A Parametric Down-Conversion Source for Two-Photon Absorption Experiments

T. B. Pittman, S.M. Hendrickson, and J. D. Franson
Department of Physics
University of Maryland, Baltimore County
Baltimore, MD 21250 USA
todd.pittman@umbc.edu

Abstract: We describe a Parametric Down-Conversion source based on a low-power (< 1mW), narrowband (<1 MHz) fiber-coupled pump laser. The source is designed for two-photon absorption experiments related to quantum Zeno gates.

OCIS codes: (270-0270) Quantum Optics; (999-9999) Quantum Information

1. Introduction

The failure mechanisms in most base-level Linear Optics Quantum Computing (LOQC) gates can be overcome by using the quantum Zeno effect to suppress the probability of two photons exiting a device in a single mode [1]. One method to implement these "Zeno gates" involves the use of strong two-photon absorption at single-photon intensity levels. Although the large two-photon absorption cross-sections that would be required are difficult to achieve in conventional systems, it is well known that these cross-sections can be enhanced by reducing the mode-volume associated with the photons [2], and exploiting any frequency entanglement of the photon-pairs to be absorbed [3-7].

In this work, we describe the development of a fiber-coupled Parametric Down-Conversion (PDC) source for use in two-photon absorption experiments in several mode-reducing devices placed inside Rubidium vapor [8]. The key feature is an attempt to maximize the frequency entanglement of the photon pairs by using an extremely narrowband pump laser. The pump beam is delivered to a bulk PDC crystal through a single-mode fiber, which facilitates alignment of the photon pair-collection system, and locking the pump frequency to the relevant two-photon transition in Rubidium.

2. The need for a narrowband pump laser

As shown by the experiments of Dayan et.al [6], the energy-time entanglement inherent in the PDC process can greatly enhance two-photon absorption rates. Roughly speaking, this is due to the fact that the two photons can arrive at an atom at the same time (eg. they are "broadband wavepackets"), but the sum of their energies equals that of the pump laser, which can be tuned to match the relevant two-photon atomic transition frequency. Figure 1 illustrates the need for a narrowband pump laser in order to

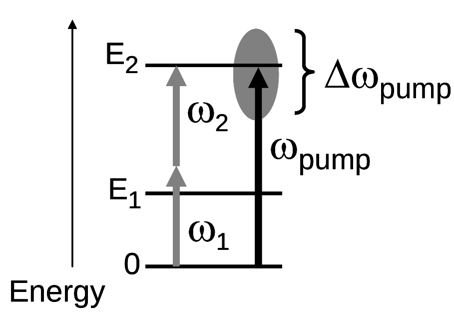

Figure 1. Energy level diagram illustrating the need for a narrowband pump laser for the PDC source. The sum of the PDC photons' frequencies equals that of the pump laser, which is tuned to match the two-photon transition frequency. If the bandwidth of the pump laser Δωp is much wider than the linewidth of the two-photon transition, the two-photon absorption probability will be reduced.

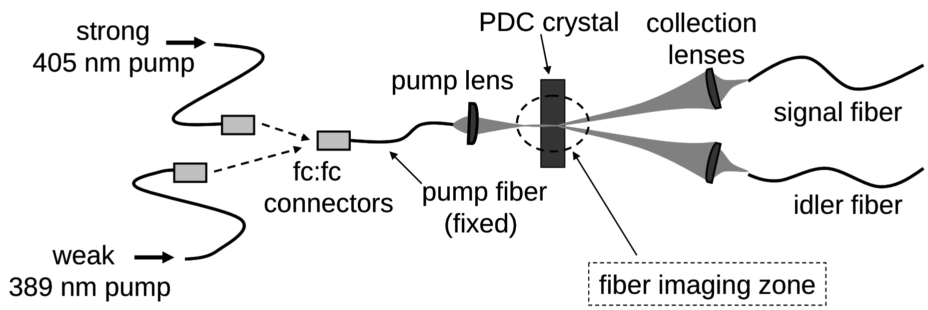

Figure 2. Fiber-coupled pumps for Parametric Down-Conversion (PDC). A relatively strong pump laser at 405 nm is used to align the type-I PDC system. Once the fiber imaging zone is optimized for entangled photon-pair collection, the 405 nm pump is removed and the weak 389 nm pump is coupled into the system.

realize the large two-photon absorption cross sections needed for Zeno gate experiments. The focus of the present work is essentially to realize a situation analogous to Figure 1 by using a very narrowband pump laser in the PDC process. The goal is to achieve a situation in which each PDC pair has a substantial probability of being absorbed, which would lead to an observable reduction in the coincidence-counting rate between single-photon detectors. In our experiments, we utilize photon pairs at 778 nm to work with the strong $5S_{1/2}$ to $5D_{5/2}$ two-photon transition in Rubidium. The mode-volumes associated with the entangled photons are reduced by using sub-micron diameter tapered optical fibers and holey-fiber microcavities [9].

3. Fiber coupled pump lasers for PDC

We are currently experimenting with two-different narrowband pump lasers: a low-power tunable external cavity diode laser at 389 nm, and the frequency doubled output of a higher-power tunable CW diode laser at 778 nm. In both cases, the pumping power is very low (typically < 1 mW), which makes alignment of the fiber coupled type-I PDC source difficult. We therefore utilize the fiber-coupled pump scheme shown in Figure 2. The basic idea is to pre-align the fiber-imaging system with a broadband (but strong) diode laser pump at 405 nm. The narrowband (but weak) 389 nm laser is then sent in, and photon pairs are found by applying a known phase-matching tweak (crystal tilt) to account for the different pump wavelengths. The 389 nm pump is then tuned to the correct frequency by locking it to a strong ("classical") Doppler-free two-photon signal generated in an auxiliary Rubidium vapor cell [10].

4. References

[1] J.D. Franson, B.C. Jacobs, and T.B. Pittman Phys. Rev. A. **70**, 062302 (2004).

[2] Y.R. Shen, *The principles of nonlinear optics*, Wiley Interscience USA (1984).

[3] J. Gea-banacloche, Phys. Rev. Lett **62**, 1603 (1989).

[4] N. Ph. Georgiades, E.S. Polzik, K. Edamatsu, and H.J. Kimble, Phys. Rev. Lett. **75**, 3426 (1995).

[5] H.B. Fei, B.M. Jost, S. Popescu, B.E.A. Saleh, and M.C. Teich , Phys. Rev. Lett. **78**, 1680 (1997).

[6] B. Dayan, A. Pe'er, A.A. Friesem, and Y. Silberberg, Phys. Rev. Lett **93**, 023005 (2004); *ibid*. **94**, 043602 (2005).

[7] Dong-Ik Lee and T. Goodson III, J. of Phys. Chem. B **110**(51), 25582-25585 (2006)

[8] T.B. Pittman, Proceedings of "Quantum Communications and Quantum Imaging V", SPIE **6710**, 67100B (2007).

[9] S.M Hendrickson, T.B. Pittman, and J.D. Franson, IEEE J. Lightwave Tech. **25**, 3068 (2007).

[10] R.E. Ryan, L.A. Westling, and H.J. Metcalf, J. Opt. **B** 10, 1643 (1993).