*Application Note*

# *Digital Micromirror Device Thermal Considerations Including Pulsed Optical Sources*

TEXAS INSTRUMENTS


**ABSTRACT**

Many applications for the DLP® Digital Micromirror Device (DMD) use Continuous Wave (CW) illumination. Under CW illumination conditions, the temperature rise of the DMD is straightforward to calculate, and equations needed are provided in the data sheet for each DMD. There are also applications where pulsed illumination is used. The temperature rise of the DMD is more complicated to calculate with pulsed illumination, but is important to understand to make sure the DMD micromirror temperature is kept within a reliable operating range. The time required for DMD mirror heating can be longer than the pulse duration of the optical source, creating the need for a transient thermal model instead of a steady-state thermal model to accurately calculate the thermal rise at the DMD mirror surface. This application note describes the equations necessary for calculating DMD mirror surface temperature rise and DMD mirror bulk temperature rise as a function of pulse duration and pulse rate of the optical source.


## Table of Contents



## List of Figures



## List of Tables



## Trademarks

DLP® is a registered trademark of Texas Instruments.
All trademarks are the property of their respective owners.

# 1 Heating of a DMD Micromirror

When light from an optical illumination source is applied to the DMD, the majority of the light is incident on the mirror surface and is reflected. However, a small portion of that incident light is absorbed by the mirror material and must be dissipated through the DMD mirror structure into the DMD silicon, and then from the DMD silicon die to the backside of the DMD ceramic package. Another small portion of the incident light on the DMD falls within the gaps between mirrors directly on the DMD silicon along with any light that overfills the array and falls directly onto the silicon. This light is absorbed by the silicon as heat and combines with the heat generated by the electrical circuits on the silicon and the heat absorbed through the mirror surface to create an overall temperature rise at the DMD silicon. This heat is then dissipated through the DMD ceramic package. A model describing the path of DMD heat absorption and cooling is illustrated by the simple 1-D resistor network in Figure 1-1.

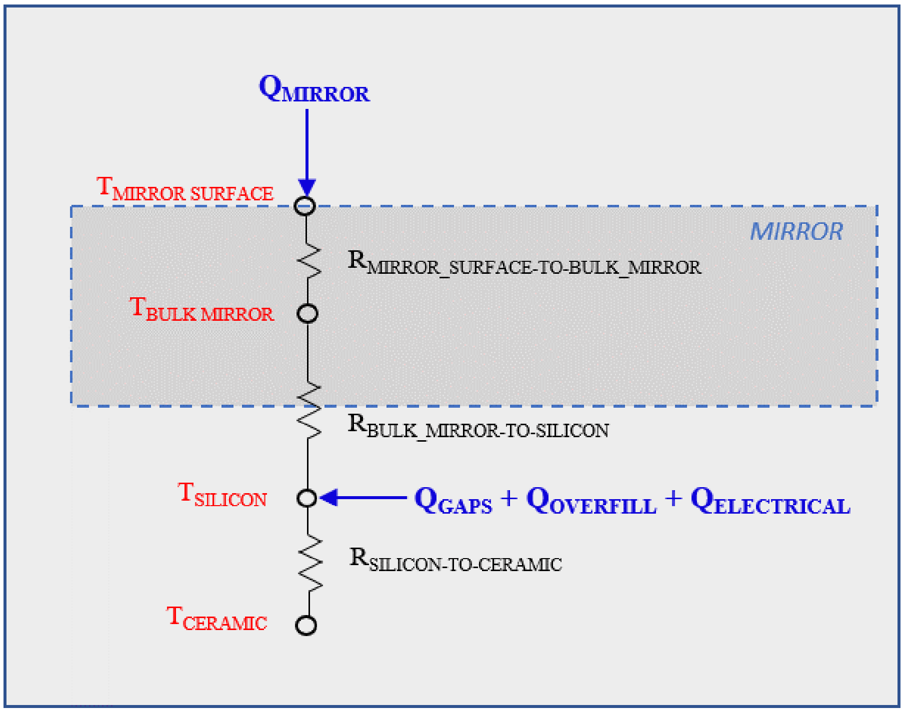



**Figure 1-1. Simplified DMD Thermal Resistor Network**

This resistor network shows three temperature rises that must be calculated to determine the mirror surface temperature. $T_{CERAMIC}$ can be measured in a system using an attached thermocouple, but $T_{SILICON}$, $T_{BULK\ MIRROR}$, and $T_{MIRROR\ SURFACE}$ cannot be directly measured. Therefore, we need to calculate the following temperature delta's:

## 1.1 Mirror Surface to Bulk Mirror Delta ($\Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}BULK\_MIRROR}$)

The bulk mirror to mirror surface temperature rise represents the temperature rise of the top of the mirror (surface) to the bulk mirror temperature. It is possible to generate a significant temperature rise above the bulk mirror temperature through the thickness of the mirror if the pulse duration is short enough and the optical pulse power incident on that mirror is high enough. An example of this calculation is shown in Section 2.1.

## 1.2 Bulk Mirror to Silicon Delta ($\Delta T_{BULK\_MIRROR\text{-}TO\text{-}SILICON}$)

The silicon to bulk mirror temperature rise represents the heat load absorbed in the mirror that must be conducted through the mirror structure to the silicon surface. An example of this calculation is shown in Section 2.2.

### 1.3 Silicon to Ceramic Delta ($\Delta T_{SILICON\text{-}TO\text{-}CERAMIC}$)

The ceramic to silicon temperature rise is calculated in a similar manner to how a standard semiconductor device die temperature is calculated. The thermal resistance of the DMD ceramic package is multiplied by the total DMD power at the silicon and then added to the temperature measured at $T_{CERAMIC}$. An example of this calculation is shown in Section 2.3.

## 2 Calculating Mirror Surface Temperature With Pulsed Optical Sources

Absorbed heat is input on top of the DMD mirror, causing the top surface of the mirror to be the hottest location. The mirror surface temperature will rise and fall as pulsed illumination is applied, and the three temperature rises described previously can be calculated individually and added together to find the resulting mirror surface temperature.

### 2.1 Mirror Surface to Bulk Mirror Delta ($\Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}BULK\_MIRROR}$)

Absorbed heat load must be transferred from the top of the mirror to the bottom of the mirror before it can be conducted from the bulk mirror to the silicon. Heat conduction through the mirror thickness is normally very efficient since the aluminum mirror is thin and has a high thermal conductivity, however pulsed illumination can create a condition where the mirror surface temperature is much higher than the bulk mirror temperature.

Since these short pulses heat the mirror surface very quickly without affecting the bottom surface of the mirror, the mirror can be treated as a semi-infinite solid. The equation for temperature of a semi-infinite solid with a constant heat flux is shown in Equation 1.

$$T(x,t) = T_i + 2q*\frac{\left(\frac{\alpha t}{\pi}\right)^{\frac{1}{2}}}{k}*\exp\left(\frac{-x^2}{4\alpha t}\right) - \frac{qx}{k}*erfc\left(\frac{x}{2\sqrt{\alpha t}}\right) \tag{1}$$

**Where:**

$T(x,t)$ = temperature at depth = x, and time = t

$T_i$ = initial mirror temperature

q = absorbed heat flux on mirror surface [$W/m^2$]

α = Mirror thermal diffusivity = $6.4667 \times 10^{-5}$ $m^2/s$

k = Mirror thermal conductivity = 160 W/m-ºC

$erfc$ (x) = complementary error function

Because we are only interested in the mirror surface temperature,

depth (x) = 0 in the equation above simplifies to Equation 2.

$$T(t) = T_i + 2q*\frac{\left(\frac{\alpha t}{\pi}\right)^{\frac{1}{2}}}{k} \tag{2}$$

To calculate the mirror surface temperature at the end of the pulse where it is at a maximum, t = duration of the pulse. The temperature rise is only a function of the absorbed heat flux on the mirror surface (q) and the pulse duration (t). All other variables are constant for an aluminum mirror. Therefore, the temperature rise is proportional to $qt^{1/2}$. As pulse duration becomes smaller with a constant average power density, the peak pulse power increases and causes a large temperature rise at the mirror surface. Also, the mirror surface temperature rise is not a function of mirror pitch because the mirror thickness can be treated as a semi-infinite solid, and the area of the pixel does not affect this 1-dimensional heat flow.

## 2.2 Bulk Mirror to Silicon Delta ($\Delta T_{BULK\_MIRROR\text{-}TO\text{-}SILICON}$)

Absorbed heat must be transferred from the DMD mirror to the underlying silicon. This is true in a CW application as well as a pulsed application. Normally the temperature rise of the bulk mirror above the silicon in CW applications is small, but in pulsed applications, the peak optical power can be much higher than the average power. This results in a rise and fall of the bulk mirror temperature with each pulse. The bulk mirror temperature rise is defined by Equation 3.

$$T\left(t\right) = T_f + \left(T_i - T_f\right)e^{\left(\frac{-t}{\tau}\right)} \tag{3}$$

**Where:**

$T(t)$ = mirror temperature at time = t

$T_f$ = final mirror temperature at t = ∞ (steady-state)

$T_i$ = initial mirror temperature at t = 0

$\tau$ = thermal time constant of the mirror (R × C) [Table 2-1]

$T_f = T_i + Q_{MIRROR} \times R_{MIRROR-TO-SILICON}$ [Table 2-1]

$Q_{MIRROR} = Q_{INCIDENT\_MIRROR} \times \left[FF_{MIRROR} \times \left(1 - MR\right)\right]$

**Where:**

$Q_{INCIDENT\_MIRROR}$ = total incident power per mirror [incident power density × (mirror pitch)$^2$]

$FF_{MIRROR}$ = fill factor of mirror array (on-state calculates highest temperature) [Table 2-2]

$MR$ = mirror reflectivity [Figure 2-1, Figure 2-2, Figure 2-3]

**Table 2-1. Bulk Mirror Thermal Time Constant Versus Mirror Pitch**

| Pixel [µm] | $R_{MIRROR\text{-}TO\text{-}SILICON}$ [ºC/W] | $C_{MIRROR}$ [J/ºC] | $\tau$ = R*C [µs] |
|---|---|---|---|
| 5.4 (12º) | $7.63 \times 10^5$ | $1.14 \times 10^{-11}$ | 8.70 |
| 5.4 (17º) | $9.54 \times 10^5$ | $1.14 \times 10^{-11}$ | 10.88 |
| 7.56, 7.60, 7.637 | $4.47 \times 10^5$ | $2.57 \times 10^{-11}$ | 11.49 |
| 9.0 | $4.53 \times 10^5$ | $4.21 \times 10^{-11}$ | 19.07 |
| 10.8 | $3.39 \times 10^5$ | $9.52 \times 10^{-11}$ | 32.27 |
| 13.68 | $2.52 \times 10^5$ | $1.53 \times 10^{-10}$ | 38.56 |

The thermal time constant of the mirror, $\tau$ , is defined as $R_{MIRROR} \times C_{MIRROR}$

**Where:**

$R_{MIRROR}$ is the thermal resistance from the mirror to the silicon

$C_{MIRROR}$ is the thermal capacitance of the mirror

In Table 2-1, R was calculated using a finite element model of the pixel superstructure and distance between the mirror and the silicon. C was calculated as $\rho V C_p$ where;

ρ = density of the aluminum mirror

V = volume of the aluminum mirror

$C_p$ = specific heat of the aluminum mirror

Therefore, $\tau$ is different for each mirror pitch

**Table 2-2. Mirror Fill Factor Versus Mirror Pitch**

| | $FF_{MIRROR}$ | | |
|---|---|---|---|
| **Pixel [µm]** | **On-state** | **Off-state** | **Illumination Angle [Degrees]** |
| 5.4 (12º) | 0.901 | 0.720 | 24 |
| 5.4 (17º) | 0.911 | 0.765 | 34 |
| 7.56, 7.60 | 0.931 | 0.724 | 24 |
| 7.637 | 0.936 | 0.728 | 24 |
| 9.0 | 0.967 | 0.600 | 29 |
| 10.8 | 0.931 | 0.726 | 24 |
| 13.68 | 0.950 | 0.728 | 24 |

**Note**

Please see DLPA083 for more details pertaining to Mirror Fill Factor.

**Note**

The on-state and off-state fill factors are calculated using illumination at the native $f$-number corresponding to the tilt nominal angle.

1. 12º tilt = $f$/2.4
2. 14.5º tilt = $f$/2.0
3. 17º tilt = $f$/1.7

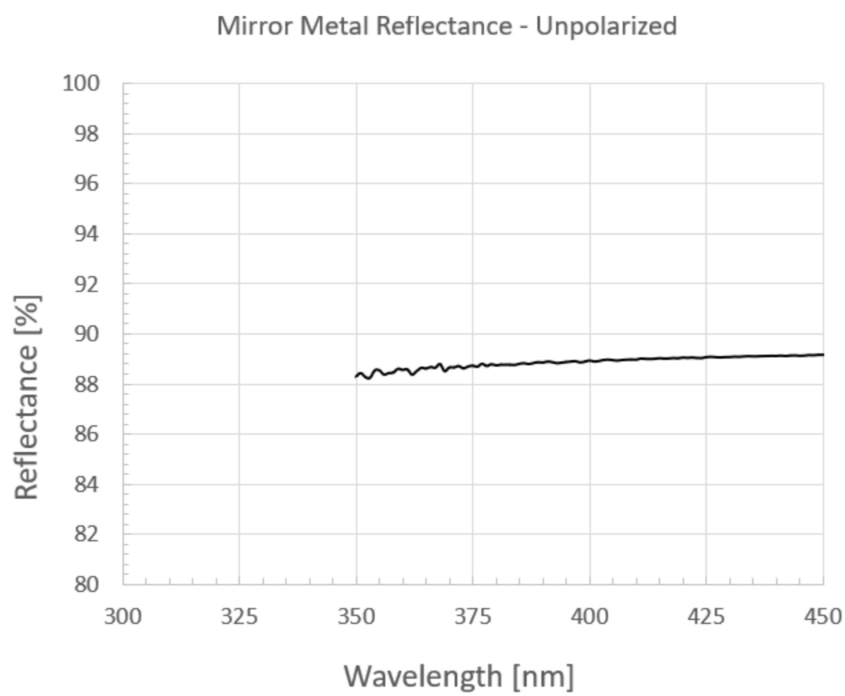



**Figure 2-1. Mirror Reflectivity versus Wavelength (UV)**

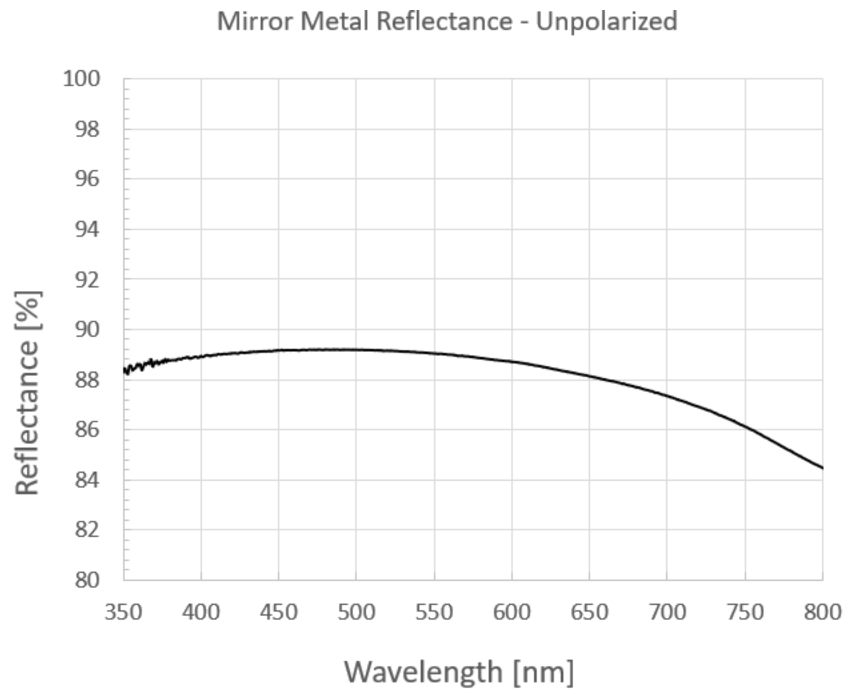



**Figure 2-2. Mirror Reflectivity versus Wavelength (Visible)**

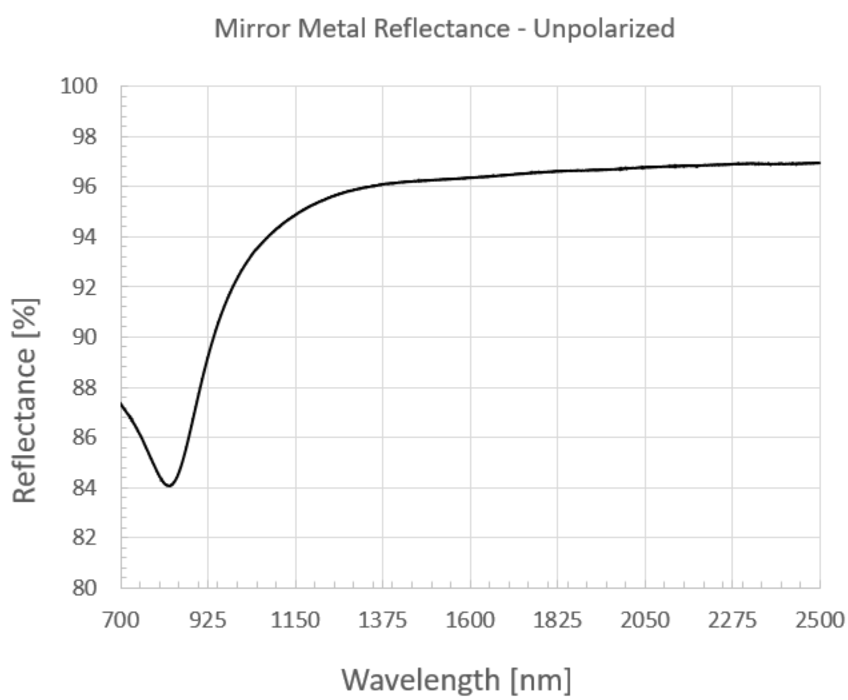
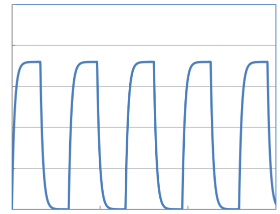
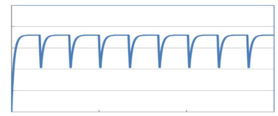
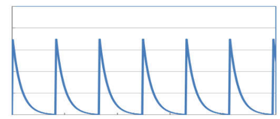
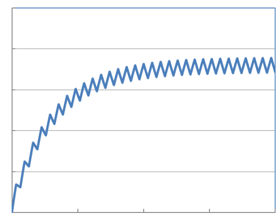



**Figure 2-3. Mirror Reflectivity versus Wavelength (Near-Infrared)**

**Table 2-3. Set of Possible Bulk Mirror Heating Conditions**

| $t_{pulse}$ | $t_{off}$ | Mirror Heating Condition | Temperature Plot vs. Time |
|---|---|---|---|
| $> 5\tau$ | $> 5\tau$ | Mirror fully heats and cools during each pulse |  |
| $> 5\tau$ | $< 5\tau$ | Mirror fully heats and partially cools during each pulse |  |
| $< 5\tau$ | $> 5\tau$ | Mirror partially heats, then fully cools during each pulse |  |
| $< 5\tau$ | $< 5\tau$ | Mirror partially heats and partially cools during each pulse until finally reaching steady-state after many pulses |  |

There are several possibilities of the resulting transient response of the mirror depending on the duration of $t_{pulse}$ and $t_{off}$ relative to the thermal time constant of the mirror. These possibilities are shown in Table 2-3.

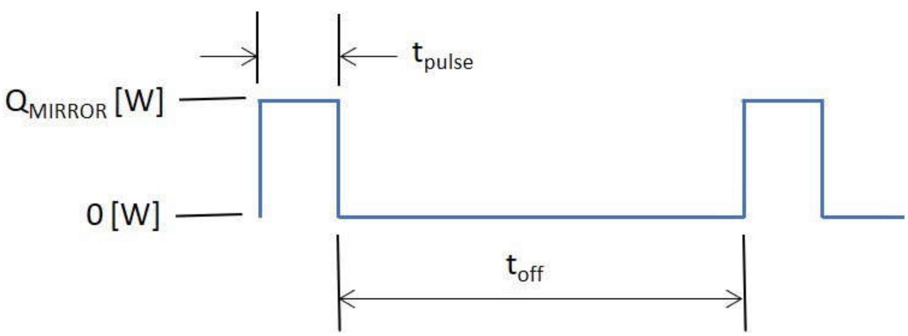



**Figure 2-4. Pulse Parameters**

## 2.3 Silicon to Ceramic Delta ($\Delta T_{SILICON-TO-CERAMIC}$)

In a CW system, this is often the only consideration and the temperature rise is defined by total heat load to the silicon multiplied by the package thermal resistance from silicon to the backside ceramic of the package.

$$\Delta T_{SILICON-TO-CERAMIC} = Q_{SILICON} \times R_{SILICON-TO-CERAMIC}$$

**Where:**

$Q_{SILICON} = Q_{ELECTRICAL} + Q_{ILLUMINATION}$

$Q_{ILLUMINATION} = (\alpha_{DMD} \times Q_{INCIDENT})$

$Q_{ELECTRICAL}$ = total electrical power on DMD [from DMD data sheet]

$R_{SILICON-TO-CERAMIC}$ [from DMD data sheet]

$Q_{INCIDENT}$ = total incident average optical power to DMD

$\alpha_{DMD}$ = DMD thermal absorptivity

$$\propto_{DMD} = (1 - Overfill) * \{[FF_{MIRROR} * (1 - MR)] + (1 - FF_{MIRROR})\} + (2 * \propto_{WINDOW}) + Overfill$$

**Where:**

$FF_{MIRROR}$ = fill factor of mirror array (off-state calculates highest temperature) [Table 2-2]

$MR$ = mirror reflectivity [Figure 2-1, Figure 2-2, Figure 2-3]

$\alpha_{WINDOW}$ = absorptivity of window single pass

$$Overfill = 1 - \frac{Array\ Area}{Incident\ Area}$$

$Incident\ Area$ = total illuminated area on the DMD

Because the thermal time constant of the silicon is on the order of seconds, the silicon can see the pulsed heat sources as a continuous heat source equal to the average absorbed power of the optical power to the DMD.

Fill factor of the mirror array ($FF_{MIRROR}$) is higher in the on-state than the off-state [Table 2-2]. This is because mirrors tilted away from the illumination source (off-state) expose more of the silicon to illumination through the mirror gaps. For worst case thermal modeling only the off-state fill factor needs to be used.

## 2.4 Calculating Mirror Surface to Ceramic Delta ($\Delta T_{MIRROR\_SURFACE-TO-CERAMIC}$)

We have shown how to calculate the temperature rise of the silicon above the backside ceramic of the package, the bulk mirror temperature rise above the silicon, and the mirror surface temperature rise above the bulk mirror temperature. The total mirror surface temperature rise is simply the sum of these three:

$$T_{MIRROR\ SURFACE} - T_{CERAMIC} = \Delta T_{SILICON-TO-CERAMIC} + \Delta T_{BULK\_MIRROR-TO-SILICON} + \Delta T_{MIRROR\_SURFACE-TO-BULK\_MIRROR} \quad (4)$$

## 3 Sample Calculations

Below are detailed sample calculations that show how mirror surface temperature is calculated using the three temperature rises:

1. Mirror Surface to Bulk Mirror Delta
2. Bulk Mirror to Silicon Delta
3. Silicon to Ceramic Delta

In the first example calculation, $t_{off}$ is greater than $5\tau$ , therefore the bulk mirror fully cools after each pulse and only one pulse needs to be analyzed.

**Example 1**

A pulsed laser illuminates a DLP650LNIR DMD with 1064 nm wavelength light and fills the active array with no overfill.

Pulse duration ($t_{pulse}$) = 1 $\mu s$

$t_{off}$ = 999 $\mu s$ (pulsed repetition rate of the optical source is 1 kHz)

Peak incident power during the pulse is 25 kW/cm$^2$

Calculation of the temperature rise of the mirror surface above the DMD ceramic temperature:

1. **Mirror Surface to Bulk Mirror Delta: $\Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}BULK\_MIRROR}$**

$$T(t) = 2q^{*}\frac{\left(\frac{\alpha t}{\pi}\right)^{\frac{1}{2}}}{k} + T_i$$

$T(t)$ = temperature at time = t

$T_i$ = initial mirror temperature

q = absorbed heat flux on mirror surface [W/m$^2$]

α = Mirror thermal diffusivity = 6.4667 x 10$^{-5}$ m$^2$/s

k = Mirror thermal conductivity = 160 W/m-ºC

q = 25 kW/cm$^2$ × (1 – 0.94) = 1.50 kW/cm$^2$

$t_{pulse}$ = 1 $\mu s$

T(1 $\mu s$ ) = 2 × 1.50 kW/cm$^2$ × {[(6.4667e-5 m$^2$/s × 1.0e-6 s)/π] $^{1/2}$ /160 W/m-ºC} + 0 = 0.85 ºC

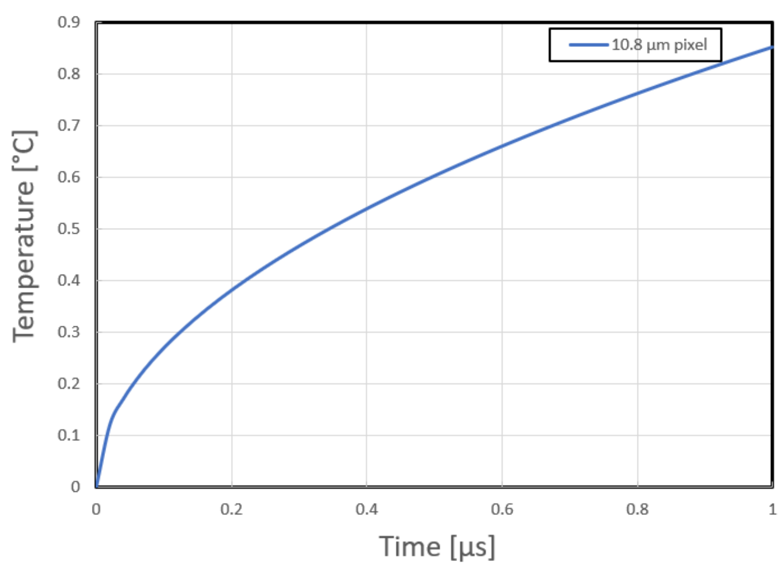



**Figure 3-1. DMD Mirror Surface Temperature Rise at 25 kW/cm$^2$**

2. **Bulk Mirror to Silicon Delta: $\Delta T_{BULK\_MIRROR\text{-}TO\text{-}SILICON}$**

$$T(t) = T_f + (T_i - T_f)e^{\left(\frac{-t}{\tau}\right)}$$

$$T_f = T_i + Q_{MIRROR} \times R_{MIRROR-TO-SILICON}$$

$$Q_{MIRROR} = Q_{INCIDENT\_MIRROR} \times [FF_{MIRROR} \times (1 - MR)]$$

$Q_{INCIDENT\_MIRROR}$ = 25 kW/cm$^2$ × (10.8 µm)$^2$ = 0.02916 W

$FF_{MIRROR}$ = 0.931 (on-state)

$MR$ at 1064 nm = 0.94

$Q_{MIRROR}$ = 0.02916 W × [0.931 × (1 – 0.94)] = 1.629 mW

$R_{SILICON-TO-CERAMIC}$ = 3.39 x 10$^5$ ºC/W

$T_f$ = 0 + 1.629 mW × (3.39 x 10$^5$ ºC/W) = 552.23 ºC

$\tau$ = 32.27 $\mu s$

$t_{off}$ = 999 $\mu s$

$t_{pulse}$ = 1 $\mu s$

$5\tau$ = 5 × 32.27 $\mu s$ = 161.35 $\mu s$

Since $t_{off}$ = 999 $\mu s$ (> $5\tau$ ) the bulk mirror fully cools to the initial temperature $T_i$ and analyzing a single pulse cycle is sufficient.

T(1 $\mu s$ ) = 552.23 ºC + (0 – 552.23 ºC)e$^{-(1\ \mu s/32.27\ \mu s)}$ = 16.85 ºC

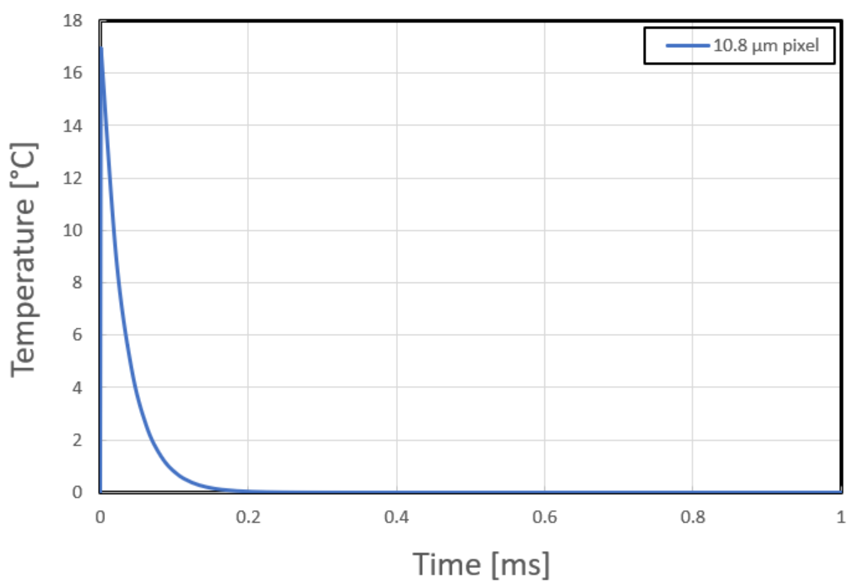



**Figure 3-2. DMD Bulk Mirror Temperature Rise 25 kW/cm$^2$**

3. **Silicon to Ceramic Delta: $\Delta T_{SILICON\text{-}TO\text{-}CERAMIC}$**

From the DLP650LNIR data sheet:

$\Delta T_{SILICON-TO-CERAMIC} = Q_{SILICON} \times R_{SILICON-TO-CERAMIC}$

$R_{SILICON-TO-CERAMIC}$ = 0.5 ºC/W

$Q_{ELECTRICAL}$ = 1.8 W

$Q_{SILICON} = Q_{ELECTRICAL} + Q_{ILLUMINATION}$

$FF_{MIRROR}$ = 0.726 (off-state)

$MR$ at 1064 nm = 0.94

$\alpha_{Window}$ at 1064 nm = 0.007 (per pass)

$Overfill$ = 0

$\propto_{DMD} = (1 - Overfill) * \{[FF_{MIRROR} * (1 - MR)] + (1 - FF_{MIRROR})\} + (2 * \propto_{WINDOW}) + Overfill$

$\alpha_{DMD}$ = (1 - 0) × {[0.726 × (1-0.94)] + [1-0.726]} + (2 × 0.007) + 0

$\alpha_{DMD}$ = 0.33 (off-state)

$Q_{INCIDENT}$ = total incident average optical power to DMD

Active array area = (1280 × 10.8 μm) × (800 × 10.8 μm) = 1.1944 $cm^2$

$t_{pulse}$ = 1 $\mu s$ , $t_{off}$ = 999 $\mu s$

Therefore pulse duty cycle = 1 $\mu s$ / ( 1 $\mu s$ + 999 $\mu s$ ) x 100% = 0.1%

Average optical power density = (25 $kW/cm^2$) × 0.1% = 25 $W/cm^2$

Average optical power = 25 $W/cm^2$ × 1.1944 $cm^2$ = 29.86 W

Average absorbed optical power = 29.86 W × 0.33 = 9.85 W

$\Delta T_{SILICON-TO-CERAMIC}$ = (1.8 W + 9.85 W) × 0.5 ºC/W = 5.8 ºC

**Mirror Surface to Ceramic Delta: ($\Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}CERAMIC}$)**

$T_{MIRROR\ SURFACE} - T_{CERAMIC} = \Delta T_{SILICON\text{-}TO\text{-}CERAMIC} + \Delta T_{BULK\_MIRROR\text{-}TO\text{-}SILICON} + \Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}BULK\_MIRROR}$

$T_{MIRROR\_SURFACE} - T_{CERAMIC}$ = 5.8 ºC + 16.85 ºC + 0.85 ºC = 23.5 ºC

In the second example calculation, since $t_{pulse}$ and $t_{off}$ are both < $5\tau$ , analysis is required over several pulses until the temperature rise stabilizes.

**Example 2**

A pulsed laser illuminates a DLP650LNIR DMD with 1064 nm wavelength light and fills the active array with no overfill.

Pulse duration ($t_{pulse}$) = 10 ps

$t_{off}$ = 99.99999 $\mu s$ (pulsed repetition rate of the optical source is 10 kHz)

Peak incident power during the pulse is 250 MW/cm$^2$

Calculation of the temperature rise of the mirror surface above the DMD ceramic temperature:

1. **Mirror Surface to Bulk Mirror Delta: $\Delta T_{MIRROR\_SURFACE\text{-}TO\text{-}BULK\_MIRROR}$**

$$T(t) = 2q^* \frac{\left(\frac{\alpha t}{\pi}\right)^{\frac{1}{2}}}{k} + T_i$$

$T(t)$ = temperature at time = t

$T_i$ = initial mirror temperature

q = absorbed heat flux on mirror surface [W/m$^2$]

α = Mirror thermal diffusivity = 6.4667 x 10$^{-5}$ m$^2$/s

k = Mirror thermal conductivity = 160 W/m-ºC

q = 250 MW/cm$^2$ × (1 – 0.94) = 15 MW/cm$^2$

$t_{pulse}$ = 10 ps

T(10 ps) = 2 × 15 MW/cm$^2$ × {[(6.4667e-5 m$^2$/s × 1.0e-11 s)/π] $^{1/2}$ /160 W/m-ºC} + 0 = 26.9 ºC

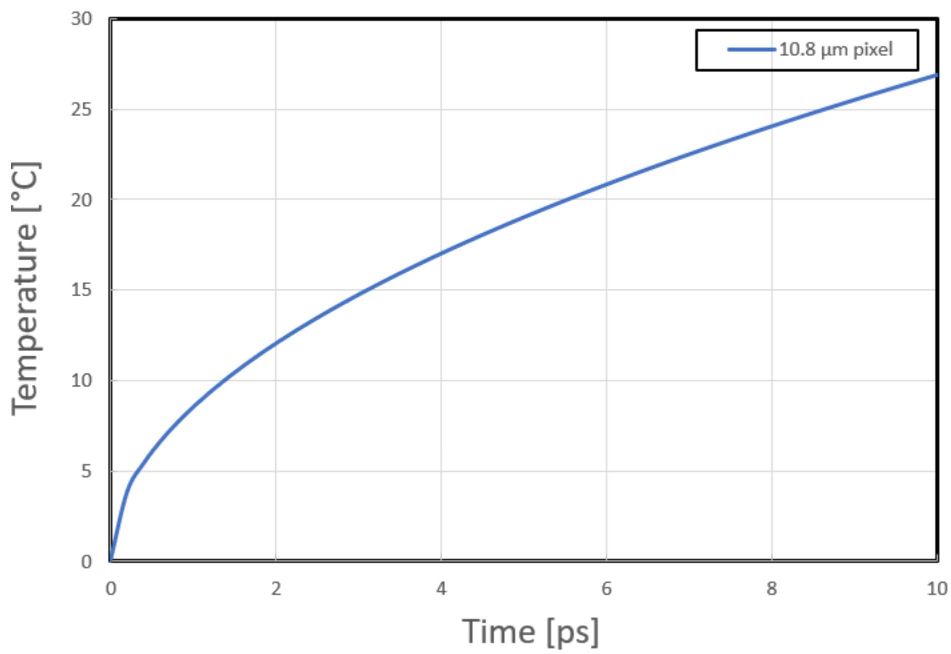



**Figure 3-3. DMD Mirror Surface Temperature Rise at 250 MW/cm$^2$**

2. **Bulk Mirror to Silicon Delta: $\Delta T_{BULK\_MIRROR-TO-SILICON}$**

$$T(t) = T_f + (T_i - T_f)e^{\left(\frac{-t}{\tau}\right)}$$

$$T_f = T_i + Q_{MIRROR} \times R_{MIRROR-TO-SILICON}$$

$$Q_{MIRROR} = Q_{INCIDENT\_MIRROR} \times [FF_{MIRROR} \times (1 - MR)]$$

$Q_{INCIDENT\_MIRROR}$ = 250 MW/cm$^2$ × (10.8 $\mu$ m)$^2$ = 291.6 W

$FF_{MIRROR}$ = 0.931 (on-state)

$MR$ at 1064 nm = 0.94

$Q_{MIRROR}$ = 291.6 W × [0.931 × (1 – 0.94)] = 16.289 W

$R_{SILICON-TO-CERAMIC}$ = 3.39 x 10$^5$ ºC/W

$T_f$ = 0 + 16.289 W × (3.39 x 10$^5$ ºC/W) = 5.522 x 10$^6$ ºC

$\tau$ = 32.27 $\mu s$

$t_{off}$ = 99.99999 $\mu s$

$t_{pulse}$ = 10 ps

$5\tau$ = 5 × 32.27 $\mu s$ = 161.35 $\mu s$

Bulk mirror only partially heats and partially cools between pulses and we need to iterate and analyze a series of pulses until the mirror temperature no longer changes.

**1st $t_{pulse}$ heating:**

T(10 ps) = 5.522 x 10$^6$ ºC + (0 – 5.522 x 10$^6$ ºC)e$^{-(10 \text{ ps}/32.27 \text{ µs})}$ = 1.710 ºC

**1st $t_{off}$ cooling:**

T(99.99999 µs) = 0 ºC + (1.720 – 0 ºC)e$^{-(99.99999 \text{ µs}/32.27 \text{ µs})}$ = 0.077 ºC

**2nd $t_{pulse}$ heating:**

T(10 ps) = 5.522 x 10$^6$ ºC + (0.077 ºC – 5.522 x 10$^6$ ºC)e$^{-(10 \text{ ps}/32.27 \text{ µs})}$ = 1.787 ºC

**2nd $t_{off}$ cooling:**

T(99.99999 µs) = 0 ºC + (1.787 – 0 ºC)e$^{-(99.99999 \text{ µs}/32.27 \text{ µs})}$ = 0.081 ºC

**3rd $t_{pulse}$ heating:**

T(10 ps) = 5.522 x 10$^6$ ºC + (0.081 ºC – 5.522 x 10$^6$ ºC)e$^{-(10 \text{ ps}/32.27 \text{ µs})}$ = 1.791 ºC

**3rd $t_{off}$ cooling:**

T(99.99999 µs) = 0 ºC + (1.791 – 0 ºC)e$^{-(99.99999 \text{ µs}/32.27 \text{ µs})}$ = 0.081 ºC

**4th $t_{pulse}$ heating:**

T(10 ps) = 5.522 x 10$^6$ ºC + (0.081 ºC – 5.522 x 10$^6$ ºC)e$^{-(10 \text{ ps}/32.27 \text{ µs})}$ = 1.791 ºC

**4th $t_{off}$ cooling:**

T(99.99999 µs) = 0 ºC + (1.791 – 0 ºC)e$^{-(99.99999 \text{ µs}/32.27 \text{ µs})}$ = 0.081 ºC

Notice the temperature did not change from the 3rd pulse to the 4th pulse. When the temperature after each pulse iteration stops changing, it has reached steady-state. The bulk mirror temperature rise above the silicon is 1.8 ºC.

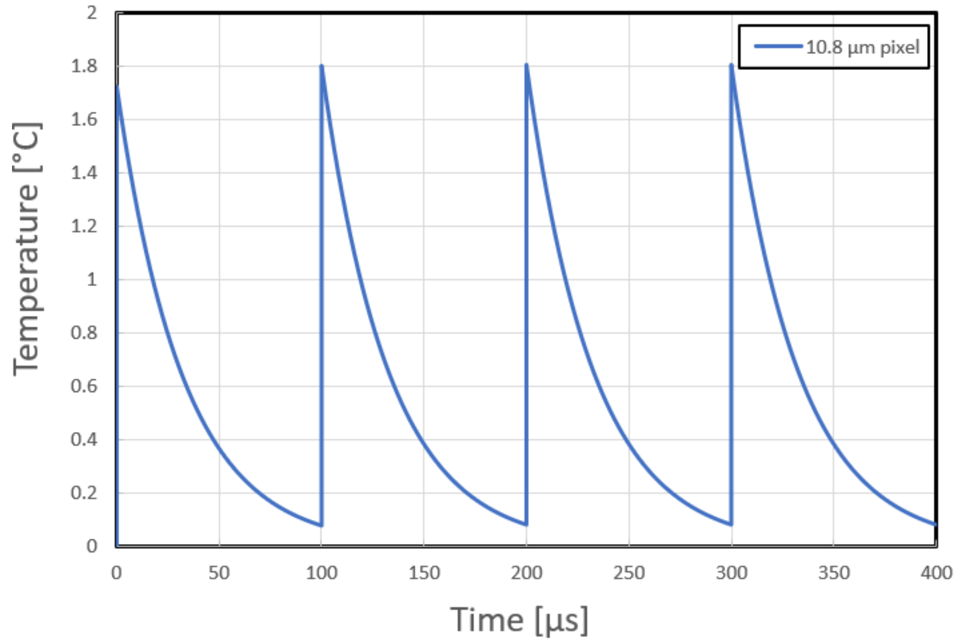



**Figure 3-4. DMD Bulk Mirror Temperature Rise at 250 MW/cm²**

3. **DMD silicon temperature rise above ceramic: $\Delta T_{SILICON\text{-}TO\text{-}CERAMIC}$**

From the DLP650LNIR data sheet:

$\Delta T_{SILICON-TO-CERAMIC} = Q_{SILICON} \times R_{SILICON-TO-CERAMIC}$

$R_{SILICON-TO-CERAMIC}$ = 0.5 ºC/W

$Q_{ELECTRICAL}$ = 1.8 W

$Q_{SILICON} = Q_{ELECTRICAL} + Q_{ILLUMINATION}$

$FF_{MIRROR}$ = 0.726 (off-state)

$MR$ at 1064 nm = 0.94

$\alpha_{Window}$ at 1064 nm = 0.007 (per pass)

$Overfill$ = 0

$\propto_{DMD} = (1 - Overfill) * \{[FF_{MIRROR} * (1 - MR)] + (1 - FF_{MIRROR})\} + (2 * \propto_{WINDOW}) + Overfill$

$\alpha_{DMD}$ = (1 - 0) × {[0.726 × (1-0.94)] + [1-0.726]} + (2 × 0.007) + 0

$\alpha_{DMD}$ = 0.33 (off-state)

$Q_{INCIDENT}$ = total incident average optical power to DMD

Active array area = (1280 × 10.8 µm) × (800 × 10.8 µm) = 1.1944 $cm^2$

$t_{pulse}$ = 10 ps, $t_{off}$ = 99.99999 $\mu s$

Therefore pulse duty cycle = 10 ps / ( 10 ps + 99.99999 $\mu s$ ) x 100% = 0.00001%

Average optical power density = (250 $MW/cm^2$) × 0.00001% = 25 $W/cm^2$

Average optical power = 25 $W/cm^2$ × 1.1944 $cm^2$ = 29.86 W

Average absorbed optical power = 29.86 W × 0.33 = 9.85 W

$\Delta T_{SILICON-TO-CERAMIC}$ = (1.8 W + 9.85 W) × 0.5 ºC/W = 5.8 ºC

**Mirror Surface to Ceramic Delta: ($\Delta T_{MIRROR\_SURFACE-TO-CERAMIC}$)**

$T_{MIRROR\ SURFACE} - T_{CERAMIC} = \Delta T_{SILICON-TO-CERAMIC} + \Delta T_{BULK\_MIRROR-TO-SILICON} + \Delta T_{MIRROR\_SURFACE-TO-BULK\_MIRROR}$

$T_{MIRROR\_SURFACE} - T_{CERAMIC}$ = 5.8 ºC + 1.8 ºC + 26.9 ºC = 34.5 ºC

In the second example, the mirror surface temperature rise above the bulk mirror is much larger than the bulk mirror temperature rise above the silicon. This is common with very short pulses of high intensity. Notice the average power is the same between examples 1 and 2 (29.86 W) and therefore the temperature rise of the silicon above the ceramic is equal in the two examples.

## 4 Summary

This application note demonstrates a method to calculate temperature rise of a DMD mirror when illuminated with a pulsed optical source. The tables and equations allow calculation of this temperature rise over a wide range of operating conditions allowing the determination of safe optical power operating conditions for the DMD. The relationship between the pulse duration and the thermal time constant of the mirror is critical to determining the bulk mirror temperature, while the mirror surface temperature rise above bulk is only a function of incident power density and pulse duration.

## 5 References

1. *Fundamentals of Heat and Mass Transfer*, 3rd Edition, 259-263 (1990), Incropera, Frank P., DeWitt, David P.
2. Texas Instruments, *DMD Optical Efficiency for Visible Wavelengths*, application note.

# 6 Revision History