard photorefractive two-wave mixing in a reflection grating geometry and a tunable single feedback. A p-polarized 532 nm laser beam is focused inside an undoped $BaTiO_3$ crystal to a 350 μm diameter. The mirror, enabling the feedback, can be precisely moved longitudinally, to vary the position of the corresponding virtual mirror, created by a 2f:2f lens system (Fig.1). This allows to adjust positive or negative effective propagation lengths L (Fig.1.). To create an advection-like effect in the system, the mirror can also be precisely tilted in x or y direction.

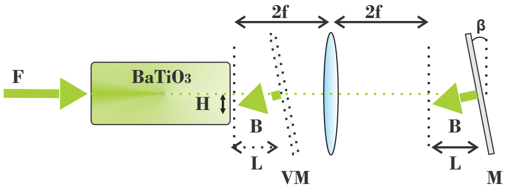

Figure 1: Photorefractive crystal in a single feedback configuration. M- mirror, VM- virtual mirror, $BaTiO_3$- photorefractive crystal, L- distance between the virtual mirror and the crystal, β- mirror tilt angle, H=L.sinβ- transverse shift (in μm), F and B correspond respectively to the forward and backward beams responsible for the pattern formation.

In this counterpropagating configuration, for a particular intensity threshold (I_{TH}), the pump laser beam (I_P) becomes unstable against modulational instability (MI). Above this threshold, MI leads to the formation of patterns. Depending on the distance mirror-crystal (L in Fig.1) and above I_{TH}, a finite set of wave vectors pairs is selected, leading to the formation of different patterns whose the principal is the hexagonal one [intensity distributions shown in Fig.2(a)].

Results and Discussion

In figure 2, we show, for a virtual mirror located inside the medium, how the strength of the advection (depending on the transverse shift H) influences the geometry of the forming patterns: from stripe to rectangular patterns [Figs.2 a-f]. A new particular structured state is observed in Fig. 2(g). It is obtained for large values of H and does not depend drastically on Ip. This disordered state does not occupy the whole available space, and is located at the edge of the outgoing flow created by the strong misalignment. The corresponding far-field shows noisy hexagonal expended spots located all around a ring of instabilities. This behavior, corresponding to typical noise-sustained structures was predicted in [2] for large values of the parameter H.

By properly adjusting the intensity of the pump beam, we identify three important mechanisms: [Fig. 3(a)] the noisy precursor of the absolute instability modes; [Fig.3(b)] the seeding of convective patterns and noise-sustained structures; [Fig.3(c)] the bifurcation toward absolute instability modes.

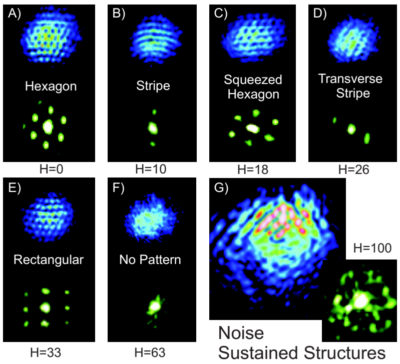

Figure 2: Different pattern states obtained for different transverse shifts H (in μm). The virtual mirror is located inside the crystal (L≈-2mm). The intensity of the pump beam Ip is fixed far above Ith. Top: near-field, bottom: far-field.

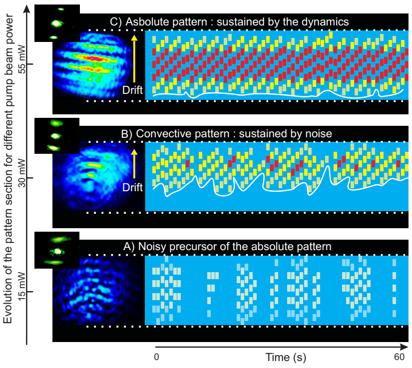

Figure 3: Spatiotemporal evolution of the transverse profile of the stripe pattern obtained in Fig.2(b) for different power of the pump beam. The dotted lines depict the available space for the growing process of the pattern. From blue to red, the colors indicate respectively an evolution from low to high intensities in the near-field pattern. Inset: far-field.

For low input intensities, the output beam shows erratic stripes that appear randomly in time and space with short time duration [Fig.3(a)]. In addition, the two corresponding spots in the far-field [inset Fig.3(a)] are very broad and move in time. All these observations are associated with a precursor, induced by noise, of the pattern that emerges for high intensities in the absolute regime [2].

When the input intensity is increased, stripes, drifting outside the pump beam [Fig.3(b)], arise continuously. The far-field pattern is now stable in its transverse plane, but still present expended spots [inset Fig.3(b)]. In this case, the perturbations are amplified, then are advected away [drift in Fig.3(b)] and reappear recursively. Such instabilities would not have been observed if noise had not been present in the system: this regime is known to be convective, sustained by noise [2].

Finally, for high input intensities, the stripe pattern extends downstream and invades almost all the available pumping region [Figs.3(c)] of the system. Moreover, the spatiotemporal trace shows a strong periodicity of the advection effect. The far-field spots [inset Fig.3(c)] are now concentrated on two well-defined circles. Finally, by comparison with the convective regime, note that the pattern arises almost at the same position in space [see the white lines following the downstream edges of the stripe pattern in Figs.3(b,c). All these phenomena are linked to a regime of absolute or dynamics-sustained instabilities [2-4].

Conclusions

These results, observed in a photorefractive medium, contribute to the studies of spatiotemporal dynamics in presence of feedback and noise.

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