Curriculum Vitae of Ioannis Chatzakis

Personal

US Naval Research Laboratory
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Nationality: Greek (U.S.A. permanent resident)

Employment

US Naval Research Laboratory (NRL), Electronic Science and Technology Division
American Society of Engineering Education (ASEE) Postdoctoral Research Fellow 2016 – Present
(Advisors: J. Caldwell, josh.caldwell@vanderbilt.edu; K. Hobart, karl.hobart@nrl.navy.mil)
– Leading the investigation of *(i)* static and dynamic optical properties of polaritonic materials in nanoscale, *(ii)* ultrafast carrier dynamics in low dimensional materials, and *(iii)* light confinement by nanostructres

University of Southern California, Electrical Engineering Dept.
Research Associate / Postdoctoral Researcher 2013 – 2015
(Advisor: S. B. Cronin, scronin@usc.edu)
– Examined the optical and electronic properties of two dimensional dichalcogenide materials
– Conducted independent research on Graphene-based THz modulators

Stanford University, Materials Science and Engineering Dept.
Stanford Institute for Materials & Energy Sciences (SIMES) – SLAC
Postdoctoral Research Fellow 2012 – 2013
(Advisor: A. M. Lindenberg, aaronl@stanford.edu)
– Investigated phase-change materials (e.g. GeSbTe) using ultrafast THz spectroscopy

Iowa State University, Physics and Astronomy Dept.
Ames Laboratory – DOE, Division of Materials Sciences and Engineering
Postdoctoral Research Associate 2009 – 2012
(Advisors: J. Wang, jwang@ameslab.gov; C. M. Soukoulis, soukoulis@ameslab.gov)
– Led the investigation of THz modulators based on metamaterials and the the study of intra-excitonic transitions in carbon nanotubes by THz spectroscopy

Photographer, Freelance and for Greek Newspapers and Magazines (Patris, Ktirio, Stigmes)
Aerial, Architectural, Documentary, and Portrait photography & Photojournalism 1995 – 2003

Education

Kansas State University, Physics Dept. 2009
Degree awarded: Ph.D. (Physics)
Advisor: P. Richard
Dissertation: *Ultrafast dynamics of electrons and phonons in graphitic materials*

University of Crete, Greece, Chemistry Dept. 2004
Degree awarded: M.Sc. (Applied Molecular Spectroscopy)
Advisor: T. N. Kitsopoulos
Thesis: *Nonlinear phenomena in the amplification of modulated UV (248nm) femtosecond laser pulses*

Technological Educational Institute of Crete, Electrical Engineering Dept. 1996
Degree awarded: B.Sc. (Electrical Engineering)
Diploma thesis: *Development of step motor controller*

Research Interests

My research focuses on light-matter interactions at the nanoscale. When the dimensionality of the system is reduced to 1-D or 2-D, novel physical phenomena emerge related to the electron or phonon confinement. In particular, I investigate *(i)* the static and dynamic optical properties of nanomaterials and heterostructures, *(ii)* new ways of light confinement beyond the diffraction limit, and *(iii)* enhanced light-matter interactions using atomically thin heterostructures. Furthermore, by using femtosecond laser spectroscopic techniques, I study the fundamental processes related to the relaxation and transport dynamics of electrons, phonons, and electron-phonon interactions in nanoscale systems in a broad spectrum of frequencies ranging from UV to THz. In parallel, I investigate the generation and modulation of THz radiation by metamaterials and graphene-based nanostructures.

Funding Proposals

Title: Trilayer graphene phototransistors for THz electronics *(P.I.: I. Chatzakis)*
Organization: University of Southern California Office of Postdoctoral Affairs
Duration: 2014 – 2015 **Funds:** *$25K*
Notes: Awarded Provost's Postdoctoral Scholar Research Grant, one of seven among 71 submissions. Supported independent research on terahertz devices based on artificial multilayer graphene.

Fellowships & Awards

American Society for Engineering Education (ASEE) Postdoctoral Fellowship
$225K sponsored by the U.S. Naval Research Laboratory — 2016 – 2019
Gerondelis Foundation graduate study scholarship
$5K awarded to exceptional students of Greek nationality — Academic Year 2008 – 2009

International Schools

12th & 13th Advanced Physics Summer School — 2000 & 2001
Organized by the University of Crete, Department of Physics and the Institute of Electronic Structure and Laser (IESL) – Foundation of Research & Technology - Hellas (FORTH); Held in Heraklio, Greece

Research Experience

U.S. Naval Research Laboratory
American Society of Engineering Education (ASEE) Postdoctoral Research Fellow — 2016 – Present
– Explore novel methods to control the optical properties of hyperbolic polaritonic materials by THz radiation
– Lead effort investigating single photon sources; design and development of a confocal microscope and HBT setup
– Developed a THz spectrometer and time-resolved photolumiscence apparatuses for nanomaterials
– Led the study of ultrafast carrier dynamics in low dimensional materials and of light confinement beyond the diffraction limit by nanostructures
– Led the investigation of the static and dynamic optical properties of nanomaterials and heterostructures
– Contributed to the investigation of the optical tuning of the reflectivity in 4H-SiC in the IR spectral range by utilizing a pump-probe method

University of Southern California, Electrical Engineering Dept.
Research Associate / Postdoctoral Researcher — 2013 – 2015
– Developed a THz spectrometer and time-resolved photolumiscence apparatuses for nanomaterials
– Led the investigation of the broad band THz modulation by artificial trilayer graphene
– Contributed to the study of the optical and electronic properties of two dimensional dichalcogenide materials
– Supervised a graduate student in experimental techniques and data analysis

Stanford University, Materials Science and Engineering Dept.
Stanford Institute for Materials & Energy Sciences (SIMES) – SLAC National Accelerator Laboratory

Postdoctoral Research Fellow 2012 – 2013

– Developed a THz spectrometer based in a two-color plasma source
– Led the investigation of the carrier dynamics in amorphous and crystalline GeSbTe by means of optical-pump THz-probe spectroscopy
– Contributed to the study of the time-resolved ultrafast THz-induced response of phase-change materials (e.g. GeSbTe)
– Supervised a junior postdoc and a graduate student in experimental techniques and data analysis

Iowa State University, Physics and Astronomy Dept.
Ames Laboratory – DOE

Postdoctoral Research Associate 2009 – 2012

– Led the study of THz generation and modulation by metamaterials
– Led the investigation of internal excitonic transitions in carbon nanotubes using THz spectroscopy
– Developed a THz spectrometer in reflection mode for circumventing the limitations associated with materials opaque to the THz radiation
– Supervised undergraduate and graduate students in experimental techniques and data analysis

Columbia University, Physics & Electrical Engineering Depts.

Visiting Graduate Research Assistant 2007 – 2009

– Measured the temperature dependence of the anharmonic decay rate in both graphite and single-wall carbon nanotubes using time-resolved anti-Stokes Raman spectroscopy
– Probed the ultrafast dynamics and interactions of optical phonons

Kansas State University, Physics Dept.

Graduate Research Assistant 2004 – 2009

– Investigated the charge carrier dynamics in carbon nanotubes by means of time-resolved Two-Photon Photoemission spectroscopy

Kansas State University, Physics Dept.

Visiting Scholar 2004

– Studied ion-atom collisions by zero-degree Auger projectile electron spectroscopy

University of Crete, Greece, Chemistry Dept.
Institute of Electronic Structure and Laser (IESL) – Foundation of Research & Technology - Hellas (FORTH)

Graduate Research Assistant 2001 – 2003

– Investigated the amplification of modulated femtosecond laser pulses in the UV spectral range
– Trained in ultrafast laser pulse diagnostics in the IR and UV wavelength regimes

Skills

◇ Over 16 years of hands-on experience in laser/terahertz pump-probe spectroscopy techniques
◇ Proficient in designing, building, and troubleshooting laser/terahertz spectrometers
◇ Extensive knowledge in Ti:Sa laser systems, ultrafast laser pulse diagnostics, diode lasers, optical design
◇ Design and development of Laser Scanning Confocal Microscopes
◇ Engineering design & development of electronic devices
◇ Scanning Electron Microscopy (SEM)
◇ Atomic Force Microscopy (AFM)
◇ Ellipsometry (IR-VASE ellipsometer)

Teaching Experience

Mentoring 2009 – 2015

Extensive mentoring of several graduate and undergraduate students in my field of research, and lecturing on my research to both scientists and non-scientists

Teaching Assistant, Kansas State University, Physics Dept. 2006

Graded students' biweekly exams for the undergraduate course "Engineering Physics" and monitored individual students' progress

Provided students with feedback regarding class assignments and course progress

Tutor, Heraklio, Greece 2001 – 2003

Assisted high school students with Physics and Mathematics

Memberships

American Physical Society (APS), The Optical Society (OSA)

Service in the Physics Community

Reviewer

OSA The Optical Society
ACS Photonics - American Chemistry Society
Applied Physics A: Materials Science & Processing
Defense Threat Reduction Agency (DTRA): Basic Research Program
NSF Graduate Research Fellowship Program (GRFP)

Peer Reviewed Journal Articles

1. **I. Chatzakis**, R. B. Davidson II, A. D. Dunkelberger, J. Freitas, A. Giles, C. T. Ellis, J. G. Tischler, J. D. Caldwell, and J. C. Owrutsky, *"Observation of rapid bimolecular and defect-assisted electron-hole recombination of free carriers in hexagonal Boron Nitride"*, Nano Letters (2018), subm.

2. **I. Chatzakis**, A. Krishna, J. Gilberstone, A. Giles, N. Sharac, M. G Spencer, and J. D Caldwell, *"Strong confinement of optical fields using localized surface phonon polaritons in cubic boron nitride"*, Optics Letters **43**, 2177 (2018)

3. D. C. Ratchford, C. Winta, **I. Chatzakis**, C. T. Ellis, N. Passler, J. Winterstein, P. Dev, I. Razdolski, J. G. Tischler, I. Vurgaftman, M. Katz, N. Nepal, M. T. Hardy, J. A. Hachtel, J. C. Idrobo, T. Reinecke, A. J. Giles, D. S. Katzer, N. D. Bassim, R. Stroud, M. Wolf, A. Paarmann, and J. D. Caldwell *"Controlling the Infrared Dielectric Function through Atomic-Scale Heterostructures"*, Nature Materials (2018), arXiv:1806.06792, under review

4. A. J. Giles, S. Dai, I. Vurgaftman, T. Hoffman, S. Liu, L. Lindsey, C. Ellis, N. Assefa, **I. Chatzakis**, T. L. Reinecke, J. G. Tischler, M. M. Fogler, J. H. Edgar, D. N. Basov, and J. D. Caldwell, *"Ultralow-Loss Polaritons in Isotopically Pure Materials: A New Approach"*, Nature Materials **17**, 134 (2018)

5. **I. Chatzakis**, Z. Li, A. V. Benderskii, and S. B. Cronin, *"Broadband terahertz modulation in electrostatically-doped artificial trilayer graphene"*, Nanoscale **9**, 1721 (2017)

6. R. Dhall, K. Seyler, Z. Li, D. Wickramaratne, M. R. Neupane, **I. Chatzakis**, E. Kosmowska, R. K. Lake, X. Xu, and S. B. Cronin, *"Strong circularly polarized photoluminescence from multilayer MoS2 through plasma driven direct-gap transition"*, American Chemical Society Photonics **3**, 310 (2016)

7. Z. Li, G. Ezhilarasu, **I. Chatzakis**, C-C. Chen, R. Dhall, and S. B. Cronin, *"Indirect band gap emission by hot electron injection in metal/MoS_2 and metal/WSe_2 heterojunctions"*, Nano Letters **15**, 3977 (2015)

8. L. Luo, **I. Chatzakis**, A. Patz, and J. Wang, *"Ultrafast THz probes of interacting dark excitons in chirality-specific semiconducting single-wall carbon nanotubes"*, Physical Review Letters **114**, 107402 (2015)

9. M. J. Shu, P. Zalden, F. Chen, B. Weems, **I. Chatzakis**, F. Xiong, R. Jeyasingh, M.C. Hoffmann, E. Pop, H.-S. Philip Wong, M. Wutting, and A. M. Lindenberg, *"Ultrafast terahertz-induced response of GeSbTe phase-change materials"*, Applied Physics Letters **104**, 201907 (2014)

10. L. Luo, **I. Chatzakis**, J. Wang, F. B. P. Niesler, M. Wegener, T. Koschny, and C. M. Soukoulis, *"Broadband terahertz generation from metamaterials"*, Nature Communications **5**, 3055 (2014)

11. **I. Chatzakis**, *"Electrons temperature dependence of the electron-phonon coupling strength in double-wall carbon nanotubes"*, Applied Physics Letters **103**, 043110 (2013)

12. M. J. Shu, **I. Chatzakis**, Y. Kuo, P. Zalden, and A. M. Lindenberg, *"Ultrafast sub-threshold photo-induced response in crystalline and amorphous GeSbTe thin films"*, Applied Physics Letters **102**, 201903 (2013)

13. **I. Chatzakis**, P. Tassin, L. Luo, N. H. Shen, L. Zhang, J. Wang, T. Koschny, and C. M. Soukoulis, *"One-and two-dimensional photo-imprinted diffraction gratings for manipulating terahertz waves"*, Applied Physics Letters **103**, 043101 (2013)
    Selected as Cover Article for Applied Physics Letters (July 22, 2013; Issue 4)

14. **I. Chatzakis**, L. Luo, J. Wang, N-H. Shen, T. Koschny, J. Zhou, and C. M. Soukoulis, *"Reversible modulation and ultrafast dynamics of terahertz resonances in strongly photoexcited metamaterials"*, Physical Review B **86**, 125110 (2012)

15. **I. Chatzakis**, H. Yan, D. Song, S. Berciaud, and T. Heinz, *"Temperature dependence of the anharmonic decay rate of optical phonons in carbon nanotubes and graphite"*, Physical Review B **83**, 205411 (2011)

16. H. Yan, D. Song, K. F. Mak, **I. Chatzakis**, J. Maultzsch, and T. F. Heinz, *"Time-resolved Raman spectroscopy of optical phonons in graphite: Phonon anharmonic coupling and anomalous stiffening"*, Physical Review B **80**, 121403 (2009)

17. T. J. M. Zouros, E. P. Benis, and **I. Chatzakis**, *"Optimization of the energy resolution of an ideal ESCA-type hemispherical analyzer"*, Nuclear Instruments and Methods in Physics Research Section B **235**, 535 (2005)

In preparation

- ◇ **I. Chatzakis**, D. Ratchford, C. Winta, N. Passler, P. Dev, S. Katzer, I. Razdolski, C. Ellis, J. Tischler, I. Vurgaftman, T. Reinecke, A. Giles, N. Bassim, J. Winterstein, R. Stroud, N. Nepal, M. Wolf, A. Paarmann, and J. D. Caldwell, *"Atomic scale heterostructures: Layer thickness dependence of hybrid optical phonon modes"*
- ◇ R. B Davidson II,*, A. D. Dunkelberger, D. C. Ratchford, **I. Chatzakis**, A. J. Giles, and J. Owrutsky *"Wavelength Dependent Reststrahlen Band Softening in 4H-SiC"*

Conference Papers

- ◇ A. J. Giles, I. Vurgaftman, S. Dai, T. Hoffman, S. Liu, L. Lindsey, C. Ellis, N. Assefa, **I. Chatzakis**, T. L. Reinecke, J. G. Tischler, M. M. Fogler, J. H. Edgar, D. N. Basov, and J. D. Caldwell, *"Ultra low-loss polaritons in hexagonal boron nitride"*, in Proc. SPIE 10722, Plasmonics: Design, Materials, Fabrication, Characterization, and Applications XVI, 1072214 (2018)

- R. B. Davidson, A. D. Dunkelberger, **I. Chatzakis**, B. B. Pate, J. D. Caldwell, and J. C. Owrutsky, "Ultrafast carrier dynamics in wide bandgap semiconductor materials", in Laser Science, OSA Technical Digest (online) (Optical Society of America, 2017), paper JTu3A.47

- **I. Chatzakis**, L. Luo, J. Wang, N. Shen, T. Koschny, and C. M. Soukoulis, *"Dynamic tunability of the electric dipole resonance in highly photo-excited metamaterials"*, in Quantum Electronics and Laser Science Conference, OSA Technical Digest (CD) (Optical Society of America, 2011), paper QThK3

- H. Yan, D. Song, K. F. Mak, **I. Chatzakis**, J. Maultzsch and T. F. Heinz, *"The Lifetime of Optical Phonons in Graphite"*, in Laser Science XXIV, OSA Technical Digest (CD) (Optical Society of America, 2008), paper LWH2

Selected Presentations

Seminars

- *"Ultrafast dynamical processes in solids"*, Dec. 2015, Naval Research Laboratory (NRL), Electronic Science and Technology Division / American Society of Engineering Education (ASEE), Washington, DC *(invited)*
- *"Ultrafast dynamics in solids"*, Apr. 2015, University of Dayton, Physics Dept., Dayton, OH *(invited)*
- *"Ultrafast spectroscopy of nanomaterials and metamaterials"*, Jan. 2012, Stanford Institute for Materials & Energy Science (SIMES), SLAC National Accelerator Laboratory, Palo Alto, CA *(invited)*
- *"Ultrafast spectroscopy of nanomaterials and metamaterials"*, July 2011, Lawrence Berkeley National Laboratory, Materials Science Division, Berkeley, CA *(invited)*
- *"Temperature dependence of the lifetime of optical phonons in carbon nanotubes & graphite"*, Oct. 2008, Kansas State University, Physics Dept., Manhattan, KS
- *"Lifetime of photo-excited charged carriers in double-wall carbon nanotubes"*, Feb. 2006, Kansas State University, Physics Dept., Manhattan, KS
- *"Nonlinear effects in the amplification of modulated femtosecond laser pulses"*, Jan. 2004, University of Crete, Chemistry Dept., Heraklio, Greece

Contributed Talks

- *"Ultrafast Carrier Dynamics in Nitride-based wide band gap semiconductors: Hexagonal Boron Nitride and Aluminum Nitride"*, Mar. 2018, 2018 APS March Meeting, Los Angeles, California

- *"Atomic scale heterostructures-controlling the reststrahlen bandwith superlattice design"*, Nov. 2017, MRS Fall Meeting, Boston, Massachusetts

- *"Investigationof unpatterned etching of nanostructures in immobilized cubic-Boron Nitride"*, Nov. 2017, MRS Fall Meeting, Boston, Massachusetts

- *"Terahertz modulators based on multiple non-Bernal graphene layers"*, Mar. 2015, 2015 APS March Meeting, San Antonio, Texas
- *"Ultrafast terahertz probes of interacting dark excitons in chirality-specific semiconducting single wall nanotubes"*, Sept. 2014, 30th Panhellenic Conference on Solid-State Physics and Materials Science, Heraklio, Greece
- *"Electrons temperature dependence of the electron-phonon coupling strength in double-wall carbon nanotubes"*, Mar. 2014, 2014 APS March Meeting, Denver, Colorado

- *"Photo-imprinted diffraction gratings for controlling terahertz radiation"*, Mar. 2013, 2013 APS March Meeting, Baltimore, Maryland
- *"Dynamic tunability of the electric dipole resonance in highly photo-excited metamaterials"*, May 2011, CLEO 2011: Laser Science to Photonic Applications Conference, Baltimore, Maryland
- *"Carrier concentration dependence of the tunability of the dipole resonance peak in optically excited metamaterials"*, Mar. 2011, 2011 APS March Meeting, Dallas, Texas
- *"Ultrafast Terahertz probes of individualized, chirality-enriched single wall carbon nanotubes"*, Mar. 2011, 2011 APS March Meeting, Dallas, Texas
- *"Temperature dependence of the anharmonic decay of optical phonons in carbon nanotubes and graphite"*, Mar. 2009, 2009 APS March Meeting, Pittsburgh, Pennsylvania

Posters

- *"Broadband terahertz modulation in electrostatically-doped artificial trialayer graphene"*, Nov. 2017, MRS Fall Meeting, Boston, Massachusetts
- *"Electrons temperature dependence of the electron-phonon coupling strength in double-wall carbon nanotubes"*, June 2014, NT14: The fifteenth international conference on the science and applications of nanotubes, Los Angeles, California
- *"Temperature dependence of the anharmonic decay of optical phonons in carbon nanotubes and graphite"*, Nov. 2009, Gotham-Metro Condensed Matter Meeting, New York Academy of Science, New York
- *"Lifetime of charge carriers in double-wall carbon nanotubes"*, May 2006, 37th DAMOP Meeting, Knoxville, Tennessee
- *"Ultimate energy resolution of an ideal ESCA-type hemispherical spectrometer"*, Sept. 2004, 12th International Conference on the Physics of Highly Charged Ions (HCI-2004), Vilnius, Lithuania

RESEARCH STATEMENT

IOANNIS CHATZAKIS

My research focuses on the optical and electronic properties of nanomaterials and nanostructures, and in particular, on understanding the fundamental processes related to the dynamics of charge carriers, phonons, and other excitations (i.e. excitons, polaritons). Understanding the principles that govern these excitations will enable the fabrication of optoelectronic and photonic devices with novel and enhanced functionalities. I am also interested in developing new methods for THz generation and modulation by nanomaterials (e.g. graphene) and metamaterials, in addition to the investigation of novel methods for light confinement beyond the diffraction limit. In my research I use femtosecond pump-probe techniques from UV to THz frequencies, complemented by other optical spectroscopy methods.

I envision myself establishing a versatile *Ultrafast Spectroscopy of Quantum Materials Laboratory* with strong capabilities in ultrafast optical spectroscopy and microscopy of nanoscale systems. I plan to approach my research topics from three directions: *(i)* Develop instruments for ultrafast optical and THz time-domain spectroscopy, and confocal photoluminescence microscopy apparatuses; *(ii)* Characterize and investigate materials, and artificial structures for optoelectronic and nanophotonic devices; and *(iii)* Interact and collaborate with professors from other departments to employ these techniques in new research areas. *The goal of my research is to have a significant impact on the understanding of the fundamental Physics of nanostructures, as well as their practical applications in the next generation photonic/electronic devices.*

Proposal

When the dimensionality of a system is reduced to one atom-thick, novel physical phenomena emerge from the confinement of electrons. The recent advances in these atomically-thin materials hold enormous promise, as novel systems are characterized by exceptional properties. Using these materials, it is feasible to assemble novel nanostructures that allow enhanced light-matter interaction, and light manipulation in nanoscale. Here I propose a research project that aims at building a common framework for photonic/optoelectronic devices development, and their characterization, based on a combination of atomically-thin sheets across a broad range of materials. One type of materials is the Transition Metal Dichalcogenides (TMDCs) [1], which are semiconductors with their band gap in the optical frequencies, and in an atomically thin form, demonstrating fascinating optoelectronic properties. For instance, they offer a huge flexibility in tuning their electronic properties. Another type of materials is the topological insulators (TIs; e.g. Bi_2Se_3, Bi_2Te_3, and Sb_2Te_3). They behave as insulators in bulk, and conductors on their surface. In the list of the materials of interest can be included the polar dielectrics (e.g. h-BN). These materials support phonon polaritons, i.e. collective oscillations of photons coupled with lattice vibrations. *In particular, I propose to study the:*

Ultrafast dynamics in topological insulators (TIs). Due to their unprecedented properties, the TIs are promising materials for high efficiency THz detectors, spintronics and quantum computing devices. High velocities, and low masses characterize the electrons in TI's owing to existence of the surface electronic states. Recently, it was demonstrated that the TIs also support plasmon polaritons, which are collective oscillations of free electrons in conductive media. In these materials the light can excite plasmons with frequencies few THz. [3]. Hence, the THz spectroscopy is the ideal tool for investigating the plasmons in TIs. Moreover, many of their lattice vibrational frequencies are within the THz spectrum. Thus, THz pulses can resonantly excite particular phonon modes in TIs. I will study the properties of plasmons and phonons in TIs using time-resolved THz spectroscopy. In particular, I will investigate *(i)* the lifetime of these plasmons, and how this is affected by the thickness of the material, *(ii)* what mechanisms are governing the non-radiative plasmon decay [4] and the subsequent generation of hot-carriers, and *(iii)* how these timescales are influenced by the dielectric environment. Furthermore, I will examine the THz-induced phonon dynamics in these materials. In a pump-probe scheme, THz pulses will excite the phonon modes that will subsequently be probed by a second laser beam.

Photoluminescence (PL) engineering by hybrid nanophotonics. Manipulating the PL properties of light-emitting materials is essential for a wide variety of optoelectronic applications. Multifold enhancement and spectrally narrow PL can be achieved by a semiconducting material hybridized with plasmonic periodic nanostructures (metamaterials) that could support collective plasmonic excitations [2]. This occurs when the PL frequency of a semiconductor lies near the plasmon resonance of the metamaterial. However, there are competing mechanisms to the enhancement, and the PL can be quenched if the emitters are very close (few nm) to the metallic elements of the metamaterial. Energy can be transferred from the emitter to the metal resulting in the quenching of the light emission and simultaneous excitation of surface plasmons in the metal. Hence, careful design of the device is needed. I will use TMDCs-based heterostructures integrated into nano-metamaterials in order to investigate the characteristics and control the PL emitted by these hybrid systems. There are several open questions that I will address: *(i)* Does the dielectric environment of the hybrid structure plays a role in the PL emission, and what principles govern this role? *(ii)* What are the geometrical characteristics of the metamaterial that will result in the best possible PL emission enhancement? *(iii)* Will it be feasible to obtain a fast tunability of the PL by externally applied voltages? *(iv)* Which is the suitable combination of materials for an efficient response in a given spectral range? (*v)* How does the plasmons respond to the external applied voltages? PL engineering by hybrid nanophotonics has many practical applications (e.g. fluorescence imaging, low-threshold lasing devices, quantum computing, optical communications, sensing, and enhanced light-energy conversion).

Phonon-Plasmon Polaritons based nanophotonics. The realization of light confinement in dimensions typically smaller than its wavelength is one of the main challenges in the field of nanophotonics. Plasmonic devices successfully demonstrate sub-diffractional confinement but suffer from high optical losses and the short lifetime of the surface plasmons (*SPP*). On the other hand, in polar crystals the coupling between lattice vibrations (phonons) with photons results in surface phonon polaritons (*SPhP*). Systems that support these quasi-particles have demonstrated sub-diffractional light confinement similar to that in plasmonics. Their lifetime, in comparison to that in plasmons, is orders of magnitude longer, and shows very low losses [5]. However, despite the long lifetime of the phonon polaritons and the long distance they can propagate, they are lacking bandwidth and tunability. A solution to this problem could be a hybrid system comprised by a polar material integrated with a plasmonic material. It has been demonstrated recently that the coupling of *SPhP* with the *SPP* results to hybrid modes characterized by the functionality of the plasmons (i.e. large operating bandwidth and tunability), and the low optical losses originated from the phononic nature of the *SPhP* in the polar material. In the basis of the above findings, my research will be focused on the investigation of the fundamental properties of the polaritonic systems. By investigating the dynamics of these quasi-particles, a deep insight in the nature of the associated interactions and time scales that occur can be provided. Moreover, it is of fundamental importance to understand how the properties of the polaritons vary with the dimensionality, doping, different strain conditions, and other applied external perturbations to the constituent materials. The ideal method to study the dynamics of these quasi-particles is by means of ultrafast pump-probe techniques, where my expertise lies in. Understanding the mechanism by which the hybridization effects occur and how they can be best leveraged could provide the first realistic pathway towards overcoming the limitations of polaritonic media that have, up until now, kept most of these photonic devices from commercial applications in the infrared frequencies.

Long-term research plans. My long-term research plans include the investigation of *(i)* single photon sources based on layered structures, and *(ii)* photon-photon interactions in nanophotonic cavities combined with a highly nonlinear material, for applications in optical-based computing technologies.

Realization at Texas Tech University

I strongly believe that this vision is well placed with respect to the priorities of the physics department at TTU. From my perspective, while I will bring a new approach towards exploring this exciting discipline, the faculty at TTU is exceptional in its achievements and provides an exciting opportunity for me to realize my above stated vision.

Collaborations with members in Center of Quantum Phenomena, and other institutes. A very fruitful collaboration can be established with Prof. Grave de Peralta as our interests overlap in the research field of nanophotonics, and plasmonics while the differences in our research directions make us quite complementary. Collaborations with Prof. Duncan could prove quite beneficial to his efforts in the field of materials development and characterization. In particular, investigating the optical properties of materials by optical-pump THz-probe spectroscopy. This method is an ideal tool as the energy of the elementary excitations e.g. phonons, spin waves etc. in materials are in the same scale as the THz photons. As theory and experiment go hand in hand, collaborations with Prof. Estreicher, Prof. Myles, and Prof. Sanati is of course a possibility. Theoretical predictions motivate experiments but also the models can be reassessed in the light of the experimental results. Moreover, simulations and modeling on the development of bottom-up strategies for novel materials and heterostructure designs can be realized. Furthermore, the development of novel materials for plasmonics and phonon polaritons could prove quite beneficial to the efforts of Prof. Huang towards biosensing, in addition to the imaging capabilities of biological systems in the THz range that I will be able to provide. The needs of my research in the realm of sample fabrication can be met from current ongoing collaborations I have established through the years at various research institutes and universities (e.g. NRL, Ames Laboratory, Stanford University, University of Southern California).

However, while the above succinctly outline the potential for how the Faculty at TTU can assist me in achieving my vision, the *Quantum Materials Laboratory* that I envision establishing would also serve the department in providing characterization of the materials and devices in nanoscale. While it may not be reasonable to anticipate that all of these collaborations would come to fruition, the incredible potential for such successful interactions has me extremely excited for the potential of joining the team. I believe it is through such interactions that I can assist in enhances and complement the existing thematic coverage in physics department at TTU.

Funding and undergraduate/graduate students' involvement

In order to finance my research, I intend to propose and compete for funds through the appropriate channels (e.g. national institutes, government agencies – NSF, DoD, DARPA – and industrial sector). My research program will provide a superb training environment for young students with diverse backgrounds and interests. Along with training in research, I will encourage the graduate student involvement as direct preparation for the students' future careers, providing them with the necessary skills that translate to their current and future careers.

Summary

Nanoscience is an extremely demanding, and rapidly changing field. It has emerged as a technological advancement that could develop and transform the entire electronic and photonic devices sector. With this in mind, I plan to accomplish my research goals quickly and efficiently. I will investigate and characterize novel materials and artificial structures for next generation photonic devices. For accomplishing these research activities, I will develop instruments for ultrafast optical, and THz time-domain spectroscopy, and apparatuses for confocal photoluminescence microscopy. Moreover, I will interact and collaborate with other faculty members at TTU and other institutes and organizations.

References

[1] K. F. Mak *et al.*, *"Atomically thin MoS_2: A new direct-gap semiconductor"*, Phys. Rev. Lett. **105**, 136805, (2010); M.-Y. Li *et al.*, *"Epitaxial growth of a monolayer WSe2-MoS2 lateral p-n junction with an atomically sharp interface",* Science **349**, 6247 (2015)

[2] M. Fang *et al.*, *"Electrodynamic Modeling of Quantum Dot Luminescence in Plasmonic Metamaterials",* ACS Photonics **3**, 558 (2016)

[3] P. Di Pietro *et al.*, *"Observation of Dirac plasmons in a topological insulator",* Nature Nanotech. **8,** 556 (2013)

[4] R. Sundararaman, P. Narang, A. S. Jermyn, W. A. Goddard & H. A. Atwater, *"Theoretical predictions for hot-carrier generation from surface plasmon decay"*, Nature Communications **6**, 5788 (2014)

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TEACHING STATEMENT

IOANNIS CHATZAKIS

For as long as I can remember, I have always been passionate about Physics. I still recall how fascinated I was when I connected a flash light lamp to a battery with two wires and made it glow. I was only 6 years old and in complete awe! This feeling was the spark that ignited my passion for Physics. At the same time, I will never forget the disappointment after disassembling old radio devices trying to discover where the sound was coming from, only to find there was no one hidden in there. Later, I realized that this curiosity was the foundation of my love for learning and understanding the world around me.

While attending University of Crete, Greece, for my M.Sc. degree, I tutored high school students in Physics and Math. Later on, during the course of my Ph.D., I assisted in teaching the undergraduate course Engineering Physics. I provided each individual with feedback regarding class assignments and monitored his/her progress. Following that, and throughout my time as a postdoc, I had the distinct pleasure of serving in an advisory role to both graduate and undergraduate students, who had come from broad ethnic backgrounds and all different levels. From my interactions with them, I have been able to hone my mentoring skills and I believe I have successfully instilled the necessary understanding, motivation and self-sufficiency that is required for success in education within my former students. For instance, an undergraduate student, whom I supervised while I was a postdoctoral researcher at Iowa State University, designed and developed a balance detector for detecting very weak optical signals, typically used in terahertz spectrometers. In addition, another Ph.D. student worked under my guidance on a project that led to a Nature publication in which I am the second author.

Over the years, I have formed a comprehensive view of the learning processes, not only as a teaching assistant, but also as an advisor and a student, which I plan to incorporate into my teaching methods. Sharing my knowledge and expertise with students is very important to me. Lecturing is a significant part of how I will teach each of the class sessions, and I will provide very clear guidelines for how I want tasks completed in each course. I will often show students how they can use various principles and concepts, and students will receive frequent comments on their performance. They will typically work independently on scaffolding course projects. Activities in the class that will take place will encourage students to develop their own ideas about content issues, and small group discussions will be employed to help students develop their ability to think critically. Thinking is an internal process that is activated by a range of internal or external stimuli, such as observation, challenging questions and triggering of student's imagination. The thinking process is also unbreakably connected to creativeness. Using inexpensive materials one can perform various Physics experiments, thus prompt the students, spark their imagination, and stimulate their creativity.

Solving homework and exam problems demands thinking and deep understanding of the subject. It involves conversion of the problem's words into mathematical formulas, which cannot be achieved by emulating the provided examples. One of the most fruitful classroom moments I had was during the problem session of the Electrodynamics graduate course. Each of the students had to present a problem of his/her choosing to the class in a comprehensive manner showing the most important steps in Mathematics. Classmates and the Professor exposed the presenter to questions, who was able to answer only after obtaining deep understanding of the principle related to the specific problem. Only then the homework was accepted, while its evaluation was based both on the problem solution and the presenter's performance. Along with deep learning of the subject, conceptual approach, mathematical practicing, and teaching skills development were also obtained. I found this pedagogical method very effective, thus whenever the class size allows me to do so, I plan to adopt it. The student's assessment will also include a final exam. I will employ similar methods for achieving my teaching objectives.

I want my students to leave the class well prepared for further work in a higher level of the course. I want them to:

i) *Develop problem-solving skills and the ability to think and work both independently and productively with others*. For instance, this will be achieved with independent activities in the class as follows: *a*) Identify the nature of the problem. Einstein once said "The formulation of the problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill"; *b*) Define the main elements of the problem. Breaking down the problem into small pieces (steps), so it is easier to handle them; *c*) Examine possible solutions. This step demands some intuition that can be developed with practicing in addition to knowing the background material; *d*) Act on resolving the problem. Developing step by step an execution plan; *e*) Look for lessons to learn. After the problem has been solved, evaluate the entire process and formulate the lessons needed to be learned.

ii) *Develop the ability to apply principles and generalizations already learned to new problems and situations, and improve their analytical skills.* Applying the principles is sometimes tricky, but can be achieved with in-class problem solving and discussion. Analytical skills refer to the ability to deconstruct the "big picture" and identify details, treads, and links between each piece. An effective way for the students to improve their analytical skills is to work on group projects. The feedback between the team members will be encouraged, and will help them self-assess their skills.

iii) Develop the ability to draw reasonable inferences from observations, to synthesize and integrate information and ideas, to think creatively, and improve their mathematical skills.

iv) Improve the ability to organize and use time effectively, and develop a lifelong love of learning.

Recently, I was invited to lecture students at an undergraduate university and as I began to put my notes together, I quickly came to realize that I needed to make the material not only explanatory, but also interesting to be followed with attention for the whole duration of the lecture. In addition, I had to present my research to professors, researchers, postdocs and students. I needed to expand on the introductory material to ensure that the undergraduate students could follow the themes presented, appreciate the material and hopefully become excited by the topic. As the majority of my talks have been presented at international conferences this was an uncommon opportunity for me, which I thoroughly enjoyed it. In the end, the talk was very well received and I was delighted to have the opportunity to interact after the talk with over a dozen students that had additional questions. While I love performing research, the joy I had in getting these relatively complicated concepts across to this promising group of students made it plain just how much I enjoy interacting with students in both a laboratory and classroom environment, and how much teaching actually benefits the teacher him/herself.

My diverse background lends itself to teaching a wide array of classes, from the curriculum e.g. Semiconductor Characterization and Processing Laboratory (5332), Instructional Laboratory Techniques in Physics (5104), general physics I (Phys 1401) and II Phys (1402). At the same time, the teaching of graduate level courses naturally requires incorporating the most up-to-date advances in research for the topical areas of discussion, and thus provides perhaps the most exciting and challenging lecturing opportunities. One of my hopes would be to create a course focused on ultrafast measurements techniques. I believe this is especially important for Materials Physics, as the new discoveries in the Materials Science field have changed our daily lives.

In conclusion, I am confident my scientific expertise could prove a strong asset at the TTU. While I feel my research interests mesh exceptionally well with those of the current Faculty, I believe I also bring a new perspective, one that has spent several years tailoring my postdoctoral work, that could enhance what appears to already be a vibrant teaching department.

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- R. B Davidson II,*, A. D. Dunkelberger, D. C. Ratchford, **I. Chatzakis**, A. J. Giles, and J. Owrutsky *"Wavelength Dependent Reststrahlen Band Softening in 4H-SiC"*

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BACKGROUND

IOANNIS CHATZAKIS

Increasingly in recent years I found myself engaged in Materials Science, and in particular in studies of nanoscale materials. During the course of my graduate work I studied the electron and phonon dynamics, as well as their interactions in low-dimensional systems. I applied time-resolved Raman scattering to probe the ultrafast dynamics of optical phonons in graphite. In this work, we measured the lifetime of the optical phonons and observed a transient stiffening of these phonon modes [15]. In addition, I performed temperature-dependent measurements of the phonon dynamics in carbon nanotubes and graphite from 6 K up to 700 K, providing a quantitative understanding of the available decay channels for the energy relaxation [14]. While the phonon-phonon coupling has been investigated theoretically in this system, no experimental measurements have been previously made. Furthermore, I employed time-resolved photoemission spectroscopy to probe the temperature dependence of the electron-phonon coupling strength in double-wall carbon nanotubes [10][1]. I found a linear dependence of the energy transfer rate from electrons to the lattice as a function of the temperature, evidence for ballistic conductance, and an electron energy decay rate similar to that in graphene.

In my post-doctoral work, I used THz time-domain spectroscopy to investigate the interactions of non-optically activated excitations in single-wall carbon nanotubes. We found that the strong correlation between electrons regulates the exciton formation [7]. Moreover, I demonstrated an ultrafast reversible modulation of THz radiation in photoexcited metamaterials, and I established a simple approach to achieving nonlinear and frequency-agile functions in THz devices [13][2]. Building on previous work, I designed and engineered a reconfigurable THz component that can be switched between a wide class of functionalities (e.g. beam shaping, beam steering, etc) [12]. Taking this a step further, we developed a method for generating THz radiation based on metamaterials [9]. We demonstrated efficient emission up to 4 THz from optical rectification in a single split-ring resonator layer (40 nm thick). I also used strong electromagnetic fields at THz frequencies to study the ultrafast photo-induced response in crystalline and amorphous GeSbTe [8,11]. We directly observed the carrier heating process, and the energy transfer rate from the electrons to the lattice in both crystalline and amorphous phases, and found that the energy relaxes faster in more disordered systems. While I was at University of Southern California, I was awarded a *Provost's postdoctoral scholar research grant in the amount of $25,000* to perform independent research. I developed a THz modulator, and I obtained broadband THz modulation in electrostatically-doped artificial trilayer graphene [4]. Furthermore, I investigated novel methods for photoluminescence enhancement in 2-D dichalcogenide materials, such as MoS_2 and WSe_2 [5,6].

My ongoing research at the Naval Research Laboratory involves the investigation of tailoring the dielectric function of heterostructures comprised by atomically thin layers. It also includes the exploration of new methods for realizing nanophotonic elements for light confinement beyond the diffraction limit, using the polar materials AlN, GaN, h-BN, SiC [1-3]. Currently, I work on a project for controlling the optical properties of an AlN/GaN multilayered atomically thin heterostructure. We epitaxially grew layers of AlN and GaN (each 2.5 nm thick) in a vertical stack, synthesizing the AlN/GaN heterostructure. We observed new phonon modes stemming from the coupling of the modes of each layer that in turn resulted in a modified dielectric function due to its dependence on the phonon frequencies. Moreover, I investigate the ultrafast carrier dynamics in h-BN, and AlN. This research will contribute to the development of next generation nanophotonic devices and IR/optical components, like antennas for communication, enhanced emitters, sources and detectors to name a few.

References:
Can be found in the list of my publications

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[1] *Single-author paper*
[2] *Featured cover of Applied Physics Letters, Volume 103, Issue 4, 22 July 2013*