Ito et al.: Spectrally Selective Thermal-radiation Coating Using Metal Particle (1/4)

[Short Note]

Design and Heat-dissipation Characteristics of a Novel Spectrally Selective Thermal-radiation Material

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Abstract

Improvement of heat dissipation from electronics devices is demanded. It has been reported that heat dissipation can be improved by coating thermal-radiation material on the heat element. However, most of radiated heat from the conventional thermal-radiation material is absorbed by an external resin package, resulting in decreased heat-dissipation characteristics. In this report, we newly developed the coating-type spectrally selective thermal-radiation material (C-SSTRM) with emits infrared light through a resin package. C-SSTRM is composed of densely arranged the metallic particles with a specific particle size. The metallic particles are fixed in the resin layer. C-SSTRM was applied to the surface of a heating element, and its heat-dissipation characteristic in a sealed resin case was evaluated. The results of the evaluation confirm that the surface temperatures of the heating element and the resin case were decreased when C-SSTRM was applied compared with the temperatures when the conventional material was applied.

Keywords: Thermal-radiation Material, Heat-dissipation Characteristics, Spectrally Selective, Metamaterial, Thermal Management

1. Introduction

To satisfy the needs for functional integration and downsizing, heat dissipation from electronics devices must be improved. It has therefore been reported that the heat dissipation can be improved by coating thermal-radiation materials on the heat-dissipation surface of the electronic parts.[1] This is because heat energy in a part is converted into electromagnetic waves (infrared light) and radiated by the thermal-radiation materials. Conventional thermal-radiation materials consist of dispersed ceramic particles, such as SiO₂, in an external resin package. However, as shown in Fig. 1(a), most of the heat radiated from a conventional thermal-radiation material is absorbed by the resin package, resulting in degraded heat-dissipation characteristics. Emissivity and absorption ratio are equal by Kirchhoff’s law.[2] The absorption spectra of the resin and SiO₂ is shown in Fig. 2. Since the absorbing region of SiO₂ overlaps with the radiative region of the resin, it is necessary to suppress the absorption of the resin by devising a novel technology. As for one such technology, a spectrally selective thermal-radiation material (SSTRM) that emits infrared light through the resin package, as shown in Fig. 1(b), has been reported.[3] The SSTRM selectively emits infrared light in the wavelength region of the resin with low absorption (blue portion in Fig. 2) by the localized

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Fig. 1 Concept of heat dissipation by thermal-radiation material.

Fig. 2 Absorption spectra of resin and SiO₂.
plasmon resonance. This technology is inferior in terms of versatility because a fine periodic structure is formed on the surface of a thin metal film. However, SSTRM faces several problems. For example, this technology requires a semiconductor manufacturing process, and it can only form fine structures in small areas. Accordingly, the purpose of this study is to (i) develop a coating-type SSTRM (C-SSTRM) with a high degree of freedom in shape at a low cost and (ii) verify its heat-dissipation characteristic.

2. Structure of C-SSTRM

The basic structure of the C-SSTRM is shown in Fig. 3. It has been reported that the localized plasmon resonance occurs in the vicinity between the metallic particles.\[4\] C-SSTRM was therefore investigated by using localized plasmon resonance in the vicinity between the metallic particles. It is composed of the metallic spherical particles arrayed on the bottom of a resin layer, which is the surface of a heating element. Heat energy transmitted from the heating-element surface to the metallic-particle-array layer is converted into light energy. Localized plasmon resonance is generated from the metallic-particle-array layer and emitted as infrared light. It is known that the emissivity (absorption ratio) increases at the wavelength at which the localized plasmon resonance becomes strong. As shown in Fig. 2, if the emissivity of the metallic-particle-array layer increases in the low-wavelength region (blue portion in Fig. 2), emitted infrared light is transmitted through the resin layer and heat dissipation of the resin package is increased. Consequently, heat dissipation from the heating element is improved.

3. Experimental

The solution for C-SSTRM was prepared by mixing metallic particles, resin, and solvent. After the coating material was applied, the metallic particles (having a specific gravity higher than that of the resin) were spontaneously settled in the resin to form the metallic-particle-array layer.

The evaluation sample for verifying the heat-dissipation characteristics of C-SSTRM is shown in Fig. 4. The heating element with the thermal-radiation material coated on both sides in shown in Fig. 4(a). The heating element consists of a film heater sandwiched between aluminum plates. A thermocouple is placed between the film heater and the aluminum plate (size: 20×20 mm; thickness: 1 mm). The evaluation method using a resin case is shown in Fig. 4(b). The evaluation sample was installed so as not to contact the case. The surface temperature of the sample was measured 60 minutes after applying a constant voltage to the heater. The evaluation environment was kept at ambient temperature of 25°C under natural convection. Temperatures were measured at the surfaces of the heater and the resin case.

4. Results

A. Spectral selectivity of C-SSTRM

A cross-sectional image of C-SSTRM (made of metallic particles with average size of 1.6 µm) is shown in Fig. 5. The metallic-particle-array layer was formed at the bottom of the resin layer.

Absorption spectra of C-SSTRM and the resin are shown in Fig. 6 that was measured by specular reflectance FTIR–microscopy using a gold mirror as a standard reference. In the wavelength region of less than 5.3 µm, the absorption spectrum of the resin was low. On the contrary, the absorp-
tion spectrum of C-SSTRM in the same wavelength range was higher than that of the resin. The difference between these spectra is due to the localized plasmon resonance excited in the metallic-particle-array layer. The absorption in the wavelength region of 2 to 6 μm is important for heat dissipation by thermal radiation in the temperature range of the electronics devices. This is because that as the temperature of the electronics devices rise, the radiant intensity of the wavelength region between 2 to 6 μm become stronger than other the wavelength region, by Planck’s law.[5] This result infers that infrared light from the metallic-particle-array layer of C-SSTRM can effectively transmit heat through the resin.

**B. Heat-dissipation characteristics of C-SSTRM**

In general, the heating element is packed into the package. The heat-dissipation characteristics of C-SSTRM were evaluated by using a sealed resin case.

The evaluation samples consisted of an aluminum plate with the conventional thermal-radiation material, with C-SSTRM, or without the thermal-radiation material. The conventional thermal-radiation material used this time is consisted of dispersed ceramic particles. Thickness of each material was approximately 100 μm.

Heat-dissipation characteristics in the sealed resin case are shown in Fig. 7. The temperature of the heating element without the thermal-radiation material was 122.4°C, that with the conventional material was 102.5°C, and that with the C-SSTRM was 100.6°C. The temperature of the resin case without the thermal-radiation material was 44.7°C, that with the conventional material was 48.7°C and that with the C-SSTRM was 41.2°C.

Comparing the three samples reveals that coating the aluminum plate with C-SSTRM results in the lowest surface temperatures of the heating element and the resin case. This result thus confirms that heat dissipation is improved by applying C-SSTRM.

The surface temperature of the heating element with C-SSTRM was 1.9°C lower than that with the conventional material. The difference in the surface temperature of the heating element when applying C-SSTRM and the conventional material is considered to be due to the surface temperature of the resin case.

The surface temperature of the resin case with C-SSTRM was 3.5°C lower than that without the thermal-radiation material, and 7.5°C lower than with the conventional material. The reason that the surface temperature of the resin case without the thermal-radiation material is lower than with the conventional material is following. It is difficult to emit heat energy from the heat element because emissivity of the evaluation sample without the thermal-radiation material is low. As a result, the heat energy was hardly absorbed in the resin case, and the surface temperature of the resin case was lower than that when the thermal-radiation material was used. The difference in the surface temperature of the resin case when applying C-SSTRM and the conventional material is considered as follows. The conventional material emits infrared light at the wavelength where the resin has a large infrared absorption. Therefore, infrared light is emitted from the conventional material is absorbed by the resin case. On the other hand, as shown in Fig. 6, C-SSTRM emits infrared light that include the wavelength region in which infrared absorption of the resin is low. That is, C-SSTRM emits infrared light that passes through the resin case. For that reason, rise in surface temperature of the resin case can be suppressed by applying C-SSTRM; in other words, it is suggested that the heat dissipation of the case was improved by C-SSTRM.

**5. Conclusion**

A coating-type selective thermal-radiation material, C-SSTRM, which emits infrared light through a resin layer, was developed, and its heat-dissipation characteristic was verified. C-SSTRM is composed of densely arranged metallic particles, with a specific particle size, fixed to the resin layer. As part of this structure, C-SSTRM provides efficient spectral emission. In particular, the effect of C-SSTRM on spectral emission is remarkable in the case C-SSTRM is applied to a sealed case.

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