

Selective and Dynamic Control of Optical and Radiative Properties with Film-Coupled Metamaterials: Numerical Modeling and Temperature-Dependent Spectrometric Characterization

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Selective control of thermal radiation has numerous applications in energy harvesting, thermal management, and microelectronics. Past work has demonstrated that surface radiative properties can be successfully tailored with multilayer structures and micro/nanostructures. However, temperature-dependent radiative properties are little studied, which are crucial for applications at elevated temperatures. Besides, reported radiative properties are mostly static, while active tuning of surface emission or absorption is greatly beneficial to radiative thermal control. We will present our recent progresses in both numerical design and spectrometric characterization of film-coupled metamaterials with an emphasis on temperature-dependent optical and radiative properties. With finite-difference time-domain method, a metamaterial solar absorber with strong spectrally-selective absorption/emission has been designed. Optical and thermal radiative properties of fabricated samples will be characterized in a broad spectral regime from UV to mid-IR regime under different temperatures. An FTIR spectrometer along with a variable-angle reflectance accessory is used to indirectly measure the room-temperature absorptance/emittance spectrum. A novel FTIR fiber optics method along with a home-built heater assembly is developed to measure the temperature-dependent optical reflectance from room temperature up to 400degC. Along with a blackbody source and external optics, the spectral-directional emittance of the sample will be directly measured at higher temperatures up to 1000degC. Thermal stability and temperature effect on the optical and radiative properties will be experimentally studied, which is crucial particularly for the practical high-temperature applications such as concentrated solar power with these advanced materials. On the other hand, we have designed a switchable film-coupled metamaterial with a spacer layer made of VO₂, which experiences metal-insulator transition at 68degC. Upon the VO₂ phase change, magnetic resonance could be either turned on or off, resulting in a switchable spectrally-selective emission peak in the mid-infrared. With a temperature-controlled heating stage inside the reflectance accessory, we will measure the infrared emittance of a fabricated switchable metamaterial sample at temperatures below and above its phase transition point, thereby experimentally demonstrating the dynamic control of thermal emission with a thermally induced mechanism. Such a “smart” coating material could find applications in radiative cooling for buildings and spacecraft systems.