Research Outline at UC-Berkeley

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Due to global climate change and the security of energy supplies, a major scientific challenge of the 21st century is to change our current fossil-fuel-based economy to the one that is more sustainable. Among the various sources of renewable energy, solar energy is essentially unlimited and consequently, one of the most promising sources to meet the world's growing energy demand. Solar photovoltaic systems can convert directly photons to electrical power, but the main limitations with present solar cells are their high material cost and low conversion efficiencies. Another attractive solution to the energy problem is to harness heat sources such as geothermal heat, solar heat and waste heat dissipated in energy conversion processes. Thermoelectric and thermophotovoltaic systems are both capable of directly converting heat into electricity, but again, the main barrier is their low efficiency. With many advances in nanostructured materials and nanoscale designs, it is clear that nanoscale engineering will play an important role in resolving these issues for solar and thermal energy conversion. During my PhD study at MIT, I have carried out both theoretical and experimental research on nanoscale energy transport/conversion including nanoscale thermal radiation, optical and thermal characterization of nanostructures, and molecular gas transport in hard drive. My broad research experience, together with interdisciplinary education with a focus in nanotechnology and energy, positions me well to continue my contributions in our quest to transit our energy infrastructure into one that is more efficient and renewable. In an effort to provide practical solutions to the global energy problem, my proposed research in Professor Xiang Zhang's group at University of California-Berkeley will cover two main areas:

(1) ***Nanostructured Materials for Solar Energy Conversion***

Nanostructured semiconductors offer several advantages such as the ability to improve charge collection efficiency due to the small size and the potential for low cost solar cell structures using self-assembled nanostructures (for example, nanorods or nanowires arrays). The optical properties of such nanostructured solar cells over the solar spectrum are crucial for their performance. Optimized designs of nanostructures can significantly increase the light trapping of the solar cells, and thus reduce their cost by using smaller amount of materials. Nanophotonics is a promising tool to improve light trapping and has made significant contributions in designing nanostructures for solar cells. My research at Berkeley will combine numerical and experimental efforts to characterize the optical properties of nanostructures for solar photovoltaic applications. I will study the performance of plasmonic solar cells which increase light trapping by surface plasmons excited on metal surfaces, and find a strategy to reduce the significant loss in metals. I will also explore the possibility of electromagnetic metamaterials, which are artificial materials with structures much smaller than the wavelength of light, for efficient light trapping. Numerically I will solve Maxwell's equations to calculate the optical properties of periodic nanostructures. The numerical techniques include the Finite-Difference Time-Domain (FDTD) method and the Finite Element Method (FEM). My experience with solving Maxwell's equations during my thesis research [1, 2] provided me the necessary background to conduct the numerical analysis of nanostructured solar cells.

I will also seek to experimentally measure the optical properties of nanostructures using spectroscopic measurement techniques. I will apply micro/nanofabrication (e.g. electron beam lithography, focus ion beam lithography, etc.) and self-assembly techniques to fabricate nanostructured solar cells. Then, I will use spectrometers to measure the optical properties of the nanostructures and compare with the corresponding calculation results. This work on both theoretical calculation and experimental measurement will guide the optimization of dimension, shape, and material selections of nanostructures in order to maximize the efficiencies of solar cells.

(2) ***Manipulate Thermal Emission for Thermal Energy Conversion***

Thermophotovoltaic systems can reduce energy loss by recycling wasted heat in existing systems and can also serve as an alternative means of utilizing solar energy where solar radiation is first converted to heat. However, the efficiency of current thermophotovoltaic systems is far less than the thermodynamic limit due to insufficient control over thermal emission. A basic thermophotovoltaic system consists of a photovoltaic cell and a thermal selective emitter. The "ideal" emitter will emit photons within a narrow band that matches the band gap of the photovoltaic cell. In solar thermophotovoltaic systems, an intermediate selective absorber is used to absorb sunlight and convert it to heat. The heat is then subsequently transferred to the emitter. The selective absorber must absorb most of the solar spectra whilst minimizing the heat loss at infrared wavelengths in order to achieve high efficiency. My research will first concentrate on improving the spectral control of the emitter and the absorber. Based on the numerical techniques discussed above, I will explore the potential of designing and fabricating nanophotonic structures such as plasmonic structures for the emitter and the absorber.

Surface plasmon is a well established collective oscillation of electrons on metallic surfaces in the range of visible or near UV. But Sir John Pendry [3, 4] at Imperial College of United Kingdom has demonstrated that a simple metallic microstructure comprising an array of thin wires can shift the plasma frequency into the infrared range or even GHz range, analogous to those by a solid metal in the visible and near UV ranges. I will explore this novel low-frequency plasmonic structure to manipulate thermal emission in the infrared range. Similar to surface plasmons, surface phonon polaritons on the surface of polar dielectrics such as SiC and SiO_2 exist in the infrared range and thus can be thermally excited. During my thesis research, I demonstrated that surface phonon polaritons mediated thermal radiation can exceed Planck's blackbody radiation limit by three orders of magnitude [1]. I will also study the coupling or hybridization of surface phonon polaritons and surface plasmons in the infrared range and utilize this effect of coupling to control thermal emission. Finally, I will build a temperature control apparatus and use Fourier transform infrared spectroscopy (FTIR) to characterize the emissive properties of the designed plasmonic structures at both room and high temperatures.

Professor Zhang is a well-known expert in the field of nanophotonics. In the past decade, a number of breakthroughs on plasmonics and matamaterials have been made in his lab. Under his guidance on my research in the two proposed areas, I hope to contribute the alternative energy research at University of California-Berkeley.

References

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