



PURDUE QUANTUM CENTER

## PQC WORKSHOP 2017

# COHERENT EFFECTS IN PHYSICS AND CHEMISTRY

**April 28<sup>th</sup> (Fri), 1-5pm in MRGN 121**

12:30pm – 1:00pm: Refreshments

1:00pm – 1:10pm: Opening remarks

**1:10pm – 2:00pm: Alexander K. Popov**

*Coherent nonlinear optical propagation processes in hyperbolic metamaterials*

**2:00pm – 2:50pm: Yong P. Chen**

*Quantum coherent transport in electrons and atoms*

*Coffee break*

**3:10pm – 4:00pm: Timothy S. Zwier**

*Coherence transfer in manifolds of molecular rotational levels: Strong field effects in the microwave region*

**4:00pm – 4:50pm: Daniel S. Elliott**

*Precision measurements of weak transition moments using interfering coherent optical interactions*

4:50pm – 5:00pm: Closing remarks

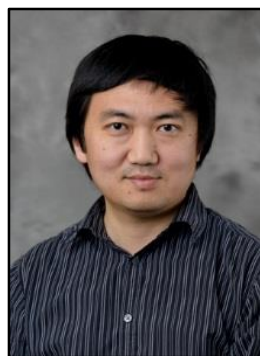
## INVITED SPEAKERS



Alexander K. Popov  
Research Professor  
at Birck Nanocenter



Daniel S. Elliott  
Professor of ECE



Yong P. Chen  
Professor of Physics



Timothy S. Zwier  
Professor of Chemistry

**Workshop chair: Vladimir M. Shalaev**



for questions email Mikhail Shalaginov: [shalaginov@purdue.edu](mailto:shalaginov@purdue.edu)

**Speaker:** Alexander K. Popov

**Title:** Coherent nonlinear optical propagation processes in hyperbolic metamaterials

Coherence and interference play an important role in classic and quantum physics. Processes to be employed can be significantly enhanced and the unwanted ones suppressed through the deliberately tailored constructive and destructed interference at quantum transitions and at nonlinear optical (NLO) coupling of waves in bulk materials. Phase matching of the coupled waves at different frequencies is the requirement of a paramount importance for frequency conversion and energy harvesting of the electromagnetic waves by the means of NLO. Unusual beneficial NLO processes were predicted at the coherent coupling of ordinary and extraordinary backward electromagnetic waves (BEMWs). Energy flux and phase velocity are counter-directed in BEMWs. Herewith, we show that deliberately engineered spatially dispersive metamaterial slab can enable the co-existence and phase matching of contra-propagating ordinary fundamental and extraordinary backward second harmonic surface electromagnetic modes. We show that frequencies, phase, and group velocities, as well as nanowaveguide losses inherent to the electromagnetic modes supported by such metamaterial, can be tailored to maximize frequency conversion and to reverse propagation direction of the generated wave. Such a possibility in THz is proved with a numerical model of the hyperbolic frequency-doubling metareflector made of carbon nanotubes standing on the metal surface. The possibility to extend this approach to other coherent NLO processes and materials will be discussed too.

**Speaker:** Yong P. Chen

**Title:** Quantum coherent transport in electrons and atoms

I will discuss some recent experimental examples from my lab studying quantum coherent transport and interferometry in electrons as well as cold atoms. For example, phase coherent electron transport and interference around a cylinder realized in a nanowire of topological insulator gives rise to a novel “pi phase shifted” Aharonov-Bohm oscillation in the electrical conductance versus magnetic field. The phase of this electron interferometer can be further switched between 0 and pi by tuning the chemical potential of the electrons using a gate voltage, and the electronic conductance oscillates whenever the circumference of the cylinder encloses an integer number of the Fermi wavelengths. These observations reveal the unique signatures of the so called “spin-helical” Dirac electrons on the surface of a topological insulator. In another example, we realize an atomic interferometer in the momentum space in a Bose-Einstein condensate (BEC) subjected to a Raman optical coupling with time-periodic modulation. This creates a so called “synthetic” spin-orbit-coupling and “dressed” band structures (modified energy-momentum dispersions) for the atoms with two avoided crossings in the band structures acting as two beam splitters in the momentum space. Transporting (using for example gravity) the atomic BEC across this “synthetic” bandstructure with two beam splitters gives rise to the Landau-Zener-Stueckelberg interference, manifesting as an oscillation in the spin polarization versus experimental parameters that varies the phase difference between the two pathways traversed by the atoms in the momentum space.

**Speaker:** Timothy S. Zwier

**Title:** Coherence transfer in manifolds of molecular rotational levels:  
Strong field effects in the microwave region

This talk will describe the Zwier group's recent forays into the relatively uncharted territory of strong-field coherence effects in molecular rotational manifolds. Using technological advances from the communications industry, there has been a revolution of sorts in the use of arbitrary waveform generators, high-powered microwave amplifiers, sensitive detectors, and fast digitizers to collect huge swaths of the microwave and millimeter wave spectrum of a gas phase molecular sample on the microsecond timescale. With signal averaging, these spectra have impressive sensitivity and resolution. The community engaged in such studies is just now beginning to put together sequences of pulses that can be used to control and read-out information, much as is done in NMR. We have begun to explore some of these possibilities here at Purdue, using an instrument that records spectra over the 8-18 GHz region.

Using standard hardware available in chirped-pulse Fourier transform microwave (CP-FTMW) spectroscopy, we have developed a multiple-pulse method that uses strong-field coherence breaking to selectively extract from the microwave spectrum of an otherwise complicated multicomponent mixture a set of transitions due to a single component, thereby speeding spectral assignment. In the process of developing these methods, we have realized that a much simpler experiment, involving Rabi cycling the rotational population of a single rotational transition, also shows interesting physics associated with the propagation of these coherences out into the rotational manifold. We are just beginning to model these results in collaboration with the Robicheaux group here at Purdue. Our current understanding of these spectra will also be described.

**Speaker:** Daniel S. Elliott

**Title:** Precision measurements of weak transition moments using interfering coherent optical interactions

We can understand almost everything we need to know about the structure and properties of atoms and molecules in terms of electromagnetic interactions. But nucleons and electrons also interact through the weak force, and this interaction slightly changes the structure of atoms and molecules. Optical transitions that are not allowed in the absence of the weak force become slightly allowed, due to the different parity laws of the weak force. Precise measurements of these amplitudes can therefore provide us a tool for measurement of the weak force in a table-top experiment. These measurements play a critical role in the search for dark matter, and for understanding the structure of the nucleus. We discuss our experimental efforts toward measurement of two parity-violating transitions in atomic cesium, using the interference between different optical interactions. These techniques are analogous to homodyne or heterodyne detection of weak optical signals, and allow us to measure transition moments that are so weak that direct detection is not feasible.