

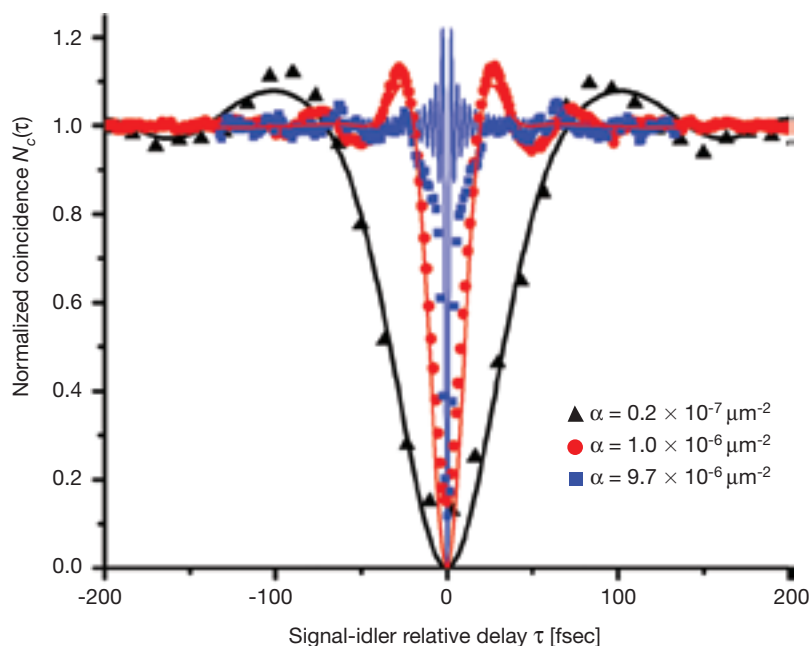
# Generating Ultra-Broadband Biphotons via Chirped QPM Down-conversion

Malvin C. Teich, Magued B. Nasr, Silvia Carrasco, Bahaa E.A. Saleh, Alexander V. Sergienko, Juan P. Torres, Lluís Torner, David S. Hum, Martin M. Fejer

An important research goal in quantum optics is the design and implementation of new sources of quantum light, such as entangled photons (biphotons) with tunable spectral properties that match the specific application under consideration. The optimum biphoton bandwidth can stretch from ultra-narrow (on the order of MHz) for certain atom-photon interactions to ultra-broad for applications such as high-axial-resolution quantum optical coherence tomography (QOCT).<sup>1</sup>

The most widely used method for generating biphotons is through spontaneous parametric down-conversion (SPDC), in which two lower-frequency photons are generated when a strong pump field interacts in a nonlinear crystal. One way of generating ultra-broadband biphotons is to make use of a quasi-phase matched (QPM) nonlinear grating with a nonuniform poling period.<sup>2</sup> The poling pattern  $\Lambda(z)$ , where  $z$  is the spatial coordinate along the direction of pump propagation, provides a collection of phase-matching conditions over the length of the grating, which leads to broadband biphoton generation; at the same time, the poling pattern can be chosen to engender a special phase relation among the various spectral components, thereby allowing the biphoton wavepacket to be compressed using the techniques of ultrafast optics.

An international collaboration, comprising groups at the Quantum Imaging Lab at Boston University, the Institute of Photonic Sciences in Barcelona and the Ginzton Lab at Stanford University, used a continuous-wave laser pump, together with an appropriately designed linearly chirped periodically poled stoichiometric lithium tantalate grating,



Normalized HOM coincidence interferograms (dips) for various degrees of linear chirp, indicated by the chirp parameter  $\alpha$ . Symbols represent measured data points, whereas solid curves are numerical simulations.

to generate biphotons with the largest bandwidth ever observed, about 300 nm.<sup>3</sup> It is fitting that, on the 20<sup>th</sup> anniversary of the development of the Hong-Ou-Mandel (HOM) interferometer,<sup>4</sup> these biphotons were used to observe the narrowest HOM dip measured to date, with a FWHM of 7.1 fs, (see figure) corresponding to an axial resolution of 1.1  $\mu\text{m}$  in QOCT.

The generation of such ultra-broadband nonclassical light opens the door to the production of a high flux of nonoverlapping biphotons with optical powers of the order of  $\mu\text{W}$ —which is essential for implementing applications such as entangled-photon microscopy,<sup>5</sup> spectroscopy<sup>6</sup> and photoemission.<sup>7</sup>  $\blacktriangle$

M.C. Teich (teich@bu.edu), M.B. Nasr, B.E.A. Saleh and A.V. Sergienko are with Boston University's

Quantum Imaging Lab in Boston, Mass., U.S.A. S. Carrasco, J.P. Torres and L. Torner are with ICFO—The Institute of Photonic Sciences in Barcelona, Spain. D.C. Hum and M.M. Fejer are with the Ginzton Lab at Stanford University in Stanford, Calif., U.S.A.

## References

1. M.B. Nasr et al. "Dispersion-Cancelled and Dispersion-Sensitive Quantum Optical Coherence Tomography," *Opt. Express* **12**, 1353-62 (2004).
2. S. Carrasco et al. "Enhancing the Axial Resolution of Quantum Optical Coherence Tomography by Chirped Quasi-Phase-Matching," *Opt. Lett.* **29**, 2429-31 (2004).
3. M.B. Nasr et al. "Ultrabroadband Biphotons Generated via Chirped Quasi-Phase-Matched Optical Parametric Down-Conversion," *Phys. Rev. Lett.* **100**, 183601 (2008).
4. C.K. Hong et al. "Measurement of Subpicosecond Time Intervals between Two Photons by Interference," *Phys. Rev. Lett.* **59**, 2044-6 (1987).
5. M.C. Teich and B.E.A. Saleh. *Cesk. Cas. Fys.* **47**, 3-8 (1997) [translation: "Entangled-Photon Microscopy," <http://people.bu.edu/teich/pdfs/Cesk-English-47-3-1997.pdf>]; U.S. Patent No. 5,796,477 (1998).
6. B.E.A. Saleh et al. "Entangled-Photon Virtual-State Spectroscopy," *Phys. Rev. Lett.* **80**, 3483-6 (1998).
7. F. Lissandrini et al. "Quantum Theory of Entangled-Photon Photoemission," *Phys. Rev. B* **69**, 165317 (2004).