Cw diode 레이저 기반 자발매개하향변환과정 광자의 결맞음 특성 측정

Coherence properties of spontaneous parametric down-conversion pumped by a multi-mode cw diode laser

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Entangled states of photons play essential roles in photon-based quantum technologies, such as, photonic quantum information, quantum information, quantum communication, quantum cryptography, quantum metrology, etc. Among currently available schemes for generating entangled states of two photons experimentally, by far, spontaneous parametric down-conversion (SPDC) offers the most versatile and efficient method of generating entangled two-photon states. In SPDC process, a higher energy pump photon is spontaneously split into a pair of lower energy photons due to $\chi^{(2)}$ nonlinear interactions in a crystal.

With regard to the pumping conditions, in particular, there exist numerous studies on the properties of SPDC photons generated with the monochromatic pump laser and the ultrafast broadband (mode-locked) pump laser. The studies on interference properties of SPDC photons generated with the multi-mode cw pump laser, however, are lacking. To the best of our knowledge, Ref. (1) is the only paper, to date, that reports an interferometric effect due to multi-mode cw pumped SPDC. Due to the long cavity length and relatively narrow bandwidth of the mainframe ion lasers, it is actually difficult to observe a uniquely multi-mode effect in the biphoton interference[(1)]. With the development of inexpensive high-power blue diode lasers (easily providing over 100mW at 405nm) in the recent years, however, the multi-mode cw laser pumped SPDC is expected to become an important entangled photon source in photonic quantum information experiments.

Here, we report experimental and theoretical studies on the coherence properties of SPDC photon pairs generated with a multi-mode cw laser as the pump[(2)]. By using a Mach-Zehnder interferometer with the SPDC photon pairs at the input ports, both the Hong-Ou-Mandel interference and the photonic de Broglie wave interference have been studied. Theoretical analysis of the biphoton interference is also done by considering the multi-mode nature of the pump laser.

Experimental scheme is shown in **Fig. 1**. The SPDC pair photons are sent to the different input ports, a and b, of the interferometer and the relative input time delay $t_1=x_1/c$ is adjusted by axially moving one output collimator of the single-mode fiber. Path difference in the interferometer x_2 is obtained by changing the length of one arm, and the coincidence count in the two-photon detector is measured as functions of x_1 and x_2.

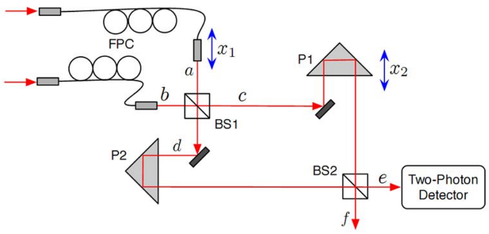

Fig. 1. Experimental scheme. FPC is a fiber polarization controller and P is a trombone prism. BS is 50:50 a beam splitter. Note that x_1 and x_2 should be understood as path length differences.

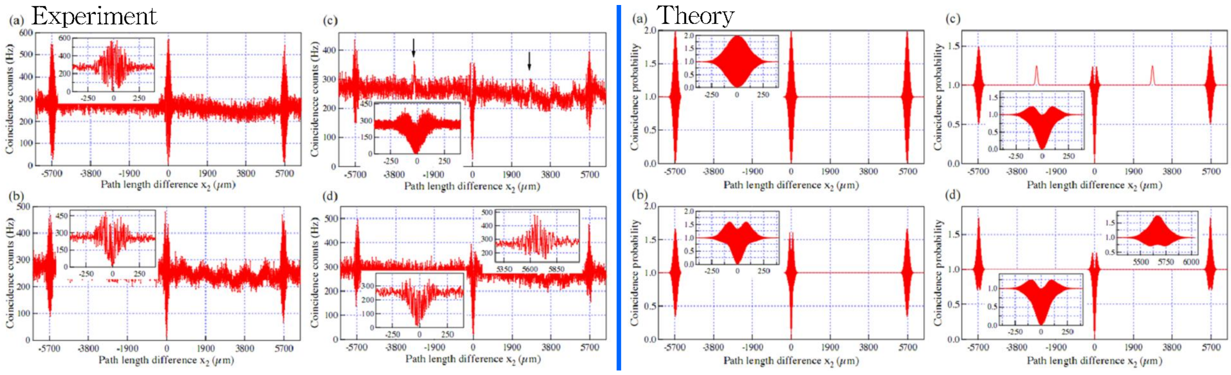

Fig. 2. The biphoton de Broglie wave packet measurement with different x_1 values (Left : Experiment, Right : Theory). (a) x_1=0 μm, (b) x_1=73 μm, (c) x_1=2834 μm, (d) x_1=5668 μm.

The biphoton interference reported in **Fig. 2(a)** (Left) exhibits a number of interesting features. First, biphoton wave packets are observed to be periodically recurring at $x_2=L_p$, where L_p is the pump coherence recurring period. Second, the shapes of the individual wave packets are nearly identical to the pump wave packet. Third, the interference fringes exhibit the maximum visibility of 98% and the period of oscillation is λ/N (N=2), which is a signature of the biphoton NOON state.

Let us examine the biphoton de Broglie wave interference when the relative input delay is non-zero, $x_1 \neq$ which are in **Fig. 2(b)**, **Fig. 2(c)**, and **Fig. 2(d)** (Left). We also note a couple of interesting features in the data sets. First, the periodic recurrence of biphoton interference is still observed, regardless of the input delay. Second, the shapes of the central wave packets (near x2=0) become asymmetrical (with respect to the random coincidence rate). The side peaks (recurring biphoton wave packets) also become asymmetrical but in the opposite sense, see **Fig. 2(d)**. Third, the visibilities of the central wave packets, interestingly, remain the same as that of **Fig. 2(a)**. The side-peaks, however, start to lose visibilities. It is also interesting to note that two small peaks (without modulations) appear where $x_2=\pm x_1$, marked with arrows in **Fig. 2(c)**.

The experimental results are analyzed theoretically by assuming that the pump photon is consisting of multiple incoherent longitudinal modes with the modes weighted by Gaussian function. We then calculate the count rate of the SPDC photons at the two photon detector. The resulting plots are in **Fig. 2** (Right) which give very precise agreements with the experiments.

1. A. V. Burlakov, M. V. Chekhova, O. A. Karabutova, and S. P Kulik, Phys.Rev.A **63**, 053801(2001)
2. O. Kwon, Y.-S. Ra, and Y. -H. Kim, Opt. Express **17** 13059(2009)