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

Ryan S. Bennink, Vincent Wong, Alberto M. Marino, David L. Aronstein, Robert W. Boyd, C. R. Stroud, Jr. and Svetlana Lukishova,
The Institute of Optics, University of Rochester, Rochester, NY 14627

Daniel J. Gauthier
Department of Physics, Duke University, Durham, NC 27708

We recently observed [1] a striking form of optical pattern formation (see Fig. 1) in which a single laser beam breaks up into a stable, regularly structured beam in passing without feedback through a sodium vapor cell. 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 utilizing such patterns in image formation and manipulation. Spontaneous pattern has been studied previously in a variety of material systems [2]. 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 counter-propagating beams. In contrast, the patterns that we observe occurs when *single* laser beam (i.e. with no feedback mechanism) passes through an atomic sodium vapor. Honeycomb pattern formation in the far field of the interaction region resulting from feedback-free propagation through an atomic vapor appears to have been previously unreported, although pattern formation has been observed in sodium vapor under somewhat different experimental conditions.

In our experiment, we inject a 150 mW collimated laser beam with a diameter of 220 μm into a 7 cm-long sodium vapor cell containing 8×10^{12} atoms/cm^3. The laser is tuned 2 GHz to the blue side of the D2 resonance line. The beam is found to break into multiple components in passing through the cell as a consequence of self-focusing and diffraction effects. Under certain input conditions, the beam breaks up into three components of comparable power whose positions 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.

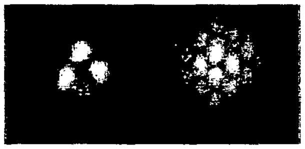

Fig. 1. Example of pattern formation as observed in the near (left) and far (right) fields of the sodium vapor cell.

In summary, we have observed a dramatic example of optical pattern formation in which a single laser beam propagating through atomic sodium vapor without feedback 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 are also found [1] to be in good agreement with numerical simulations of filamentation in a two-level atomic medium.

1. R. S. Bennink, V. Wong, A, M. Marino, D, L. Aronstein, R, W. Boyd, C. R. Stroud, Jr., S. Lukishova, and D. J. Gauthier, Phys. Rev. Lett. **88**, 113901, 2002.

2. See, for instance, the special issues of J. Opt. Soc. Am. B (Vol. 7, issues 6 and 7, 1990) dealing with transverse effects in nonlinear optical systems and especially the overview article by N. B. Abraham and W. J. Firth, J. Opt. Soc. Am. B **7**, 951, 1990.