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ABSTRACT

The conception, design and development of artificial materials with tailored functional responses are of fundamental importance for the ever-growing needs of modern technology. In the past fifteen years, metamaterials have provided a powerful platform for this purpose, offering breakthroughs for basic science and for applied technologies. While metamaterial concepts today span several wave phenomena, including electromagnetics, acoustics, mechanics and photonics, in these areas metamaterial concepts have evolved quite separately, without significant interactions and with limited impact in the specific field of thermal management and control. Thermal radiation and heat flow, on the other hand, play a fundamental role in basic science and in a wide range of technologies of DoD relevance, including photovoltaics, lighting, temperature and heat management, infrared detection, noise and thermal signature control.

Here, we propose an inherently basic research endeavor aimed at creating disruptive discoveries and technologies in the area of artificial engineered materials for extreme manipulation of thermal emission and heat flow. To this end, we will leverage the unique opportunities offered by metamaterials as a platform enabling strong and unusual multi-physics wave interactions with matter, ideally suited to open groundbreaking opportunities to control thermal emission and flow. As outcomes of our program, we envision disruptive opportunities for engineered materials, taking advantage of synergistic interactions of different phenomena strongly coupled over a nanoengineered platform, applied to broadly advance the field of artificial materials with a focus on thermal management and control. We will show how metamaterials that combine multiple interactions with different physical responses may be able to offer unprecedented manipulation of thermal energy. Our complete, interdisciplinary program will draw from the latest advances in nano-optics, condensed-matter physics, material science, electronics and thermodynamics to open a new paradigm for engineered materials, with impact on basic science and several civil and military applications, including communications, nanophotonics, imaging and sensing, energy harvesting and thermal management.

Our group has a history of excellence in the mentioned areas, and it is in a unique position to push forward the proposed research program to provide a disruptive advancement in the field of metamaterials in its broader context, and its extension and application to thermal management and control throughout the mentioned areas of research and science. Enabling multi-physics interactions on the metamaterial platform will enable to overcome the current challenges and limitations, providing new ways to control thermal flow, taking advantage of spatio-temporal modulation, nonlinearities, hyperbolic propagation, topological transport, nanophotonic and quantum engineering of materials. The proposed effort is highly ambitious, and it has the realistic potential of realizing groundbreaking advances in several areas of science and technology of primary relevance for DoD and society in general. It will enable the suppression or transformation of the thermal signature of objects, the realization of thermal sources and detectors with unique thermal signatures, including highly selective, tunable and reconfigurable temporal and spatial profiles, the realization of nanophotonic structures overcoming Planck's and Kirchhoff's laws of thermal radiation, offering thermal emission significantly larger than would be expected from their geometrical size, and breaking the symmetry in which objects emit and absorb, as well as enabling the use of thermal radiation for communications and multiplexing. These unique opportunities will largely benefit heat management, light emitting diode technology, energy-efficient lighting, photovoltaics, noise management in circuits and quantum computing systems, and energy harvesting.