Nonlinearly Induced Refractive Index Measurements by Using a Probe Beam.
Nonlinearly Induced Refractive Index Measurements by Using a Probe Beam

Ujitha Abeywickrema
Advisor: Dr. Partha Banerjee

Abstract
We investigate nonlinearly induced refractive index variation in different ways. Self phase modulation creates far-field diffraction rings which are observed by focusing a cw Ar-Ion laser on to a sample with thermal nonlinearity. Simultaneously, the sample is probed with a low power He-Ne laser, and shows two sets of diffraction rings in the far field. The experimental results are simulated by solving the steady state heat equation. Information about the induced refractive index change can be determined from the probe beam far field pattern. Additionally, an interferometric technique is set up to determine the induced refractive index change.

Introduction
Self phase modulation is a nonlinear effect that can be observed when a high power laser beam is focused on to a high-absorbing thermal medium. The refractive index of the medium changes due to the heat generated by the focused laser (pump) beam. The whole process causes the thermal medium to act as a lens which is usually called a thermal lens. This thermal lens can create the diffraction ring patterns when a laser propagates through it.

Objective
The objective of this project is to observe these ring patterns by another laser beam travelling through the material in the opposite direction and explain theoretically by using computer simulations.

Methodology

Experimental Setup

Integrating ring patterns are recorded on a normal digital camera as well as with a CCD camera from each side of the sample. It can be clearly seen that there are two sets of rings with the unfocused Helium Neon (red) laser beam. A filter that filters green color is also used to see the rings evolve from the probe beam. Ring patterns are observed in different powers of the Argon Ion laser.

Photographs of the tea sample (a) without a filter (b) with a filter (Filter is used to see the focused high power Argon Ion beam clearly.

Theory
Obtained ring patterns are simulated using MATLAB. Fresnel–Kirchhoff diffraction integral (1) and the Fraunhofer approximation of that integral (2) are used for the simulations.

\[
U(x, y) = \frac{e^{ikx}}{\lambda z} \int_{0}^{\infty} \int_{0}^{\infty} U(x', y') e^{i \frac{k}{2z} (x'^2 + y'^2)} e^{-\frac{2ix'x}{\lambda z}} e^{-\frac{2iy'y}{\lambda z}} dx' dy' \tag{1}
\]

\[
U(x, y) = \frac{e^{ikx}}{\lambda z} \int_{0}^{\infty} \int_{0}^{\infty} U(x', y') e^{-\frac{i2k}{\lambda z} (x'^2 + y'^2)} dx' dy' \tag{2}
\]

Heat equation (steady state) is solved to obtain the temperature profile inside the nonlinear sample. (at the boundary \( r = a, dT = 0 \))

\[ \nabla \cdot T(r) = -\alpha \nabla T \]

\[ dT = \frac{\alpha w^2}{8} \left[ Ei \left( -\frac{2r^2}{w^2} \right) - Ei \left( -\frac{2a^2}{w^2} \right) - 2 \ln \left( \frac{r}{a} \right) \right] \]

\[ \Delta n = n(r) - n_0 = \frac{dn}{dT} \Delta T(r) \]

Results
Ring patterns obtained for different pump powers

Temperature profile (from the heat equation)

Simulated self phase modulation ring patterns

Future Work

Simulate the ring patterns observed from the probe beam.

Find the refractive index change using interferometric technique.

Use this method to check the purity of Nonlinear samples.

References