Aerospace Engineering Doctoral Defense

Dynamic Radiative Thermal Management and Optical Force Modulation with Tunable Nanophotonic Structures Based on Thermochromic Vanadium Dioxide

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Abstract

This research focuses mainly on employing tunable materials to achieve dynamic radiative properties for spacecraft and building thermal management. A secondary objective is to investigate tunable materials for optical propulsion applications. The primary material investigated is vanadium dioxide (VO2), which is a thermochromic material with an insulator-to-metal phase transition. VO2 typically undergoes a dramatic shift in optical properties at T = 341 K, which can be reduced through a variety of techniques to a temperature more suitable for thermal control applications. A VO2-based Fabry-Perot variable emitter is designed, fabricated, characterized, and experimentally demonstrated. The designed emitter has high emissivity when the radiating surface temperature is above 345 K and low emissivity when the temperature is less than 341 K. A uniaxial transfer matrix method and Bruggeman effective medium theory are both introduced to model the anisotropic properties of the VO2 to facilitate the design of multilayer VO2-based devices. A new furnace oxidation process is developed for fabricating high quality VO2 and the resulting thin films undergo comprehensive material and optical characterizations. The corresponding measurement platform is developed to measure the temperature-dependent transmittance and reflectance of the fabricated Fabry-Perot samples. The variable heat rejection of the fabricated samples is demonstrated via bell jar and cryothermal vacuum calorimetry measurements. Thermal modeling of a spacecraft equipped with variable emittance radiators is also conducted to elucidate the requirements and the impact for thermochromic variable emittance technology. The potential of VO2 to be used an optical force modulating device is also investigated for spacecraft micropropulsion. The preliminary design considers a Fabry-Perot cavity with an anti-reflection coating which switches between an absorptive “off” state (for insulating VO2) and a reflective “on” state (for metallic VO2), thereby modulating the incident solar radiation pressure. The visible and near-infrared optical properties of the fabricated vanadium dioxide are examined to determine if there is a sufficient optical property shift in those regimes for a tunable device.

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