論 文 の 内 容 の 要 旨

論文題目　Optimal design of spectrally selective photonic structures for thermal radiation applications
（熱輻射応用のための波長選択的フォトニック構造の最適デザイン）

氏　　名　　郭　江

Thermal radiation originated from the random fluctuation of charges or ions plays an important role in energy or heat transfer process. Natural bulk materials usually show broadband and graybody thermal radiative properties which are not desirable for high energy conversion efficiency such as solar thermal, solar photovoltaics, radiative cooling and so on. Metamaterials which can artificially control the electromagnetic wave interaction with materials or micro/nano structures provide an effective and promising way to tailor the far-field thermal radiative property as demand. However, inverse design of micro/nano structures is rather difficult due to the complex underlying physical mechanism for interaction between metamaterials and electromagnetic wave with similar scales and the relative high cost either for simulation or experiment. Materials informatics which combines the materials design and machine learning informatics algorithm has been proposed to accelerate the micro/nano structures design in order to achieve high energy conversion efficiency. This dissertation explores the potential of materials informatics in tailoring thermal radiative properties for high energy transfer efficiency and analyzes the underlying physical mechanism.

A highly wavelength selective thermal radiator is designed by hybrid grating and multilayer structure for the radiative cooling application by Bayesian optimization. The optimization histories show that only less than 1% of total candidates need to be evaluated for Bayesian optimization to identify the global optimal structure. Quantum annealing with factorization machine has been proposed to design nearly idea spectral selective metamaterial composite for sky radiator design. Real quantum annealing process is applied during optimization process and the proposed design strategy achieves superior optimization efficiency than simulated annealing and greedy search. Transmissive type radiative coolers with RGB colors and highly visible transparent but near infrared reflective type radiative coolers are designed by Bayesian optimization. The transmissive radiative cooler can realize about 8 C below ambient under moderate heat transfer condition. The reflective radiative cooler can largely reduce the thermal load and maximize thermal radiation dissipation in the infrared range.

Spectrally matched selective thermal absorber and emitter are designed for high temperature concentrated solar thermophotovoltaic application using Molybdenum photonic crystal with HfO2 coating via Bayesian optimization. The designed selective absorber and emitter show nearly doubled efficiency for converting solar photons to photons emitted by nanophotonic emitters than blackbody absorber and emitter module.

Thermal emitters with dynamic optical response by VO2 phase change material are rapidly optimized for high Q factors by Monte Carlo tree search. The aperiodic Distributed Bragg Reflector (DBR) in designed structures enable the ultra-narrow band optical response with over 99% emissivity by localized mode of electromagnetic wave.

The exploration work of applying materials informatic for thermal radiation applications demonstrate the high optimization efficiency for nanophotonic design. The optimized nanophotonic structures not only largely improve the energy conversion efficiency on one hand. The insights from underly physical mechanism of optimal nanophotonic structure can also further deepen people’s understanding about light and matter interaction behavior and help to better control of thermal radiative property.