Available online at www.sciencedirect.com
ScienceDirect
PHOTONICS AND NANOSTRUCTURES Fundamentals and Applications
Photonics and Nanostructures – Fundamentals and Applications 12 (2014) 93–113
www.elsevier.com/locate/photonics

Review

An overview of micro/nanoscaled thermal radiation and its applications

Yimin Xuan *

School of Energy and Power Engineering, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China

Received 26 August 2013; received in revised form 21 February 2014; accepted 21 February 2014
Available online 6 March 2014

Abstract

With the rapid development of micro/nanoscaled technologies, we are confronted with more and more challenges related to small-scale thermal radiation. Thorough understanding and handling of micro/nanoscaled radiative heat transfer is vital for many fields of modern science and technology. For example, proper utilization of near-field thermal radiation phenomenon greatly improves light-electric conversion efficiency. This review introduces theoretical and experimental investigation on near-field thermal radiation, especially progress in application and control of micro/nanoscaled radiative heat transfer, which addresses problems in developing renewable and sustainable energy techniques.

Keywords: Near-field thermal radiation; Micro/nanoscale structures; Spectral properties; Evanescent waves; Metamaterial

Contents

* Tel.: +86 025 84890688; fax: +86 025 84891512.
E-mail address: ymxuan@nuaa.edu.cn.

http://dx.doi.org/10.1016/j.photonics.2014.02.003
1569-4410/

1. Introduction

As one of several modes of heat transfer, thermal radiation commonly exists in nature. Since early in the last century, investigation of basic theory and applications of thermal radiation has become very active in thermoscience and thermal engineering and remarkable progress has been achieved. Most of these efforts were limited to the macroscopic scale; however, accompanying the swift development of nanoscience and technology, thermal radiation at micro/nanoscale has attracted more and more attention. Today it is widely acknowledged that any improvement in the performance and efficiency of macroscale systems depend mainly on understanding their microscopic processes. Knowledge of the mechanism of thermal radiation at small distances becomes more imperative in a variety of fields of fundamental research and engineering technology, such as energy harvesting [1–3], thermal rectification/modulation [4–9], nanofabrication devices [10,11], and thermal microscopy and imaging [12–15].

Transition of thermal radiation from macroscopic to microscopic scale faces many new challenges and the existing theory and methods for the macroscopic process may fail to deal with the microscopic process. Since Rytov [16] proposed an electromagnetic model of thermal radiation in the 1950s, investigation of micro/nanoscale thermal radiation process has gradually increased and research branches are greatly expanded [17]. Research activities may be mainly divided into two categories: the mechanism of micro/nanoscale thermal radiation and the methods of controlling heat radiation, as well as applications. In fact, suppressing or enhancing the micro/nanoscale radiative heat transfer has important academic and practical significance for many situations.

Radiative heat transfer between surfaces is affected by the spectral characteristics of thermal radiation and the emissive properties of the surfaces. Among a series of factors, the radiative properties such as emissivity and absorptivity of the surfaces are the key factor. Generally speaking, the radiative properties of a surface are dominated by microscaled structure characteristics and inherent properties of the material (for example, dielectric constant and refractive index). Therefore, adjustment of the radiative properties can be realized by modifying material properties and/or constructing periodic structures. The thermochromic materials [18,19] and subwavelength structured surfaces [20–23] are two typical examples. Here a so-called structured surface is referred to as the surface on which some microstructures whose sizes are comparable to or even smaller than the relevant wavelengths. A grating surface may be one of typical subwavelength-structured surfaces.

However, due to the technical restrictions of the past, it was relatively difficult to alter the material properties, which made it equally difficult to apply such approaches to practical cases. With the rapid progress of materials science, new technologies based on the material science have arisen to control surface radiative properties. One of the effective approaches is doping some specific dopants into a base material, which alters the properties of the base material such as permittivity and permeability and then tunes the interaction process between the material surface and incident light. Nevertheless, changing the surface structure to modulate the radiative properties is preferential for adjusting the thermal radiation process. Being compared with the doping technique, forming nanostructures on surfaces may be easy to be realized in many cases. Depending upon the fixed purposes, both of these methods may be either separately or simultaneously used for tuning the emissive properties of surfaces. To determine the spectral properties of such doping and/or micro/nanostructured surfaces, one can resort to a series of computational methods, such as the finite difference time domain (FDTD), the rigorous coupled-wave analysis (RCWA), and the finite element method (FEM). Meanwhile, one can directly measure the properties by using proper instruments.

When the characteristic length of objects involved in thermal radiation is much larger than the dominant wavelength of thermal radiation, the radiant energy transfer process can be labeled as ‘macroscopic radiative heat transfer’ and the methods of ray-tracing, or geometrical optics, are valid. Radiative transfer equation (RTE), based on Planck’s radiation law, is a fundamental