Direct beam diagnostics in spontaneous parametric down conversion photon pair sources

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Application Note

1. Introduction

Modern experimental quantum optics relies heavily on sources of well-controlled non-classical radiation, which enable performing both experimental tests of the fundamental laws of physical reality, as well as practical implementations of quantum enhanced technologies, such as quantum communication and metrology. Despite the recent progress in design of sources based on single atoms or solid state approaches, methods provided by nonlinear optics are still prevalent. Among them, spontaneous parametric down conversion (SPDC) is arguably the best-known workhorse of the whole quantum optics field. By harnessing this process we are able to generate the non-classical states of light with exceptionally suitable temporal, spectral and spatial properties. This is realized through the appropriate selection of pump field parameters along with engineering the phase matching condition in the nonlinear optical medium [1]. Appropriate diagnostic tools are essential in achieving the desired operation of an SPDC source, however characterizing the spatial features of emitted radiation presents itself with challenges, due to its very low intensity. The techniques typically used for direct detection of the SPDC photons spatial profile rely on troublesome transverse scanning of single-pixel single photon counting detectors, which makes real time alignment of the optical setup virtually impossible. A low-noise camera with close to single photon sensitivity resolves this problem and thus can serve as a significant aid in everyday work with SPDC radiation sources.

Here we demonstrate several examples of employing the EMCCD camera (Andor Luca-r DL-604M) as a compact tool for alignment and routine diagnostics in a quantum optical laboratory operating in the visible and near-infrared spectral range.

2. Direct measurement of phase matching condition in a bulk nonlinear crystal

We used the EMCCD camera to directly measure the phase matching properties of a beta-barium borate (BBO) nonlinear crystal used in type-I SPDC source of correlated photon pairs [2]. The crystal was pumped by a 400 nm beam from a diode laser slightly focused to a 110 μm FWHM spot size. Birefringent phase matching for the chosen pump wavelength was fulfilled by choosing the appropriate cut angle of the crystal. Wave vectors of down-converted photons form a well-known conic surface with its symmetry axis along the pump direction. To detect the spatial distribution of the SPDC radiation the EMCCD camera was placed in the focal plane of a Fourier-transform lens (f = 35 mm). Each direction of the wave vector, after propagation through the lens, corresponds to a point in the focal plane. This results in a ring detected on the EMCCD detector, as shown in Fig. 1. Direct measurement of the ring radius allowed us to easily find the exact locations of optical elements used to collect correlated photons present in the SPDC cone. Additionally, since the radius of the ring for a given wavelength of detected photons is determined by the phase matching in the BBO crystal and the Fourier-transform lens focal length, this is a straightforward method to directly evaluate the orientation of the crystal optical axis.

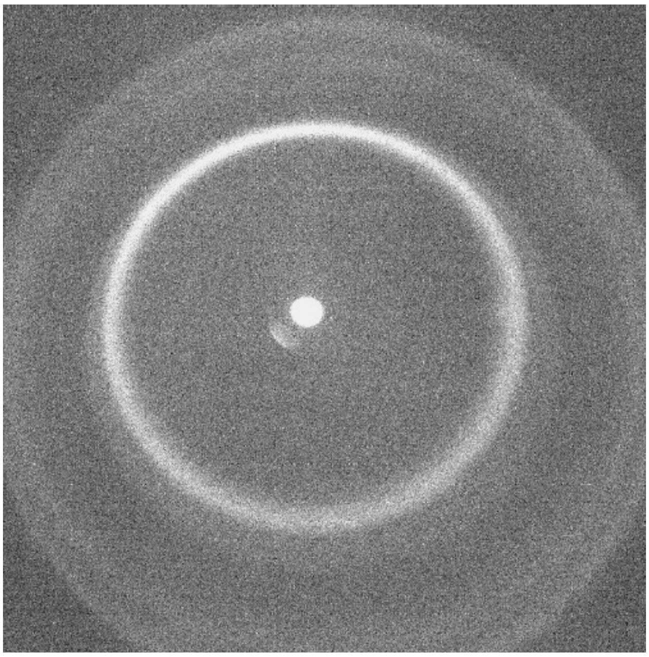

Fig. 1 Direct observation of SPDC ring from a BBO crystal with type-I phase matching. Raw EMCCD image with EM gain on. White spot in the centre is caused by fluorescence photons generated along the direction of pump propagation.

3. SPDC in a nonlinear waveguide

Spatial mode structure of photons generated in bulk nonlinear crystal is in general highly complicated. This causes the need to apply heavy spatial filtering in order to observe non-classical effects in radiation generated from such sources. For this reason significant effort has been recently put in utilizing waveguiding structures, where spatial distribution of light is limited to the finite set of well-defined transverse modes supported by the structure. Here we present images of SPDC light generated in a few-mode periodically poled potassium titanyl phosphate (PPKTP) waveguide [3, 4] by imaging the rear facet of the waveguide sample onto the EMCCD camera using a 50x microscope objective. For that purpose we used a narrowband pump laser at the wavelength of 400 nm to selectively excite the fundamental transverse mode of the waveguide by direct coupling. Then we applied appropriate spectral filtering (of 0.6 nm FWHM bandwidth) in order to obtain SPDC radiation in the fundamental spatial mode of the waveguide structure [3, 4]. Whereas the properties of the radiation generated by this source are eventually measured using nanosecond timescale coincident detection of correlated photon pairs, valuable initial information on the spatial structure of the output light can be gained from direct detection using an EMCCD camera with long integration times. In Fig. 2 we show an exemplary transverse profile of the generated SPDC radiation. The asymmetry of the profile is the reflection of the asymmetric geometry of the ion-indiffused waveguiding structure. Additionally we demonstrate the impact of the EM gain on the signal contrast, shown in Fig. 2 as well.

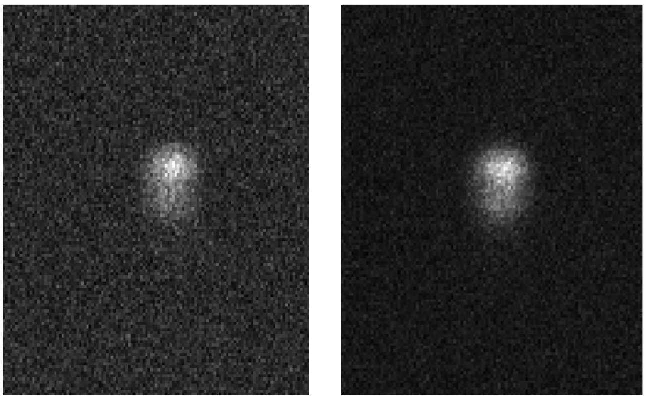

Fig. 2 Spatial structure of SPDC light obtained from the PPKTP waveguide. Raw image obtained without EM gain (left) and with EM gain (right).

4. Beam profile measurements

When working with single photon sources, estimation of the beam shape using single-pixel detectors requires inconvenient and time-consuming procedures (e.g. the knife-edge method). By exploiting an EMCCD camera one can trace full spatial profile of the beam even at the very low intensity levels. Here we apply the EMCCD camera to investigate the longitudinal beam profile of SPDC light coming from a bulk PPKTP crystal SPDC source [5]. To estimate the beam quality we used a 400 mm focal length lens to form a well-defined focus and subsequently registered the transverse light profile at several points before and after the focus with the EMCCD camera. As shown in Fig. 3, the transverse shape of the beam undergoes significant changes along the propagation. This is caused by the presence of undesired astigmatism in the optical setup. With EMCCD camera the correction of possible beam shape problems can be efficiently performed, as the SPDC light can be constantly monitored during the alignment of the optical setup. Additionally, by extending the range of measurement points in the longitudinal direction a measurement of the M2 beam quality parameter can be easily accomplished. The use of EM gain especially facilitates acquisition of the signal in the far field, where its intensity is significantly decreased.

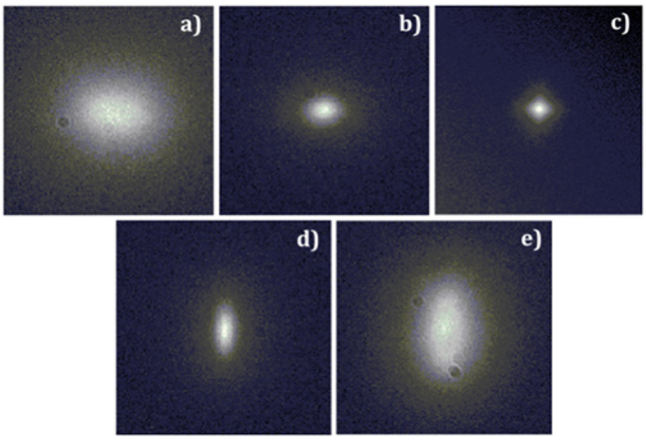

Fig. 3 Directly measured SPDC beam profiles from a bulk PPKTP crystal source at longitudinal positions of (a-e) -100, -50, 0, 50, 100 mm with respect to the beam focus.

5. Summary

We presented several examples of utilizing the Andor Luca EMCCD camera as a diagnostic and alignment tool in optical setups involving spontaneous parametric down-conversion photon pair sources. High sensitivity of the camera combined with its small footprint and ease of operation make it a well-suited tool for such applications, by enabling direct spatial profile measurements of low intensity near-infrared optical fields to be performed with minimal alterations to the optical setup.

References

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