Solar thermophotovoltaic using Al203/Er3 Al5012 eutectic composite selective emitter

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SOLAR THERMOPHOTOVOLTAIC USING Al_2O_3/ $Er_3Al_5O_{12}$ EUTECTIC COMPOSITE SELECTIVE EMITTER

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ABSTRUCT

Thermal emission properties of Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite are studied for the application of selective emitter of thermophotovoltaic (TPV) power generator. Since this material has unique structure, high mechanical performance would be expected. Selective emission bands at wavelength 1.5μm due to Er^{3+} ions is observed. Since these emission bands match up the sensitive region of GaSb PV cell, Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite is a suitable emitter material for TPV systems.

Solar TPV system with a dish-type solar concentrator (diameter=1.56m) has been made and tested using the selective emitter material. The performance and component temperature are studied for the system equipped with broad band SiC and Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite selective emitters. Low thermal load for TPV optical components is confirmed for the selective emitter system. The improvement of fill factor of GaSb PV cells is also observed for selective emitter system.

INTRODUCTION

Recently, thermophotovoltaic (TPV) generation systems have been studied as one of the new generation systems of electricity.[1, 2] In the TPV generation system, emission from a high-temperature body is directly converted into electricity by photovoltaic (PV) cells. The TPV system has no moving parts, high power density and can be driven with a wide range of heat sources. These are the key advantages of TPV systems for many potential applications, especially, for space applications[3]. In previously, solar-TPV was studied at McDonnel Douglas Corp. (MDC) by Stone et al. [4-6] They constructed solar-TPV system based on their solar stirling power generation system, and used NASA selective and SiC broad band emitters in the system.

In this paper, we focus on a unidirectionally solidified $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite (Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite) as a selective emitter for solar TPV systems. This material has excellent mechanical strength at high temperature, thermal stability and thermal shock resistance due to its isotropic structure. Originally Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite was developed by Nakagawa et al.[7,8] as structural materials, which will improve thermal efficiency in aircraft engines and gas turbine systems. It is also one of the promising materials to fabricate rare earth selective emitters since it contains 18mol% Er_2O_3, which shows a strong emission peak at 1.5μm. As the bandgap of GaSb PV cell exists at wavelength 1.7μm, Er_2O_3 is a suitable material of selective emitters for TPV generation system with GaSb cells. We measured the emissive properties of Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite and investigated its utilities as a selective emitter. Using this rare-earth selective emitter, a solar TPV power generation system (STPV system) was fabricated so as to acquire basic data and to estimate its utility for terrestrial and space applications. Small-scale experiments were carried out under the sun.

EXPERIMENT

Sample preparation

The physical properties of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite are shown in table 1. This composite has a microstructure in which continuous networks of single crystal Al_2O_3 and single crystal $Er_3Al_5O_{12}$ interpenetrate without grain boundary.[10] In other words, it has isotropic structure. Accordingly it has more superior flexural strength and thermal stability than other crystals and ceramics. In addition, it's higher thermal conductivity reduces the temperature gradient inside of emitter and enhances the efficiency. $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite was made by the following procedure. First, α-Al_2O_3 and Er_2O_3 powders were homogeneously mixed by wet ball milling using ethanol. After drying the slurry preliminary melting is performed to obtain an ingot. Next,

Table1. Physical properties of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite and YAG.

	$Al_2O_3/Er_3Al_5O_{12}$	YAG
mole ratio	Al_2O_3/Er_2O_3 =81.1/18.9	$3Y_2O_3$ $5Al_2O_3$
Density [g cm^{-3}]	5.4	4.56
Melting point [K]	~2130	~2170
Young's coefficient [GPa]	327 (@R.T.)	294
Therm. expansion [10^{-6} K^{-1}]	7.7 (@1023K)	8.2 [110]
Therm. conduct. [W m^{-1} K^{-1}]	17.1 (@R.T.)	13

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using the Brigdman-type equipment this ingot was inserted in a molybdenum crucible set in a vacuum chamber and heated by high- frequency induction of a graphite susceptor. After maintained at 2193K (about 60K above melting temperature) for 30 minutes, the molybdenum crucible was lowered at a speed of 5mm/h^{-1}, completing the unidirectional solidification. Thus Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite was fabricated.

$Al_2O_3/Er_3Al_5O_{12}$ eutectic composite was manufactured into thin film shape varying its thickness (0.1 to 1.0mm) because thin film emitter is convenient to investigate its basic emissive properties. Emitter surfaces are polished mechanically.

Strong absorption peaks due to the 4*f* electron orbit of Er^{3+} are observed at wavelength 1.5μm. When Er^{3+} is thermally excited, these absorption bands behave as emission bands. Therefore it is expected that the emission spectrum of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite has strong peaks at 1.5μm.

Experimental Apparatus

Figure 1 shows the apparatus for measurement of the emissive properties. A sample held on the sample holder is heated with a gas burner and the emission from it

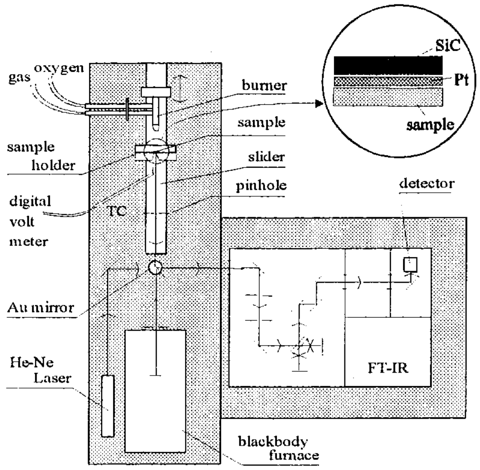

Fig.1 Apparatus for measurement of emissive properties

through a pinhole enters into Fourier transform infrared (FT-IR) spectrophotometer. The measured emission spectrum is converted into an emissive power spectrum possessing the absolute value with an apparatus coefficient. The apparatus coefficient is measured with a standard blackbody furnace in order to estimate the absolute emissive intensity. Only one apparatus coefficient spectrum at 1500K was used to calculate the absolute emissive power of samples at the temperature range of 1000K to 1500K because of its very little temperature dependence. The sample temperature is controlled by changing the distance between the burner and the sample and measured with thermocouple at its surface. The sample is heated through stacking SiC and Pt plates in order to prevent uneven heating and remove the emission from the burner.

RESULTS AND DISCUSSION

Emissive properties of $Al_2O_3/Er_3Al_5O_{12}$ composite

Figure.2 shows emissive power spectra of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite measured on several different temperatures. A strong emission peak appears at the wavelength of 1.5μm. Emissive power of this peak becomes stronger with going up of the temperature. Another peak at 1.0μm is also an emission peak of Er^{3+}. The drastic increase of selective emissive power shows that there is a critical temperature above which the

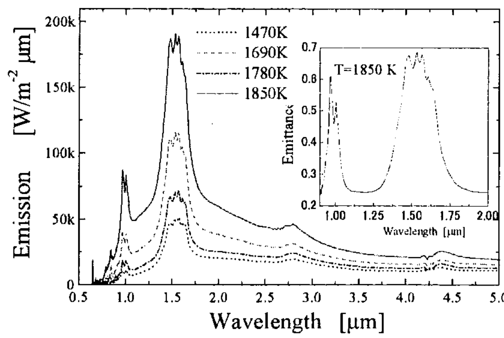

Fig.2 Emission spectra of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite measured on several different temperatures. The inset shows spectral emittance at 1850K.

emissive power is significantly enough to be used for TPV system.

The inset of Fig. 2 shows spectral emittance on $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite. The emittance at the peak position is estimated to about 0.7. However, this value should be confirmed by further experiment because the estimated temperature of samples has relatively large error in this measurement.

We used selective emission efficiency to value the performance of $Al_2O_3/Er_3Al_5O_{12}$ eutectic composite. The definition of selective emission efficiency η is the ratio of the power emitted in the sensitive region of PV cell to the total emissive power.[9] In this calculation, we define the sensitive wavelength region from 1.2 to 1.8 μm.

$$\eta = \frac{E_{1.2\sim1.8\mu m}}{E_{total}}$$

This region corresponds to the sensitive region of GaSb PV cells. The temperature and thickness dependence of η is shown in Fig.3. The maximum efficiency of over 30%

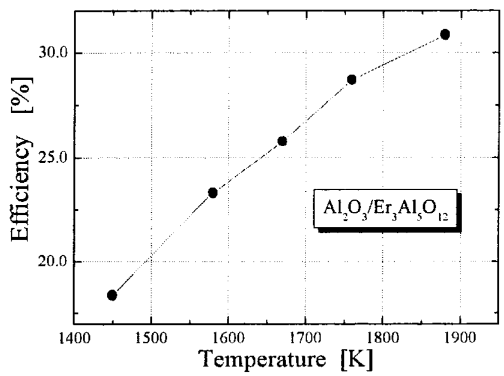

Fig. 3 Temperature dependence of selective emission efficiency.

is obtained at 1900K. Combining photon recycling technique with this selective emitter material, high efficiency and low thermal load on optical components will be realized on TPV systems.

Solar-TPV using the selective emitter

A solar TPV power generation system is constructed using a small parabolic solar concentrator with ϕ1.56m (f=0.65 m). The STPV chamber used in this experiment is shown in Fig. 4. The chamber is evacuated by a

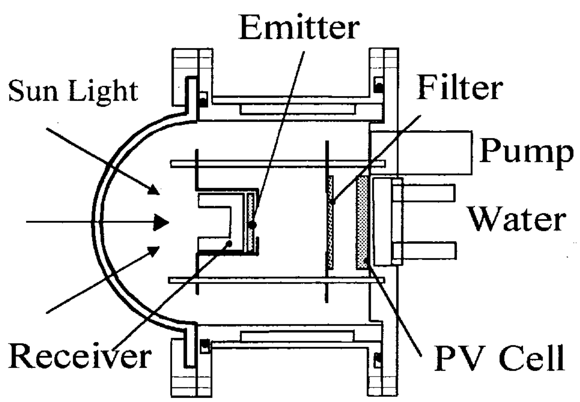

Fig. 4. Schematic diagram of STPV chamber.

vacuum pump. The concentrated sun light is converted to thermal energy by a graphite cavity receiver (inner diameter=10mm). The measured concentration ratio at the entrance of cavity is about 25000 suns. This value is about 60% of concentration ratio calculated from focal length of the concentrator. Measuring sun image at the focal point, this low concentration ratio can be attributed to the imperfect of surface shape of the dish mirror. The surface of cavity is covered by selective or SiC broad band emitters. The dimension of emitters is about 10x10x0.3 mm^3. A polished Mo cover with a hole is put outer side of receiver and emitters for radiation control. Using this cover metal, thermal radiation is preferably emitted from the emitter surface, and higher receiver temperature can be obtained. A dielectric filter was put before PV cells in order to protect the PV cells. The distance between emitter and PV cells is about 30mm. In this experiment we used GaSb PV cells[10,11]. The area of cells is about $3.7cm^2$. The temperature at receiver outer surface, emitter surface optical filter, and PV cell is monitored during the sun experiment.

Figure 5 shows the solar power dependence of filter temperature. Increasing the input power, the filter temperature increases in both emitters. However, the filter temperature using selective emitter is lower than that for

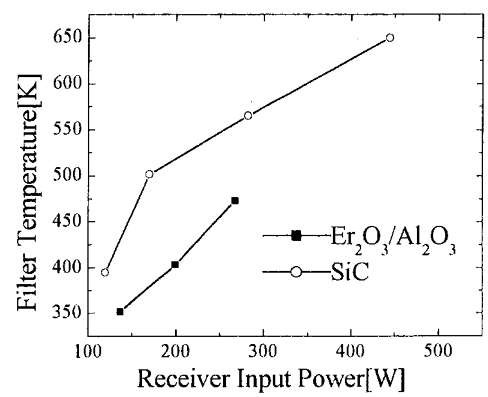

Fig. 5 Filter temperature for two different emitters

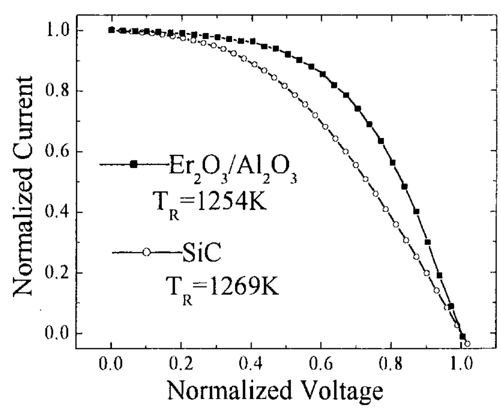

Fig.6 Normalized I-V curves for two different emitters.

SiC emitter. The difference is nearly 100K. This result indicates that the thermal load on optical components can be decreased by using the selective emitter.
This leads to improvement the current-voltage (I-V) characteristic of GaSb cell. Figure 6 shows the normalized I-V curves for selective emitter and SiC emitter. From this result, large fill factor is obtained by selective emitter system.

The PV cell output power is measured for several input one. The results for selective and broad band emitters are shown in Fig. 7. The difference of output power between two emitters increases with increasing the input power. However, the efficiency as well as power density are very low in this experiment. This would be attributed to small emitter area and relatively long distance between emitter and PV cells. This condition leads very low configuration factor between emitter and cells.

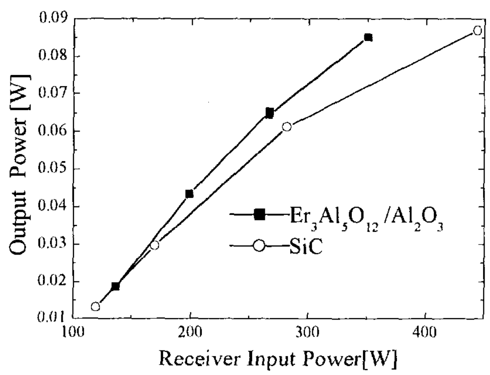

Fig. 7 Input power dependence of PV output power.

CONCLUSION

Emission properties of Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite are studied for the application of selective emitter TPV power generator. Strong selective emission bands at wavelength 1.5μm due to Er^{3+} ions is observed. Since these emission bands match up the sensitive region of GaSb PV cell, Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite is a suitable emitter material for TPV systems.

The performance of solar TPV system and component temperature are studied for the system equipped with broad band SiC and Al_2O_3/ $Er_3Al_5O_{12}$ eutectic composite selective emitters. Low thermal load for TPV optical components is confirmed for the selective emitter system. The improvement of fill factor of GaSb PV cells is also observed for selective emitter system. It is revealed that the optical configuration should be improved for higher performance of the system.

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