Internship proposal (2025)

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"Photonic architectures for on-chip quantum optics"

Research project description:

As the capabilities of classical integrated photonics have expanded, especially in relationship with the planar integrated silicon technology **[1]**, the research communities have begun to explore the intersection of photonics and quantum mechanics, leading to the emergence of **quantum integrated photonics**. This research field leverages the principles of quantum mechanics like superposition of states, particle-wave duality and entanglement to manipulate and transmit information in ways that classical systems cannot achieve. By integrating quantum light sources, manipulation devices, and detectors onto a single chip, this technology promises to revolutionize fields such as quantum computing **[2]**, secure communication with quantum cryptography, advanced sensing and more recently machine learning. On the other hand, quantum communications are based upon quantum key distribution (QKD) to improve secure communications. The encryption of information is protected by the laws of quantum mechanics as it is possible to know if the communication channel has been eavesdropped and a new encryption key can be established. Quantum sensing with photons has been investigated using squeezed states of light and quantum correlations **[3]**. Quantum correlations between photons have also been shown to be a valuable tool in imaging, which can be used to produce light patterns with super-resolution, surpassing the diffraction limit. A recent use of machine learning in quantum photonic systems involves developing methods to solve Schrödinger's equation instead of Maxwell's equations. By encoding an exponential number of terms describing a quantum state into a neural network using a polynomial number of qubits, this approach enables efficient quantum photonic tasks like quantum state tomography. **Yet, the integration of these quantum photonics applications onto a chip presents unique challenges**, particularly in the **areas of photon generation, manipulation, losses and detection**. Addressing these challenges is crucial for the development of scalable and reliable quantum technologies. In this respect, the recent progress has been tremendous towards the realization of early on-chip **photonic architectures enabling the realization of non-classical light states** for diverse applications (e.g. for quantum computing: see **Fig. 1** and Ref. **[5]**, and Ref. **[6]** from the host team).

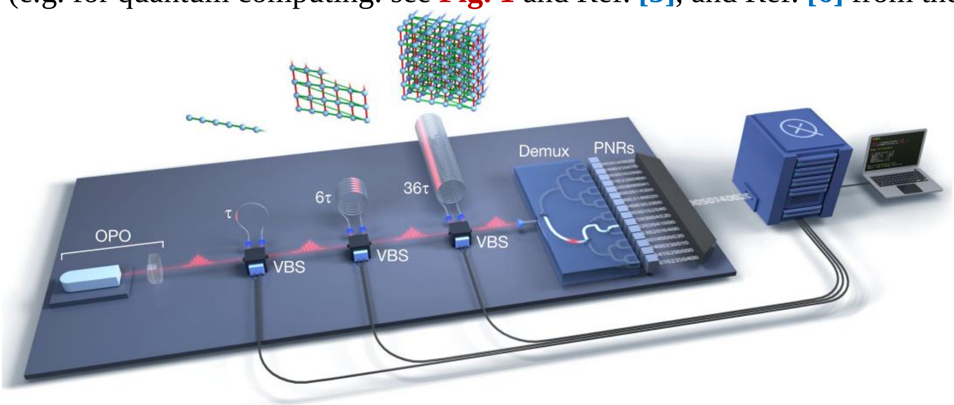

Fig. 1: Programmable quantum chip for processing non-classical light states (from Ref. [5])

The **objective of the proposed research project** is to investigate new architectures of silicon photonic waveguides and circuits for the realization of quantum light sources on a chip. One of the challenges will consist in demonstrating the possible production of entangled photon pairs with sufficient rates and low signal to noise ratio without the use of an external optical filter usually needed to remove the optical pump signal. Possible developments in the emerging field of ghost sensing will then be investigated **[7]**.

The research facilities:
The candidate will be hosted by the “Minaphot” group at C2N (https://minaphot.c2n.universite-paris-saclay.fr/en/). The research environment comprises the clean room facilities of C2N and the simulation and experimental setups of the Minaphot group (see **Fig. 2**).

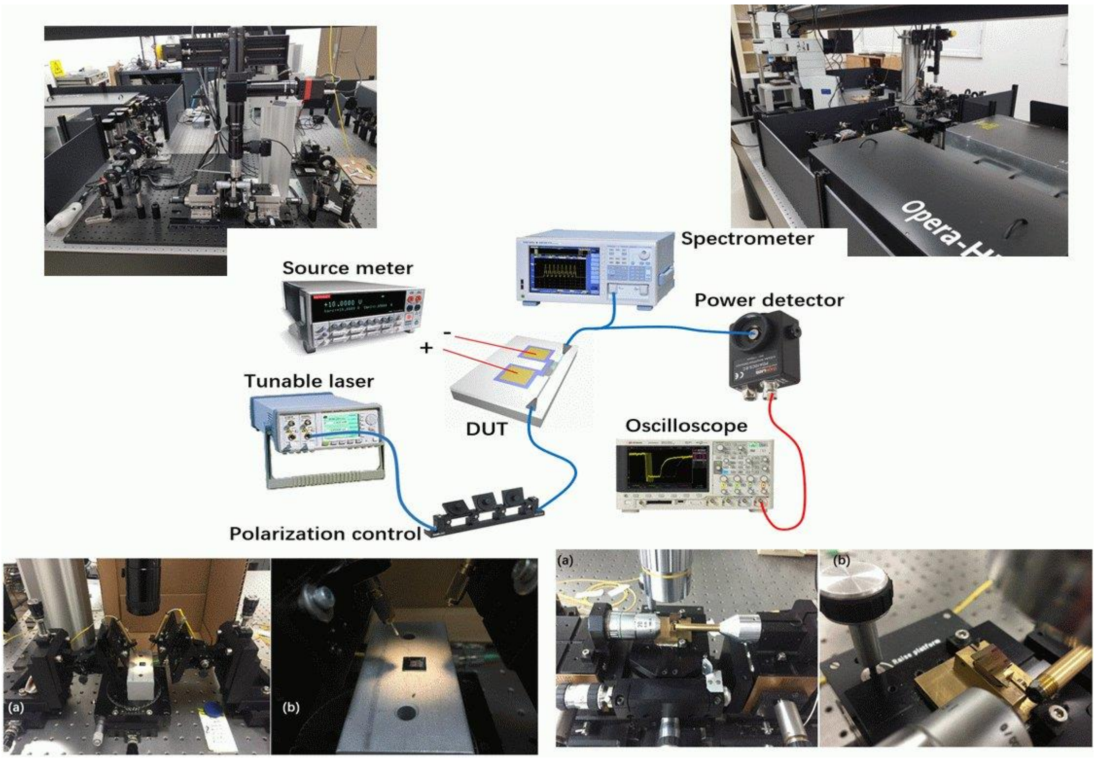

Fig.2: Some illustrations of the experimental facilities available at the C2N laboratory host team / UPSaclay-CNRS.

What we expect from you:

- Enthusiasm and strong involvement in your project, a growing autonomy
- Taste for Optics&Photonics and Quantum Physics, including simulation and experiments
- Ability to communicate and work in a group, an open-minded attitude and an ability to conduct a project by addressing questions to relevant people around you

For any questions, to ask for references, and to apply:

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References:

[1] **“Roadmap on silicon photonics”**
David Thomson, Aaron Zilkie, John E Bowers, Tin Komljenovic, Graham T Reed, Laurent Vivien, Delphine Marris-Morini, Eric Cassan, Léopold Virot, Jean-Marc Fédéli, et al., ***Journal of Optics*** 18 (7), 073003, 201, https://iopscience.iop.org/article/10.1088/2040-8978/18/7/073003

[2] **“Quantum computational supremacy”**, A. Harrow, A. Montanaro, ***Nature*** 549, 203–209 (2017). https://doi.org/10.1038/nature23458

[3] **“Integrated optical multi-ion quantum logic”**, Mehta, K.K., Zhang, C., Malinowski, M. et al., ***Nature*** **586**, 533–537 (2020). https://doi.org/10.1038/s41586-020-2823-6

[4] **“Machine learning & artificial intelligence in the quantum domain”**, V. Dunjko and H. J. Briegel., ***Reports on Progress in Physics*** 81 (7), 074001 DOI 10.1088/1361-6633/aab406

[5] **“Quantum computational advantage with a programmable photonic processor”**, LS Madsen, F. Laudenbach, et al., ***Nature*** **606**, 75-81 (2022). https://doi.org/10.1038/s41586-022-04725-x

[6] **“High-quality photonic entanglement out of a stand-alone silicon chip”**, D. Oser, S. Tanzilli, F. Mazeas, C. Alonso-Ramos, X. Le Roux, G. Sauder, X. Hua, O. Alibart, L. Vivien, E. Cassan, L. Labonté, ***npj Quantum Information*** 6 (2020): 1-6., https://www.nature.com/articles/s41534-020-0263-7

[7] **“Quantum Ghost Imaging Spectrometer”**, A. Chiuri, F. Angelini, S. Santoro, M. Barbieri, I. Gianani, ***ACS Photonics*** 2023, 10, 12, 4299–4304, https://pubs.acs.org/doi/10.1021/acsphotonics.3c01108