Radiation Heat Transfer

and Surface Area Treatments

Radiation heat transfer is often neglected in thermal design due to its complicated nature and misperceptions about its significance in electronics cooling. In fact, radiation can be a major contributor in natural convection and low-airflow velocity applications. Its application where there is a narrow design margin can be worth pursuing. An effective way to enhance radiation heat transfer is through the surface treatment of the cooling components. These include the enclosure walls, effective surface areas in heat exchangers, heat sinks, etc. This article describes the concept of radiation heat transfer and provides some examples where it is enhanced by surface treatment.

Thermal radiation refers to energy emitted by objects due to their temperatures. All bodies emit radiation at temperatures above absolute zero. Unlike other means of heat transfer, radiation does not require a medium between the cold and hot surfaces. In fact, the most effective radiation exchange occurs when there is no interfering medium. Even though the mechanism of radiation heat transfer is not fully understood, there are two popular theories for explaining the radiation propagation process. One sees the radiation as electromagnetic waves, while the other treats radiation as photons of energy [1].

When considered as electromagnetic waves, a body at temperature T will emit radiation at all wavelengths, from zero to infinity. Most engineering applications, however deal with radiations emitted anywhere from 0.1 to 100 µm. Therefore, this portion of the wavelength spectrum is known as thermal radiation. The sun radiates at wavelengths from 0.1 to 3 µm. For this reason, this portion of wave spectrum is referred to as solar radiation. Sun radiation between 0.4 to 0.7 µm is visible to human eye, so this range of wavelength is called visible radiation [1].

The concept of an idealized situation called a "blackbody" is used to compare the radiation characteristics of materials. A blackbody absorbs all incident radiation from all directions, at all wavelengths, without reflecting, transmitting, or scattering it. For a given temperature and wavelength, no body can emit more radiation than blackbody. The emission power of a blackbody versus wavelength at different values of temperatures is presented in Figure 1.

As seen from Figure 1, at any given wavelength, the blackbody's radiation power increases with increasing temperature. Also, at any given temperature, the radiation power varies with wavelength and has a peak toward smaller wavelengths.

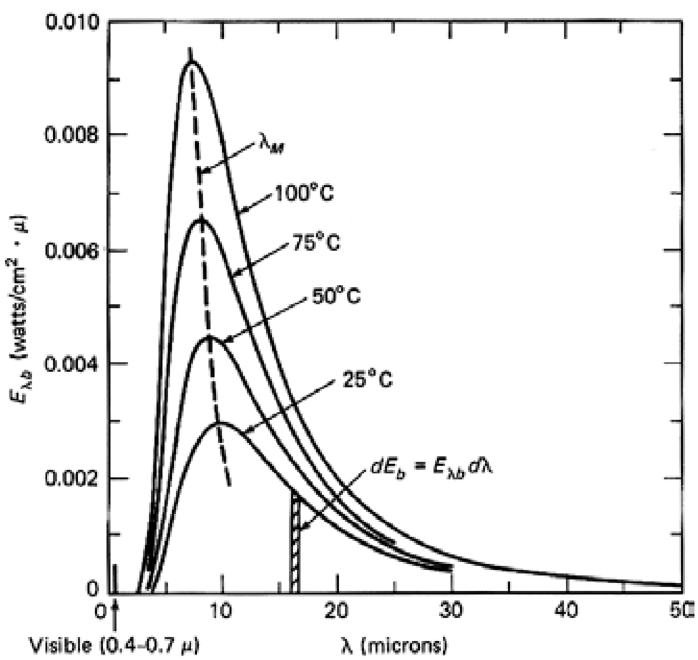

Figure 1. Low Temperature Spectral Distribution of Emissive Power [2].

In electronics, a hot component could reach 120°C and an external cabinet surface may be between 25 to 50°C. It must be noted that in the majority cases most of the radiation, about 85%, is in the range of 5 to 25 λm. Also, it is established that the peak radiation occurs in the region of 7 to 10 λm [2].

The radiation energy emitted by a blackbody at an absolute temperature T, over all wavelengths per unit time, is calculated from the Stefan-Boltzmann equation:

$$q_b = \sigma A T^4 \qquad (1)$$

Where $\sigma = 5.67 \times 10\text{-}8 \, \frac{W}{m^2.K^4}$ is the Stefan-Boltzmann constant, T is the absolute temperature in Kelvin, and A is the surface area of the blackbody in m^2.

Equation 1 is based on the idealized blackbody situation. For real surfaces, emissivity, ε is defined as the ratio of the energy emitted by a surface to that emitted by a blackbody at the same temperature. The radiation energy emitted by a surface with emissivity ε, at an absolute temperature T, over all wavelengths per unit time, is calculated from Equation 2.

$$q = \varepsilon \sigma A T^4 \qquad (2)$$

The importance of radiation heat transfer in any thermal system analysis is not only in determining surface radiation energy, but also the radiation exchange between the surface and other surfaces in its surrounding. When a hot surface is radiating to its cooler surrounding, the net radiation heat loss can be calculated from Equation 3.

$$q = \varepsilon \sigma A (T_H^4 - T_C^4) \qquad (3)$$

Where T_H is the temperature of the hot surface and T_C is its cooler surrounding temperature, both in Kelvin.

Equation 3 indicates that the temperature difference between the hot and the cold has the most significant effect in the radiation energy exchange between surfaces. However, in almost all electronics applications, neither of these temperatures is a controlled parameter. Therefore, radiation heat transfer can only be enhanced by increasing the surface area and surface emissivity.

One example where increased surface area could improve cooling is in heat exchangers. However, due to space constraints increasing the size of heat exchanger components, is usually not a viable option. An innovative solution must be developed to increase the effective surface area without increasing the size of the parts. Microscopic texturing is such a solution [3].

Microscopic surface texturing not only increases the surface area, it also increases the emissivity of the surface at the same time. This is because radiation heat transfer is primarily a surface phenomenon. Thus, certain texturing processes that provide sufficient control over surface feature morphology can increase surface emissivity [3].

There are a number of surface texturing methods. One of these, chemical etching, is commonly used in materials surface texturing. Another is ion beam texturing where ion bombardment is used to selectively etch materials in applications from electronics substrate pattering to the creation of high-surface-area pacemaker electrode tips. This method is based on sputtering, which is the process of removing material from a surface at the atomic level through collisions between energetic ions and substrate atoms. Because it is done on such a fine scale, the process provides a great degree of control over surface features. In principal, ion beam texturing can be used to create almost any type of desired surface topography, whether smoother or rougher than the original surface [3]. Examples of ion beam texturing are shown in Figure 2.

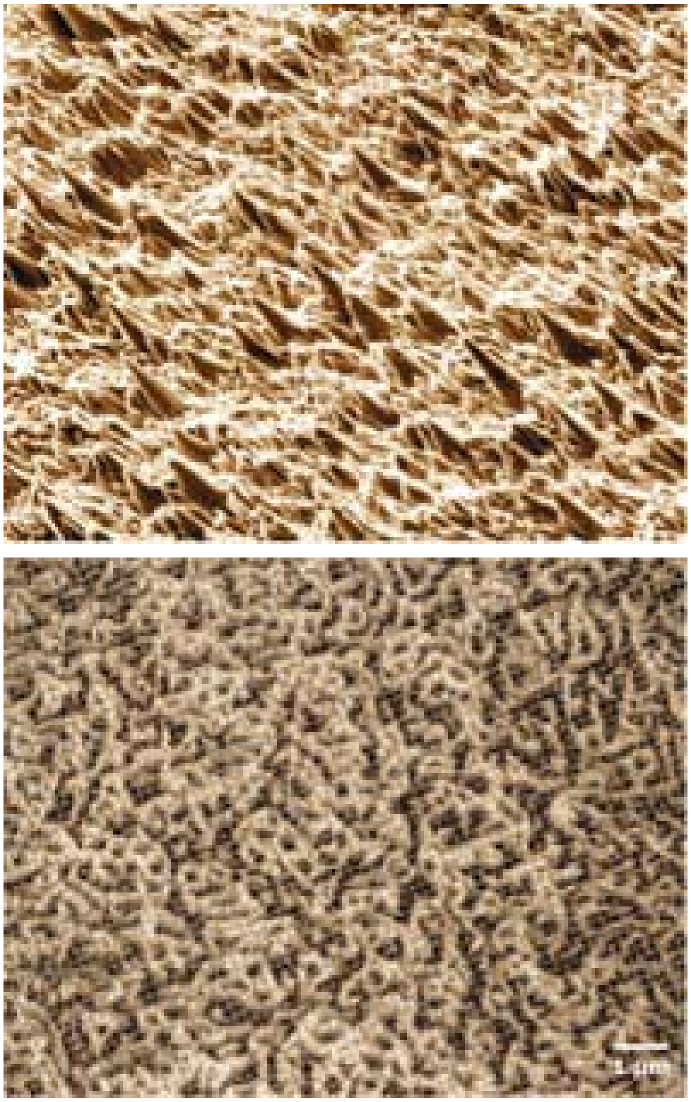

Figure 2. Ion Beam Textured Surfaces [3].

Ion beam textured surfaces typically absorb more than 90% of the incident light across a wide range of wavelengths, implying that the surface is highly emissive. Such textured surfaces would be ideal for electronics cooling due to their significantly increased surface area. The larger surface area will enhance radiation as well as convection heat transfer, provided that the texturing can provide an excellent surface for pool boiling heat transfer, which is often seen in cooling of high power electronics.

Another common surface treatment in electronics cooling is anodizing. This method is mainly used to treat effective surface areas of heat exchangers, electronics cabinets and enclosures, heat sinks, etc. Anodizing not only increases the emissivity of surfaces, it also increases their corrosion resistance, wear resistance and electrical isolation.

Anodizing is an electrochemical process that thickens and toughens the naturally occurring protective oxide layer on the surface of metal parts. It changes the microscopic texture of a metal near the surface. In the process, the metal to be anodized forms the anode (the positive electrode) of an electrolytic circuit. Through an acidic electrolytic solution, the electronic current releases hydrogen at the cathode (the negative electrode) and oxygen at the surface of the metal anode (the positive electrode), building up a deposit of metal oxide. The acid action is balanced with the oxidation rate to form a coating with microscopic pores, 10-150 nm in diameter. The thickness of the metal oxide depends on the electrolyte concentration, acidity, solution temperature and the process current and voltage [4].

The pores created by acidic anodizing on aluminum can easily absorb dyes. Dyes in a variety of colors are often used in heat sinks for cosmetic and marketing purposes. The color of the anodization has no impact on radiation heat transfer. A clear anodized surface has the same emissive characteristics as a black anodized surface. To further protect the surface of dyed anodized heat sinks from corrosion, they are usually sealed by immersion in boiling–hot de-ionized water or steam [4].

There are many processes for anodizing different types of metals. The most common of these are chromic, sulfuric, and organic acid anodizing. Irrespective of the method, anodizing will texture the metal surface which will in turn increase its emissivity; thus increasing radiation heat transfer. The increase in emissivity is usually in the order of 0.83-0.86 μm [5]. When compared to the emissivity of bare aluminum, 0.04-0.06 μm [1], this would indicate an enhancement of radiation heat transfer. Other benefits are increased resistance to corrosion and wear, increased electrical isolation, and an appealing appearance due to a wide range of color anodizing. The color has negligible effect on emissivity.

To demonstrate the contribution of anodizing in low airflow velocity applications, two ATS maxiFLOW™ heat sinks, one anodized and the other non-anodized, were thermally characterized using the exact same method. The heat sink tested, ATS-440-C1-R0, has a footprint of 45 x 38 mm, its overall height is 24 mm and its fin offset on each side is 21 mm. The heat sink was thermally characterized at natural convection and airflow velocities up to 3 m/s at increments of 0.5 m/s. Figure 3 compares the thermal resistance of the two heat sinks at different velocities. As shown, the thermal resistance of the anodized heat sink at all airflow velocities is lower than that of the non-anodized heat sink. However, the difference is most significant at natural convection and becomes smaller as the airflow increases.

At natural convection, an anodized surface improves the thermal performance of the heat sink by 16.8 percent. This

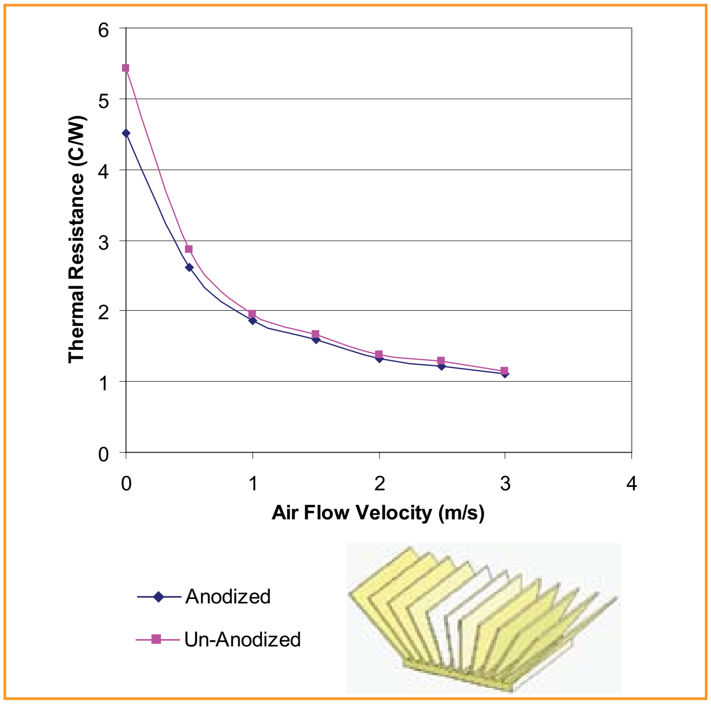

Figure 3. Effect of Anodizing on Thermal Resistance of an ATS-440-C1-R0 Heat Sink

improvement diminishes to 9.1 and 5.1 percent at 0.5 and 1 m/s, respectively.

As discussed earlier, the thermal improvement at natural convection and low airflow conditions is attributed to the enhancement of radiation heat transfer due to the emissivity of the anodized surface. At higher airflows, convection heat transfer becomes the dominant heat transfer mode narrowing the gap between the performance curves of the heat sinks.

Contrary to popular opinion, radiation heat transfer can be as important as convection heat transfer in electronics cooling, especially in natural convection and low airflow applications. To further enhance radiation, surface treatment is a viable option that not only increases the effective surface area but also increases surface emissivity. Surface treatment also provides corrosion resistance and wear resistance, and electrically isolates the cooling components from the electrically charged electronics.

References:

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