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Guest Editorial

Special Issue on Nano/Microscale Radiative Transfer

Since the mid 1980s, the heat transfer community has made significant advances in experimental and theoretical understanding of sub-continuum thermal conduction and fluidics at small length scales; these activities coincided with the increased interest in micro/nanotechnology. The special issue of the *Journal of Heat Transfer* (JHT) on Micro/Nanoscale Heat Transfer, published in April 2002, covered the breadth of most of these contributions. On the other hand, much less attention has been paid to the understanding of thermal radiation at micro/nanoscales until recently. The current special issue is devoted to Nano/Microscale Radiative Transfer and should give a glimpse of the state of the art in the field.

Thermal radiation is key to many fundamental phenomena surrounding us, from solar radiation to fire to incandescent lamp, and has played a major role in combustion and furnace design, materials processing, energy utilization, temperature measurements, remote sensing for astronomy and space exploration, food processing, and cryogenic engineering, as well as numerous agricultural, health, and military applications. At the dawn of the twentieth century, the study of thermal radiation produced two Nobel laureates (Wien in 1911 and Planck in 1918) and led to the discovery of the Bose-Einstein quantum statistics. While Planck's law has been successfully applied to a large number of practical problems for some 100 years, questions have been raised about its limitation in micro/nanosystems, especially at subwavelength distances, i.e., in the near field. The advancement of nanotechnology has enabled precise manufacturing of structures with feature sizes smaller than the characteristic wavelength of thermal radiation. Radiative properties can be largely modified by interference, diffraction, localization, and surface polaritons, resulting in engineered surface microstructures with numerous practical applications in sensors, imaging, manufacturing, and energy devices. Thus, the study of engineered microstructures for controlling surface radiative properties has become an active area of research, along with nanomaterials, nanophotonics, and nanoscale thermophysical engineering.

Discussions with a number of participants at the Fourth International Symposium on Radiative Transfer held in Istanbul, Turkey in June 2004, suggested that there was a strong desire in the community to have focused sessions on nanoscale radiative transfer in order to boost this emerging research frontier. Subsequently, we organized the first Mini-Symposium on Nano/Microscale Radiative Transfer and Properties (NanoRad), at the 2005 International Mechanical Engineering Congress and Exposition (IMECE) in Orlando, Florida in November 2005. This mini-symposium included five sessions with a total of 21 papers/posters and a panel discussion about significant issues, challenges, funding trends, and opportunities in this area. The panel consisted of Professor Alfonso Ortega, then Director of the NSF Thermal Transport and Thermal Processing Program, Professor Gang Chen from the Department of Mechanical Engineering of MIT, Professor Yongfeng Lu from the Department of Electrical Engineering of the University of Nebraska Lincoln, along with the Editors of this Special Issue. The panelists raised significant questions related to the maximum achievable thermal emissive power, applicability of Kirchhoff's law in nanostructures, and the entropy of near-field radiation, among others. The mini-symposium showed that great opportunities and needs exist in the study of near-field radiation, which we also dub as nanoscale radiative transfer. The field is rich and exciting, as it requires deeper understanding of the interplay among optical, thermal, electrical, and mechanical properties of materials and structures at nanoscales, for applications in spectral and directional control of thermal emission, photovoltaic and thermophotovoltaic devices, biological sensors, remote sensing, materials processing, and nanothermal manufacturing.

This special issue is based on selected papers presented at the mini-symposium, and additional manuscripts, which were broadly solicited. All papers went through the rigid review process of JHT, followed by extensive revisions. A total of 12 papers are included, beginning with a survey article by Ruan and Kaviany (p. 3) on the advances in laser cooling of solids. This phenomenon relies on the anti-Stokes fluorescence, where the emitted photons have a mean energy higher than that of the absorbed photons. The thermodynamics of laser cooling and the potential advantages of using nanostructured materials due to quantum size effect were discussed. In the second paper, Marquier et al. (p. 11) expanded their earlier works to study the effect of polarization and anisotropy in the emission behavior of surface relief gratings. Coherent thermal emission has been demonstrated for gratings and shows promise in thermal control and remote sensing. Lee and Zhang (p. 17) examined coherent thermal emission characteristics from a proposed multilayer structure consisting of a thin SiC layer on a one-dimensional photonic crystal. They distinguished three different mechanisms for coherent emission due to surface electromagnetic waves, optical cavity resonance, and the Brewster mode. Chandrasekharan et al. (p. 27) experimentally observed the effect of heat treatment on the optical properties of Ta_2O_5 thin films for their application as radiation shields in microcombustion systems. Attention was paid to the formation of an interfacial oxide layer on the radiative properties and the effect of wave interference. In the next paper, Jin and Xu (p. 37) focused on the near-field effect of subwavelength apertures and demonstrated nanoscale concentration of light through H-shape apertures using near-field scanning optical microscopy (NSOM). These light sources may enable lithographic fabrication and materials process at the nanometer scale. Optical microcavities have enormous applications in quantum electrodynamics (QED), enhancement and suppression of spontaneous emission, and biochemical sensors, due to their extremely high quality (Q) factor. Guo and Quan (p. 44) used the finite element method (FEM) to investigate the energy coupling (through evanescent waves) between a waveguide and a whispering-gallery-mode optical microdisk. On the other hand, Heltzel et al. (p. 53) demonstrated submicrometer manufacturing using a femtosecond laser pulse with the assistance of the patterned silica microspheres on a borosilicate glass substrate. Venkata et al. (p. 60) described a technique to characterize metallic particles and agglomerates based on surface plasmon waves. The effects of size, shape, and orientation of gold nanoparticles on their scattering patterns were explored in the visible spectrum, especially at the resonance wavelengths. Surface roughness and patterns can significantly affect the radiative properties and are important for semiconductor manufacturing. Fu and Hsu (p. 71) used a finite-difference time-domain (FDTD) to numerically solve the Maxwell equations for scattering from random rough surfaces, and showed that the results compared favorably with other methods. Chen et al. (p. 79) modeled the radiative properties of patterned silicon wafers with the smallest feature dimension down to 30 nm, considering the effects of temperature, wavelength, polarization, and angle of incidence. Rigorous coupled wave analysis (RCWA) was employed to obtain accurate solutions and to assess the applicability of the method of homogenization based on effective medium theories (EMTs). Hu et al. (p. 91) used an infrared microscope to characterize the thermal interface formed between two opposing, partially overlapped carbon nanotube (CNT) arrays. Hammonds (p. 94) employed a Green function approach based on the fluctuation-dissipation theorem to model the radiation heat transfer across an evacuated spherical cavity inside a SiC medium.

In summary, this special issue reflects a variety of contemporary research in nano/microscale radiative transfer and is expected to promote further research activities and development opportunities. We would like to thank all contributors, reviewers, and panelists, who have made the mini-symposium a success and this special issue possible. Our special thanks go to Professor Neil Wright of Michigan State University, Chair of the K-7 Thermophysical Properties Technical Committee, for his enthusiastic support and K-7's sponsorship of the mini-symposia. We appreciate the encouragement and help from the Editor of JHT, Professor Yogesh Jaluria, throughout the editorial process.

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