Abstract Book

Romania's National Quantum Communication Strategy (QTSTRAT) – Considerations on its Development and Content

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Abstract: The intervention presents Romania's endeavor to develop a national strategy in an emerging technological domain, namely quantum communication (which is not yet considered a mature technology on the TRL scale). The Romanian Ministry of Research, Innovation and Digitalization started the formulation of a national strategy for the development of quantum communication capabilities (QTSTRAT from here on) in the summer of 2021; the contract was attributed to an association consisting of Babeș-Bolyai University (as project coordinator) and the National Institute for Material Physics (as main partner). The project was successfully completed by November 2023.
The paper reviews the methodological approach for developing the strategy and analyzes the main milestones of this process, focusing on the nature of the emerging technology and stakeholder involvement (the quadruple innovation helix framework: university-industry-government-public-interactions).
The presentation also includes the key results of the Strategy for the Development of National Quantum Communication Capabilities (QTSTRAT), which can influence the future of quantum technologies in Romania: the vision, mission, four general (or strategic) objectives (referring to research and development, education, infrastructure and the industrial ecosystem), as well as programs and directions for actions.

QUANTEC: An Open Hub for Advancing Quantum Communication Technologies in Romania

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Abstract: The successfully completed QUANTEC Center stands as a crucial hub for the development of quantum technologies in Romania, offering an open infrastructure for professional training, academic research, and commercial collaborations. This platform interconnects expertise, resources, and innovations, facilitating knowledge exchange
and accelerating technology transfer in the quantum field. The presentation will highlight how QUANTEC strengthens connections between the scientific community and the industrial sector, thus shaping the future of quantum technologies within the national ecosystem and beyond.

Quantum technologies: turning a threat into an opportunity

Radu Ionicioiu

Abstract: Quantum technologies pose a serious threat to cybersecurity, as a future quantum computer will break current public-key encryption and digital signatures. This so-called Quantum Apocalypse, or Q-Day, has serious implications for the digital economy: internet, critical infrastructure, government communications, online banking etc.

However, quantum technologies also present an opportunity -- quantum communications and the future quantum internet will ensure unbreakable security and privacy.

I will give a brief overview of quantum technologies and the current state-of-the-art. I will discuss what we can do to ensure Romania will actively engage and participate in the Second Quantum Revolution.

High Vacuum Proton Exchange PPLN waveguides: fabrication and application to quantum communications

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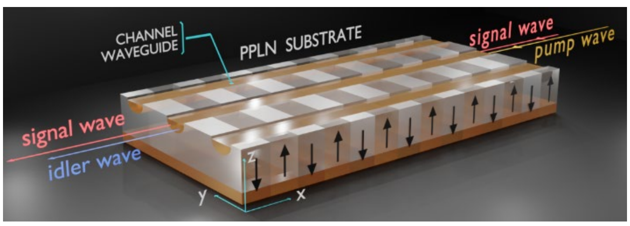
Abstract: Considerable research efforts of our group are oriented toward nonlinear applications of Lithium Niobate ($LiNbO_3$), one of the most commonly used materials because of its excellent nonlinear optical properties. Moreover, periodically poled lithium niobate (PPLN) has become the nonlinear-optical platform of choice in many infrared and visible light applications based on quasi-phase-matching (QPM). QPM is very versatile technique in which the ferroelectric domains of the material and thus the nonlinear coefficient are periodically inverted to compensate for dispersion.

Many of these applications require a mandatory element called optical waveguide (OWg) for which the most significant parameters are the refractive index contrast and the optical propagation losses. To effectively play its role and to meet the modern photonics applications demands, the OWg must exhibit well-controlled tunability of index contrast over a large range of values from high-index contrast to low-index contrast respectively.

To satisfy these conditions, our group proposes the new methods of High Vacuum Proton Exchange [1, 2] for realizing waveguides on PPLN that preserves both the nonlinearity and the domain inversion in view of applications to Quantum Communication.

Taking advantage of these developments, we have in charge to build an ultralow-noise single-photon wavelength conversion to the telecom C-band. Our wavelength conversion interface will be based on an integrated periodically poled waveguide chip (PPLN/W) on LN platform. As sketched in figure below, in the PPLN/OWg, laser light at 2.245 nm will be overlapped with single photons at 917 nm, which are then converted to 1.550 nm via Difference Frequency Generation (DFG). As the wavelength is less than doubled, we expect essentially zero photonic excess noise at 1.550 nm due to parasitic down-conversion and Raman scattering. The wavelength conversion interface will be fabricated on LN substrates in which MgO doping leads to higher power handling. Quasi phase matching engineering is done using standard



electric field poling and the waveguides will be fabricated by one of our recently reported HiVac-PE [1] and HiVac-VPE techniques [2]. The resulting high-index contrast LN waveguides (up to 0.1) exhibit low propagation loss. This opens the possibility of very tight mode confinement and consequently one order of magnitude increased nonlinear conversion efficiency compared to low-index contrast LN waveguides. Further, special attention will be paid to both: waveguide to fiber coupling using tapers as optical mode adapters, as well as antireflection coatings of LN waveguides. Thanks to these techniques, an increased in- and out-coupling of photons to a pigtailed fiber is expected, which will offer more than 60% full device conversion efficiency (input-to-output-fiber).

Acknowledgments

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Optimal Photon Counting with Visible Light

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Abstract**.** Photon counting is one of the most basic operations in quantum optics experiments. In quantum optical or photonic devices, photon counting depends on various device parameters such as the latency of the electronics, the dead time of the detectors, or the pulse width of the photon source. None of these parameters can be set to zero, and in many cases, they are of the same order of magnitude with the clock time of the electronics and inverse frequency of the light. We developed a measurement protocol to optimize our photon counting device. We performed measurements to obtain detection rates, photon numbers, correlation functions, to determine the optimal size of the measurement window for which the maximum information can be extracted from photon counting. The time window size is directly correlated to the detector dead time.

Computational assessment of Aluminum-based Josephson junctions as building blocks for quantum processors

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Abstract: One of the main directions of research within the Group of Structural and Computational Analysis in ITIM is the study of materials dedicated to the fabrication of superconducting qubits [1-3] that use aluminum-based tunnel Josephson junctions as the sources of nonlinearity needed for

quantum operations. Our activities are carried out within successful international collaborations, such as QuCos QuantERA Project (Quantum Computation with Schrodinger cat states). Under the leadership of University of Innsbruck, this project brings togheter ENS Lyon, ENS Paris, KIT, ITIM and Quantum Machines, with the aim to develop the quantum processor architecture, control systems, and associated protocols into the first European full-stack error-corrected quantum computer.
Our investigations [4,5] are focused on three aspects: (i) structural analyses in 2D systems (nanojunctions/interfaces); (ii) structural analyses on 0-D systems (spherical, non-periodic structures of granular aluminum); (iii) exploring the transport properties across the aforementioned systems. The data produced relies on highly precise molecular dynamics simulations (i.e., reactive force fields like ReaxFF, allowing a rigorous description of bond formation/breaking). These involve analyzing correlations between manufacturing conditions (roughness, temperature, pressure, etc.) and properties of the material, such as grain size and their physical attributes for the end product, i.e. diverse Josephson nanojunctions of the form Al-AlOx-Al. The study of transport processes is focused on the connection between structure and current density transmitted in nanojunctions and is carried out in collaboration with the group led by Jared Cole, Australia.

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Skyrmionic materials and devices as platforms for quantum spintronics

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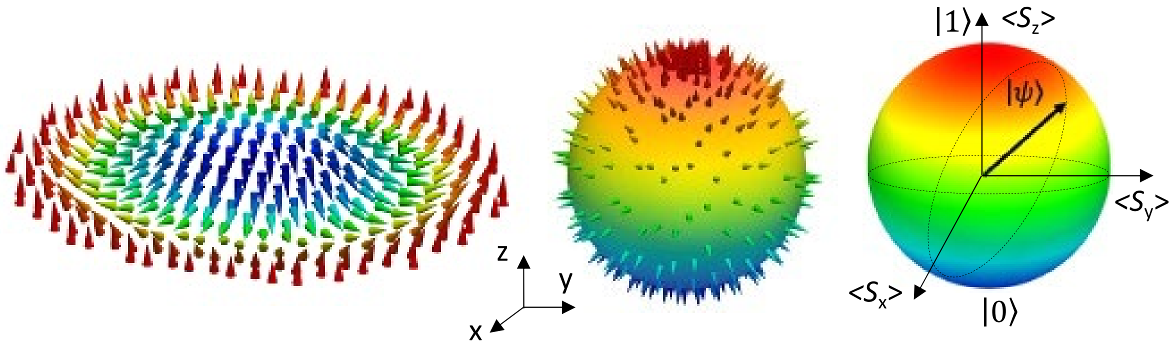
Abstract: One of the most recent challenges in the information technologies is based on device implementation of topological magnetic textures, namely skyrmions [1], special class of solitonic structures. As recently shown, the nanometer-sized skyrmions can encode quantum information in their helicity degree of freedom [2], that can be manipulated using electric or magnetic fields, within a wide operating range providing a large anharmonicity.



Skyrmionic spin texture and Bloch sphere projection: qubit $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$

Moreover, the antiferromagnetically coupled skyrmions in multi-layered synthetic antiferromagnets or genuine antiferro/ferri-magnetic materials, provide the qubit coupling scheme required for implementation in quantum gates. Beyond their potential for quantum applications, the skyrmions represent one of the best candidates for integration in spintronic neuromorphic devices [3] . Within this complex context, we will briefly discuss the skyrmionic paradigm from several perspectives: the alternative in quantum information applications, the material science request for skyrmionic occurrence and stability, possibilities for skyrmion manipulation in some dedicates spintronic devices. Our experimental studies cover the area of ferrimagnetic materials based on Rare-Earths – Transition-Metal (RE-TM) alloys in structural configurations providing tuneable ferrimagnetism: net magnetization, compensation temperatures and provide demonstrated skyrmionic potential at room-temperature [3]. Theoretically, we follow a complex multiscale approach, from quantum exact diagonalization techniques [4], ab-initio [5], atomistic [6] and micromagnetic simulations [7] to investigate quantum and classical behaviour of skyrmions, depending on their dimensions and main physical mechanisms and material properties that determine their occurrence and stability. Facing the applicative challenges, we will briefly discuss some aspects related to the skyrmionic qubits and possible implementation of quantum gates, thermal effects and spin relaxation mechanisms and their impact on the qubit coherence time.

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State of the art for building quantum computers

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Abstract: The development of quantum computers is at the border between art and science. The challenges, as well as the opportunities, are immense. The methods of building quantum computers are currently extremely varied and there is no clear winner. In this session, we will review the most relevant construction methods and the latest achievements in this field.

Utilizing Machine Learning for Backward Analysis of Quantum Devices to Pinpoint Efficiency Constraints

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Qruise

Abstract: What is the state of the art in Quantum Computing and how can we go beyond? Qruise is advancing a toolset powered by machine learning to accelerate the development of quantum computing and sensing technologies. Our methods swiftly initialize and intricately characterize devices, allowing for precise identification of performance bottleneck sources. By addressing the inverse problem, Qruise focuses on disassembling the device in development to rapidly pinpoint the precise causes of performance issues. The solution is adaptable and applicable to a variety of quantum platforms, including superconductive qubits, Rydberg atoms, ion traps, NV-centers, spin qubits in silicon, and
photonics.

Quantum sensing and metrology: to the shot-noise limit and beyond

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Abstract: Quantum sensing is a rapidly growing branch of research within the area of quantum science and technology. This field is expected to provide new opportunities in applied physics and other areas of science. Indeed, quantum sensors allow the estimation of parameters with precision higher than that obtained with classical means. In this presentation I will review the key concepts of this field as well as some practical applications.

Airy photons for quantum communications

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Optical Airy beams present exotic propagation properties such as free-acceleration and self-healing properties. In our study we extend their applications in the quantum regime by creating Airy photons via spontaneous parametric down conversion and passive optical elements. The main advantage of our approach is given by the cost-effective and high-quality optical elements which are not influenced by temperature being fabricated with standard micro-nanofabrication techniques. Our results have great potential to facilitate the generation of compact, secure and resilient quantum communication links.

ZnO-based optical microcavities

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Abstract: Optical microcavities are possible candidates for entangled photon pair sources that can be integrated in optical chips [1-3]. We propose a design of microcavity heterostructure based on ZnO.

Because its high excitonic binding energy of 60 MeV, the ZnO excitons can survive at room temperature. The three excitonic resonances of ZnO at 300 K are in the wavelength range of 370 nm to 380 nm. The excitons coupled with the cavity resonance allow for polaritonic scattering in the semiconductor microstructure and emission of entangled photons [4,5].
In this work we consider the design of a ZnO microcavity formed by two Bragg mirrors with l/4 sequences of TiO_2 and SiO_2 layers and a ZnO cavity layer with thickness of l/2. The cavity resonance l is designed to be at the same wavelength as the excitonic resonance of ZnO. The strong coupling between the cavity's photons and ZnO excitons gives rise to the polaritonic states in the microcavity. The dispersion curve of the polaritons in the cavity is numerically studied for different detuning parameters between the cavity and exciton resonance.
A ZnO cavity have been produce by Pulse laser deposition (PLD). The reflectance spectra of the sample were measured at different incidence angle. The polaritonic branches and their anti-crossing were observed in our sample from the angle resolved spectra of ZnO-based microcavity. The parametric polaritonic scattering mechanisms in such structures is discussed.

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Quantum circuit representation of entangling and CNOT qubit gates
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Abstract: We give a very short introduction to quantum circuits, starting with several simple two-qubit circuits whose output is a Bell state. In this case the two qubits are supposed to interact directly. Then we consider a system of two ions localized in a linear Paul trap and coupled by a quantized vibrational mode which acts as a quantum bus via its sidebands. It has been proposed theoretically and confirmed in experiments that a suitable sequence of pulses applied to this hybrid quantum system leads to atomic Bell states and CNOT gate operations. Using the Qiskit toolkit for IBM quantum computers we implement and run the quantum circuit corresponding to the entangling gate. We also discuss its fidelity, as well as the quantum state tomography

SIC-POVM tomography in integrated photonics chips
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Reconstructing the state of a quantum system, called quantum state tomography, is an essential task in quantum technologies. Standard methods are inefficient, as they scale exponentially with the number of qubits. Better scaling methods, such as SIC-POVM tomography, are not yet widespread due to their measurement complexity. As such, there is an urgent need to find efficient and compact devices for performing tomography of photonic states. Here we present simulations of photonic devices implementing SIC-POVM tomography in photonic chips. We obtain fidelities F = 0.8452 (for qubits) and F = 0.7609 (for qutrits). Our results show that we can design efficient and compact SIC-POVM tomography modules for integrated-photonics quantum chips. Since integrated photonics is a major quantum technology platform, we expect our results to be instrumental in the future development of compact, cost effective quantum devices. Applications include quantum communications, quantum computing, quantum sensing and quantum imaging.