SPATIAL PATTERNS IN NONLINEAR OPTICS

Pattern Formation in Optical Cavities With Incoherent Light

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Nonlinear optical cavities attract attention since they exhibit various kinds of nonlinear phenomena such as pattern formation,[1] solitons[2] and chaos.[1] Pattern formation refers to the fact that above a specific threshold, any uniform intensity distribution of light becomes unstable and splits into space- (time-) correlated domains.[1] Thus far, all work on nonlinear optical cavities has been carried out with spatially and temporally coherent light, that is, in cavities in which the characteristic dimensions are much smaller than the spatial and temporal coherence lengths of the light. In such systems, resonance (interference) effects are crucial to the pattern formation process.[1] Here, we summarize recent results on dynamics in the opposite limit: optical cavities with *incoherent* light,[3,4] in which pattern formation occurs despite the lack of interference.

These experimental and theoretical studies have focused on optical cavities the characteristic dimensions of which exceed the temporal coherence length of the light and in which the spatial coherence of the light could be varied from zero to infinity.[3,4] In these cavities, there is no interference between the fields from different cycles. Hence, pattern formation relies on a different physical mechanism than it does in coherent cavities. In particular, the response of the medium is noninstantaneous, so that it is unable to follow the fast phase fluctuations of the incoherent light and thus responds only to the smooth time-averaged intensity. As a first step, we analyzed a cavity with temporally incoherent, but spatially coherent, light.[3] It was shown that patterns form above a well-defined cavity threshold determined by the interplay of nonlinear gain and cavity loss. The patterns of this *non-resonant* system exhibit spatial line narrowing with the increase of feedback, resembling the line narrowing in (resonant) lasers (see Fig. 1). In fact, despite the incoherence of the light, this cavity threshold is analogous to many thresholds in resonant feedback systems with gain.[1] In a subsequent paper, we theoretically analyzed a cavity in which the light was also spatially incoherent.[4] The pattern formation process in such a cavity is always associated with two consecutive thresholds of different character. The first threshold is the point at which the uniform intensity beam becomes unstable as the nonlinearity overcomes the diffusive tendency of spatially incoherent light. In marked contrast to what occurs in coherent cavities, this threshold is independent of the cavity boundary conditions. The second threshold is the aforementioned "cavity threshold." These theoretical results have recently been confirmed experimentally.

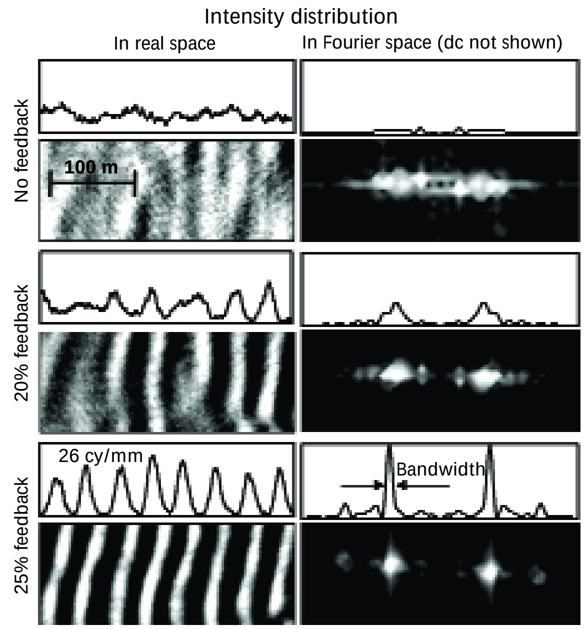

Figure 1. Experimental results, showing pattern formation in a temporally incoherent nonlinear optical cavity, displaying the narrowing of the spatial spectrum of the pattern with increasing feedback intensity. Shown are photographs of the intensity distribution along with their calculated spatial (Fourier) power spectrum (*right*), at various feedback values. The bandwidth narrowing is obvious in these pictures as the stripes become sharper and more regular with increasing feedback.

In conclusion, we have summarized features of optical pattern formation that result from the interplay between the statistical (coherence) properties of light, the nonlinearity of the medium and the feedback of the cavity. These results open a new direction of research in which nonlinear optical cavities are viewed as a class of statistical systems with variable characteristic length scales: (i) the temporal (spatial) coherence length of the light, (ii) the length of the nonlinear medium and (iii) the length of the cavity. These systems are fundamental to optics, with potential applications using statistical light, and are intimately related to (non-equilibrium) statistical physics in other fields.

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References

1. F. T. Arecchi, S. Boccaletti and P. Ramazza, Phys. Rep. **318**, 1 (1999).
2. S. Barland et al., Nature (London) **419**, 699 (2002).
3. T. Carmon, M. Soljačić and M. Segev, Phys. Rev. Lett. **89**, 183902 (2002).
4. H. Buljan, M. Soljačić, T. Carmon and M. Segev, Phys. Rev. E **68**, 016616 (2003)

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