Breakup of Ring Beams Carrying Orbital Angular Momentum in Sodium Vapor

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Laguerre-Gaussian beams \((LG_{m,p})\) have ring-shaped intensity pattern and an \(e^{im\phi}\) field dependence.

- Carry orbital angular momentum (OAM) of \(m\hbar\) per photon
Background

- Rings with $m \leq 2$ studied in different media experimentally
- Possible to stabilize high-power solitons ($m = 1, 2$) in competing cubic-quintic and quadratic medium [1, 2]
- In all nonlinear models, it’s believed that any $(2 + 1)$D solitons with $m \geq 3$ are unstable [3]
- Ring-shaped solitons are shown to suffer from strong azimuthal instability in saturable self-focusing media
- Break up into $2m$ filaments and drift away tangentially from the original ring [4]

Motivation

The objective for doing the experiment was two-fold:

- To study experimentally the azimuthal modulational instability suffered by ring beams which carry orbital angular momentum in a fully saturable medium (hot, dense sodium vapor).

- To study the stability of high-power Laguerre-Gaussian modes which carry orbital angular momentum in sodium vapor.
Experimental setup

- FWHM $\sim 15$ ns
- Conversion efficiency of the computer-generated hologram (CGH) into the first diffraction order $\sim 5\%$
- Beam diameter $\sim 50 \, \mu m$
- Typical number density $\sim 8 \times 10^{14} \, cm^{-3}$, effective interaction length $\sim 5$ cm
Numerical simulation

Propagation Equation

\[ \frac{\partial A(x, y, z)}{\partial z} = \frac{i}{2k} \nabla^2 A(x, y, z) + \left( -\alpha + ik\Delta n \right) A(x, y, z). \]

- Laser wavelength detuning \( \Delta \approx 40 - 47 \) GHz from the \( D_2 \) resonance line of sodium.
- The susceptibility \( \chi \) is given by

\[ \chi = -\frac{\alpha_0(0)c}{4\pi\omega_{ba}} \frac{\Delta T_2 - i}{1 + \Delta^2 T_2^2 + |E|^2/|E_s|^2} \]
$m = 1$ case

- Input beam $A_{1,0}$
- 40.6 GHz detuned to the blue side of $D_2$
- Input energy = 76 nJ (beam filaments at a relatively low energy due to large nonlinearity)
- Two spots over pulse energies: 65 – 710 nJ
- No intentional perturbation put on the beam experimentally
- 1.5\% random amplitude noise (numerical simulation)
\[ m = 2 \text{ case} \]

- Input beam \( A_{2,0} \)
- 46.7 GHz detuning, Input energy = 234 nJ
- Input beam breaks up into four filaments
- Result repeatable over pulse energies: 0.2 – 1.3 \( \mu \)J
- 1.5\% random amplitude noise
- Poor beam quality could lead to other than four spots
\( m = 3 \) case

- Input beam \( A_{3,0} \)
- 46.7 GHz detuned to the blue side (\( D_2 \) line)
- Input energy = 359 nJ
- Six spots over pulse energies: 0.35 – 2.5 \( \mu \)J
- 1.0% random amplitude noise
- Occasional five or seven spots seen due to misalignment of optics/light scattering off dust on optical surfaces
Higher power beam propagation

(a) $m = 1$, input energy = 9.1 $\mu$J

(b) $m = 2$, input energy = 24.1 $\mu$J

(c) $m = 3$, input energy = 6.63 $\mu$J

• Beam almost completely saturating the nonlinearity, and filamentation suppressed
Conclusion and future work

- Ring beams with orbital angular momentum $m\hbar$ tend to break up into $2m$ filaments
- $2m \pm 1$ filaments seen for imperfect input beam
- Numerical propagation of (randomly) perturbed Laguerre-Gaussian input beams through (Doppler broadened) two level atom gives good agreement with experimental results
- Stable beams observed at higher input power levels
  - Stability of vector solitons carrying equal but opposite OAM through sodium vapor [5]