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DIRECTIONAL AND SPECTRAL FAR-/NEAR-FIELD RADIATIVE TRANSFER FOR COOLING AND ENERGY HARVESTING: A REVIEW

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In this review presentation, we will outline the fundamentals and the most recent developments on the impacts of spectral and directional radiative transfer on radiative cooling and energy harvesting. With the recent advances in nano-fabrication techniques, we can now construct surfaces with structures specific for desired objectives. This means that we can tune the absorption, emission and reflection/scattering characteristics as a function of the operating wavelengths of incident and emitted radiation as well as for specific directions. With this approach, thermal energy management can be optimized to have higher level of energy conservation at several layers of energy systems.

It is well known that radiation transfer differs from the other two heat transfer modalities, conduction and convection transfer, by a number of reasons. First of all, radiation transfer requires no medium between two objects for the energy exchange to take place. Also, the rate of radiative energy transfer is proportional to the fourth power of the absolute temperatures of the objects involved. Consequently, radiative flux can be much more than those for conduction or convection if the temperature difference is high (Howell et al., 2015). Beyond these obvious differences, the directional and spectral behavior of radiation transfer makes radiation a prime ‘designer’ mechanism for the targeted energy transfer specific to location and process itself. The understanding and effective use of these features, however, must be based on electromagnetic wave theory. By using the governing Maxwell’s equations for this approach, deep physics behind radiation transfer can be uncovered, and the variations in spectral, directional as well as near-field features can be used for applications to new devices and processes.

The advances in nanotechnology has opened the path for different manufacturing modalities to design and build functional surfaces discussed above. Yet, the fundamental understanding in near-field radiation transfer at nano-scales was the key turning point to accomplish what was foreseen almost two decades ago. The concepts behind these developments have been discussed in the literature, starting from the seminal paper by Greffet at al. (2002). Since then, there was a significant amount of research and development on near-field radiation transfer (NFRT) that allowed clarification of physics at nano-scales. The underlying mechanism for the NFRT is the plasmonic interactions, which stem from both the material properties and the geometrical effects. With the advances in metamaterials at one hand, and the advances in precise experiments at the other where nano-scale interactions can be quantified, the path is now open for the conceptualization of further ‘designer’ tools and mechanisms. Such near-field radiative transfer applications need to involve other physical mechanisms as well, as outlined by Cahill et al. (2014). Of course, all these applications would need to be based reliable models for possible application of near-field radiative heat transfer to diverse engineering problems. Several such studies were reported in two recent Special Issues of Nano- and Micro-Scale Radiative Transfer in *JQSRT* (Zhang et al., 2014, 2015).

All these developments allow both spectral and directional tuning of surfaces. For the latter, we need to use micro-roughnesses on the surfaces, called gratings, to provide selective emission, as shown by Greffet group (see Arnold et al. (2012) and the references therein). Modeling of irregular shapes structures' effect on such surfaces is not a trivial task; recent work by Didari and Menguc (2015) presented a novel FDTD method to determine the required effects numerically. Also recently, the concept of radiative cooling was explored by Fan group (Zhu et al., 2013, 2014). Combination of the properties of 'designer' materials along with the concepts of spectral and directional tunings is likely to yield much different applications of radiative transfer. These advances along with the fundamentals will be the core topics of this presentation.

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