Single-photon states with an orbital angular momentum via SPDC process for quantum hash algorithms

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Currently, much attention is paid to the study and use of light beams with orbital angular momentum (OAM). Beams with an azimuthal phase dependence $exp(i\ell\varphi)$ carry OAM equal to $\ell\hbar$ per photon, where the azimuthal index ℓ can take any integer value [1]. Since OAM is theoretically unlimited, this gives access to a lot of states, which is of great interest for classical [2] and quantum [3] communication, studying quantum entanglement [4], and also for quantum teleportation [5]. Today, there are a number of works devoted to the preparation of multidimensional photonic states encoded in different degrees of freedom [6].

One of the simplest methods for generating single photons is the process of spontaneous parametric down-conversion (SPDC) of light. This process satisfies the energy and momentum conservation laws, respectively: $\omega_p = \omega_i + \omega_s$ and $\vec{k}_p = \vec{k}_i + \vec{k}_s$. Here ω_n and $\vec{k}_n$ are the frequency and wave vector of the signal photon (n=s), idler photon (n=i) and pump photon (n=p). For collinear SPDC process, the following condition is true (conservation law of OAM) [7]: $\ell_p = \ell_s + \ell_i$, where ℓ_n is the value of OAM of nth photon (n=p,s,i).

In this paper, we consider the preparation of single-photon states with a superposition of OAM in the basis of Laguerre-Gauss (LG) via SPDC process. We use a LiNbO3 crystal, providing generation of photon pairs at the wavelengths of 810 nm and 1550 nm (fig. 1).

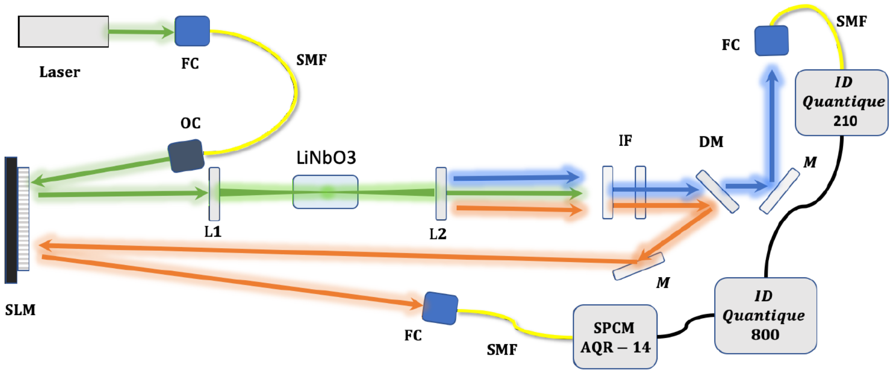

Figure 1: Experimental setup: FC — fiber coupling, OC — optic collimator, $L1 = 200$ mm, $L2 = 150$ mm, IF — spectral filter, DM — dichroic mirror

To generate photons with a superposition of OAM, phase masks for SLM were simulated using the method proposed in Ref [8]. For example, we prepared a superposition of two LG beams with OAM values ℓ=0, 1. The resulting single-photon state has the following form: $|\psi\rangle = 1/\sqrt{2}\,(|\ell, m\rangle + e^{i\varphi}|\ell, m\rangle)$, where $|\ell, m\rangle$ denotes the single-photon state in the LG basis with the radial index m and the azimuthal index ℓ, φ the additional phase. As a result of the experiment, a contrast of 30 times was obtained between the maximum and minimum of coincidences counts in the case of compensation.

These results form the basis for quantum hashing algorithms adapted for this physics model [9, 10].

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