Theoretical aspects of Practical Quantum Key Distribution

Charles LIM CI WEN
National University of Singapore, ECE, CQT, Singapore

Quantum key distribution (QKD) is a crypto-technology that enables two parties to exchange secret keys using an untrusted quantum channel. In the lectures, we will review the basic concepts and security of QKD, and present examples on how to compute the secret key rates of popular QKD protocols like BB84 and decoy-state QKD. If time permits, we will review measurement-device-independent QKD and device-independent QKD, which are capable of providing additional security against weakly characterised devices. Students will be expected to perform calculations during the lectures; hence please remember to bring along writing materials.

The Technology behind QKD

Alexander LING
National University of Singapore, CQT, MajuLab, Singapore

In two 90 minute sessions, I will discuss the technology behind practical QKD. Starting with the original demonstration of QKD, I will present the device physics for a number of concepts such as Single Photon Detectors, Quantum Random Number Generators, modulators and other related technology. I will also be discussing some of the latest achievements in QKD, the practical challenges of getting these experiments to work, and future concepts. Due to a lack of time, the focus will be on polarization-based QKD.

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Optomechanics

Florian MARQUARDT
Max Planck Institute for the Science of Light, Erlangen, Germany

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NV Color Centers in Diamond: Physics and Applications to Sensing

Jean-François ROCH
Laboratoire Aimé Cotton, Ecole Normale Supérieure Paris-Saclay, France

The NV color center in diamond was identified in 1965 as a luminescent point defect with an electron spin structure. It then received a lot of attention after the discovery in 1997 that it can be isolated as an individual quantum system inside the solid state matrix. Its remarkably stable photoluminescence even at room luminescence makes this system an efficient and practical single-photon source. Its electron spin can be addressed and coherently manipulated using a combination of optical and microwave excitations. The understanding of the NV center physical properties, in parallel with remarkable progresses in diamond material fabrication, has now led to many applications in sensing and quantum information which this series of four lectures will try to review.

Lecture 1 - The NV color center: Spectroscopy and energy levels
Lecture 2 - The electron spin of the NV center and application to magnetic sensing
Lecture 3 - Advanced magnetometry techniques
Lecture 4 - Nuclear spins in diamond as a quantum ressource

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Chiral Quantum Optics

Arno RAUSCHENBEUTEL
Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Wien, Austria

Controlling the interaction of light and matter is the basis for diverse applications ranging from light technology to quantum information processing. Nowadays, many of these applications are based on nanophotonic structures. It turns out that the confinement of light in such nanostructures imposes an inherent link between its local polarization and its propagation direction, also referred to as spin–momentum locking of light [1]. Remarkably, this leads to chiral, i.e., propagation direction-dependent effects in the emission and absorption of light, and elementary processes of light–matter interaction are fundamentally altered [2]. For example, when coupling plasmonic particles or atoms to evanescent fields, the intrinsic mirror symmetry of the particles' emission can be broken. In our group, we observed this effect in the interaction between single rubidium atoms and the evanescent part of a light field that is confined by continuous total internal reflection in a whispering-gallery-mode microresonator [3]. In the following, this allowed us to realize chiral nanophotonic interfaces in which the emission direction of light into the structure is controlled by the polarization of the excitation light [4] or by the internal quantum state of the emitter [5], respectively. Moreover, we employed this chiral interaction to demonstrate an integrated optical isolator [6] as well as an integrated optical circulator [7] which operate at the single-photon level and which exhibit low loss. The latter are the first two examples of a new class of nonreciprocal nanophotonic devices which exploit the chiral interaction between single quantum emitters and transversally confined photons.

References

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Integrated Quantum Photonics

Fabio SCIARRINO
Dipartimento di Fisica, Sapienza Università di Roma
P.le Aldo Moro 2, 00185 Roma, Italy
www.quantumlab.it
e-mail: fabio.sciarrino@uniroma1.it

Integrated photonic circuits have a strong potential to perform quantum information processing. Indeed, the ability to manipulate quantum states of light by integrated devices may open new perspectives both for fundamental tests of quantum mechanics and for novel technological applications. By exploiting waveguides fabricated by femtosecond laser waveguide, integrated circuits with three dimensional geometry can be designed to carry out several quantum information processing tasks. Our aim has been to develop and implement quantum simulation by exploiting 3-dimensional integrated photonic circuits. As first we will discuss the implementation of fundamental devices: sources, circuits and detectors. As following step we will address the implementation of discrete quantum walk: we investigated how the particle statistics, either bosonic or fermionic, influences a two-particle discrete quantum walk both in ordered and disordered systems. We will then discuss the perspectives of optical quantum simulation: the implementation of the *boson sampling* to demonstrate the computational capability of quantum systems and the development of integrated architecture with three-dimensional geometries.

Lecture 1 - Introduction to integrated quantum photonics
Lecture 2 - Architecture for integrated quantum photonics
Lecture 3 - Quantum walks
Lecture 4 - Boson Sampling on a chip

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Polaritonics

Timothy LIEW
Nanyang Technological University, Singapore

Exciton-polaritons are hybrid light-matter particles forming in semiconductor microcavities. Their hybrid nature gives them a mix of properties, which blend the borders of condensed matter physics, photonics and quantum optics. In this course we will review the basic theory used to understand a variety of physical phenomena, including: strong light-matter coupling, the optical spin Hall effect, topological band structures, solitons, superfluidity, polariton condensation, bistability, and quantum interference. We will also highlight how these phenomena can be relevant to applications in low threshold lasers, terahertz sources, and optoelectronic information processing.