Self-organized patterns by optical nonlinearity in 4-(4-pentenyloxy)benzonitrile

Mónica Trejo-Durán,1(a) Edgar Alvarado-Méndez,1(b) and Víctor M. Castaño2(c)
1Facultad de Ingeniería Mecánica, Eléctrica, y Electrónica, Universidad de Guanajuato, Carretera
Salamanca-Morelia, km 3.5 + 1.4, Comunidad Palo Blanco, Salamanca, 36790 Guanajuato, Mexico
2Centro de Física Aplicada y Tecnología Avanzada, Universidad Nacional Autónoma de México,
Boulevard Juriquilla 3001, Querétaro, 76230 Querétaro, Mexico

(Received 26 August 2008; accepted 27 December 2008; published online 14 January 2009)

Optical characterization of the organic compound 4-(4-pentenyloxy)benzonitrile under two different conditions was carried out. The experiments show deformation of the scattered light spots upon heating as well as evidence of a thermally self-induced nonlinearity. In consequence, self-diffraction pattern, self-bending, and filamentation of the impinging beam appear as a function of the laser power, creating self-organized patterning during the filamentation due to modulation instabilities.

© 2009 American Institute of Physics. [DOI: 10.1063/1.3072609]

Instabilities of several kinds (e.g., instability modulation) are known to produce periodic spatial patterns in a number of physical, chemical, and biological systems1,2 and reports. Ranging from atomic sodium vapor3 and photorefractive materials4–7 to liquid crystals, organic liquids and others8 are available in the literature. In particular, the phenomenon of filamentation has been studied both experimentally and theoretically9–13 since it can be employed for the design of multiplexers, switches, optical limiters, and other optoelectronic devices. The order of magnitude of electronic nonlinearities is smaller than that of thermal nonlinearities, but their response time is faster. Thus, to analyze thermal nonlinearities, a strong continuous optical field is required since thermal nonlinearities are basically changes in optical properties due to density fluctuations within the material caused by heating, as a result of optical absorption. In this paper self-deflection and elliptic deformation of an impinging laser beam, as a function of temperature, is reported. Filamentation and subsequent patterning were obtained with increasing beam power, thus causing modulation stability.

4-(4-pentenyloxy)benzonitrile was prepared as reported elsewhere.14 UV-visible spectra show the maximum absorption at 205 and 250 nm. The refractive index is 1.534 and the calculated nonlinear refractive index is \( n_2 = 2.796 \times 10^{-14} \) esu. The emission spectrum presents maxima at 366 and 658 nm (wavelength excitation 334 nm). Melting and boiling points are 4.6 and 248.7 °C, respectively. A cw Ar-ion laser at 514 nm with variable power, a heater, charge coupled device (CCD) camera, an optical cell (2 mm), and lenses (50 and 75 mm focal length) were employed to study the elliptic deformation (when sample heated and at minimum power beam) and self-deflection, filamentation, and pattern formation (without external heating and while increasing the power of the beam) in far-field conditions. The setup for the first experiment consisted in the optical cell with the 4-(4-pentenyloxy)benzonitrile liquid and external heating from 22 to 200 °C, a power laser of 34 mW, and CCD camera in far-field condition. The beam began to deflect upwards and deformed at 80 °C, from a circular into an elliptic shape, as the temperature increased (Fig. 1). Deformation was caused by the optical anisotropy of the compound due to local changes in refractive index.

The setup for the second experiment is shown in Fig. 2. The laser beam traveled through a lens (50 mm). The input face of cell was placed at its focus, whereas the output face was focused with another lens (75 mm) and the image was registered by a CCD camera (pixel resolution of \( 9.6 \times 7.5 \) μm\(^2\)) after attenuation by a filter to avoid saturation. The power of the incident beam varied from 150 to 2650 mW, without external heating. The central section of the image was analyzed and the filamentation phenomenon was observed (Fig. 3). Initially, the beam was circular but at 650 mW an ellipse formed and began to filament into three spots (900 mW). At 1150 mW, the symmetry breaks and only three spots are observed. Each spot would, in turn, filament, each producing two spots, rescaling the original pattern. Notice the elliptic deformation in the bottom spot, which, along with a self-bending, appears as the power increased. The effect of the beam ellipticity on the dynamics of multiple filamentation, using a borosilicate (BK7) glass, has been reported before.11 In the present case, modulation instability was responsible for the spontaneous formation of optical patterns, which had been observed only in nonlinear media under coherent illumination.

The self-bending effect was strong along the y-direction, as compared to the x-direction [see Figs. 4(a) and 4(b)]. This effect has been reported in sodium vapor15 and films of the liquid crystal “4-cyano-4’-pentylbiphenyl” (5CB).16 From Figs. 4(c) and 4(d), displacements of 120 mm along

![FIG. 1. Self-deflection and elliptic deformation due to heating at (a) 22 °C and (b) 200 °C.](image-url)
the y-axis and 25 μm along the x-axis were measured. The self-bending angle was estimated as 17 mrad.

At 1200 mW a pattern is formed (Fig. 3) by the interference of three patterns: two Fabry–Pérot, due to the effect of input and output faces of the cell and the self-diffraction pattern, due to the nonlinearity of the sample. There is evidence of energy transfer among the various patterns involved, as a function of the power level of the laser. In the linear case, the energy transfer between the Fabry–Pérot patterns and the pattern diffraction (not the self-diffraction pattern) goes from the central spot to outer ones, and the energy decays uniformly for each ring. However, in the nonlinear case, more spots are instead formed due to the modulation instability and thus the distribution of the energy is uneven. It is important to mention that the effect of the input power was nonlinear in nature and gave rise to the appearance of self-organized patterns during the filamentation (Fig. 5).

In summary, three effects are reported in this paper: self-bending, filamentation, and self-organized patterns in the range of 100–1000 mW of the laser beam. The symmetry of the wave front changes from circular to elliptical at a critical value of the incident power when the modulation instability takes place and the filamentation effect is evident. Self-bending effect was mainly noticed along the y-direction. In the range of 1000–2500 mW, the self-organized pattern appeared (repetitive filamentation continued but self-bending

FIG. 2. Second experimental setup to study the filamentation and pattern formation at different power levels.

FIG. 3. Central part of the image at different powers of laser (a) 650 mW, (b) 900 mW, (c) 1150 mW, (d) 1400 mW, (d) 2650 mW, and (e) complete image at 2650 mW.

FIG. 4. (Color online) Self-bending effect when the power is increased from (a) 200 mW at (b) 1000 mW, (c) x-direction, and (d) y-direction.
was now smaller due to the nonlinear interaction between the two Fabry–Pérot and the self-diffraction patterns. The fact that the number of spots depended nonlinearly on the power laser could be relevant to designing beam scanners, optical bistable devices, or optical power limiters.

The financial support by Consejo de Ciencia y Tecnología del Estado de Guanajuato (CONCyTEG) (Grant No. 07-16-K662-061 A07), Universidad de Guanajuato (UG, grants “Atrapamiento de Microorganismos por presión de radiación en líquidos nolineales” and “Materiales fotonicos basados en mezclas de cristal líquido contenidos en una base de silicio por técnica sol-gel,”), and SEP/PROMEP (Grant no. 103.5/08/3252) are gratefully acknowledged.


