Switchable mode entangled photon pairs from integrated optic Mach Zehnder interferometeric circuit and an elctro-optic modulator

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One of the most common sources of photon pairs is spontaneous parametric down conversion (SPDC), which can take place either in bulk crystals or integrated waveguides. The latter gives rise to high brightness and has an inherent advantage of discretizing the spatial degree of freedom into well defined modes of the structure [1]. With this motivation, we proposed a scheme for generating spatial mode entangled photon pairs in an integrated optic Mach Zehnder interferometer (MZI) device (see fig. 1a) [2]. We further utilize the fast electro-optic (EO) effect in lithium niobate ($LiNbO_3$) as a tool/switch to manipulate this spatial modal basis.

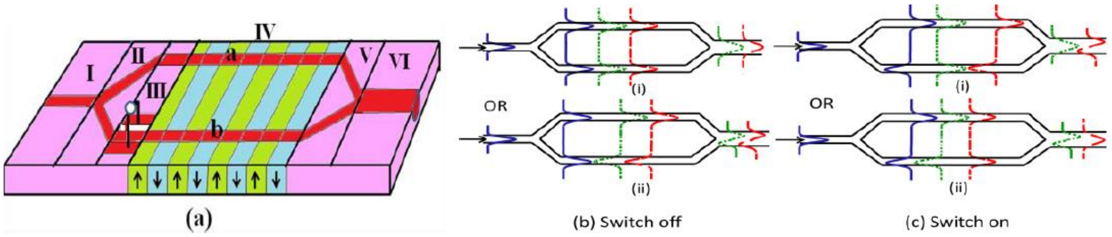

Fig.1 : (a) Schematic of the device to generate a mode entangled bi-photon state (b) Propagation of the fields: pump (solid blue), signal(dotted green) and idler(dashed red) in the device when EO switch is off and (c) switch on.

The device is fabricated in titanium indiffused $LiNbO_3$ and consists of six Regions: Region I is a single mode (SM) waveguide, Region II is a symmetric Y-splitter, splitting into two identical SM waveguides constituting the MZI. Region III has an EO modulator in one of the waveguides, Region IV is periodically poled, Region V is a Y-combiner in which the two waveguides merge to form a single two-mode waveguide in Region VI. It is to be noted that the waveguides in Region IV are far apart and there is no evanescent coupling between them, thus, the propagation constant (β) of the symmetric (0) and the antisymmetric (1) 'normal' modes of this structure is equal to that of the fundamental mode of the individual waveguides. This has an important consequence as it enables multiple SPDC processes using a single phase matching period [2]. The purpose of the EO modulator here is to transform the mode of the pump. Let us first assume that the switch is off and the pump entering region III as mode 0 remains unchanged (Fig 1b). Region IV is poled such that it enables multiple SPDC processes: pump photon in mode 0 downconverting into either (i) signal and idler both in mode 0 or (ii) both in mode 1, giving rise to a mode entangled state as $|\psi\rangle = \int d\omega_s \int d\omega_i (|0,0\rangle + |1,1\rangle)$. The photon pairs then pass through a Y combiner (region V) and exits through a two moded waveguide (region VI).

Now, let us consider that the EO switch is on, and it introduces a phase difference of π in the pump field profile in arm b w.r.t arm a. The pump mode then gets transformed from 0 to 1 (Fig 1c). Because of the parity considerations, it can now downconvert into either (i) signal in mode 0 and idler in mode 1 or (ii) signal in mode 1 and idler in 0, switching the output state to another Bell state: $|\psi\rangle = \int d\omega_s \int d\omega_i (|0,1\rangle + |1,0\rangle)$. Similarly, an arbitrary phase difference can be introduced between the pump field profiles in arms a and b and the state can be accordingly manipulated. The electro-optic switch is known to be very fast and hence, the modal basis can be manipulated efficiently and be used as an alternative to the polarization qubit. Such a device is quite versatile and can be further modified to generate a doubly entangled state in both polarization and modal basis, which offers further interesting applications in quantum information processing [3].

References

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