Effective Temperature of Non-uniform Temperature Distribution and Size Effect of Effective Temperature

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Abstract

Thermal radiation properties from non-uniform temperature distribution are investigated and the effective temperature for non-uniform distribution is defined. The thermal radiation spectra for non-uniform temperature distributions are shown as a function of frequency and are compared to the effective temperature. The thermal radiation from arbitrary size of particle is derived and the effective temperature of the body is shown as a function of the particle size.

Thermal radiation from non-uniform temperature distribution

- The thermal radiation intensity coming from two different temperatures can be expressed as

$$I(\nu,T)=\frac{h\nu^3}{Vc^2}\left[\frac{V_1}{\exp(\frac{h\nu}{k_BT_1})-1}+\frac{V_2}{\exp(\frac{h\nu}{k_BT_2})-1}\right] \quad (1)$$

- The total energy density can be calculated as

$$u_B(T)=\frac{4\sigma}{c}T_{eff}^4 \quad (2)$$

where $\sigma=\frac{2\pi^5k_B^4}{15h^3c^2}$

- From Eqs. (1) and (2), the effective temperature of the body having two different temperature distributions can be expressed as

$$T_{eff}=\left[\left(\frac{V_1}{V}\right)T_1^4+\left(\frac{V_2}{V}\right)T_2^4\right]^{1/4} \quad (3)$$

- For n segments of different temperature distribution, the effective temperature of the body can be generalized as

$$T_{eff}=\left[\frac{1}{V}\sum_n V_nT_n^4\right]^{1/4} \quad (4)$$

- By considering the minimum energy, the energy density is changed to

$$u(T)=\frac{8\pi}{(hc)^3}\int_{E_{\min}}^{\infty}\left(\frac{E^3dE}{\exp(E/k_BT)-1}\right) \quad (5)$$

where $E_{\min}=\frac{\sqrt{3}hc}{2L}$

- Effective temperature of the thermal radiation for arbitrary size can be expressed as

$$T_{eff}=\left[\left(\frac{15}{\pi^4}\right)\left[6Li_4(e^{-x})+6xLi_3(e^{-x})+3x^2Li_2(e^{-x})-x^3\ln(1-e^{-x})\right]\right]^{1/4}T \quad (6)$$

Thermal Radiation Spectrum

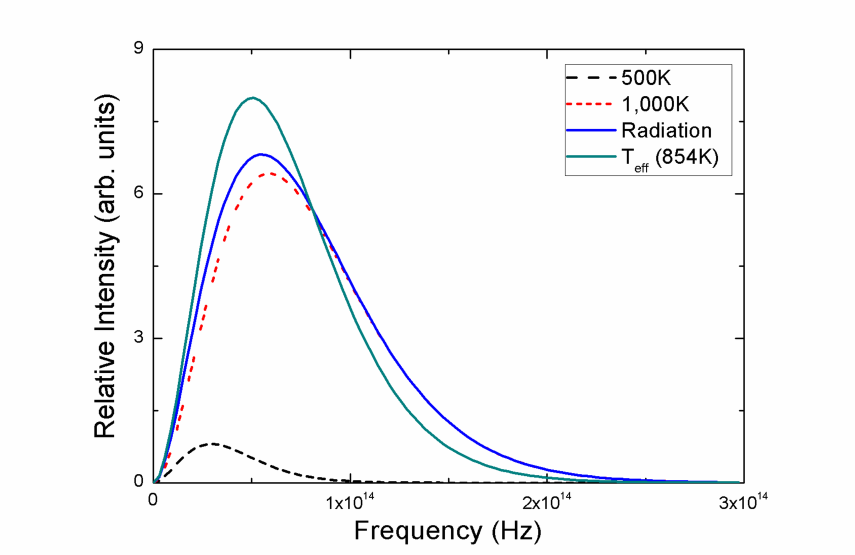

Fig. 1 Thermal radiation spectrum from two different temperatures, 500 K and 1,000 K.

- The effective temperature calculated from Eq. (3) is 854 K.
- The peak frequency of the effective temperature is almost same as that of the total thermal radiation spectrum.

Relative Intensity vs. Frequency

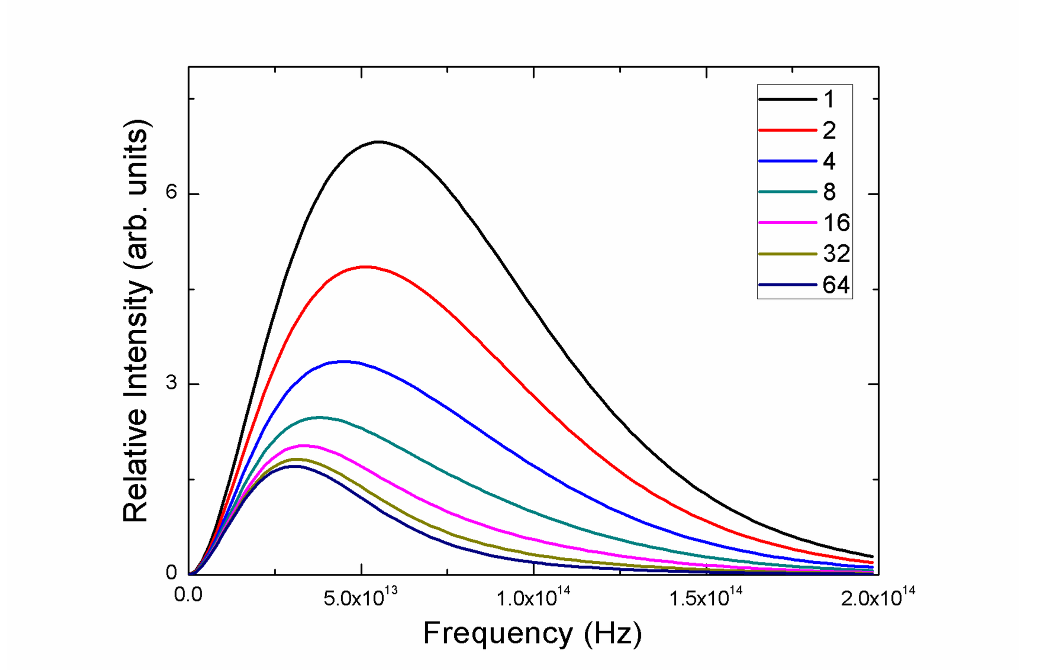

Fig. 2 Thermal radiation spectrum vs. volume ratio for regions at 500 K and 1,000 K.

- Fig. 2 represents thermal radiation spectrum as a function of volume ratio for two different temperatures.
- Two temperatures are 500 K and 1,000 K. The volume ratios of 500 K to 1,000 K are 1, 2, 4, 8, 16, 32, and 64.
- As the volume ratio increases, the peak frequency decreases.

Effective Temperature vs. Particle Size

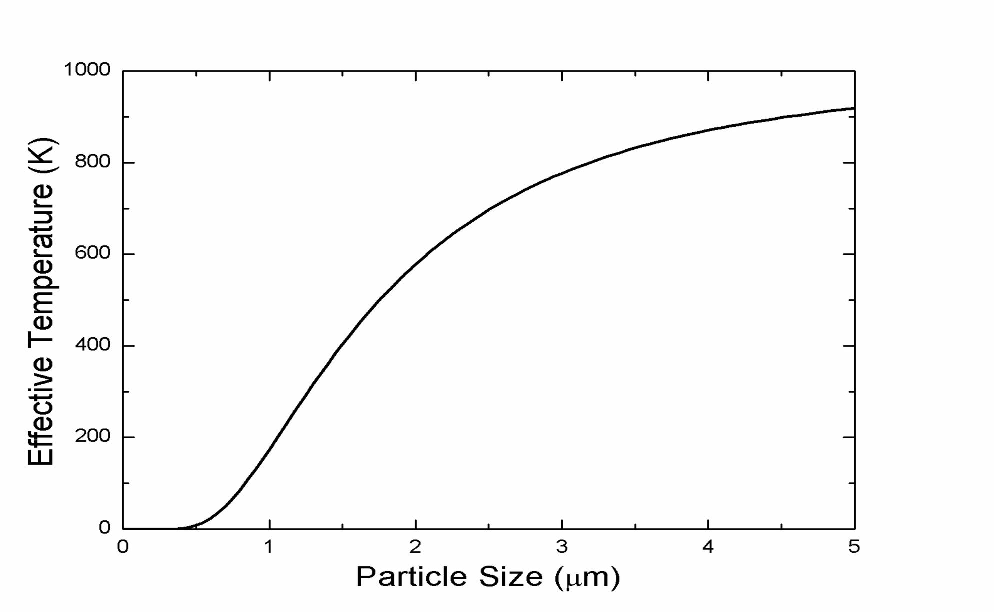

Fig. 3 Effective temperature as a function of particle size.

- Fig. 3 shows the effective temperature as a function of particle size. Here, the body temperature is 1,000 K.
- The energy density of thermal radiation from a small particle is reduced due to the size effect.
- Thus, the effective temperature is decreased as the size of the body decreases..

Conclusions

- The effective temperature of thermal radiation was derived from two different temperatures and was generalized for non-uniform temperature distributions.
- Thermal radiation properties from two different temperature regions were compared with the effective temperature.
- The energy density of thermal radiation from nanoparticles was derived and the effective temperature was shown as a function of particle size.
- The effective temperature can be useful to understand the thermal radiation from non-uniform temperature distribution.

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