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Project descriptions

L. Arissian (NRC)

Detection of air turbulence with a dual frequency comb system

A frequency comb consists of well-defined optical frequencies spaced by laser cavity round trip over an octave spanning spectrum. A dual comb system consists of two frequency combs with a slightly offset cavity round trip, as a result the optical beat between the two combs are transferred to a measurable signal in radio frequency. Dual frequency comb provide the precision and accuracy in spectroscopic detection beyond existing Fourier-transform infrared spectroscopy (FTIR) over a large bandwidth. The system is widely used for remote detection of gases and for time and frequency transfer over the space. This project is to develop data analysis software for detection of air turbulence using dual frequency comb. The Doppler shift between the sample and reference frequency comb provides information on the Doppler shift in air, moreover the detection over the wide optical spectrum provides a complete mapping of index of refraction of air.

X. Bao

Noise suppression of Brillouin fiber laser

A laser consists of three essential elements: pump, gain medium and cavity. Traditional Brillouin fiber laser use a single mirror or loop to form a fixed cavity. As the cavity length determines the longitudinal mode spacing, the laser is often multimode. In contrast, random Brillouin fiber laser use the distributed Rayleigh scattering to replace a single mirror, which can eliminate the multimode with the single mode operation. The aim of this project is to use weak FBG array to mimic the distributed feedback of Rayleigh scattering in optical fiber to enhance the Q of the laser. A theoretical model will be developed to explore the multimode suppression mechanism for low noise operation.

Fiber optic ultrasound generation and detection

Fiber-optic ultrasound transmitters with compact size and broad bandwidth are widely used in structural health monitoring, material characterization, and biomedical imaging. Ultra-compact in-fiber dual-cavity Fabry-Perot interferometer (DC-FPI) ultrasound transmitters with broad bandwidth could be realized by covering different photo-absorption materials such as the mixture of graphite or carbon nanotube and polymer materials.

R. Boyd

General description of work:

In our research group, you will have the opportunity to be an important part of novel cutting-edge research. The projects cover a broad range of research activities, such as programming and interfacing software with the utilized experimental devices, building modern quantum optics setups including the advanced control of light down to the single photon level and discussing novel research findings within a world-class research group. An ideal candidate would be highly motivated, hard-working and interested in optical quantum physics and information science. Knowledge of Matlab, Python or similar programming languages will be advantageous. For interested students, all projects can be extended to a two-term project.

Quantum communication with mode sorting

Photons are simple objects: they can be completely described by their frequency spectrum, polarization, and spatial structure. The first two properties are routinely used for quantum communication, but spatial modes containing angular and radial orbital momentum have proven more challenging to use. In the last few years, significant advances have been made in generating and measuring these spatial modes, using recently invented devices called mode sorters. In this project, we will determine how a mode sorter can be used to stabilize a free-space data link against losses caused by atmospheric turbulence, enabling higher-capacity classical and quantum communication.

Optical cavities with a twist

An optical cavity consists of several mirrors that trap light as it bounces back and forth between them. The enhancement in light-matter interactions produced by this simple idea has led to revolutionary quantum information processing and communication technologies. Existing optical cavities use unstructured mirrors that reflect light without affecting its mode. Using dielectric metasurfaces, it is possible to manipulate the spatial structure of light by giving it a twist, going beyond what is possible with a normal mirror. In this project, we will investigate the exotic structures of photon modes defined by such twisted cavities, and potential applications in quantum control and metrology.

Characterizing an optical system with quantum light

The spontaneous generation of photon pairs can only be predicted by quantum mechanics. In quantum metrology, we use the peculiar properties of those photon pairs to enhance the capabilities of conventional measurements. In particular, the intensity of that quantum light is known from first physical principles. In this project, we want to develop a bench for the production and characterization of bright quantum light. Then, we will use that light to completely characterize an optical system. We will explore ways to make the process more efficient and compact.

K. Dolgaleva (EECS)

Nonlinear photonics devices on-a-chip

Overview of Research Field

Modern communication systems rely on electronic signal processing. However, this technology has been found to have fundamental limitations associated with the bandwidth which is responsible for the information transfer capacity as well as the switching speed, responsible for the speed of computations.

Our research focuses on addressing the current challenges and needs in the fields of information and communication technologies and quantum information through an all-optical signal processing approach that relies on integrated photonic circuits. An integrated photonic circuit is a network of tiny optical devices defined on a small optical chip by a set of waveguides, which are the channels guiding light on the chip. A large part of our research is devoted to developing new integrated photonic devices and functions, presently unavailable or lacking optimal performance in modern integrated photonic circuits. Such devices include optical pulse shapers, wavelength converters, all-optical switches, and integrated optical autocorrelators for optical pulse metrology; they form the basis of all-optical signal processing which is especially crucial for the optical communication networks of the future. These networks are expected to overcome existing problems associated with the fundamental limitations of electronic signal processing, among which are limited bandwidth (information transfer capacity) and switching (computation) speed.

All-optical switching and signal processing, needed to overcome the limitations of electronics, fully relies on nonlinear optical interactions of light with matter. These interactions result in the generation of new spectral components and the modifications of the optical response of the medium supporting the propagation of the optical beams. The appearance of new frequencies in the optical spectrum of the information streams is crucial for wavelength conversion, used for transferring the information channels from one frequency band to another. The modifications of the response of the optical media due to the nonlinear interactions are necessary for optical switching. Generation of correlated photon pairs for secure information encoding in quantum optics also relies on nonlinear optical interactions. Therefore, it is imperative to use proper optical material exhibiting a strong nonlinear optical response. III-V class semiconductors meet this criterion in the telecommunication (telecom) wavelength range, and thus represent very promising material platforms for developing highly efficient wavelength converters, optical switches, and integrated sources of correlated photons.

Project Description

The project focuses on a variety of activities associated with integrated optical devices. Such devices are comprised of tiny optical waveguides (optical wires that guide light similar to electrical wires that guide electrons). As the light propagating through the waveguides and optical components made of these waveguides interacts with the optical medium, nonlinear optical phenomena can be observed. Nonlinear optical interactions can be accompanied by a change of the spectral component of the light (e.g., generation of new frequency components).

Project-Related Activities

There is an opportunity for the student to get involved in simulations where he/she will be designing an integrated optical component that will further be fabricated by senior students in our group. Depending on the availability of fabricated samples in our lab at the time of the project (the chance is 90%), the student may be able to participate in the laboratory experiment where he or she will learn the methods of optical characterization of integrated optical components. A combination of activities where the student performs simulations and laboratory experiments is also possible.

P. Finnie (NRC)

Raman spectroscopic analysis of the structure and properties of carbon nanotube materials for semiconductor applications

Raman spectroscopy (RS) provides detailed information about the structure and properties many materials, including carbon nanotubes. In this project, RS, imaging, and excitation mapping will be used to analyze purified carbon nanotube materials intended for semiconductor applications. Students will examine state-of-the-art nanotube materials, determine what allotropes and contaminants are present, their physical properties, abundances, and purity. Work will include sample manipulation, acquisition of spectral data on unique optical setups, and the computational reduction/analysis of spectral data. Experience with the Python programming language would be helpful. This work will be based at the National Research Council (Montreal Road campus).

B. Joós

Cell death

Living systems are not in an energy ground state but in a dynamic steady state, called homeostasis. Maintaining homeostasis requires a steady input of energy. When a cell is damaged, the energetic demands or simply the supply requirements may not be sustainable. The cell then embarks on an itinerary toward cell death that can take various pathways. Using simple kinetic models, the student will explore different scenarios towards a ground state.

J. Krich

Device simulations of intermediate band solar cells

Intermediate band solar cells (IBSC) have the potential to radically improve the efficiency with which sunlight is converted to electricity. An intermediate band materials is like a semiconductor but with an extra band of allowed electron energy levels contained entirely inside the the band gap between the valence and conduction bands. These levels allow the material to absorb lower-energy photons while still getting a large voltage, exceeding the efficiency of all simple semiconductor designs. The search for ideal materials to realize the intermediate-band concept is still in its infancy. This project will use Simudo – a newly developed device model for intermediate band materials, recently released by the Krich group – to explore the physical properties of intermediate band materials and devices and to determine the requirements for making an efficiency IBSC. The project will begin by considering the so-called detailed-balance limit, in which all nonradiative processes are neglected, and find the ideal properties of IB materials as a function of solar concentration. The project will then use Simudo to consider reasonably attainable levels of non-radiative processes and determine how stringently materials must be engineered to make viable IBPV devices. Simudo is written in python, and familiarity with that language or other programming languages (e.g.,Matlab, Java) will be helpful for this project.

Quantum mechanics of light-matter interaction in photosynthetic complexes and related chemical systems

Photosynthetic systems are generally highly efficient at transferring energy. Since they absorb sunlight in an antenna-complex and perform chemistry in a reaction centre some distance away, they must be able to move that excitation over to the reaction centre. The process of light absorption and energy transfer depend on the ground- and excited-state wavefunctions of the molecular systems and the transition dipole moment between them. Theorists generally assume that transition dipole to be independent of vibrational coordinate, but that approximation seems to be wrong in many photosynthetic molecules. This project will make proposals for experiments to measure the change in the dipole moment with vibrational coordinate, which we will share with experimental collaborators. It will use analytical methods and a new spectroscopy-prediction platform called Ultrafast Ultrafast (UF^2) Spectroscopy, released by the Krich group in 2019. UF^2 is written in python, and familiarity with that language or other programming languages (e.g.,Matlab, Java) will be helpful for this project.

A. Luican-Mayer

Playing with Legos: new ultrathin materials made by stacking individual atomic layers

With the excitement of new physics in low dimensions as well as promise for next-generation optoelectronics, the field of two-dimensional (2D) materials is active and rapidly progressing. These crystals are the thinnest materials known - a few nanometres and below. And at these thicknesses quantum mechanical effects are so strong, that such substances no longer behave like the macroscopic materials that we are accustomed to. Historically, the first material in this class to be thinned down to a single atomic layer was graphene flat sheet of Carbon atoms. Beyond discovery of remarkable properties, which warranted the Nobel Prize award in 2010, this scientific work disproved the long-held belief that materials cannot be reduced to truly two dimensions. Since then, interest in the scientific community expanded beyond graphene to other materials made out of loosely bonded planes of atoms. A revolutionary development in the field of 2D materials came when it was shown that it is not only possible to peel them down to atomically thin layers, but also that it is indeed possible to controllably stack layers from different crystals - just as Lego pieces - to build custom novel materials. The ability to controllably stack these designer structures, guided by theoretical calculations, can lead to the realization of original materials with distinct properties that were previously inaccessible. In this project, the student will be involved in using our lab set-up to build such heterostructures.

Ultrathin environmental sensors from 2D materials

Environmental monitoring is critical for the safety and security of workers in certain industries (chemical, petrochemical, mining etc.) as well as in the broader safety of Canadian citizens. In this project, the student will be part in the fabrication and characterization of sensing devices made out of a new class of ultrathin two-dimensional (2D) materials such as graphene. These materials are concomitantly strong, bendable, highly sensitive and low power consumers making them great candidates for next-generation sensors.

Visualizing new materials at the nanoscale using Scanning Tunneling Microscopy

Understanding and controlling the properties of material systems to our advantage is an outlook that can be contemplated only with the development of experimental tools to probe and manipulate electrons and their interactions at the nanoscale. Specifically, scanning tunneling microscopy (STM) is a material characterization technique that continues to enable breakthroughs both in fundamental research and in material applications. The operation principle is based on the fact that when a voltage is applied between an atomically sharp probe within a nanometer above the studied material, a current will flow between them due to quantum mechanical tunneling. This current provides information about the probed material. Its power stems from the ability to image and manipulate surfaces at the atomic level and concomitantly, to provide information about the electronic properties of the material also with atomic precision. Examples in which this instrumentation impacts fundamental nanoscience and nanotechnology range from catalysis, imaging and manipulating biomolecules, visualizing chemical reactions, and creating quantum confined systems by moving atoms. The physical phenomena responsible for the allure of ultrathin 2D materials reside all the way down at the nanoscale and therefore STM is distinctively appealing for exploring their properties. In this project the student will be involved in STM experiments of 2D materials.

J.-M. Ménard

Resolving optically-induced ultrafast dynamics in quantum materials

Our research group uses ultrafast optical techniques such as time-resolved terahertz spectroscopy to improve the general understanding of quantum interactions in solids. The student will be involved in setting up optical experiments and low-temperature equipment to investigate low-dimensional materials at cryogenic temperatures. The studied samples will be thin films of strongly correlated materials exhibiting intriguing phase transitions. When an ultrashort optical pulse is launched on these samples, a new phase of matter can be created and destroyed on a femtosecond time scale. The ultimate goal of these experiments is to characterize these new transient states of matter and extract physical phenomena involved in the nonlinear light-matter interaction process.

Temporal compression of optical pulses inside a gas-filled hollow-core fiber

The optical energy emitted by an ultrafast laser is carried by extremely short bursts of light. When the duration of these optical pulses is reduced to a femtosecond scale, their oscillating electric field can reach an amplitude that is comparable to the internal binding electric field of atoms. This highly nonlinear regime has allowed experimentalists to explore new optical phenomena and design more performant characterization tools for condensed matter systems. The goal of this project is to compress optical pulses generated by an ultrafast laser to less than ten femtoseconds. Since time and frequency are two quantities related by the Fourier transform, the duration of an optical pulse can be reduced by broadening its spectrum. New spectral components of a high energy optical pulse will be generated by launching it inside a gas-filled hollow-core fiber. The student will design and assemble the spectral broadening scheme, which includes a gas control panel and pressure cells permitting gas flow inside the fiber. A pair of dielectric chirped mirrors will then be used to reach the minimum pulse duration. The pulse will be characterized using auto-correlation techniques.

G. Milne

Computational Geophysics

Projects are available that involve running computer models to compare against observations of the Earth System. The models are run on Linux servers and compute the response of ice sheets and sea level to climate change. A variety of projects are available that are ideally suited to students with an interest in climate change and computational physics. Please contact Dr. Milne (gamilne@uottawa.ca) to obtain details on possible projects.

L. Ramunno

Inverse design of epsilon-near-zero waveguides

Epsilon-near-zero materials interact with light in very unique and exotic ways. The aim of this project is to design a nanostructured ENZ waveguide that will emit plane waves along its length, but only in one direction, in collaboration with the research group of Prof. Boyd who is fabricating such structures. A potential application is long-range waveguide coupling for all-optical chips, for which there is currently no competing technology. You will be using state of the art computational tools to simulate electromagnetic waves in ENZ waveguides, and apply and develop optimization methods, such as deep learning, to create a prototype structure for fabrication. Inverse design is a new and exciting direction in nanophotonics, and the computational methods developed here could have potentially large impact in their own right.

Z. Stadnik

Coexistance of magnetism and superconductivity in Fe-based superconductors studied by Mössbauer spectroscopy

While magnetism and superconductivity are traditionally antagonistic phenomena, there is growing experimental evidence that unconventional superconductivity in the high-transition temperature (high-Tc) superconductors is closely linked to magnetism. This project is devoted to experimental studies of magnetism of the high-Tc, Eu-based, iron-pnictide superconductors using ^{151}Eu and ^{57}Fe Mössbauer spectroscopy and magnetic measurement techniques.

Magnetism of crystalline garnet and its amorphous counterpart: Mössbauer spectroscopy study

It occurs very rarely that a compound can be synthesized both in crystalline and amorphous forms. Comparing the physical parameters of such two types is of significant scientific interest. This project will employ the ^{57}Fe Mössbauer spectroscopy technique to study local physical parameters of such a compound.

Mössbauer spectroscopy study of Fe-based spinels

Although spinels have been studied for many years, there are still several questions regarding the nature of their magnetic ordering that remain open. Advancement in our understanding of the physics of these compounds can be only achieved when these questions are answered unambiguously. This project will use the Mössbauer spectroscopy method to investigate local magnetism in several magnetically complex spinels.

I. Tamblyn (NRC)

Can an artificial intelligence learn some physics? Deep learning applied to time propagators

This project will use recurrent neural networks with long short term memory (LSTM) to learn the dynamics of interacting particles in an external field. Deep neural networks are now commonly used within the tech industry to solve problems relating to image-recognition, text-synthesis, and real-time language translation. They have also shown great promise in the physical sciences as an approach for dimensionality reduction and approximating computationally demanding partial differential equations. Here, our goal is to produce a neural network capable of estimating the time propagation of complex systems without prior knowledge of the underlying equations of motion or conserved quantities. We will investigate the relationship between the networks ability to learn and the nature of inter-particle interactions (e.g. short vs long range, many-body, etc). The transferability of learning will also be considered.