Temporal-Mode-Selective Upconversion Single-Photon Detector with Femtosecond Time Resolution

Naoto Namekata[1] and Shuichiro Inoue[1]

[1]1-8-14 Kanda-Surugadai, Chiyoda-ku, Tokyo, 101-8308, Japan

Frequency-upconversion single-photon detectors (UCSPDs) have been considered promising candidates for single-photon detection at near-infrared (NIR) wavelengths, offering high photon-detection efficiency and low noise counts without cryogenic operation [1]. Here, we report on a UCSPD with a time resolution of 340 fs using a commercial periodically poled $LiNbO_3$ waveguide (PPLN-wg). The very high time resolution, which results from the temporal-mode-selective upconversion process [2], is beneficial for optical deep tomography [3] and ultra-high-speed quantum communications.

Figure 1 shows a schematic diagram of the UCSPD with temporal-mode selectivity. The frequency upconverter for signal photons at 1530 nm is based on a 10-mm-long PPLN-wg pumped at 1570 nm. The signal and pump pulses are extracted from the same femtosecond optical pulse using wavelength filters. Therefore, the pulses are naturally synchronized. By compensating dispersion using optical fibers and a pulse shaper based on a spatial light modulator (SLM), the temporal widths of these optical pulses are compressed to as short as 200 fs (Lorentzian temporal shape). The pump wavelength is only 40 nm away from the signal wavelength, which results in a group delay between the signal and pump pulses of ~30 fs over the PPLN-wg. The nonzero but small dispersion satisfies the condition for temporal-mode-selective upconversion [2,3].

Figure 2 shows the upconversion efficiency of our system as a function of time delay between the signal and pump pulses with an average pump power of 3.5 mW. The temporal resolution of 340 fs and the maximum upconversion efficiency of 57% was obtained. The experimental value did not reach the theoretical value of 80%. This discrepancy might be attributed to imperfect temporal-mode matching between the signal and pump pulses in the experiment. The system efficiency (photon-detection efficiency at 1530 nm) of the UCSPD is expected to reach 10–20% with a noise count rate of less than 10 kHz. The figure of merit of the temporal-mode-selective UCSPD would be improved by 15 dB compared with that of the previously reported system [3].

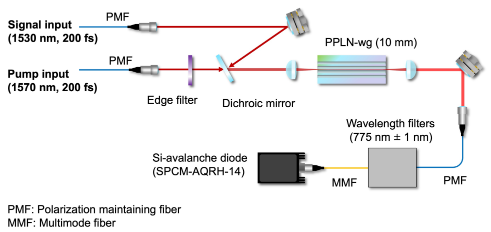

Fig. 1: *Experimental setup.*

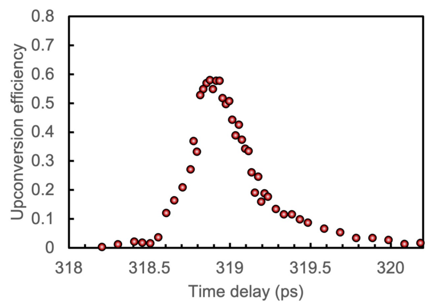

Fig. 2: *Upconversion efficiency as a function of time delay.*

References

[1] J. S. Pelc, L. Ma, C. R. Phillips, Q. Zhang, C. Langrock, O. Slattery, X. Tang, and M. M. Fejer, Opt. Express **19**, 21445 (2011).

[2] A. Shahverdi, Y. M. Sua, L. Tumeh, and Y.-P. Huang, Sci. Rep. **7**, 6495. (2017).

[3] N. Namekata, N. Kobayashi, K. Nomura, T. Sako, N. Takata, and S. Inoue, Sci. Rep. **13**, 21080 (2023).