Development of Thermophotovoltaic Generation of Electricity using Spectral-Controlled Near-Field Thermal Radiation

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Abstract Near-field radiation transfer between pillar-array surfaces made of tungsten was enhanced through an interference of SPP (Surface Plasmon Polariton) compared with that between flat surfaces. With decreasing pillar-height, the frequency at the maximum radiation flux was shifted toward a high-frequency side. On the other hand, through an experiment using a flat-surface emitter made of tungsten and a GaSb cell with a bandgap of 0.67eV, with decreasing gap between those surfaces, the output power became 3.6 times higher than that obtained by far-field radiation.

Keywords: Near-field radiation, Thermophotovoltaics, Surface Plasmon Polariton

1. Introduction

Nano- and/or micro-technologies will be useful for high density power generation or low temperature heat recovery when the nanometer-scaled phenomena could be expanded into a practical length scale. There are many publications related to enhancement of radiation flux by evanescent wave effect. However, results of most of them came from experimental alliances far from a practical scale or configuration, such as a small temperature difference or heat transfer between sphere and plate. In the current study, nano-gap thermophotovoltaic generation of electricity was investigated using a millimeter-scale experimental setup and numerical simulation.

2. Experimental setup of nano-gap thermophotovoltaic generation of electricity

Figure 1 shows a schematic diagram of an experimental setup to make a parallel nanoscaled-gap. A tungsten emitter and a GaSb cell were mounted independently on each stage and were face-to-face in a vacuum chamber. The cell was pasted on a surface of a water-cooled copper block mounted on piezo-actuator system for making the nano-gap, while the emitter was mounted on double axes gonio-stage for making the parallel gap. The space-resolution of the piezo-actuator in the direction of the *z*-axis was 40nm. Figure 2 shows the diagrams of electric current and voltage (I-V curves) for the GaSb cell under the condition of the emitter temperature of 1000K. The diode-characteristics of the cell is also shown (symbols described by dark). When the cell approaches to the emitter surface from an arbitrary origin (0 μm) to a position of 1.1μm, the I-V curve didn't change because the view factor was almost unity. On further increase in moving distance up to 1.2 or 1.5μm from the origin, the short-circuit-current increased drastically. As a result, the output power by the evanescent wave effect became higher than that by the conventional propagating wave.

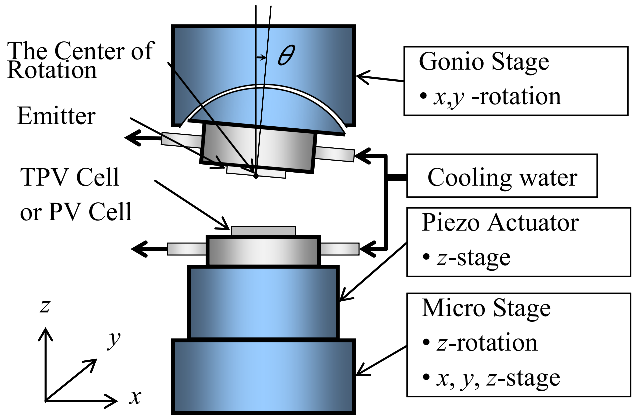

Fig.1 Schematic diagram of experimental setup

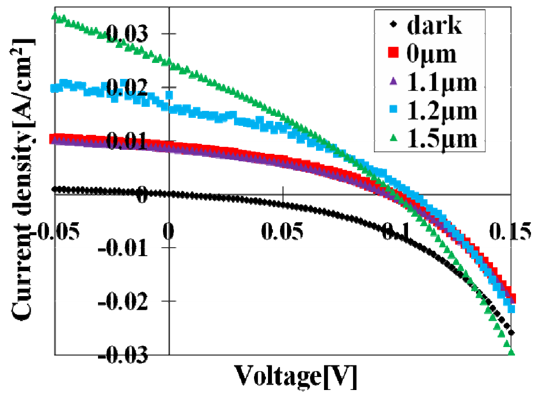

Fig.2 Electric current and voltage diagram (I-V curve) with emitter temperature

3. Radiation transfer enhancement by interference of SPP using a pillar-array structure

Figure 3 shows a pillar-array structured surface for numerical simulation model. Using the Maxwell's equation with emission sources in all nodes with random phase-angles, the radiation transfer is solved through a Finite Difference Time Domain method. Both emitter-1 (1000K) and emitter-2 (300K) were face-to-face and made of tungsten. The cross-sectional area ($a \times a$ = 360nm x 360nm) and the pitch (p = 400nm) of the pillar were fixed through simulation. As shown in Fig.4, the normalized radiation flux between plane plates increases with decreasing gap as d = 200nm, 100nm and 50nm, as described by dashed lines. In the case of pillar-array surfaces with d = 200nm, the radiation flux for the pillar-height of h = 200nm could be enhanced in a range of angular frequency from 10x10^{14} to 20x10^{14} rad/s, as described by the solid line. The peak frequency was shifted toward the high-side with decreasing pillar-height. As shown in Fig.5, the radiation flux increases and decreases periodically with increase in the pillar-height; as a result, a surface wave like a surface-Plasmon-Plariton (SPP) propagates in narrow channels between pillars and the wave is reflected at the bottom. Consequently, a kind of resonance wave in the channel might be transferred from the emitter-1 to the emitter-2.

4. Concluding remarks

A high density generation of electricity will be achieved through spectral-controlled near-field radiation transfer using a pillar-array structured surface.

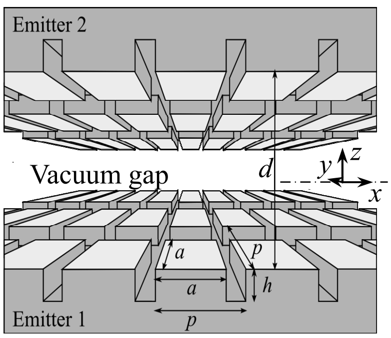

Fig.3 Schematic diagram of pillar-array structure surfaces

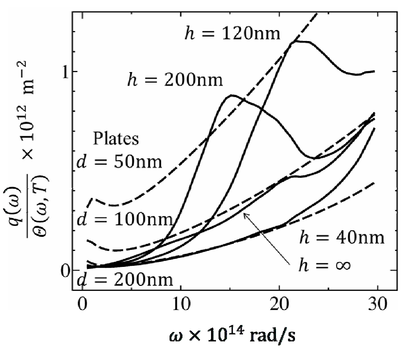

Fig.4 Comparison between Normalized radiation fluxes of pillar-array and plane plate surfaces

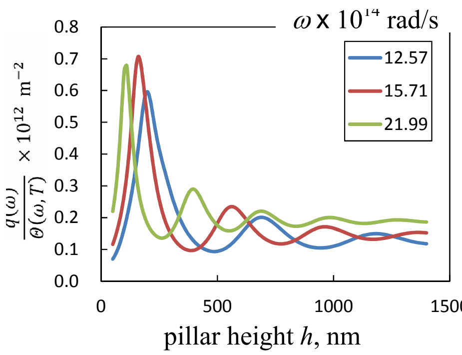

Fig.5 Schematic diagram of pillar-array structure surfaces