Thermal Performance of Tantalum Nitride Films*

Figure 1 illustrates the temperature distribution for a 15 mil (0.0381cm) square Tantalum Nitride resistor with a power density of 2,000 W/in^2 (310W/cm^2) and a heatsink temperature of 85°C. The plot shows how heat spreads from the resistor through the 15 mil (0.0381cm) thick Alumina substrate and into the 25 mil (0.0635cm) thick Kovar carrier.

Figure 2 shows the surface temperature distribution for the same resistor of Figure 1, again with a power density of 2,000 W/in^2 (310W/cm^2). Notice that the temperature within the resistor varies from 107.6°C at the center (T_{max}) to 96°C at the resistor corners. From accelerated tests, the hottest spot degrades first.

Use T_{max} to calculate MTTF for a thin-film resistor

Figure 3 is a plot of Tmax versus the length of square resistors on a 15 mil thick Alumina substrate. Power density is 2,000 W/in^2 (310W/cm^2) and the heatsink temperature is 85°C.

Two different carrier materials are considered: Kovar and W:Cu. Also shown is the “Thick Substrate” Approximation (The Alumina substrate is made so thick compared with the resistor size that the thermal spreading resistance into the substrate dominates the overall thermal resistance.)

Several important conclusions about thermal design of thin-film resistors can be drawn from Figure 3:

- Imposing an arbitrary cap on the resistor’s power density (W/in^2 or W/cm^2) is too restrictive. A thermal analysis based on the physics of heat flow is required for a sensible estimate of MTTF (For instance, power density in the 5 mil square resistor could safely be raised to 15,000 W/in^2 or 2325 W/cm^2).
- For fixed power density (W/in^2 or W/cm^2), smaller resistors have lower T_{max}.
- When the square resistor length exceeds the substrate thickness, choice of carrier material becomes important.
- For the W:Cu carrier, T_{max} increases more slowly than linear.
- The “Thick Substrate” Approximation may be much too pessimistic for high-power resistors.

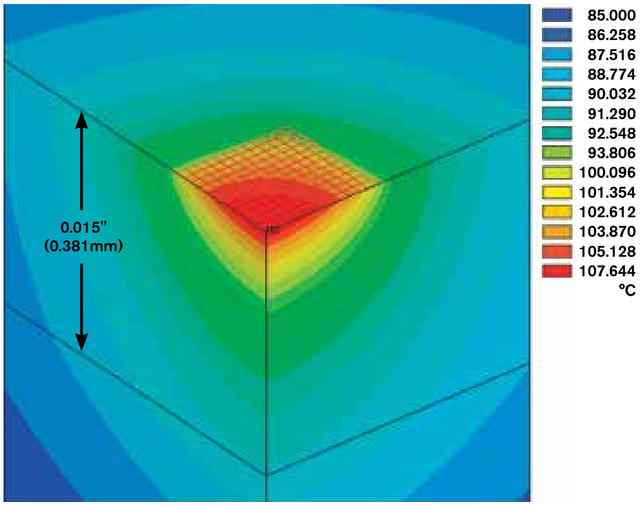

Figure 1: Surface temperature distribution through Alumina substrate

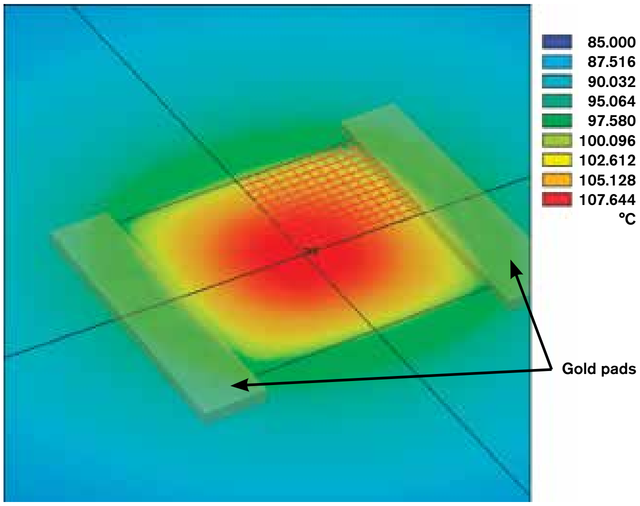

Figure 2: Surface temperature distribution across a square resistor

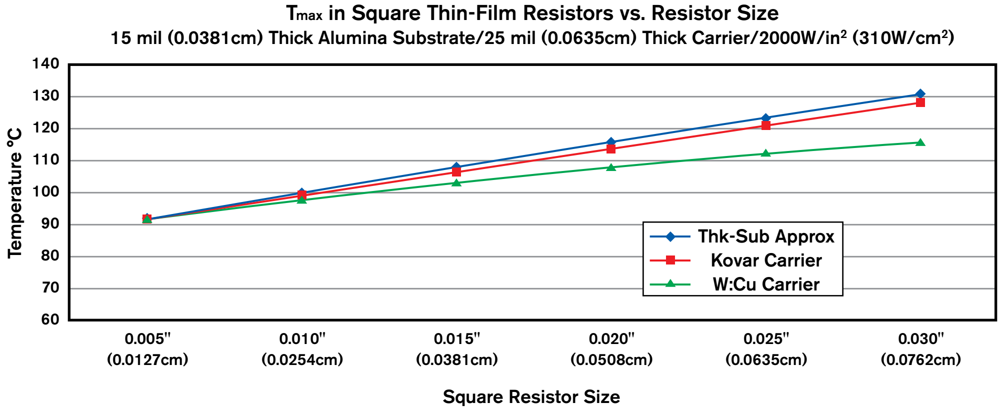

Figure 3

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* To be used as reference only. Calculations based on square resistors on listed material. Other resistor designs and materials may have different results, such as fused silica/quartz may act as an insulator and may not be recommended for this type of application. Please contact ATP with your requirement and application.

Tantalum Nitride Resistor Aging Equation

Definitions

T	Operating temperature of resistor	°C
t	Time resistor is at temperature T	hours
R_o	Initial resistor value	Ohms
ΔR	Increase in resistance after resistor at temperature, T, for time, t.	Ohms

$T(°K) = T(°C) + 273.15$

Aging Equation

$\Delta R/R_o = A\, t^n \exp[-T_o/T(°K)]$ % where,
$A = 1.51 \times 10^{12}$
$n = 0.610$
$T_o = 15{,}087$ °K.

Thermal Performance

The *Thermal Performance* section on the ATP Website discusses the calculation of a resistor's operating temperature. Figure 3 shows T_{max} for square resistors operating with 2,000 W/in^2 (310 W/cm^2) and 85°C heatsink temperature.

Example

The 5 mil (0.127 mm) square resistor in Figure 3 has $P = 50$ mW and $T_{max} = 92.2$ °C.

Assume MTTF = 1×10^8 hours. How much will the value of the resistor increase in 10^8 hours of operation with 50 mW of dissipation?

From the Aging Equation: $\Delta R/R_o = 0.13\%$, is this increase in resistance acceptable? A sensitivity analysis of the circuit's operation must be done to answer that question.

Reference

Brady, et.al., *Thermal Oxidation and Resistivity of Tantalum Nitride Films,* Thin Solid Films 66 (1980), pp. 287–302.

Resistor Stabilization
Temperature Coefficient of Resistance (TCR)

$$\mathrm{TCR} = \frac{(R2 - R1)}{R1(T2 - T1)} \times 10^6\ \mathrm{ppm/°C}$$

Where: R2 = final resistance (Ω)
R1 = initial resistance (Ω)
T2 = final temperature (°C)
T1 = initial temperature (°C)

Example: 50 Ohm resistor at 25°C which drifts to 49.5 Q at 125°C has a TCR of:

$$\mathrm{TCR} = \frac{(49.5 - 50)}{50(125 - 25)} \times 10^6 = -100\ \mathrm{ppm/°C}$$

The TCR of Tantalum-Nitride is typically measured within a range from −25 to −150 ppm/°C.

Reference

MIL-PRF-38534H Appendix C.3.7.5.3.1 b

Power Dissipation

Resistor film temperature is the critical parameter in determining the failure point of a resistor. This operating temperature is affected by resistor geometry, total circuit power dissipation, proximity to other dissipative elements, type of substrate material and the heatsinking used. A complete thermal analysis is required to precisely determine the resistor temperature T_{max}. The maximum allowable power dissipation for the circuit's critical resistor depends on the system's design lifetime (MTTF), the maximum acceptable increase in resistance over the system's lifetime and other factors that might affect the critical resistor's operating temperature such as duty cycle and average heatsink temperature. Typical CW applications indicate a resistor temperature in the 100°C to 125°C range.

Note that for every 10°C rise in resistor temperature over 100°C, resistor stability degrades by a factor of 2.8 in oxygen and does not apply to resistors in sealed nitrogen environments. Specifically, a resistor value which drifts by 0.5% at 100°C will drift as much as 1.4% if operated at 110°C. An important point to be made, however, is that this value applies in an air environment because of continued oxide growth into the resistor film.