Xenon-based Nonlinear Fabry-Perot Interferometer for Quantum Information Applications

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Abstract: We describe a nonlinear Fabry-Perot interferometer useful for optical quantum information applications. We observe self-phase modulation and other nonlinear effects with ultra-low input powers using metastable xenon in a high-finesse cavity.

OCIS codes: (270.5565), Quantum communications; (230.4320) Nonlinear optical devices.

1. Introduction

Single-photon-level optical nonlinearities and nonlinear phase shifts have important applications in quantum communication and quantum computing [1-2]. Early experiments toward achieving this kind of nonlinearity involved confining a single atom or cloud of atoms within the mode volume of a high-finesse cavity [3]. Such systems however are difficult to implement.

There is also potential for achieving single-photon-level cross-phase modulation in room temperature atomic vapor, as has recently been demonstrated using rubidium in the hollow core of a photonic bandgap fiber [4]. Use of a cavity in such a situation though would be advantageous [5]. Much work has been done investigating nonlinear, vapor-filled Fabry-Perot's for low-power nonlinear optics, but the use of alkali atoms for the intracavity medium so far has limited the attainable cavity finesse [6].

We present a new design for a highly nonlinear Fabry-Perot useful for quantum information applications, using metastable xenon within a high-finesse cavity. Metastable xenon has optical properties similar to those of rubidium, but it does not degrade the sensitive cavity mirrors. The design of this system and some of its advantages have previously been discussed in a measurement of absorption saturation at nanowatt power levels [7]. Here we show evidence of the strong nonlinearity in an observation of self-phase modulation with an input power of a few tens of nanowatts [8]. These results point towards the usefulness of this system for applications in quantum communication and quantum computation.

2. Metastable Xe in an optical cavity

The core innovation in this system consists in the use of xenon gas as the nonlinear medium. Xenon atoms can be excited into the metastable $6s[3/2]_2$ state using an RF discharge. This state has a lifetime of about 43 s and can be used as an effective ground state for experiments in nonlinear optics [9]. From the metastable state a further pair of transitions is available from $6s[3/2]_2$ to $6p[3/2]_2$ at 823 nm, and from $6p[3/2]_2$ to $8s[3/2]_2$ at 853 nm. This ladder-type configuration may be useful for generating single-photon cross-phase shifts [10], though the present experiment concerns only the $6s[3/2]_2$ to $6p[3/2]_2$ transition.

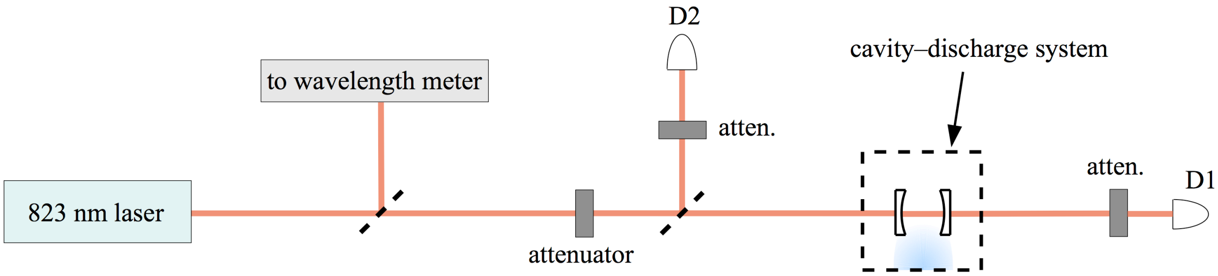

Figure 1: Experiment layout for observation of nonlinear self-phase modulation in the high-finesse cavity.

3. Experiment layout

Figure 1 shows the experiment layout. The cavity was made of a pair of super-polished dielectric mirrors in a confocal configuration with a linewidth of about 1.5 MHz. The mirrors were housed in a solid nickel block within a vacuum chamber which was filled with 1 Torr of naturally occurring xenon gas. A resonant circuit of wire coils and capacitors was used to generate a glow discharge and to excite xenon atoms into the metastable state.

A frequency-tunable diode laser was used to probe the cavity resonances. Two low-light-level photoreceivers monitored the beam intensity both before and after passing through the cavity. The beam power was adjusted manually and a Labview routine running from a computer controlled the laser frequency and governed the data collection.

The cavity transmission frequency was adjusted to the desired detuning relative to the xenon atomic transition. The laser frequency was then swept across the cavity transmission peak and the shape of the peak was recorded. The frequency sweep was repeated for various values of the input power and detuning.

4. Self-phase modulation results

Figure 2 shows the results from three frequency scans over the cavity transmission peak with different detunings and input power levels. For low power levels below about 50 nW the cavity produced a symmetric, Airy function line shape similar to that of the empty cavity. When the power was increased, nonlinear self-phase modulation caused the cavity line to become asymmetric. Noticeable asymmetry was observable with input power levels above about 50 nW. The effect became more pronounced with increasing input power.

Self-phase modulation at these low input power levels indicates the strength of the nonlinearity achievable with this system, which would not have been possible in a similar setup using rubidium or other alkali vapors. These results suggest that the system will be useful as a simple and practical Kerr medium for weak-nonlinearity-based quantum computing and quantum communication. This work was funded by DARPA grant W31P4Q-12-1-0015.

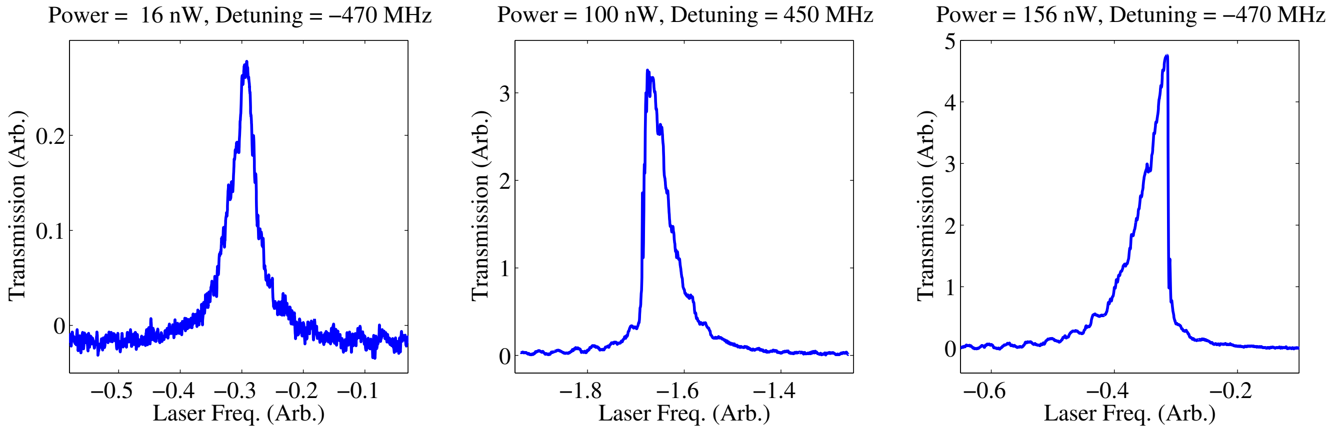

Figure 2: Cavity transmission as a function of the laser frequency sweep for several values of the detuning and of the optical input power. The transmission line shape became asymmetric with input power levels above about 50 nW, demonstrating nonlinear self-phase modulation inside the cavity.

4. References

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