Mechanical Engineering Doctoral Defense

Opto-thermal Energy Transport with Selective Metamaterials and Solar Thermal Characterization of Selective Metafilm Absorbers

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abstract

The objective of this dissertation is to study the use of metamaterials as narrow-band and broadband selective absorbers for opto-thermal and solar thermal energy conversion. Narrow-band selective absorbers have applications such as plasmonic sensing and cancer treatment, while one of the main applications of selective metamaterials with broadband absorption is efficiently converting solar energy into heat as solar absorbers. The dissertation first discusses the use of gold nanowires as narrow-band selective metamaterial absorbers. An investigation into plasmonic localized heating indicated that film-coupled gold nanoparticles exhibit tunable selective absorption based on the size of the nanoparticles. By using anodized aluminum oxide templates, aluminum nanodisc narrow-band absorbers were fabricated. A metrology instrument to measure the reflectance and transmittance of micro-scale samples was also developed and used to measure the reflectance of the aluminum nanodisc absorbers (200 µm diameter area). Tuning of the resonance wavelengths of these absorbers can be achieved through changing their geometry. Broadband absorption can be achieved by using a combination of geometries for these metamaterials which would facilitate their use as solar absorbers. Recently, solar energy harvesting has become a topic of considerable research investigation due to it being an environmentally conscious alternative to fossil fuels. The next section discusses the steady-state temperature measurement of a lab-scale multilayer solar absorber, named metafilm. A lab-scale experimental setup is developed to characterize the solar thermal performance of selective solar absorbers. Under a concentration factor of 20.3 suns, a steady-state temperature of ~500C was achieved for the metafilm compared to 375C for a commercial black absorber under the same conditions. Thermal durability testing showed that the metafilm could withstand up to 700C in vacuum conditions and up to 400C in atmospheric conditions with little degradation of its optical and radiative properties. Moreover, cost analysis of the metafilm found it to cost significantly less ($2.22 per sqm) than commercial solar coatings ($5-100 per sqm).Finally, this dissertation concludes with recommendations for further studies like using these selective metamaterials and metafilms as absorbers and emitters and using the aluminum nanodiscs on glass as selective filters for photovoltaic cells to enhance solar thermophotovoltaic energy conversion.

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