論 文 の 内 容 の 要 旨

論文題目　A study on thermal radiation control by microstructures and phase-change materials
（微細構造と相転移材料を用いた熱輻射制御に関する研究）

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This work deals with a study on thermal radiation control, which is enabled by using subwavelength structures or phase-change materials. Thermal radiation is one of the three heat transfer modes, and its control opens possibilities in various applications such as thermophotovoltaics, thermal management, and mid-infrared light sources. In this study, four types of thermal radiation control, namely dynamic control, monochromatic light source, thermal rectification, and near-field thermal radiation are investigated theoretically and/or experimentally, toward mid-infrared light source for chemical sensing and thermal management in artificial satellites.

Firstly, a novel coupling mechanism between surface waves and guided mode resonances are theoretically proposed for dynamic thermal radiation control. A developed modal analysis shows that the guided mode in silicon grating couples to the surface phonon polariton on a silicon carbide substrate or surface plasmon polariton on a doped silicon slab via evanescent waves. The modulation of the grating height from 36.2 μm to 37.3 μm allows us to control emissivity with an amplitude larger than 0.9 at a wavelength of 12.13 μm. Such a dynamic modulation improves the signal-to-noise ratio of infrared chemical sensing.

Secondary, a quasi-monochromatic incandescent light source is demonstrated theoretically and experimentally. The proximity interaction between densely-placed metal-insulator-metal (MIM) metamaterial resonators enables the suppression of the parasitic modes. The integrated parasitic heat flux decreases from 11.8 $Wsr^{-1}m^{-2}$ to 4.0 $Wsr^{-1}m^{-2}$ at an angle of 60° by adopting densely-tiled square resonators. The mechanism of the suppression is theoretically investigated, and the measured thermal emission spectra of the fabricated metamaterial verify the presented suppression. Such a quasi-monochromatic source contributes the design of non-dispersed infrared sensing (NDIR) systems.

Thirdly, radiative thermal rectifiers are developed based on the phase-change of vanadium dioxide (VO_2). VO_2 in the insulating state works as a good infrared absorber in the forward scenario, while it in the metallic state works as an emitter with low efficiency in the reverse scenario. The variation of the optical response between the insulating and the metallic states enables a high thermal rectification contrast ratio of 2 in our measurement system. The presented thermal rectification will allow novel thermal management systems.

Finally, a methodology to form submicron gaps for near-field thermal radiation is proposed. Microfabricated spacers with a height of 0.5 μm, 1 μm, or 2 μm, are employed to determine the gap width between opposing substrates with an area of 19 × 8.6 mm. Applied pressure as high as 6 kPa compensates the intrinsic mechanical deflection of substrates to keep a uniform gap, while the planarity of the gap is monitored by optical reflection spectra. The proposed methodology is applicable to thermal management utilizing photon-tunneling.

The achievements obtained for the four types of thermal radiation control will contribute to scientific communities as well as industrial implementations. Especially, dynamic and monochromatic mid-infrared light source for NDIR and thermal management system based on near-field thermal rectifier for artificial satellites will be realized based on the achievements of this thesis.