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Title: Quantum Walk in Integrated Photonics

The research path explored in my doctoral program is within the training network in Photonic Integrated Compound Quantum Encoding (PICQUE). In such framework, my research activity is focused on the study of quantum information science and integrated photonics. In particular, in collaboration with the Institute of Photonics and Nanotechnology (IFN - CNR) of Milan and Rome, the aim is to develop novel platforms for quantum simulation and quantum sensing.

Femtosecond written photonics chips have been extensively proved a viable path for photonics circuits [1-3]. The technique exploits the non-linear behavior of borosilicate glass, by changing the local refractive index with short lasers pulses, so that laser light and single photons can be coupled, guided and manipulated with a series of directional couplers (beam splitters) and phase shifters [4].
The following step in the advancement of such platform consists in the reconfigurability of the photonics devices and their compatibility with different wavelengths of light. In this framework, my first research project was to experimentally demonstrate the feasibility of a thermally reconfigurable photonic circuit operating in the telecom band, at wavelength 1550nm. Micromachining a Mach-Zehnder interferometer, the reconfigurability of the device was achieved by applying a pattern gold resistive heaters with femtosecond written technology, which, with heat diffusion due an applied voltage on the resistors, allows control over the phase of the photons. The results demonstrate an excellent controls over the photon phase and the possibility of more complex quantum experiments in the telecom band [5].

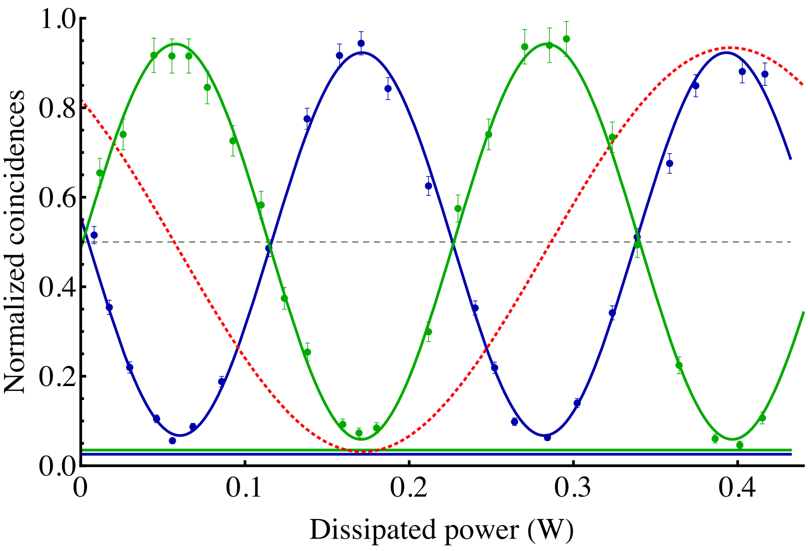

Fig 1. Experimental fringes for the Mach-Zehnder interferometer at 1550nm telecom wavelength. Red dashed line: single photon fringe. Blue dots: two photon coincidences of the output (1,1). Green dot: two photon coincidence of output (0,2). The two photon fringes show a double periodicity of the single photon fringe.

Following the results of thermal reconfigurable photonic devices, a second experiment was conducted using the same technology at 785nm wavelength, consisting in the simulation of the transport of spin states on a 1D chain on an engineered photonic lattice and entanglement generation. A 5 mode first chip was constructed to simulate the quantum walk of bosonic and fermonic particles by injecting entangled photon in a symmetric and anti-symmetric state respectively [6], engineered in such way that the temporal steps would be exactly half the steps required for a complete state transport between defined two sites. This half steps quantum transport allowed the generation of two pairs of path entangled photons at the output modes (2,4) and (1,5) of the first device, when injected with a Néel state. To verify the generated path entanglement a second device with thermally reconfigurable phases was used, which when added in series to first device it formed a Mach Zehnder interferometer between pair of waveguides, and so the coherence between such state and the entanglement fraction were measured.

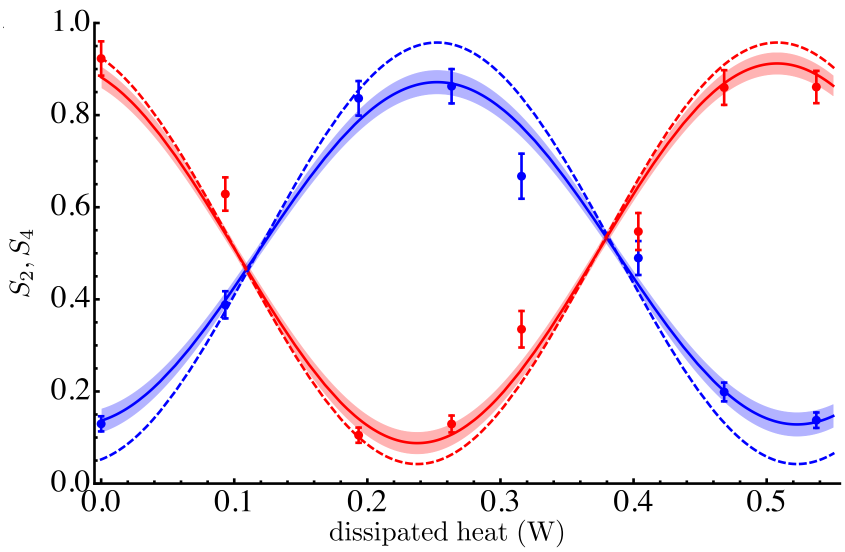

Fig 2 Interference fringes for the entanglement analysis. The blue points and solid line show experimental an theoretical prediction respectively for the output mode 2. The red points and solid line show experimental and theoretical prediction respectively for the output mode 4.
The results clearly show coherence between the two modes.

In parallel the second aspect of the research in my doctoral research project, a platform for quantum sensing is studied. The novelty in the field of single photon detectors are Superconducting Nanowire Single Photon Detectors (SNSPDs), which, due their high count rate, low dark count and high detection efficiency, allow higher level of experiments in quantum information and simulation [7-8]. The state-of-the-art superconducting detectors are based on Silicon compounds, which work at temperatures of ~4K, and offer a detection efficiency higher than 55-60%. Single photons are detectedThese detectors are currently developed for light at wavelength of 1550nm, allowing advance experiments in the telecom wavelength, as quantum teleportation on photonic chip.

The following research during my doctoral project, in strict collaboration with the IFN-CNR, will continue in the developing and testing reconfigurable photonic devices at two different wavelengths (785nm and 1550nm), with increasing precision and number of thermal phase shifter working in parallel, for increasingly complex quantum simulation experiments; moreover I will focus on setting up the cryogenic apparatus for hosting the SNSPDs.
Finally the aim is to bring close together these aspects of quantum simulation with photonic chip and quantum sensing with SNSPDs in one line of research with experiments of quantum information.

As integrant part of the PICQUE training network, in my doctoral program I will have to carry a n industrial secondment with the company QuTools GmbH in Munchen, associated partner of the project PICQUE. The QuTools company works in developing and manufacturing products for quantum information science, as two-photon interferometers, quantum random number generator, quantum key distribution and single photon detectors. In the company I will follow a training of few months in single-and two-photon commercial sources, incorporating skills and knowledge from both academic and private sector in the field of quantum optics and information.

Finally, active participation to conferences, specialized schools and workshops has been done. From a scientific prospective. In the specialized context of quantum information I have attended the Workshop in Integrated Quantum Photonics in Oxford, Rome PICQUE Scientific School in Integrated Quantum Photonics Applications and QIPC 2015 in Leeds, in the latest two contributing with a poster presentation on the thermal reconfigurable photonic device at telecom wavelength. General congresses attended were the CLEO/Europe -EQEC 2015 in Munich, 101° National Congress of SIF in Rome and the FiO/LS 2015 in San José. In addition to specialized scientific schools and workshops, I have attended schools for professional development as the School in Entrepreneurial Training supported by Confindustria in Rome and Training School in Science Communication supported by SISSA in Trieste; both of these training schools are included in the PICQUE training network.

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