Chun Hung (Joshua) LUI

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PROFESSIONAL EXPERIENCE

- **UC Riverside**
  Assistant Professor (07/2015 – Present)
- **Massachusetts Institute of Technology (MIT)**
  Postdoc (08/2012 – 06/2015)
  Adviser: Nuh Gedik
  Research topics: Investigation of 2D materials by terahertz and Raman spectroscopy
- **Columbia University**
  Postdoc (01/2012 – 08/2012)
  Ph.D. in Physics (09/2006 – 02/2011)
  Adviser: Tony F. Heinz
  Thesis: "Investigations of the electronic, vibrational and structural properties of single and few-layer graphene"
- **Hong Kong University of Science and Technology (HKUST)**
  M.Phil. in Physics (01/2005 – 08/2006)
  Adviser: Michael M. T. Loy
  Thesis: "Optical properties of InGaN/GaN multiple quantum well light emitting diodes"
  B.S. in Physics & Mathematics (Dual Degree) (09/2002 – 12/2004)

PUBLICATIONS *(updated in July 2015)*

Total citations: 1600 (ISI) / 2200 (Google Scholar); *h*-index: 14
Google scholar website: http://scholar.google.com/citations?user=wl75x9cAAAAJ&hl=en

1. **C. H. Lui**, Z. Ye, C. Ji, K.-C. Chiu, C.-T. Chou, T. I. Andersen, C. Means-Shively, H. Anderson, J.-M. Wu, T. Kidd, Y.-H. Lee & R. He, "Observation of interlayer phonon modes in van der waals heterostructures", ***Phys. Rev. B*** 91, 165403 (2015) (Link)
2. **C. H. Lui**, Z. Ye, C. Keiser, E. B. Barros & R. He, "Stacking-dependent shear modes in trilayer graphene", ***App. Phys. Lett.*** 106, 041904 (2015) (Link)
3. **C. H. Lui**, A. J. Frenzel, D. Pilon, Y. H. Lee, X. Ling, G. M. Akselrod, J. Kong & N. Gedik, "Trion-induced negative photoconductivity in monolayer MoS_2", ***Phys. Rev. Lett.*** 113, 166801 (2014) (Link). This work is selected as **Editor's Suggestion**, and is highlighted in ***MIT News*** (Link), **Department of Energy**, and **SPIE Newsroom**.
4. **C. H. Lui*,** Z. Ye*, C. Keiser, X. Xiao & R. He, "Temperature-activated layer-breathing vibrations in few-layer graphene", ***Nano Lett.*** *14, 4615-4621* (2014) (Link)
5. A. J. Frenzel, **C. H. Lui**, Y. C. Shin, J. Kong & N. Gedik, "Semiconducting-to-metallic photoconductivity crossover and temperature-dependent Drude weight in graphene", ***Phys. Rev. Lett.*** 111, 127401 (2014) (Link). This work is highlighted in ***MIT News*** (Link)

6. D. V. Pilon, **C. H. Lui**, T. H. Han, D. Shrekenhamer, A. J. Frenzel, W. J. Padilla, Y. S. Lee & N. Gedik, "Spin induced optical conductivity in the spin liquid candidate herbertsmithite", ***Phys. Rev. Lett.*** 111, 127401 (2013) (Link). This work is highlighted in ***MIT News*** (Link) and ***Novus Light Technologies Today*** (Link)

7. A. J. Frenzel, **C. H. Lui**, W. Fang, N. L. Nair, P. K. Herring, P. Jarillo-Herrero, J. Kong & N. Gedik, "Observation of suppressed terahertz absorption in photoexcited graphene", ***Appl. Phys. Lett*.** 102, 113111 (2013) (Link)

8. **C. H. Lui**, E. Cappelluti, Z. Q. Li & T. F. Heinz. "Tunable infrared phonon anomalies in trilayer graphene", ***Phys. Rev. Lett.*** 110, 185504 (2013) (Link)

9. **C. H. Lui** & T. F. Heinz. "Measurement of layer breathing mode vibrations in few-layer graphene", ***Phys. Rev. B (Rapid Communications)*** 87, 121404(R) (2013) (Link)

10. D. Boschetto, L. M. Malard, **C. H. Lui**, K. F. Mak, Z. Q. Li, H. G. Yan & T. F. Heinz. "Real-time observation of interlayer vibrations in bilayer and few-layer graphene", ***Nano Lett.*** *13, 4620-4623* (2013) (Link)

11. **C. H. Lui**, L. M. Malard, S. H. Kim, G. Lantz, F. E. Laverge, R. Saito & T. F. Heinz. "Observation of layer-breathing mode vibrations in few-layer graphene through combination raman scattering", ***Nano Lett.*** 12, 5539-5544 (2012) (Link)

12. J. Shim*, **C. H. Lui***, T. Y. Ko, Y. Yu, P. Kim, T. F. Heinz & S. Ryu. "Water-gated charge doping of graphene induced by mica substrates", ***Nano. Lett.*** 12, 648-654 (2012) (Link)

13. Z. Q. Li, **C. H. Lui**, E. Cappelluti, L. Benfatto, K. F. Mak, G. L. Carr, J. Shan & T. F. Heinz. "Structure-dependent fano resonances in the intrafred spectra of phonons in few-layer graphene", ***Phys. Rev. Lett.*** 108, 156801 (2012) (Link)

14. **C. H. Lui**, Z. Q. Li, K. F. Mak, E. Cappelluti & T. F. Heinz. "Observation of an electrically tunable band gap in trilayer graphene", ***Nature Physics*** 7, 944-947 (2011) (Link). This work is highlighted in ***Nature Physics*** 7, 925-926 (2011) (Link)

15. K. Sato, J. S. Park, R. Saito, C. Cong, T. Yu, **C. H. Lui**, T. F. Heinz, G. Dresselhaus & M. S. Dresselhaus. "Raman spectra of out-of-plane phonons in bilayer graphene", ***Phys. Rev. B*** 84, 035419 (2011) (Link)

16. **C. H. Lui**, K. F. Mak, J. Shan & T. F. Heinz. "Ultrafast photoluminescence from graphene", ***Phys. Rev. Lett.*** 105, 127404 (2010) (Link)

17. **C. H. Lui**, Z. Q. Li, Z. Chen, P. V. Klimov, L. E. Brus & T. F. Heinz. "Imaging stacking order in few-layer graphene", ***Nano Lett.*** 11, 164-169 (2010) (Link)

18. K. F. Mak, **C. H. Lui** & T. F. Heinz. "Measurement of the thermal conductance of the graphene/SiO_2 interface", ***App. Phys. Lett.*** 97, 221904 (2010) (Link)

19. **C. H. Lui**, L. Liu, K. F. Mak, G. W. Flynn & T. F. Heinz. "Ultraflat graphene", ***Nature*** 462, 339-341 (2009) (Link). This work is highlighted in ***ChemPhysChem*** 11, 1833-1835 (2010) (Link), ***Nanotechweb.org*** (Nov. 27, 2009) (Link), ***Scientific American*** (Nov. 18, 2009) (Link), and ***Chemistry World*** (Nov. 18, 2009) (Link)

20. K. F. Mak, **C. H. Lui**, J. Shan & T. F. Heinz. "Observation of an electric-field-induced band gap in bilayer graphene by infrared spectroscopy", ***Phys. Rev. Lett.*** *102*, 256405 (2009) (Link)

21. K. F. Mak, M. Y. Sfeir, Y. Wu, **C. H. Lui**, J. A. Misewich & T. F. Heinz. "measurement of the optical conductivity of graphene", ***Phys. Rev. Lett*.** 101, 196405 (2008) (Link)

* These authors contributed equally to the work.

PRESENTATIONS

Invited talks at professional meetings

1. "Probing electronic and vibrational interactions in few-layer graphene by optical spectroscopy", **APS March Meeting**, Baltimore, Maryland (2013) (Link)
2. "Real-time study of the interlayer shearing mode in few-layer graphene", **ONR-AFOSR Joint Graphene MURI Review**, Monterey, California (2011) (Link)
3. "Ultrafast photoluminescence from graphene", **Graphene Week**, College Park, Maryland (2010)
4. "Light emission from graphene induced by femtosecond laser pulses", Selected for *Young Scientist Best Poster Award* in **Gordon Research Conference**, Galveston, Texas (2010) (Link)

Selected invited talks at universities

1. "Shedding light on 2D electrons in graphene", Colloquium, **University of Texas, Dallas** (2014)
2. "Spectroscopy of 2D materials and heterostructures", Seminar, **University of Texas, Dallas** (2014)
3. "Ultrafast terahertz probe of transient photoconductivity in single-layer graphene and MoS_2", Seminar, **Harvard University** (2014)
4. "Shedding light on 2D electrons in graphene", Colloquium, **University of Alabama, Tuscaloosa** (2014)
5. "Shedding light on 2D electrons in graphene", Colloquium, **Carnegie Mellon University** (2013)
6. "Shedding light on 2D electrons in graphene", Colloquium, **University of Hong Kong** (2013)
7. "Shedding light on 2D electrons in graphene", Colloquium, **Chinese University of Hong Kong** (2013)
8. "Ultrafast optical spectroscopy of graphene and beyond", Seminar, **Chinese University of Hong Kong** (2013)
9. "Probing the interactions of few-layer graphene by optical spectroscopy", Seminar, **MIT** (2012).
10. "Probing the interactions of few-layer graphene by optical spectroscopy", Seminar, **Hong Kong University of Science and Technology** (2012).
11. "Probing the electronic and vibrational properties of trilayer graphene by optical spectroscopy", Seminar, **Cornell University** (2011)
12. "Investigations of the electronic, vibrational and structural properties of single and few-layer graphene", **University of California, Berkeley** (2011)
13. "The optical and morphological properties of graphene layers", National Research Initiative presentation, **Columbia University** (2010)

Contributed talks at APS March meetings

1. "Observation of negative terahertz photoconductivity in monolayer MoS_2 under femtosecond laser excitation", Denver, Colorado (2014)
2. "Tunable Infrared Phonon Anomalies in Trilayer Graphene", Denver, Colorado (2014)
3. "Atomically Flat Graphene on Mica Substrates", Pittsburgh, Pennsylvania, (2009)
4. "Dependence of the Low-Energy Electronic Structure of Multi-Layer Graphene on Stacking Order Probed by Infrared Absorption", Pittsburgh, Pennsylvania (2009)
5. "Measurement of the Thermal Conductance at the Graphene-Quartz Interface by Optical Pump-Probe Spectroscopy", New Orleans, Louisiana (2008)
6. "Experimental Measurement of Ultrafast Carrier Dynamic in Mono- and Multi-Layer Graphene Samples", New Orleans, Louisiana (2008)

PROFESSIONAL SERVICES

- Guest editor for *Advances in Condensed Matter Physics*
- Referee for *Physical Review Letters*, *Physical Review B*, *Nano Letters*, *ACS Nano*, *Scientific Reports*, *2D Materials* and *Vibrational Spectroscopy*

PROFESSIONAL REFERENCES

- **Prof. Tony F. Heinz (Ph.D. Adviser)**
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SUMMARY OF KEY RESEARCH ACCOMPLISHMENTS FOR C. H. LUI

Single-layer graphene

- **Ultraflat graphene:** Using atomic-force microscopy measurements, we demonstrate that single-layer graphene deposited on atomically flat surfaces of cleaved mica exhibits ultraflat morphology, with a height variation (<30 picometer) indistinguishable from that observed for the surface of cleaved graphite. This study shows that supported graphene is not subject to any intrinsic thermodynamics instability and implies that the much-discussed undulations seen for the usual case of graphene on oxidized silicon simply reflect the substrate morphology, not any intrinsic graphene rippling. Our experiment also inspires the search of other atomically flat substrates, such as hexagonal boron nitride, for high-quality graphene electronics. This work was published in *Nature* [19 in the full publication list above].
- **Investigation of the ultrafast dynamics of Dirac fermions in graphene by optical emission spectroscopy:** This is the first report of light emission from pristine graphene. Emission can be observed under excitation by ultrashort (30 fs) laser pulses. Studies of the emission properties induced by single and time-correlated pairs of excitation pulses allow us to learn about ultrafast carrier dynamics in graphene. Systematic analysis and modeling of the photoluminescence spectra reveals relaxation processes of excited charge carriers in time scales from 10 fs to 1 ps. We find that the charge carriers thermalize and cool within a few 10's of femtosecond by the emission of optical phonons, and the equilibrated subsystem of electrons and optical phonons reaches transient temperatures exceeding 3000 K and stays out of equilibrium with the other phonons in the picosecond time scale. This work was published in *Physical Review Letters* [16].
- **Demonstration of tunable photoconductivity in graphene:** By using time-resolved terahertz spectroscopy, we observe a pronounced transient change of conductivity in graphene under femtosecond laser excitation. The differential conductivity of graphene changes from positive to negative as its charge density is tuned from low to high values by electrical gating. Our experiment resolves the early conflicting results in graphene samples at different doping conditions. It also demonstrates that graphene can controllably exhibit either semiconducting (positive) or metallic (negative) photoconductivity behavior, a remarkable material property for versatile optoelectronic applications. Furthermore, simulations based on a Drude model reveal a non-monotonic temperature dependence of Drude response in graphene, a unique fundamental property of massless Dirac fermions that has been predicted but hitherto unobserved. [5, 7].

Few-layer graphene

- **Development of optical techniques to characterize the layer thickness and stacking order of few-layer graphene:** We demonstrate that the thickness (1-20 layers) and stacking order (Bernal or rhombohedral stacking) of few-layer graphene can be identified accurately by measuring the infrared absorption spectrum or the Raman spectra of 2D mode and other interlayer phonon modes. In particular, we can conveniently map out the spatial distribution of different stacking orders by using the line shape of Raman 2D-mode. These various optical characterization methods constitute a necessary component to support and accelerate the research of few-layer graphene [2, 4, 9, 11, 14, 17].
- **Comprehensive Raman study of interlayer phonons in few-layer graphene:** By using ultralow-frequency Raman spectroscopy, we observe and identify the interlayer shear modes and breathing modes in few-layer graphene, which involve the tangential and vertical displacement of individual graphene layers, respectively. As these phonons are created by interlayer couplings, they exhibit great sensitivity to the layer thickness, stacking order and surface conditions of few-layer graphene. For instance, their frequencies evolve systematically with the layer thickness; the shear-mode Raman activity depends critically on the stacking order; the breathing modes are damped by the surface adsorbates but can be activated at high temperature. Although the interlayer modes are difficult to detect due to their ultralow frequency (<10 meV), they can manifest themselves at higher frequencies through the overtone modes and combination modes with other in-plane optical phonons. These

higher-order Raman modes are also sensitive to the crystal structure of few-layer graphene and thus serve as effective probes to the material properties [2, 4, 9 - 11].

- **Observation of an electrically tunable band gap in few-layer graphene:** We observe the induction of tunable band gap of over 100 meV in bilayer and ABC-stacked trilayer graphene under electrical gating. We demonstrate that the electronic structure of few-layer graphene is highly adjustable by external perturbations, a remarkable material property that allows great flexibility in the design and optimization of graphene devices. In addition, the induced gap is not found in ABA-stacked trilayers, showing that that the tunability of electronic structure depends critically on the stacking sequence of graphene layers. These works were published in *Nature Physics* and *Physical Review Letters* [14, 20].
- **Systematic studies of structure- and doping-dependent infrared phonon anomalies in few-layer graphene:** We observe intense infrared absorption from in-plane optical phonons in few-layer graphene (3 - 6 layers) arising from their coupling to the interband electronic transitions. The phonon spectra depend critically on the layer thickness, stacking order and doping level of graphene. Few-layer samples with rhombohedral (ABC) stacking consistently exhibit larger intensities, more asymmetric lineshapes and stronger doping dependence than those with Bernal (AB) stacking, reflecting the stronger electron-phonon coupling in these systems. Our experiments reveal the distinctive variation of many-body interactions in graphene of differing thickness and stacking order, which can be controlled effectively by external perturbations. These works were published in *Physical Review Letters* [8, 13].

Other two-dimensional systems

- **Observation of electrical conduction by trions in monolayer MoS_2:** This is the first report of strong trionic effects on the conductive properties of 2D crystals. By using time-resolved terahertz spectroscopy, we find that the conductivity of monolayer MoS_2 is reduced to only 30% of its initial value under the excitation of strong laser pulses. This usual phenomenon arises from the strong electrostatic interactions in monolayer MoS_2, where photoexcited electron-hole pairs are bound to the doping-induced free charges to form trions (bound states of two electrons and one hole). The three-fold increase of effective mass of charge carriers thus strongly reduces their conductivity. Our research reveals that charge transport in MoS_2 can be conducted by trions. As trions allow the control of motion of excitons and their psudospins by an electric field, our results pave the way to develop novel excitonic and spintronic devices. This work was selected as Editor's Suggestion in *Physical Review Letters* [3].
- **Observation of layer-breathing modes in van der Waals heterostructures:** This is the first report of interlayer phonon modes in van der Waals heterostructures. By using ultralow-frequency Raman spectroscopy, we observe the out-of-plane breathing vibrations between two atomic sheets in the MoS_2/WSe_2 and $MoSe_2/MoS_2$ heterogeneous bilayer structure. The layer-breathing modes exhibit great sensitivity to the separation and relative orientation of the two layers in the heterostructure. Our experiment demonstrates the interlayer phonon modes to be an effective probe to characterize the interfacial conditions and interlayer interactions in van der Waals heterostructures, and also inspires the fabrication of atomically thin phononic crystals [1].
- **Optical studies of two-dimensional quantum spin liquids:** A quantum spin liquid is a state of matter in which magnetic spins interact strongly, but quantum fluctuations inhibit long-range magnetic order even at zero temperature. This strongly entangled system is predicted to host exotic elementary excitations that carry only spin and no charge (so-called spinons). We measure the low-frequency optical conductivity of large-area single-crystal herbertsmithite, a promising spin-liquid candidate material, by means of terahertz time-domain spectroscopy. We observe a contribution to the in-plane conductivity from the spinon excitations, with spectral characteristics consistent with the theoretical predictions based on a gapless U(1) Dirac spin liquid. Our results suggest non-negligible interactions between the spinons and charges mediated by a gauge field in a spin liquid, and provide important insight into the nature of the spin ground state in herbertsmithite [6].