Spectrally selective radiators and absorbers with periodic microstructured surface for high temperature applications

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Spectral control of thermal radiation has been one of the most important issues in improving efficiency or saving energy consumption in various thermal systems. In some cases, sharp spectral control can be obtained with inductive multi-layer coatings. However, spectrally controlled optical properties have come to be necessary under a high-temperature environment in which multi-layer coatings are damaged and therefore not available. For example, it is useful to fabricate high-efficiency incandescent lamps,[1] selective radiators for thermophotovoltaic (TPV) applications,[2] solar absorbers,[3] and so on. In TPV systems, thermal radiation from radiators heated at a high temperature converts into electricity with narrow bandgap photovoltaic (PV) cells such as GaSb. Selective radiators, whose emittance is high within PV cell's sensitive region and low outside it, have been studied to raise the efficiency of TPV systems.[2]

To realize ideal optical properties at high temperatures, optical control with periodic microstructured surfaces is one of the attractive options because it has several advantages such as adjustability of design, freedom of material choice, and so on. Recently, Heinzel et al[4] and Sai et al[5] have demonstrated and reported on spectral control of thermal emittance by two-dimensional (2D) metallic surface grating in NIR region. They have utilized some kinds of resonance between electromagnetic wave and surface plasmons modulated by periodic surface microstructures whose dimensions are nearly equal to optical wavelengths to control optical properties. Their reports have shown the possibility to high-efficiency spectrally selective devices with good thermal stability.

In this study, we have prepared two types of 2D periodic surface microstructure with different periodicity, 1.0 μm and 0.5 μm, on bulk W substrates. The former is a selective radiator aiming at high emittance in VIS-NIR region and low outside it for TPV applications. The latter is a selective solar absorber aiming at high photothermal conversion efficiency at

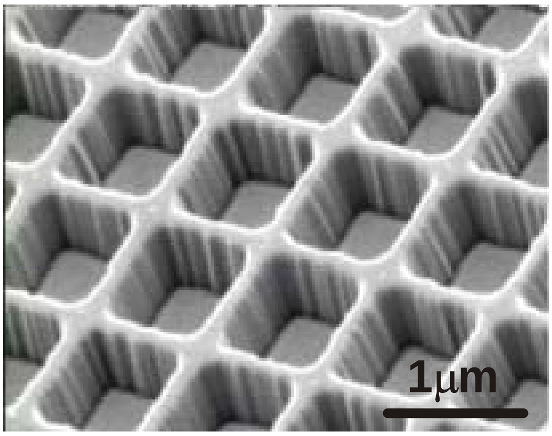

Fig. 1. A SEM image (oblique view) of a selective radiator fabricated by FAB etching.

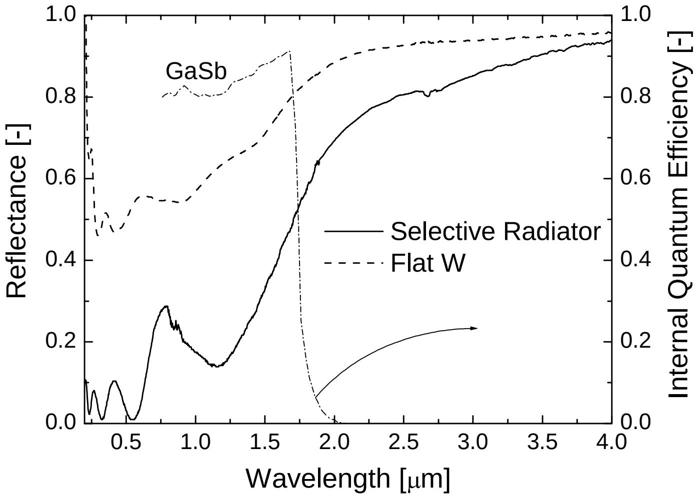

Fig. 2. Near normal reflectance spectrum of a selective radiator for the incidence angle of 5° and spectral IQE of GaSb PV cells.[2]

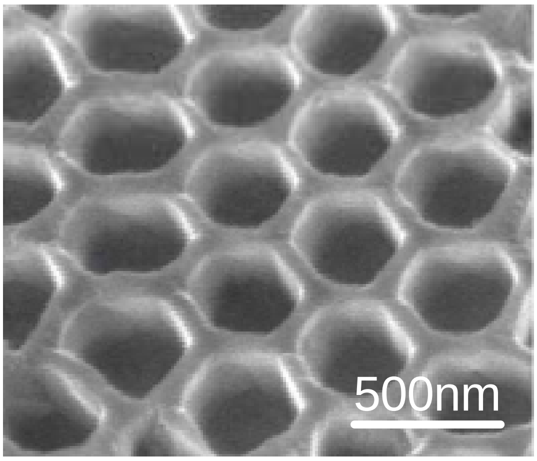

Fig. 3. A SEM image (oblique view) of a selective absorber fabricated by FAB etching with a porous alumina membrane mask.

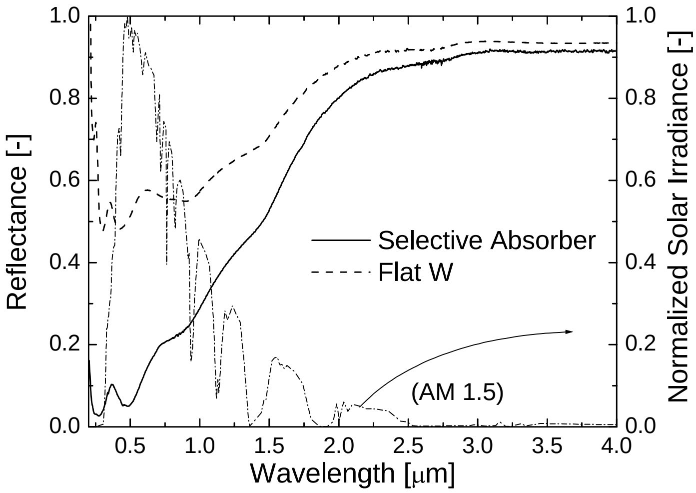

Fig. 4. Near normal reflectance spectrum of a selective radiator for the incidence angle of 5° and normalize solar spectrum under AM 1.5.[8]

high temperatures. Both of them have been fabricated by means of fast atom beam (FAB) etching[6]. Since FAB is electrically neutral atomic or molecular beam, it is possible to obtain fine patterns with nanometer order without deformation of etching shape due to accumulated charge on samples. For preparing selective radiators, resist masks which is processed with electron beam lithography and FAB etching are used. On the other hand, highly ordered anodic porous alumina membrane[7] with the period of 0.5 μm is used as etching masks for fabricating selective solar absorbers. Fig. 1 shows a SEM image of a selective radiator has 2D array of rectangular cavities on its surface. Its structural period Λ, aperture size a and depth d are 1.0 μm, 0.8 μm and 0.7 μm, respectively. This sample shows strong absorption in NIR region as shown in Fig. 2 and thereby spectrally selective thermal radiation is expected at high temperatures. Similarly to the radiator, a selective absorber, which has 2D submicron-hole array on its surface with Λ = 0.5 μm, a = 0.4 μm, and d = 0.3 μm as shown in Fig. 3, absorbs VIS lights strongly as plotted in Fig. 4. Since W has positive dielectric constants in the wavelengths of 0.2 to 1.0 μm, these broad absorptions occur in VIS to NIR region are probably originated from another physics except surface plasmon resonances. Although we have no clear explanation of these phenomena at this point, one candidate is the waveguide mode supported by relatively deep cavities on W surfaces. After preliminary heating test up to 1200K for 5 hour in a vacuum atmosphere, SEM observations and spectral measurements have been conducted and any difference has been observed between before and after heating.

Numerical calculations based on rigorous coupled-wave analysis (RCWA) have been also performed to obtain the optimum configuration of surface microstructures. The results point out that the cavities with high aspect ratio (at least higher than unity) and large aperture are essential for good spectral selectivity.

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