【Grant-in-Aid for Scientific Research(S)】

Science and Engineering (Interdisciplinary science and engineering)

Title of Project : Development of new techniques / concepts for arbitrary thermal emission control

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Research Area : Photonics

Keyword : Thermal emission, Photonic crystals, Sensors, Thermo-photovoltaic generation

【Purpose and Background of the Research】

Converting from a broadband to a narrowband thermal emission spectrum with minimal loss of energy is important for the creation of efficient environmental and biological sensors as well as thermo-photovoltaic power generation systems. In this work, we investigate new concepts and technologies to realize such an ideal control of thermal emission.

【Research Methods】

Recently, we proposed a new concept to realize thermal emission control by simultaneously manipulating photonic modes with photonic crystals and material absorption with quantum-well intersubband transitions. We have shown that the emission peak intensity for our device can be more than four times greater than that of a blackbody sample under the same input power and thermal management conditions due to an increase in the temperature compared to the blackbody reference, and the emission bandwidth and angular spread are narrowed by a factor of 30 and 8, respectively. These results indicate that the energy saved by thermal emission control can be recycled and concentrated to enhance the narrow peak emission intensity. In this work, we will expand and deepen the above concept to realize arbitrary thermal emission control. The following is a listing of our objectives along with a brief description for the approach to be pursued.

(I) Realizing High-Q thermal emission: To realize narrow-band emission spectrum, we will design a photonic crystal resonant mode having a higher radiation Q factor than our original design and match it with a Q factor determined by the absorption of intersubband transitions in quantum wells. It is expected that this method will enable us to create an even more narrow-band (Q> 100~1000) thermal spectrum.

(II) Dynamic, ultra-fast thermal emission control: We will explore a concept for ultra-fast dynamic thermal emission control by controlling the emissivity. We will control the absorption Q factor of the quantum wells dynamically in the time domain to precisely tune the Q matching condition (not the temperature of the device) in order to realize emissivity control in as the nano- to pico-second range.

(III) Near-infrared thermal emission: To realize thermal emission control at near-infrared wavelengths, we will investigate interband transitions in silicon instead of intersubband transitions in the mid-infrared. We will tailor the thickness of a silicon film to manipulate the absorption Q factor and design photonic crystal structures to match its radiation Q factor to the absorption Q to obtain narrow-band and high emissivity peaks.

(IV) Thermal emission exceeding blackbody limit: The thermal emission intensity cannot exceed that of the blackbody, at a given temperature and wavelength. This limitation is due to the mismatch of optical modes between the inside and outside of the thermal emission material. Here, we will introduce a “cavity to cavity coupling” which can in principle overcome the blackbody limit.

【Expected Research Achievements and Scientific Significance】

Our investigations will create highly efficient thermal emission sources with a very-narrow linewidth similar to lasers and be dynamically controlled at ultra-fast modulation speeds. These light sources can be utilized for various applications including environmental and biological sensors. Moreover, there is the possibility of improving the efficiency of thermo-photovoltaic systems where our enhanced thermal sources can be integrated with solar cells so as to first provide recycling of the unsable sub-bandgap components of the solar spectrum to higher energies useful for generating excitons.

【Publications Relevant to the Project】

・M. De Zoysa, S. Noda, et al: "Conversion of broadband to narrowband thermal emission through energy recycling ", ***Nature Photonics***, vol.6, pp 535-539 (2012).

・T. Asano, S. Noda, et al: "Spectrally selective thermal radiation based on intersubband transitions and photonic crystals", ***Optics Express***, vol. 17, pp.19190-1923 (2009).

【Term of Project】 FY2013-2017

【Budget Allocation】 164,600 Thousand Yen

【Homepage Address and Other Contact Information】

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