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Observation of Low-Contrast All-Optical Switching in Si_3N_4 Microdisks Based on the Zeno Effect

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Abstract: Low-contrast all-optical Zeno switching has been demonstrated in a Silicon Nitride microdisk resonator surrounded by hot Rubidium vapor. The device is based on the suppression of cavity power buildup due to non-degenerate two-photon absorption.

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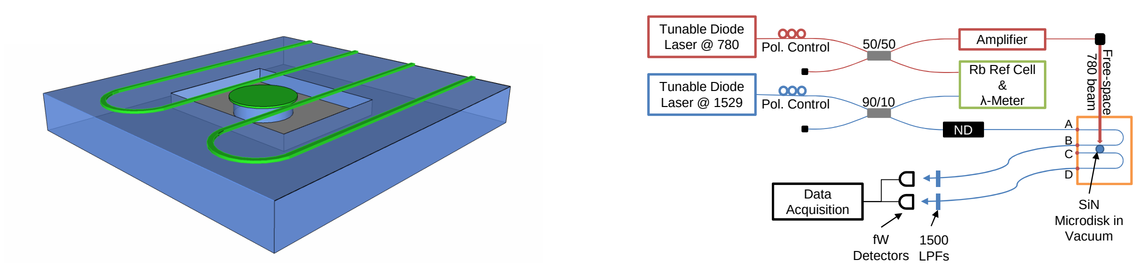
1. Introduction

The quantum Zeno effect (QZE) prevents a randomly occurring process with frequent measurements [1]. It has previously been shown [2] that this effect could be used to suppress errors in quantum logic gates using strong two-photon absorption (TPA). Recently, this work was extended to show that the QZE has a classical analog that could be used to create a low-loss all-optical switch [3] capable of operating at low powers.

Whereas the QZE prevents the buildup of a probability amplitude, the classical Zeno effect as implemented here suppresses the buildup of the electric field amplitude within a resonator. To see how this can be used to create a switch, consider a system in which a resonator is strongly coupled to a two-photon absorbing medium such that two distinct frequencies are required for absorption to take place. With the resonator critically coupled to two waveguides, the presence of an input at either of the two frequencies will result in the light coupling into the resonator and leaving the opposite waveguide. This is due to the interference between the light remaining in the waveguide and the built-up field amplitude in the cavity that couples back to the waveguide. When both frequencies are present in the resonator the TPA prevents the field buildup and the input beams pass by the resonator because there is now insufficient energy in the cavity to result in interference.

Here we present experimental progress towards a classical Zeno switch consisting of a Si_3N_4 microdisk embedded in hot Rubidium (Rb) vapor based on TPA. These results suggest that a similar scheme with both beams resonant in the cavity would correspond to input power levels below 200 nW.



(a) (b)

Fig. 1. (a) An illustration of the Si_3N_4 microdisks used in these experiments. (b) Optical diagram for the experiments described in the text.

To demonstrate Zeno switching, we used a Si_3N_4 microdisk with a diameter of 26 μm and a thickness of 250 nm. The resonators contain no cladding material, allowing the evanescent field to extend outside the device and overlap considerably with the atomic media. Each microdisk was critically coupled to two waveguides in an add-drop configuration, and then coupled to four single-mode fibers using a V-groove chip with the same spacing. A conceptual drawing of the waveguide-coupled microdisk is shown in Figure 1(a).

2. Experiment

The setup used in this experiment is shown in Figure 1(b). Two frequency-stabilized external-cavity diode lasers were used, one at 780 nm and one at 1529 nm. Both of these beams passed through fiber splitters and into a reference cell as well as a vacuum system containing a microdisk. The reference cell contained a rubidium ampule (^{87}Rb and ^{85}Rb) with counter-propagating focused beams as well as a wavelength meter. The 780 nm beam passed through a low-noise tapered amplifier and then entered the vacuum system through a view-port where it was focused onto the microdisk. The 1529 nm beam remained in fiber and was coupled to the resonator via on-chip waveguides. The 1529 nm through- and drop-ports were measured using femtowatt detectors after passing through 1500 nm long-pass filters.

Our non-degenerate TPA scheme is slightly detuned ($\sim$ 5 GHz) from the intermediate state of the $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 4D_{3/2}$ transition which consists of the well-known D_2 line near 780 nm followed by a transition near 1529 nm. The control signal (near the 780 nm transition) was excited using a focused free-space beam.

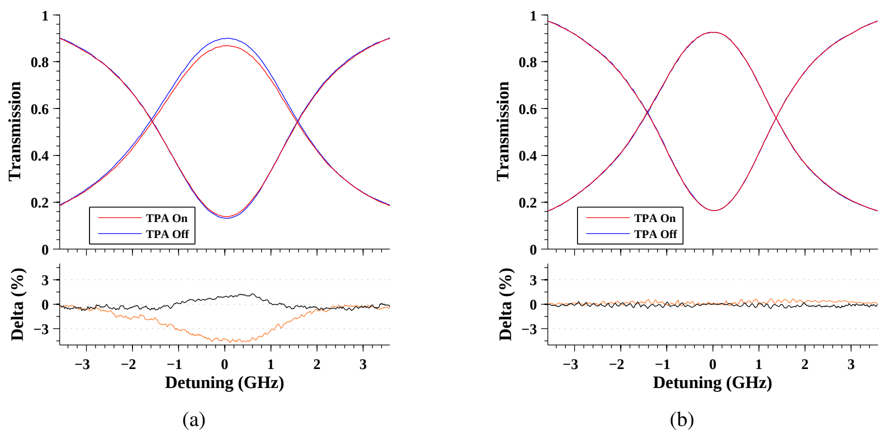


Fig. 2. (a) Switching data: The upper plot shows cavity transmission with the conditions for TPA satisfied in red and a control in blue. (b) A control showing no change without Rb.

An example of Zeno switching is shown in Figure 2(a) where the frequency of the 1529 nm was scanned by an equal and opposite amount as the 780 nm laser to maintain two-photon resonance. Approximately 100 trials were averaged for each condition. The blue lines in the upper plot show the cavity drop-port (peak) and through-port (dip) with the 780 nm laser detuned so that the conditions for TPA were not satisfied. The red lines in the upper plot show the cavity response in the presence of TPA. The difference in these two situations is highlighted in the lower plot which shows that the effect of the TPA is to increase the transmission of the through-port and decrease the transmission of the drop-port, consistent with a low-contrast switching process. Figure 2(b) shows a control case using similar data collection methods as Figure 2(a) but without Rb density. Other controls were also performed to verify the change in the signals was indeed due to atomic absorption.

These results represent progress towards an all-optical switch based on TPA and the Zeno effect. Using estimates based on the power of the free-space beam, all-optical switching in the low nanowatt range seems attainable. Although the switching contrast is currently low, we believe the switching performance can be improved by addressing challenges related to device physics.

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