Abstracts

Quantum technologies: an overview

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Abstract: What are quantum technologies and how they will impact our future? I will give a brief overview of quantum technologies and their development in Romania, Europe and worldwide.

Dezvoltarea de dispozitive optice neliniare integrate pentru comunicații cuantice

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Ghidurile de undă optice (OWg) fabricate pe substraturi de niobat de litiu cu domenii feroelectrice inversate periodic (PPLN) sunt deja unele dintre cele mai utilizate dispozitive pentru numeroase aplicații optice neliniare bazate pe procesul de cvasi-acord de fază (QPM). Un proces neliniar eficient, cum ar fi generarea a armonicii a doua (SHG), conversia parametrică spontană (SPDC) sau diferite alte variante de conversie a frecvenței optice, necesită, printre altele, tehnici de fabricare a ghidurilor de undă care să permită păstrarea cât mai puțin alterată atât a coeficientului neliniar, cât și a orientării domeniilor feroelectrice a substratului. Ghidurile de undă în fază α produse direct într-o singură etapă de fabricație sunt bine cunoscute pentru păstrarea atât a proprietăților neliniare excelente, cât și a orientării domeniilor feroelectrice ale substraturilor de niobat de litiu. Drept urmare, cristalele PPLN/OWg sunt exploatate în diverse aplicații și dispozitive precum dubloare de frecvență laser, surse de lumină reglabile pe o bandă largă, amplificarea luminii, convertoare de frecvență, comutație-Q pentru lasere, stocare de informații și imagini, acustică de suprafață senzori electromagnetici, giroscoape de precizie, comutatoare optice, modulatori optici, multiplexor, surse de perechi de fotoni intercorelați cuantic pentru aplicații de optică cuantică și comunicații cuantice și, de asemenea, pentru multe alte dispozitive de procesare optică. Pentru fiecare dintre aceste aplicații, provocarea este de a oferi configurații integrate ușor de implementat, cu *pierderi de propagare reduse*, *eficiență ridicată, stabilitate*, robustețe și, dacă este posibil, *compactitate* și *consum redus de energie*.

Quantum metrology: sensing beyond the standard quantum limit

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Quantum metrology aims to use the principles of quantum mechanics in order to make high sensitivity measurements with constraints on some resources (usually the average number of input photons). In classical metrology, there is a well-known limit, usually called the standard quantum limit (SQL) or the shot-noise limit (SNL). It has been both theoretically and experimentally shown that

this limit cannot be surpassed, given classical input states (for example a laser). However, since the pioneering work of Caves, we know that an interferometer is not limited to the SNL if one uses non-classical input states at its input (for example squeezed states of light). Thus, a new limit emerges, called the Heisenberg limit. In this talk I will try to give an overview of the important concepts in quantum metrology, such as the Fisher information (FI) and its quantum counterpart (QFI - the quantum Fisher information), the Cramér-Rao bound and, similarly, its quantum counterpart, QCRB. This information theory derived quantities come in very handy to set absolute limits one might expect in a quantum measurement, and how much information one can extract about a parameter that can be - or not - an observable. Realistic detection schemes always yield suboptimal results and their relation to the QCRB characterizes their performance. Some applications will also be discussed, where quantum metrology is already implemented and is providing sub-SQL sensitivity.

Gamma Correlated Photons

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In the context of the second quantum revolution the ability to manipulate quantum systems is already used for various technology demonstrators, mostly with photons of low energy. In this frame our aim is to extend quantum technologies to gamma photons. The advantages of having high energy together with resources like entanglement are available for any pair of annihilation quanta, which are in a pure state. Usual tools for low frequency quantum experiments are not suitable, consequently we need effects typical to the keV-MeV energy range. High energy photon protocols would range from simulators to imaging devices, from testing fundamental quantum mechanical properties to military-like applications. Here we review some important steps for the study of annihilation photon correlations, we point out the experimental differences and necessities with respect to the energy increase in quantum photonic experiments and we describe the design of a quantum gamma device meant to prove feasibility of gamma ray based protocols. The idea behind our project is to evidence the possibility to communicate via entangled quanta through media which are non-transparent for low energy photons.

Two-photon photopolymerization method for fabrication of micro-optics and photonic devices

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The expansion of quantum applications is based on technological advances that lead to the development of new methods for the integration of micro-optics and advanced photonic devices. In this work we present a laser processing technique available at CETAL and the infrastructure developed for fabrication and characterization of photonic components of integrated quantum photonics. Direct laser writing based on Two-Photon Photopolymerization (TPP) is a rapid-prototyping method for setting up various photonic geometries, such as waveguides, photonic crystals, metamaterials or micro-optics components. This manufacturing techniques is based on nonlinear optical effect of two-photons absorption in photopolymers that ensure material structuring with submicrometric resolutions. Near-infrared laser pulses with femtoseconds pulse duration are tightly focused inside a photoresist transparent to the laser wavelength. Photochemical reactions are induced in the centre of the focused laser spots. By translating the samples in 3D, complex geometries can be produced in photopolymers with resolution much below the optical diffraction limit. Fig. 1 presents examples of TPP fabricated microstructures for integrated optical circuits.

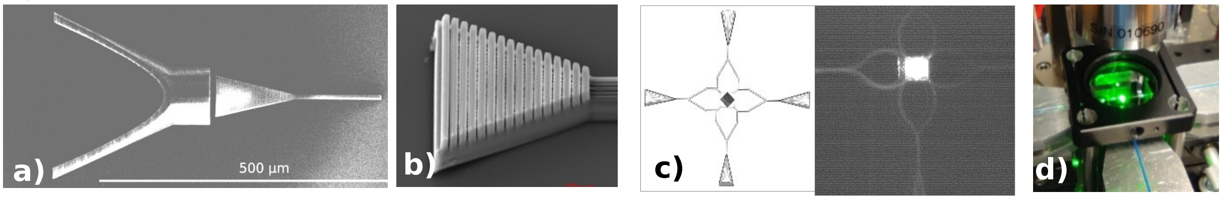

Fig. 1. Micro-optic components fabricated by TPP: a) optical fibre to waveguide couplers; b) grating coupler; c) 4-ways integrated photonic circuit with central diffraction grating, CAD geometry and optical image of the photonic circuit. d) the photonic chip under optical microscope pumped by 4 laser diodes.

For characterisation of the fabricated optical structures an optical microscope was built. The installation includes 4-channels synchronized optical sources with dedicated laser diodes drivers controlled by FPGA, generating optical pulses with repetition rates from 5 Hz to 100 MHz, bursts or random pulses. The optical signals are coupled by optical fibres to up to 4 inputs of the integrated optical circuits to be tested. The collected optical signals are collected and measured by avalanche photodiodes (APD) with high sensitivity. The input pump and output collection under microscope can be reconfigured in a flexible way, depending of the optical chip configuration.

Fabrication of components generating beams with optical angular momentum

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We present the fabrication process for the fabrication of optical components generating beams with helical wavefronts carrying orbital angular momentum. These components are operating either in reflection or transmission and consist of spiral phase plates generating Kummer beams and spiral axicons generating higher order Bessel beams. The technology used to obtain the components is based on standard microfabrication techniques, namely a series of photolithographic processes, each process being followed by dry or chemical etching. The functional characterization of the components is based on interferometrical methods which give an evaluation of both the quality of the fabricated optical components and the optical properties of the beams.

Quantum optics experiments based on entangled photons

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Entanglement plays a significant role in quantum technologies and has several applications in new devices for quantum communications, computing, sensing and imaging. We will present two types of entangled sources (a commercial one and one made in our laboratory) based on spontaneous down conversion process in nonlinear crystals: Beta Barium Borate (BBO) and periodically poled KTP (PPKTP), respectively. The Sagnac-based our source built in our laboratory was characterised in terms of entanglement visibility, Bell's ineqaulity and quantum state tomography. Several experiments were conducted to generate quantum random numbers, to test wave-particle dualism, to characterize Hong-Ou-Mandel deep and to demonstrate quantum eraser. A project for a future qantum imaging experiment will be described.

Modele efective pentru sisteme qubit-foton in regim de cuplaj puternic

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Experimentele cu atomi plasati in cavitati optice au condus la descoperirea unor efecte remarcabile ale interactiei radiatiei cu materia. Toate aceste efecte pot fi descrise teoretic in cadrul modelului Jaynes-Cummings (JC), valabil in cazul unui parametru de cuplaj slab dintre un sistem cuantic cu doua nivele (qubit) si modurile fotonice asociate unei cavitati sau unui nanorezonator. Tehnicile actuale de miniaturizare permit insa cresterea cuplajului qubit-foton in sisteme cuantice hibride cu cateva ordine de marime, astfel incat modelul JC si alte aproximatii folosite in optica cuantica devin inaplicabile.
Acest regim de cuplaj puternic a fost confirmat experimental pentru diverse sisteme cuantice hibride
(A. F. Kockum et al., Nature Reviews Physics **1**, 19 (2019)) si este abordat teoretic cu ajutorul unor modele de Hamiltonian ”efectiv” care permit calculul analitic al marimilor relevante (energii, stari, numar mediu de fotoni). Un efect important al interactiei qubit-foton este deplasarea frecventei fotonice spre rosu sau albastru, in functie de starea qubit-ului. Astfel fenomenul permite citirea indirecta a qubit-ului prin determinarea sensului deplasarii spectrale.
In acest context prezentam deducerea unui nou Hamiltonian efectiv in regim de cuplaj puternic. Analiza comparativa (analitica si numerica) arata ca rezultatele prezise de acest model sunt mai precise decat cele asociate Hamiltonianului efectiv Bloch-Siegert acceptat in literatura (P. Forn-Diaz et al., Rev. Mod. Phys. **91**, 025005 (2019)). In plus, corelatia qubit-spectru fotonic prezisa de noul model este inversa fata de cea din modelul Bloch-Siegert, ceea ce are consecinte directe asupra citirii corecte a starii qubit-ului.

Two-way quantum teleportation using non-maximally entangled states

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We discuss the possibility of teleporting [1] two qubits: one from Alice to Bob and the second one
from Bob to Alice by using a single non-maximally two-qubit entangled state. This is performed with the help of broadcasting of entanglement using local and nonlocal optimal universal asymmetric cloning machines [2]. We prove that the nonlocal broadcasting of entanglement gives better results than the local one.

This work was supported by a grant of the Romanian Ministry of Research, Innovation and
Digitalization, CNCS-UEFISCDI, project number PN-III-P4-ID-PCE-2020-1142, within PNCDI III.

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[2] I. Ghiu, Phys. Rev. A 67, 012323 (2003)