

The Chinese University of Hong Kong

Division of Physics

Experimental Projects

1. Simultaneous conversion of sunlight and solar thermal energy into electricity in solar cell (MPhil or PhD) (Prof. Chen, T., E-mail: taochen@phy.cuhk.edu.hk)

Solar energy consists of light and solar thermal energy. Conventional solar cells convert only sunlight into electrical energy, solar thermal energy is often ignored or considered as “waste heat”. In this project, we aim to develop new device structures to simultaneously harvest solar thermal and light energy, achieving both thermoelectric and photovoltaic effect in an integrated device. [One student may be admitted.]

References :

1. A. Hagfeldt, G. Boschloo, L. Sun, L. Kloo and H. Pettersson, “Dye-sensitized solar cells”, *Chemical Reviews* 110, pp. 6595-6663 (2010).
2. T.M. Tritt and M.A. Subramanian, “Thermoelectric materials, phenomena, and applications: A bird's eye view”, *MRS Bulletin* 31, pp. 188-194 (2006).
3. J. Weickert, R. B. Dunbar, H.C. Hesse, W. Wiedemann, and L. Schmidt-Mende, “Nanostructured organic and hybrid solar cells”, *Advanced Materials* 23, pp. 1810-1828 (2011).

2. Formation and properties of nanostructures by liquid state spinodal decomposition (MPhil or PhD) (Prof. Kui, H.W., Room 308, ☎ (852) 3943 6368, E-mail: hwkui@phy.cuhk.edu.hk)

Recently, we discovered that nanostructures can be prepared by a spinodal decomposition method that takes place in the liquid state. These novel nanostructures have three important features: (i) absence of pores; (ii) uniform grain size; and (iii) bulk in size. Interestingly, they are exceptionally strong, in sharp contrast to nanostructures prepared by other methods. Students will work mainly in two areas. First, we like to search for more novel nanostructures. Second, we like to determine their physical properties. [One student may be admitted.]

Reference :

H.W. Kui, “Formation of bulk nanostructured alloys”, *Encyclopedia of Nanoscience and Nanotechnology*, Edited by H.S. Nalwa, Volume 3, pp. 485-495 (2004).

3. Electronic structure study of nanostructured hetero-junctions in solar cell materials (MPhil or PhD) (Prof. Li, Q., Room 310, ☎ (852) 3943 6323, E-mail: liquan@phy.cuhk.edu.hk)

Solar energy conversion based on the photovoltaic effect is one of the most viable choices to meet the increasing energy demand in the near future. Among various forms of solar energy conversion devices, nanostructured semiconductor architectures, which normally consist of two basic units — the light harvesting material and the electrode, serve as one of the most promising categories. In general, the e n e r g y c o n v e r s i o n

efficiency of the device is limited by two factors, i.e., (1) carrier production; and (2) carrier (electrons and holes) separation and transport. By manipulating the electronic structure of the materials based on quantum mechanical principles, one can achieve high carrier generation efficiency (e.g. via multiple exciton generation effect realized in the light harvesting materials) and effective carrier separation (e.g. by satisfying specific band alignment at the interface of the light harvesting unit and the electrode material). In this project, we will investigate the electronic structure at the interface between the light harvesting material and the electrode, possibly with nanometer scale resolution, and identify the underlying physics that determines the carrier separation mechanisms.

References :

1. P.V. Kamat, “Meeting the clean energy demand: Nanostructure architectures for solar energy conversion”, *Journal of Physical Chemistry C*, 111, pp. 2834-2860 (2007).
2. A. Luque, A. Marti, and A.J. Nozik, “Solar cells based on quantum dots: Multiple exciton generation and intermediate bands”, *Materials Research Society Bulletin* 32, pp. 236-241 (2007).
3. P.V. Kamat, “Native and surface modified semiconductor nanoclusters”, *Progress in Inorganic Chemistry* 44, pp. 273-343, John Wiley & Sons, Inc. (1997).
4. Y. Zhang, L.W. Wang, and A. Mascarenhas, “Quantum coaxial cables for solar energy harvesting”, *Nano Letters* 7, pp. 1264-1269 (2007).

4. Nanoparticulate systems for cancer therapeutics (PhD) (Prof. Li, Q., Room 310, ☎ (852) 3943 6323)

With the recent development of nanotechnology, it is now possible to utilize various nanoparticulate systems in many innovative ways for medical applications such as drug delivery, with improved drug efficiency and reduced side effects. In this project, we are interested in developing functionalized nanoparticulate systems for cancer therapies. The specific magnetic/optical/electrical properties of nanoparticles not only provide novel means for tumor cell recognition, target delivery and effective treatment, but also make them effective biomarkers for tracing the drug delivery process, serving as feed-back messengers for identifying the mechanisms of drug uptake, functioning, and metabolism at the molecular and cellular level. Design and synthesis of nanostructured particles with controllable size and desired physical properties, functionalization of the particle surface, identification of the interaction between nanoparticles and cancer cells, as well as investigating the physiologic impact of nanoparticles to normal and cancer cells such as apoptosis and mutagenesis, will be the main focus of this project. Through integrated physical property measurements and biological evaluation of the nanoparticles, we will find out their delivery and functioning mechanisms in human cells, and also evaluate the efficacy of these nano-medicines. [One student may be admitted.]

Reference :

S. Nie, Y. Xing, G.J. Kim, and J.W. Simons, “Nanotechnology applications in cancer”, *Annual Review of Biomedical Engineering* 9, pp. 257-288 (2007).

5. Single molecules studies (MPhil or PhD)
(Prof. Ong, D.H.C., Room G10, ☎ (852) 3943 6324,
E-mail: hcong@phy.cuhk.edu.hk)

Single molecules techniques such as confocal scanning optical microscopy will be applied to study the optical properties of semiconductor quantum dots and molecular dyes in the presence of near field created by plasmonic or photonic crystals. Appropriate modeling based on finite-difference-time-domain method will be used. The method will eventually be extended to biological materials. [Up to two students may be admitted.]

Reference :

F.D. Stefani, K. Vasilev, N. Bocchio, N. Stoyanova, and M. Kreiter, "Surface-plasmon-mediated single-molecule fluorescence through a thin metallic film", Physical Review Letters 94, pp. 023005(1-4) (2005).

6. Topics in plasmonics (MPhil or PhD)
(Prof. Ong, D.H.C., Room G10, ☎ (852) 3943 6324)

Recently, surface plasmon polaritons (SPPs) arising from metal/dielectric interface have evolved into a new research area in bio- and nano-technologies. Not only that they have been used for making chemical and biological sensors, SPPs are being proposed as a new medium to deliver light signal at the length scale beyond diffraction limit. Several unexpected phenomena including extraordinary transmission, superlensing,

waveguiding, etc., have been observed from the world. "Plasmonic" is coined on this subject after the eras of "Photonics" and "Electronics". In this project, we will investigate the effects of SPP on the light emission of semiconductors and phosphors by using a variety of near field optical spectroscopic techniques. In particular, special attention will be paid on the interactions between semiconductor and individual metal nanoparticles and/or clusters. Theoretical calculation based on finite-difference-time-domain method will be used. [Up to two students may be admitted.]

References :

1. *A.V. Zayats, I.I. Smolyaninov, and A.A. Maradudin, "Nano-optics of surface plasmon polaritons", Physics Reports 408, pp. 131-314 (2005).*
2. *C.W. Lai, J. An, and H.C. Ong, "Surface-plasmon-mediated emission from metal-capped ZnO thin films", Applied Physics Letters 86, pp. 251105(1-3) (2005).*

7. Two species ultracold quantum gases (PhD)
(Prof. Wang, D.J., Room G7, ☎ (852) 3943 6395,
E-mail: djwang@phy.cuhk.edu.hk)

Because of the recent successful production of ultracold heteronuclear polar molecules and the possibility to study quantum phenomena driven by inter-species interactions using atomic mixtures, there has been an increasing interest in studying multi-components ultracold quantum gases. In this project, we will investigate mixture of two different atoms at temperatures ranging from 10^{-6} K to 10^{-9} K. These ultracold temperatures are readily achieving by standard laser cooling + evaporative cooling techniques. Advanced spectroscopic

methods, including laser photoassociation and magnetic Feshbach resonances, will be applied to characterize interactions between these two kinds of atoms. The knowledge obtained will enable us to investigate quantum fluid mixtures with tunable interactions and linking atom pairs to form polar molecules with strong dipolar interactions. [Up to two students may be admitted.]

8. Plasmonics of gold nanostructures (MPhil or PhD)
(Prof. Wang, J.F., Room G9, ☎ (852) 3943 4167,
E-mail: jfwang@phy.cuhk.edu.hk)

Noble metal nanostructures exhibit rich localized surface plasmon resonance properties, and are therefore potentially useful in many areas, including optics, optoelectronics, photocatalysis, energy harvesting, and nanobiotechnology. In this project, we will develop nanoparticle-based reactions to modify the shape of gold nanostructures, discover chemical and physical methods to assemble and organize gold nanostructures both on the single particle level and on the macroscopic level, and integrate gold nanostructures with other optical and optoelectronic devices. Our goals are to (1) understand the fundamental properties of localized surface plasmon resonances and their interactions with each other and with molecular resonances, fluorescence, absorption, Raman, etc.; (2) use surface plasmon resonance-enhanced absorption, scattering, and local electric field to enhance the efficiencies of photocatalysis and solar energy harvesting and conversion; (3) fabricate ultrasensitive devices for chemical and biological sensing. Please see <http://www.phy.cuhk.edu.hk/~jfwang/> for more information. [One student may be admitted.]

9. Scanning tunneling microscopy studies of surface quantum diffusion (PhD)
(Prof. Wang, K.D., N8 Lab., ☎ (852) 3943 7961,
E-mail: kdwang@phy.cuhk.edu.hk)

Observation and understanding of surface diffusion phenomenon in the past largely depend on the development of techniques. Among the techniques, scanning tunneling microscopy (STM) is advantageous in directly providing the atomistic mechanisms of diffusion but was severely limited to slow diffusion rates (<10 Hz). Thus, processes in quantum diffusion of light atoms with fast diffusion rates were inaccessible by the STM technique in the past. Recently, we had established a new STM-based method that can expand the range by at least 3 orders of magnitude faster (~ 10000 Hz). This leads to significant overlaps in measurable diffusion rates with other techniques while retaining the atomic resolution. Using this new technique, we are studying the fast quantum diffusion of hydrogen atoms on metal surfaces. [One student may be admitted.]

References :

1. *Kedong Wang, Chun Zhang, M.M.T. Loy, and Xudong Xiao, "Time-dependent tunneling spectroscopy for studying surface diffusion confined in nanostructures". Physical Review Letters 94, pp. 036103(1-4) (2005).*
2. *R. Gomer, "Diffusion of adsorbates on metal surfaces". Reports on Progress in Physics 53, pp. 917-1002 (1990).*

10. Topics in nonlinear optics (MPhil or PhD)
(Prof. Wong, K.Y., Room 345, ☎2609 6161,
E-mail: kywong@phy.cuhk.edu.hk)

Nonlinear optics is important to the development of photonic technologies. Students interested in this field are expected to work on one of the ongoing experiments in our group. These experiments include: nonlinear optical properties of doped polymers using poling induced optical second harmonic generation, nonlinear optics of thin polymer films, and hyper-Rayleigh scattering in organic liquids. [One or two students may be admitted.]

References :

1. C.W. To and K.Y. Wong, "Comparative studies of molecular reorientations in thermal-assisted and photo-assisted electric-field poled nonlinear optical polymers", *Journal of Applied Physics* 100, pp. 073505(1-6) (2006).
2. J. Chen and K.Y. Wong, "Study of intermolecular interactions in liquid nitrobenzene by depolarized hyper-Rayleigh scattering", *Journal of Chemical Physics* 122, pp. 174505(1-5) (2005).

11. Organic electronic and optoelectronic devices based on polymeric materials (MPhil or PhD)
(Prof. Wong, K.Y., Room 345, ☎2609 6161)

Organic electronic and optoelectronic devices are important technologies of the future. Polymeric materials have shown great promises in flat-panel display and photovoltaic technologies. In this project we will study the basic mechanisms that affect the operations and performances of the devices, and investigate new device concepts. This project is multi-disciplinary in nature, which will involve polymer physics and chemistry, surface and interface sciences, and optical physics. [One or two students may be admitted.]

References :

1. X.J. Wang, W.M. Lau, and K.Y. Wong, "Display device with dual emissive and reflective modes", *Applied Physics Letters* 87, pp. 113502(1-3) (2005).
2. X.Y. Deng, K.Y. Wong, Y.Q. Mo, "Three-color polymeric light-emitting devices using selective photo-oxidation of multilayered conjugated polymers", *Applied Physics Letters* 90, pp. 063505(1-3) (2007).

12. Topics in polymer and colloidal physics (PhD)
(Prof. Wu, C., Room 239, ☎ (852) 3943 6106,
E-mail: chiwu@cuhk.edu.hk)

Using a combination of synthetic chemistry, polymer physics and molecular biology, we design and execute decisive experiments to answer important physical questions of polymers, colloids and biology, including 1) development of non-viral vectors for molecular medicines; 2) nucleation of neuron-degenerative diseases related protein aggregation; 3) design, synthesis and assembly of functional macromolecules; 4) dynamics and structures of polymer solutions and gel networks; 5) molecular characteristic properties of intractable and special polymers. [One student may be admitted.]

References :

1. C. Wu and X.H. Wang, "Globule-to-coil transition of a single homopolymer chain in solution", *Physical Review Letters* 80, pp. 4092-4094 (1998).

2. T.J. Hu and C. Wu, "Clustering induced collapse of a polymer brush", *Physical Review Letters* 83, pp. 4105-4107 (1999).
3. G.Z. Zhang and C. Wu, "The reentrant coil-to-globule-to-coil transition of a single linear homopolymer chain in a water/methanol mixture", *Physical Review Letters* 86, pp. 822-825 (2001).
4. G.Z. Zhang, F.M. Winnik, and C. Wu, "Structure of a collapsed polymer chain with stickers: A single- or multiflower?," *Physical Review Letters* 90, pp. 035506(1-4) (2003).
5. F. Jin and C. Wu, "Observation of the first-order transition in ultrafiltration of flexible linear polymer chains", *Physical Review Letters* 96, pp. 237801(1-4) (2006).

13. Experimental Studies of Convective Turbulence (MPhil or PhD)
(Prof. Xia, K.Q., Room 110, ☎ (852) 3943 6102,
E-mail: kxia@phy.cuhk.edu.hk)

Our turbulence research program consists of both experimental investigations and numerical simulations. Students interested in pursuing either MPhil or PhD degrees may be admitted to study topics such as turbulent convections in multilayer fluids and nanofluids, and flow dynamics and transport in horizontal convection, which is a conceptual model for oceanic convection. [One or two students may be admitted.]

References :

1. D. Lohse and K.-Q. Xia, "Small-scale properties of turbulent Rayleigh-Bénard convection", *Annual Review of Fluid Mechanics* 42, 335 (2010).
2. Q. Zhou and K.-Q. Xia, "Universality of local dissipation scales in buoyancy-driven turbulence", *Physical Review Letters* 104, 124301 (2010).
3. H.-D. Xi, S.-Q. Zhou, Q. Zhou, T.-S. Chan and K.-Q. Xia, "Origin of the temperature oscillation in turbulent thermal convection", *Physical Review Letters* 102, 044503 (2009).
4. X.-L. Jin and K.-Q. Xia, "An experimental study of kicked thermal turbulence", *J. Fluid Mech.* 606, 133 (2008).
5. C. Sun, Q. Zhou, and K.-Q. Xia, "Cascades of Velocity and Temperature Fluctuations in Buoyancy-Driven Turbulence", *Physical Review Letters* 97, 144504 (2006)

14. Study of magnetotaxis of magnetotactic bacteria (MPhil or PhD)
(Prof. Xia, K.Q., Room 110, ☎ (852) 3943 6102,
E-mail: kxia@phy.cuhk.edu.hk)

Magnetotactic bacteria (MB) are microorganisms that contain magnetic crystals 30-50 nm in size. These crystals are enclosed by a lipid bilayer membrane and are called magnetosomes, which are usually formed in chain structures inside the cell. It is generally believed that MBs use their magnetosomes to align with the local magnetic field and move along the magnetic field lines. Such a behavior is referred to as magnetotaxis (or magneto-aerotaxis). An important issue in the studies of MB is whether the magnetotaxis is passive or active. In the former case, the magnetic field only aligns the MBs and their motion are driven by the oxygen gradients. This presumably simplified their search for favorable oxygen environment in aquatic habitat. In the latter case, MBs are thought to possess magnetic receptors similar to chemotaxis. In this project,

student will carry out experiments that are designed to address the issue of whether the magnetotaxis of MBs are passive or active. [One student may be admitted.]

References:

1. Arash Komeili, "Molecular mechanisms of magnetosome formation", *Annu. Rev. Biochem.* 76, 351 (2007).
2. Christian Jogler and Dirk Schuler, "Genomics, genetics, and cell biology of magnetosome formation", *Annu. Rev. Microbiol.* 63, 501 (2009).
3. Nadège Philippe and Long-Fei Wu, "An MCP-like protein interacts with the MamK cytoskeleton and is involved in magnetotaxis in *magnetospirillum magneticum* AMB-1", *J. Mol. Biol.* 400, 309 (2010).

15. Experimental studies of surfaces and nanostructures (PhD)

(Prof. Xiao, X.D., Room 210, ☎ (852) 3943 4388,
E-mail: xdxiao@phy.cuhk.edu.hk)

Matters are made of atoms. In an era of "Seeing is believing", direct observation of atoms and their behaviors becomes increasingly important in scientific research. Using scanning tunneling microscopy (STM) and scanning tunneling spectroscopy (STS) at low temperatures or variable temperatures, we are studying various structural and electronic properties of surfaces and nanostructures with atomic resolution. The current topics include observations of single atom diffusion on surfaces and on thin films, formation of nano-clusters with atomic precision control, and superconductivity of nano-islands. [One student may be admitted.]

References :

1. Kedong Wang, Xieqiu Zhang, M. M. T. Loy, T.-C. Chiang, Xudong Xiao, "Pseudogap Mediated by Quantum-Size Effects in Lead Islands", *Physical Review Letters* 102, 076801 (2009). Selected for the March 2, 2009 issue of *Virtual Journal of Nanoscale Science & Technology*.
2. Kedong Wang, Gang Chen, Chun Zhang, M. M. T. Loy, and Xudong Xiao, "Intermixing of intra-basin and inter-basin diffusion of a single Ag atom on Si(111)-(7×7)", *Physical Review Letters* 101, 266107 (2008).
3. Aidi Zhao, Xieqiu Zhang, Gang Chen, M.M.T. Loy, and Xudong Xiao, "Initial stages of the adsorption of Ge atoms on the Si(111)-(7×7) surface", *Physical Review B* 74, pp. 125301(1-8) (2006); Selected for publication in *Virtual Journal of Nanoscale Science & Technology*, September 18, 2006.
4. Kedong Wang, Chun Zhang, M.M.T. Loy, and Xudong Xiao, "Time-dependent tunneling spectroscopy for studying surface diffusion confined in nanostructures", *Physical Review Letters* 94, pp. 036103(1-4) (2005); Selected for publication in *Virtual Journal of Nanoscale Science & Technology*, February 7, 2005.
5. Chun Zhang, Gang Chen, Kedong Wang, Hongwei Yang, Tao Su, C.T. Chan, M.M.T. Loy, and Xudong Xiao, "Experimental and theoretical investigation of single Cu, Ag and Au atoms adsorbed on Si(111)-7×7", *Physical Review Letters* 94, pp. 176104(1-4) (2005).

16. Liquid impacts on structured substrates (PhD)
(Prof. Xu, L., Room G6, ☎ (852) 3943 6307,
E-mail: xulei@phy.cuhk.edu.hk)

We want to study the impact and splash behaviors of liquid drops on the structured substrates. We will make various substrates including nano-scale structures and visualize the impacts with high-speed camera. The goal is to find what kind of structure can increase or decrease the liquid breakup and achieve a good control on the impacts. [One student may be admitted.]