NONLINEAR OPTICS

Honeycomb Pattern Formation by Laser-Beam Filamentation in Atomic Sodium Vapor

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We recently observed[1] a striking form of optical pattern formation (see Fig. 1) in which, in passing through a sodium vapor cell, a single laser beam without feedback breaks up into a stable, regularly structured beam. Pattern formation in optical systems[2] is an area of widespread interest, both from the conceptual point of view of understanding how regular patterns can emerge from uniform or randomly structured input fields, and from the practical point of view of using such patterns in image formation and manipulation. Spontaneous pattern formation has been studied previously in a variety of material systems,[2] including atomic vapors, liquid crystals, photorefractive crystals, organic liquids, glasses, semiconductors and bacteriorhodopsin. Most previous observations of regular pattern formation were obtained in systems in which optical feedback plays an important role. This feedback can be produced by the use of optical resonators and/or by the use of counterpropagating beams. In contrast, the patterns that we observe occur when a *single* laser beam (i.e., with no feedback mechanism) passes through an atomic sodium vapor. Pattern formation of this type appears to have been previously unreported, although pattern formation has been observed in sodium vapor under somewhat different experimental conditions.[2]

In our experiment, we inject a 150-mW collimated laser beam with a diameter of 220 μm into a 6-cm-long sodium vapor cell containing 8×10^{12} atoms/cm^3. The laser is tuned 1.5 GHz to the blue side of the D2 resonance line. In passing through the cell, the beam is found to break into multiple components as a consequence of self-focusing effects. Under certain input conditions, the beam breaks up into three components of comparable power, the positions of which form an equilateral triangle. An example of such an arrangement is shown in the left panel of Fig. 1. The far-field pattern of this emission has the symmetric honeycomb pattern shown in the right panel of the figure. We find both the near- and far-field patterns to be stable for tens of minutes. The highly structured yet stable beam of the sort we have observed may constitute a system in which to study quantum statistical effects such as quantum images.[8]

In summary, we have observed a dramatic example of optical pattern formation in which a single laser beam propagating without feedback through atomic sodium vapor develops a stable, regular, transverse structure. In particular, a three-filament near-field pattern leading to a honeycomb far-field pattern occurs at intensities near the saturation intensity and at powers larger than (but of the order of magnitude of) the critical power for self-focusing. The three-filament pattern has a uniform phase profile and strongly correlated power fluctuations, which suggest that it is perhaps a quantum image. These observations were also found to be in good agreement with numerical simulations of filamentation in a two-level atomic medium.[1]

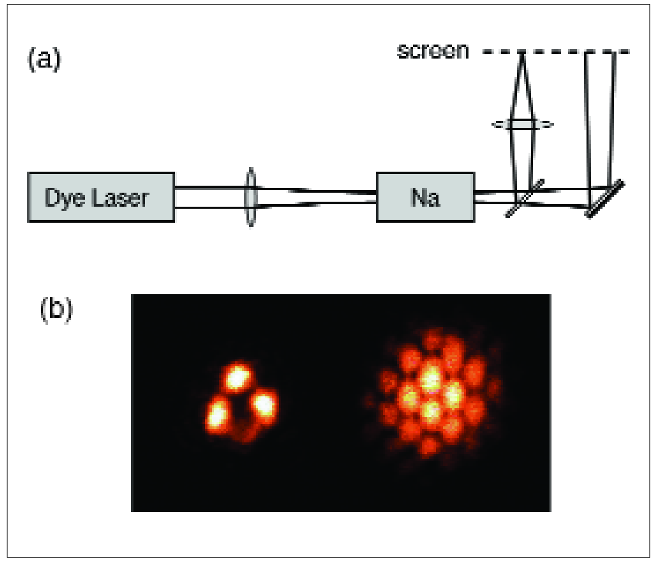

Figure 1. (a) Experimental setup used to study optical pattern formation; patterns were recorded both in the near and far fields. (b) Example of pattern formation as observed in the near field (*left*) and far field (*right*).

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References

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