# A Comprehensive Study on Failure Modes and Mechanisms of Thin Film Chip Resistors

# Sarat Kumar Dash, Sandhya V. Kamat



Abstract: Usually, resistors and capacitors populate the majority portion of a standard electrical circuit; hence, the miniaturisation drive of any package or subsystem starts with miniaturised resistors and capacitors. In this context, thin film chip resistors are the most sought-after components for any electronic or electrical circuit due to their small size, wide range of values, military temperature range, stringent tolerance, and low TCR value (recognised with PPM). The increased use of thin-film surfacemount chip resistors in military and space applications has led to a heightened awareness of their potential failure modes in harsh environments. Thin film resistors with lower TCR (5PPM, 10PPM, and 25PPM) are most preferable and widely used due to their verv low temperature coefficient of resistance (TCR) and high resistivity, which makes them suitable for high-precision measurement applications. The low temperature coefficient characteristics of thin film resistors also make them stable and reliable. Due to their high-volume usage in recent times, failures in thin film resistors with lower TCR/PPM (Parts per Million) are also being seen more predominantly. In general, there are two types of thin film chip resistors: discrete type and die type, also known as wire bondable type. Discrete-type chip resistors are used directly on cards, whereas die-type or wire-bondable chip resistors are used in hermetically sealed HMC packages. The standard failure mode of a resistor is open mode or high resistance mode, whereas short mode failure has a very low probability. Hence, in this paper, the failure modes and mechanisms of both types of thin film chip resistors, concerning common failure causes such as EOS and ESD, are discussed, which is in continuation of the fabrication/workmanship-related failures addressed in our earlier technical paper. With this, all possible failure modes and mechanisms related to thin film chip resistors are explained. Discussion in totality always provides an in-depth analysis of a subject of concern, which in turn facilitates a reliability assessment of the component and, if necessary, corrective action.

Key Words: Electrical Overstress (EOS); Electrostatic Discharge (ESD); Temperature Coefficient of Resistance (TCR); Parts Per Million (PPM); Moisture Ingression; Corrosion, Hybrid Micro Circuit (HMC)

# I. INTRODUCTION

Chip resistors are a type of resistor among passive components, primarily used to reduce circuit voltage and limit current in electronic products. They are essential components of most high-tech electronic products.

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Chip resistors have several advantages, including small size, light weight, and no inductance, and they are widely used in electronic equipment and populated PCBs for adapting to high-density surface mount applications. The chip resistors can be divided into thin-film chip resistors and thickfilm chip resistors. The former offers better precision and lower temperature coefficients, which means more stable and reliable resistance. With the development of high-precision electronic devices, thick-film chip resistors are unable to meet higher performance requirements due to their high temperature coefficient of resistance. Therefore, thin film chip resistors are most preferable because they have low temperature coefficients, which makes them stable and reliable. The predominant film systems used in the manufacture of thin-film resistors today are nickel-chrome and tantalum nitride [1]. The vast majority of these, however, are derivatives of Nickel-Chrome (Ni-Cr) or Tantalum Nitride (TaN). Ni-Cr thin film has a low temperature coefficient of resistance (TCR) and high resistivity, which increases its importance and technical applications as a resistor in the electronics industry [2-4]. However, in the case of thin film chip resistors or other miniature products, it is necessary to encapsulate the film and prevent corrosion in humid environments [5]. The increased use of thin-film surface-mount chip resistors in military and space applications has led to a heightened awareness of potential failure modes in harsh environments.

To understand the failure mode and mechanism of thin film chip resistors, it is necessary to know about their physical construction. Construction of a thin film resistor (discrete type) was already explained in an earlier publication [6], however, for the sake of completeness construction of both types of film resistors (discrete type and wire bondable/die type) are shown in figure-1 and figure-2 respectively. Usually, thin film resistors are fabricated by vacuum evaporation or sputtering of thin films of resistive materials (mostly Nichrome) directly on top of the ceramic substrate or silicon wafer. These materials exhibit good adhesion on the oxide as thin films, and are usually built with a film thickness of about 100-1000Å. The value of a thin film resistor can be set precisely to its final value by laser trimming. For a discrete-type thin film resistor, both sides of the chip have solder-coated nickel end-caps for electrical contact with the chip resistor. The resistor film (Nichrome) is protected by a passivation layer of thickness  $\leq 10 \mu m$  and covered by a hard epoxy coating. The role of the passivation layer is very critical in chip resistors, as it protects the resistor film from moisture and contaminants. By their construction, passivation layers and end caps are susceptible to temperature fluctuations, which the chip resistor typically experiences during manual soldering or post-reflow solder touch-up.



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Improper fabrication process of thin film chip resistors usually ends up in moisture-induced open mode failure as a result of corrosion of internal resistive material [6].

For wire-bondable/die-type thin film resistors, aluminium bond pads are provided along with a resistive thin film track for wire bonding connection. Thin film materials are the same as those of a discrete-type thin film chip resistor (Nichrome), but there is no passivation layer in the case of wirebondable/die-type thin film resistors. Therefore, these types of resistors are intended for use inside hermetically sealed packages.



Figure 1: Internal Construction of Discrete Thin Film Chip Resistor



wire bondable pad (unpasivated)

# Figure 2: Internal Construction of Wire-Bondable (Die Type) Thin Film Chip Resistor

Electrical Overstress (EOS), Electrostatic Discharge (ESD), and Fabrication/Workmanship-induced failures are the primary failure causes of EEE components, which were source-screened and qualified as per respective MIL/ESA/NASA standards. Manufacturing-related defects or component design-related defects, if any, are typically identified and addressed during the screening process. Thin film chip resistors, used in onboard applications of ISRO projects, are being sourced as high-reliability parts; hence, it is prudent to understand various failure modes and mechanisms, which in turn help identify the root cause of failure and inform subsequent corrective actions.

# II. REFERENCE TO EARLIER SIMULATION STUDY ON THIN FILM CHIP RESISTORS

In an earlier study, fabrication/workmanship induced failure simulation experiments were carried out on discrete type thin film chip resistors RM1206, 0.1%, 25PPM, 1/8W (many values) to understand the root cause of failure of a large number of thin film resistors in a satellite project during various ground level tests [6]. A simulation study was conducted on Nichrome-based thin film resistors, as these types of chip resistors are used in ISRO projects, and the following conclusions were made.

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- Thin film resistors soldered using a proper soldering method (either manual or reflow) did not show any timedependent failure, even when biased with higher voltage. However, the open-mode failure of one 100kw resistor, which was reflow-soldered, highlighted a reliability concern with Nichrome-based thin-film resistors. In this case, there are two possible scenarios for open mode failures: either multiple solder touch-ups were performed on this particular resistor after reflow soldering for some reason, or the passivation layer for this particular piece has a manufacturing defect. The first reason is slightly unlikely, as the reflow soldering process was carried out on the resistors under strict Quality Control (QC) guidance. There is a possibility for the second reason, as thin film resistors do not undergo any screening tests that could identify defects such as cracks and porosity in the passivation layer. Therefore, Nichrome-based thin film resistors are not environmentally friendly.
- To establish the exact failure mechanism for open-mode failure in Nichrome-based thin-film resistors, a biased humidity test was conducted on the chip resistor. According to the test results, when the solder time exceeds 15 seconds, those resistors, although they do not show any anomalies immediately after soldering, subsequently fail in open mode after different periods of testing. Two interesting facts were observed from the simulation study: (i) as the soldering time increases, the time for open-mode failure in the resistors decreases, and (ii) the time taken for higher-value resistors is less than that of lower-value resistors. Based on the above two observations, the failure mechanisms for open-mode failure in chip resistors can be explained as follows. As the soldering time increases, the damage probability to the passivation layer also increases, as does the likelihood of moisture ingression, which results in oxide formation on the Nichrome metal and ultimately causes the metal film to fail in an open mode. Hence, the failure mechanism in this case can be related to corrosion.
- From the above discussion, it is inferred that open-mode failure in Nichrome-based thin film chip resistors is timedependent and related to moisture-induced corrosion.

## III.FURTHER SIMULATION STUDIES ON THIN FILM CHIP RESISTORS

To understand a few other failure mechanisms in both discrete-type thin film chip resistors and wire-bondable/dietype thin film resistors, a few more simulation studies were conducted, and they are as follows

- (a) Electrical Overstress (EOS) Simulation Study on discrete type thin film chip resistors RM1206, 0.1%, 25PPM, 1/8W (a few values).
- (b) Electrostatic Discharge (ESD) Simulation Study on discrete type thin film chip resistors RM1206, 0.1%, 25PPM, 1/8W (a few values).
- (c) Electrostatic Discharge (ESD) simulation study on die/wire bondable type thin film chip resistors RM1206, 0.1%, 25PPM, 1/8W (a few values).

The details of the studies are explained in the subsequent subsections.



# A. Electrical Overstress (EOS) Simulation Study on Discrete Type Thin Film Chip Resistors RM1206, 0.1%, 25PPM, 1/8W (Few Values)

Electrical Overstress (EOS) is one of the most common failure causes in EEE components, occurring due to improper testing or handling procedures. To determine the susceptibility of discrete thin film chip resistors to electrical overstress, several chip resistors (RM1206, 0.1%, 25PPM, 1/8W, with different values) were subjected to EOS using the step-stress method. The following steps were adopted in the course of the aforesaid simulation study.

a. Initial Visual Examination and Electrical Measurement of Chosen Components:

RM1206, 0.1%, 25PPM, 1/8W (five values, 2nos. each) were chosen for the study. Details about the components are shown in Table 1.

# TABLE 1: Component Details Taken for Simulation Study

| Resistor Type       | Resistance<br>Value | Sample<br>Nos. | Sample<br>Marking |
|---------------------|---------------------|----------------|-------------------|
| RM1206EB,           | 10.0kΩ              | 2nos.          | R1 to R2          |
| $\pm 0.1\%,$ 25PPM, | 27.10kΩ             | 2nos.          | R3 to R4          |
| 1/8W                | 100.00kΩ            | 2nos.          | R5 to R6          |
|                     | 150.00kΩ            | 2nos.          | R7 to R8          |
|                     | 301.00kΩ            | 2nos.          | R9 to R10         |

Chip resistors were visually inspected using an optical microscope at a magnification of 100X. No visual anomalies were observed. Optical photographs of a few chip resistors are shown in Figure 3. The values of the chip resistors were chosen based on feedback from field failure data. Initial electrical test results for each resistor are shown in Table 2.

# TABLE 2: Initial Electrical Measurement Result of Chip Resistors

| Sample | Measured            | Specified           | Sample | Measured            | Specified           |
|--------|---------------------|---------------------|--------|---------------------|---------------------|
| No.    | value in k $\Omega$ | Limit in k $\Omega$ | No.    | value in k $\Omega$ | Limit in k $\Omega$ |
| R1     | 9.992               | 9.90 to             | R7     | 150.075             | 149.85 to           |
| R2     | 10.009              | 10.01               | R8     | 150.098             | 150.15              |
| R3     | 27.102              | 27.073 to           | R9     | 300.947             | 300.699 to          |
| R4     | 27.098              | 27.127              | R10    | 301.078             | 301.301             |
| R5     | 99.927              | 99.9 to             |        |                     |                     |
| R6     | 99.981              | 100.1               |        |                     |                     |



RM1206,301kΩ,0.1%,25PPM,1/8W (R9)

## Figure 3: Optical Image of One Resistor from Each Value Shows no Visual Anomali. EOS simulation study by Step Stress Method:

According to the data sheet, the voltage rating of the thin film chip resistor RM1206, 0.1%, 25PPM, 1/8W, is 100V. An EOS simulation study was conducted on the chip resistors by applying a voltage starting from 100V up to 220V (more than double the rating) in a step of 20V initially, and then in a step of 10V after 180V. For lower-value resistors, the power dissipation limit was exceeded from the beginning of the test. In contrast, for higher-value resistors, the power dissipation limit was exceeded when applying higher voltages. A Lambda make power supply (300V, 5A) was used for voltage application, and a six-digit multi-meter (make: Keysight, model: 34401A) was used for current measurement. The resistors were mounted on a card using reflow soldering, and the terminations were connected with 26 AWG wires (~5 cm in length) as a provision for voltage application. The results are shown in Table 3.

# **TABLE 3: EOS Simulation Test Result**

|                       |       |          |           |            |                | - <b>- - - - - - - - - -</b> | <b>7</b> 5 51 | inuna  | ion i | i est result  |
|-----------------------|-------|----------|-----------|------------|----------------|------------------------------|---------------|--------|-------|---|
| <b>Initial Values</b> | Appli | ed Volta | ge in Vo  | lts (V), V | /oltage A      | pplied f                     | `or ~30       | sec an | d Gap | Remarks   |
| of Resistors in       |       |          | between   | Voltage    | <b>Applica</b> | tions ~2                     | min           |        |       |   |
| kΩ                    | 100   | 120      | 140       | 160        | 180            | 190                          | 200           | 210    | 220   |   |
|                       |       | Me       | easure Cu | rrent Act  | ross Each      | Resistor                     | r in mA       | ۱.     |       |   |
| 9.992 (R1)            | 10.09 | 12.008   | 14.010    | 16.011     | 18.014         | 19.013                       | 6.608         |        |       | At an applied voltage of 200V, the resistance value changed to    |
|                       |       |          |           |            |                |                              |               |        |       | 28.750 k $\omega$ , and the current decreased appropriately.      |
| 10.009(R2)            | 9.911 | 11.891   | 13.874    | 15.856     | 17.838         | 18.830                       | 4.197         |        |       | At an applied voltage of 200V, the resistance value changed to    |
|                       |       |          |           |            |                |                              |               |        |       | 45.270 k $\omega$ , and the current decreased appropriately.      |
| 27.102(R3)            | 3.688 | 4.427    | 5.165     | 5.902      | 6.641          | 7.010                        | 7.37          | 4.830  |       | At an applied voltage of 210V, the resistance value changed to    |
|                       |       |          |           |            |                |                              |               |        |       | 41.4 kω, and the current decreased accordingly.                   |
| 27.098(R4)            | 3.69  | 4.428    | 5.166     | 5.904      | 6.642          | 7.011                        | 7.38          | 5.025  |       | Upon applying 210V, the resistance value changed to 39.8 kω,      |
|                       |       |          |           |            |                |                              |               |        |       | and the current decreased accordingly.                            |
| 99.927(R5)            | 1.00  | 1.2      | 1.4       | 1.6        | 1.8            | 1.9                          | 2.0           | 2.1    | 1.349 | Upon applying 220V, the resistance value changed to 155.6kω,      |
|                       |       |          |           |            |                |                              |               |        |       | and the current decreased accordingly.                            |
| 99.981(R6)            | 1.00  | 1.2      | 1.4       | 1.6        | 1.8            | 1.9                          | 2.0           | 2.1    | 2.2   | The resistor did not degrade even after being subjected to 220V.  |
| 150.075(R7)           | 0.666 | 0.799    | 0.932     | 1.066      | 1.199          | 1.266                        | 1.332         | 1.399  | 1.465 | The resistors did not degrade even after being subjected to 220V. |
| 150.098(R8)           | 0.666 | 0.799    | 0.932     | 1.066      | 1.199          | 1.266                        | 1.332         | 1.399  | 1.465 |   |
| 300.947(R9)           | 0.332 | 0.398    | 0.465     | 0.531      | 0.598          | 0.631                        | 0.664         | 0.697  | 0.731 | The resistors did not degrade even after being subjected to 220V. |
| 301.078(R10)          | 0.332 | 0.398    | 0.464     | 0.531      | 0.597          | 0.631                        | 0.664         | 0.697  | 0.730 |   |

NOTE: Resistor R3 and R4 were decapped after a simulation study and an optical photograph revealed that internal resistive patterns are melted and partially discontinued at specific locations due to electrical overstress (refer to Figures 4 & 5). However, this signature is not similar to moisture-induced corrosion-related failure.

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Figure 4: Localized Melting of Resistive Tracks of the Degraded Resistor R3

Figure 5: Localized Melting of Resistive Tracks of The

Degraded Resistor R4

B. ESD Simulation Study on Discrete type Thin Film Chip Resistors RM1206, 0.1%, 25PPM, 1/8W (Few Values)

Electrostatic Discharge (ESD) is one of the most common failure causes in EEE components, often occurring due to improper testing or handling procedures. To determine the susceptibility of discrete thin film chip resistors to electrostatic discharge, a few chip resistors (RM1206, 0.1%, 25PPM, 1/8W, with different values) were subjected to ESD using the step stress method. The following steps were taken during the aforementioned simulation study.

| R5  | 10.005 |          | R15 | 33.216  |            |
|-----|--------|----------|-----|---------|------------|
| R6  | 20.012 | 19.98 to | R16 | 300.947 | 300.699 to |
| R7  | 20.009 | 20.02    | R17 | 301.078 | 301.301    |
| R8  | 20.010 |          | R18 | 301.291 |            |
| R9  | 19.989 |          | R19 | 301.105 |            |
| R10 | 19.995 |          | R20 | 300.867 |            |

*b. ESD Simulation Study by Step Stress Method:* 

To understand the effect of ESD on thin-film chip resistors, the above resistors were subjected to an ESD simulation study. Resistors above 10 ko were chosen based on feedback from reported failures. Almost 95% of chip resistors that fail in open mode have a value of  $\geq 10 \text{ k}\omega$ . All the above resistors were hand-soldered and mounted on the card with proper precautions. A wire termination (~5 cm) was provided with each resistor for the appropriate application of ESD stress. ESD pulses were applied using the Human Body Model ESD simulator, as specified in MIL-STD-883K, Method 3015.7. ESD pulses were applied using the step stress method, with a step size of  $\pm 1000$  V, starting from a value of  $\pm 1000$  V. However, a final applied ESD pulse is shown for the sake of brevity. Pre- and post-ESD resistance measurements were performed on the chip resistors, and the obtained test results are presented in Table 6.

a. Initial Visual Examination and Electrical Measurement Jable 6: ESD Simulation Test Results on RM1206 Chip Chosen Components: Resistors

RM1206, 0.1%, 25PPM, 1/8W (four values, 5nos. each) were chosen for the study. Details about the components are shown in Table 4.

 TABLE 4: Component Details Taken for Simulation

 Study

| <b>Resistor Type</b> | <b>Resistance Value</b> | Sample Nos. | Sample Marking |
|----------------------|-------------------------|-------------|----------------|
| RM1206EB,            | 10.0kΩ                  | 5nos.       | R1 to R5       |
| ±0.1%,               | 20.0kΩ                  | 5nos.       | R6 to R10      |
| 25PPM,               | 33.2kΩ                  | 5nos.       | R11 to R15     |
| 1/8W                 | 301.00kΩ                | 5nos.       | R16 to R20     |

Chip resistors were visually inspected using an optical microscope at a magnification of 100X. No visual anomalies were observed. Optical photographs of a few chip resistors are shown in Figure 6. The values of the chip resistors were chosen based on feedback from field failure data. Initial electrical test results for each resistor are shown in Table 5.



RM1206,0.1%,33.2kΩ,25PPM,1/8W RM1206,0.1%,301kΩ,25PPM,1/8W

Figure 6: Optical Image of One Resistor from Each Value Shows no Visual Anomalies

# TABLE 5: Initial Electrical Measurement Result of Chip Resistors

| Sample<br>No. | Measured<br>value in<br>kΩ | Specified<br>Limit in<br>kΩ | Sample<br>No. | Measured<br>value in<br>kΩ | Specified<br>Limit in<br>kΩ |
|---------------|----------------------------|-----------------------------|---------------|----------------------------|-----------------------------|
| R1            | 9.994                      | 9.90 to                     | R11           | 33.178                     | 33.166 to                   |
| R2            | 10.009                     | 10.01                       | R12           | 33.182                     | 33.233                      |
| R3            | 10.008                     |                             | R13           | 33.201                     |                             |
| R4            | 9.996                      |                             | R14           | 33.198                     |                             |

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| Resistor Type              | SI. | Measured         | Applied      | Measured         |
|----------------------------|-----|------------------|--------------|------------------|
|                            | No. | Resistanc        | ESD          | Resistanc        |
|                            |     | e (Initial)      | Pulses       | e                |
|                            |     |                  | (5 pulses)   | (Final)          |
| RM1206 10.0kΩ 0.1% 1/8W-R  | R1  | 9.998 kΩ         | $\pm 6000 V$ | 9.998 kΩ         |
| RM1206 10.0kΩ 0.1% 1/8W-R  | R2  | 9.997 kΩ         | $\pm 6000 V$ | $9.997  k\Omega$ |
| RM1206 10.0kΩ 0.1% 1/8W-R  | R3  | 10.003 kΩ        | $\pm 6000 V$ | 10.003 kΩ        |
| RM1206 10.0kΩ 0.1% 1/8W-R  | R4  | 10.002 kΩ        | $\pm 6000 V$ | 28.5 kΩ          |
| RM1206 10.0kΩ 0.1% 1/8W-R  | R5  | 9.996 kΩ         | $\pm 6000 V$ | 9.996 kΩ         |
| RM0505 20.0kΩ 0.1% 1/40W-S | R6  | 20.002 kΩ        | $\pm 7000 V$ | 20.002 kΩ        |
| RM0505 20.0kΩ 0.1% 1/40W-S | R7  | 20.005 kΩ        | $\pm 7000 V$ | 48.7 kΩ          |
| RM0505 20.0kΩ 0.1% 1/40W-S | R8  | 19.996 kΩ        | $\pm 7000 V$ | 19.996 kΩ        |
| RM0505 20.0kΩ 0.1% 1/40W-S | R9  | 19.997 kΩ        | $\pm 7000 V$ | 19.997 kΩ        |
| RM0505 20.0kΩ 0.1% 1/40W-S | R10 | 20.005 kΩ        | $\pm 7000 V$ | 20.005 kΩ        |
| RM1206 33.2kΩ 0.1% 1/8W-R  | R11 | 33.202 kΩ        | $\pm 8000 V$ | 33.202 kΩ        |
| RM1206 33.2kΩ 0.1% 1/8W-R  | R12 | $33.198k\Omega$  | $\pm 8000 V$ | 33.198kΩ         |
| RM1206 33.2kΩ 0.1% 1/8W-R  | R13 | 33.197 kΩ        | $\pm 8000 V$ | 33.197 kΩ        |
| RM1206 33.2kΩ 0.1% 1/8W-R  | R14 | 33.203 kΩ        | $\pm 8000 V$ | 33.203 kΩ        |
| RM1206 33.2kΩ 0.1% 1/8W-R  | R15 | 33.202 kΩ        | $\pm 8000 V$ | 33.202 kΩ        |
| RM1206 301.0kΩ 0.1% 1/8W-S | R16 | $301.03k\Omega$  | $\pm 8000 V$ | 301.03kΩ         |
| RM1206 301.0kΩ 0.1% 1/8W-S | R17 | 300.99kΩ         | $\pm 8000 V$ | 300.99kΩ         |
| RM1206 301.0kΩ 0.1% 1/8W-S | R18 | $30.995 k\Omega$ | $\pm 8000 V$ | 30.995kΩ         |
| RM1206 301.0kΩ 0.1% 1/8W-S | R19 | $301.06k\Omega$  | $\pm 8000 V$ | 301.06kΩ         |
| RM1206 301.0kΩ 0.1% 1/8W-S | R20 | 301.05kΩ         | $\pm 8000 V$ | 301.05kΩ         |

**NOTE**: Resistor R4 was decapped after a simulation study and an optical photograph revealed that the internal resistive pattern was melted and partially discontinued at specific locations due to electrical overstress (refer to Figure 7). However, this signature is not similar to moisture-induced corrosion-related failure.



Figure 7: Localized Melting of Resistive Tracks of the Degraded Resistor R4



#### С. **Electrostatic Discharge (ESD) Simulation Study** on Die/Wire Bondable Type Thin Film Chip Resistors RM1206, 0.1%, 25PPM, 1/8W (Few Values)

Die-wire bondable type thin film resistors are being used in HMCs, wherein a few resistors failed in open mode during screening and qualification tests. The construction of die-type thin film chip resistors differs from that of discrete-type thin film chip resistors. Die-type chip resistors are silicon-based, whereas discrete-type thin-film chip resistors are ceramic (Al2O3)-based. However, in both cases, the resistive element is the same, i.e., Nichrome thin film. After studying the ESDinduced failure mechanism in discrete-type thin film chip resistors, the aim was to understand the failure mechanism in die-type thin film resistors related to ESD.

Initial Visual Examination а. and Electrical Measurement of Chosen Components:

A few die-type thin film resistors of different values were chosen for the study. Details about the components are shown in Table 7.

# **TABLE 7: Component Details Taken for Simulation** Study

|                         | •           |                |
|-------------------------|-------------|----------------|
| <b>Resistance Value</b> | Sample Nos. | Sample Marking |
| 100Ω±0.1%               | 3nos.       | R1 to R3       |
| 1.5kΩ±0.1%              | 3nos.       | R4 to R6       |
| 12.0kΩ±0.1%             | 3nos.       | R7 to R9       |
| 22.0kΩ±0.1%             | 3nos.       | R10 to R12     |
| 56.0kΩ±0.1%             | 3nos.       | R13 to R15     |
| 100.0kΩ±0.1%            | 3nos.       | R16 to R18     |
| 240.0kΩ±0.1%            | 3nos.       | R19 to R21     |
| 470.0kΩ±0.1%            | 3nos.       | R22 to R24     |

NOTE: Chip resistors dice were visually inspected using an optical microscope at 100X. No visual anomalies were observed.

#### b. ESD Simulation Study by Step Stress Method:

To understand the effect of ESD on die-type thin-film chip resistors, an ESD simulation study was conducted by mounting the aforementioned resistor dice in a 48-pin metallic HMC package. ESD pulses were applied between the HMC pins, which were internally connected to the pads of the chip resistor dice. ESD pulses were applied using the Human Body Model ESD simulator, following the MIL-STD-883K method 3015.7. ESD pulses were applied using the Human Body Model ESD simulator, in accordance with the MIL-STD-883K method 3015.7. ESD pulses were applied using the step stress method, with a step size of  $\pm 250$  V, starting from ±500 V. However, a final applied ESD pulse is included in the table for brevity. Pre- and post-ESD resistance measurements were performed on the chip resistors, and the obtained test results are presented in Table 8.

| Table 8: | ESD | Simulation | Study | Result |
|----------|-----|------------|-------|--------|
|----------|-----|------------|-------|--------|

| Resistor<br>Sl. No. | Initial<br>Value of<br>Resistors | Applied ESD<br>Pulses | Final Value<br>of Resistors | Remarks             |
|---------------------|----------------------------------|-----------------------|-----------------------------|---------------------|
| R1                  | 99.98 <u>Ω</u>                   | ±500V,5pulses         | 99.98Ω                      | Failed in Onen mode |
| R2                  | 99.97Ω                           | ±750V,5pulses         | 99.97Ω                      | (Figure 8)          |
| R3                  | 100.03Ω                          | ±1000V,5pulses        | Open                        | (Figure-8)          |
| R4                  | 1.498kΩ                          | ±500V, 5pulses        | 1.498kΩ                     |                     |
| R5                  | 1.501kΩ                          | ±750V, 5pulses        | 1.501kΩ                     | (Eigung 0)          |
| R6                  | 1.499kΩ                          | ±1000V,5pulses        | Open                        | (Figure 9)          |
| R7                  | 11.998kΩ                         | ±500V, 5pulses        | 11.998kΩ                    |                     |
| R8                  | 11.999kΩ                         | ±750V, 5pulses        | 11.999kΩ                    | (Eigung 10)         |
| R9                  | 11.997kΩ                         | ±1000V,5pulses        | Open                        | (Figure 10)         |
| R10                 | 21.998kΩ                         | ±500V, 5pulses        | 21.998kΩ                    | Failed in Onen mode |
| R11                 | 22.002kΩ                         | ±750V, 5pulses        | 22.002kΩ                    | (Figure 11)         |
| R12                 | 21.997kΩ                         | ±1000V, 5pulses       | Open                        | (rigule 11)         |

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| Esiled in Onen mede | 55.998kΩ         | ±500V, 5pulses | 55.998kΩ         | R13 |
|---------------------|------------------|----------------|------------------|-----|
| (Eigung 12)         | 55.999kΩ         | ±750V, 5pulses | 55.999kΩ         | R14 |
| (Figure 12)         | Open             | ±1000V,5pulses | 55.999kΩ         | R15 |
| Esiled in Onen mede | 301.003kΩ        | ±1000V,5pulses | 99.999kΩ         | R16 |
| (Eigure 12)         | 300.997kΩ        | ±1250V,5pulses | 99.998kΩ         | R17 |
| (Figure 13)         | Open             | ±1500V,5pulses | 99.999kΩ         | R18 |
| E-:1-1:- O1-        | 239.999kΩ        | ±1000V,5pulses | 239.999kΩ        | R19 |
| (Eigure 14)         | $240.002k\Omega$ | ±1250V,5pulses | $240.002k\Omega$ | R20 |
| (Figure 14)         | Open             | ±1500V,5pulses | 239.998kΩ        | R21 |
| Failed in Onen mode | 999.998kΩ        | ±1500V,5pulses | 999.998kΩ        | R22 |
| (Eigure 15)         | 999.999kΩ        | ±1750V,5pulses | 999.999kΩ        | R23 |
| (Figure 15)         | Open             | ±2000V,5pulses | 999.999kΩ        | R24 |
|                     |                  |                |                  |     |



Figure 8: Discontinuity of the thin Film track of resistor R3



Figure 10: Discontinuity of the thin film track of resistor R9



Figure 12: Discontinuity of the thin film track of resistor R15



Figure 14: **Discontinuity of Thin** Film Track of



**Figure 9: Discontinuity** of the thin Film track of resistor R6



Figure 11: Discontinuity of the thin film track of resistor R12



Figure 13: Discontinuity of the thin film track of resistor **R18** 



R24

Figure 15: **Discontinuity of Thin** Film Track of Resistor **Resistor R21** 

# **IV. RESULTS AND DISCUSSION**

As discussed in Section A, an Electrical Overstress (EOS) simulation study was conducted on discrete-type thin film chip resistors, RM1206, 0.1%,

25PPM, 1/8W. According to the EOS simulation study, it was

inferred that the simulated Published By: Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

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# A Comprehensive Study on Failure Modes and Mechanisms of Thin Film Chip Resistors

resistors failed in open mode when a voltage greater than twice the rated voltage (200V) was applied. Before openmode failure, the resistance of the resistors appreciably increased. In this case, the resistor pattern became distorted at a specific location due to high dissipation, increasing in resistance value; however, complete open-mode failure was not observed. The failure mechanism in this case can be described as the Joule heating effect. This failure mechanism differs from that of the manual soldering simulation explained in Section 2, wherein the resistor pattern near the end cap region of the chip resistor was entirely eroded due to moisture- or contaminant-induced corrosion. Therefore, the failure signature in the chip resistor RM1206, as a result of manual soldering simulation, did not match that of the EOS simulation.

As discussed in Section B, an ESD simulation study was conducted on a discrete type thin film resistor, RM1206, 0.1%, 25PPM, 1/8W. According to the ESD simulation study, it is inferred that these types of resistors are not particularly sensitive to ESD. Only lower value resistors ( $10K\Omega$  and  $20K\Omega$ ) are susceptible to 6000V to 7000V ESD pulses, whereas higher value resistors (>20k $\Omega$ ) did not show any susceptibility to ESD. The internal visual signature of an ESD-stressed chip resistor indicated localised distortion of resistive tracks at a few locations, which is similar to that of EOS-induced failure, with the exact failure mechanism being the joule heating effect. Additionally, ESD-induced resistors are failing in a higher resistance mode, rather than in a completely open mode, which is similar to EOS-induced failures. As discussed in Section C, an ESD simulation study was conducted on a die-type thin film resistor. According to an ESD simulation study, it is inferred that these types of resistors are susceptible to ESD, specifically when the resistive thin film track is opened or damaged. Resistor values  $\leq$  55 k $\omega$  failed in open mode under ESD stress  $\geq$  1000 V. In contrast, higher-value resistors failed under higher ESD stresses, such as 1500 V and 2000 V. Therefore, thin film resistors can be classified as Class-1 ESD-sensitive devices. Although the resistive elements for both discrete-type and die-type thin film resistors are the same, i.e., Nichrome, the difference between them lies in their substrates. Discrete-type thin film resistors have a ceramic (alumina) substrate, whereas die-type thin film resistors have a silicon substrate. This indicates that the ESD sensitivity of a silicon-based thin film resistor is more than that of an alumina-based thin film resistor. The reason behind the above observation is probably due to the higher electrical conductivity of silicon (~1.67 x 10<sup>-2</sup> mho/cm) compared to that of ceramic (Alumina)  $(\sim 10^{-14} \text{ mho/cm})$ . Due to the higher electrical conductivity of Silicon, ESD pulse discharges un-disruptively through the silicon die, damaging the thin film resistive element. The exact mechanism does not apply to ceramic-based thin film resistors because the ESD pulses are disrupted and dissipated on the less conductive surface. However, further study is needed to understand the ESD sensitivity of die-type thin film resistors.

#### V. CONCLUSION

Controlled experiments were conducted to demonstrate the effect of EOS and ESD on a discrete type thin film resistor (RM1206 chip resistor, 0.1%, 25PPM, 1/8 watt). From the study, it was understood that the EOS simulated resistors failed in open mode when a voltage greater than twice the rated voltage (100V) was applied. In this case, the resistor pattern became distorted at specific locations due to high dissipation, resulting in an increase in resistance value; however, complete open-mode failure was not observed. Similarly, from the ESD simulation study, it is inferred that these types of resistors are not very sensitive to ESD. Only lower-value resistors ( $10K\Omega$  and  $20K\Omega$ ) are susceptible to ESD pulses ranging from 6000V to 7000V. The internal visual signature of an ESD-stressed chip resistor indicated localised distortion of resistive tracks at a few locations, which is similar to that of EOS-induced failure. Additionally, ESD-induced resistors are failing in a higher resistance mode, rather than in a completely open mode, which is identical to EOS-induced failures.

A controlled ESD simulation study on die-type chip resistors yields different observations. According to an ESD simulation study, it is inferred that these types of resistors are susceptible to ESD, specifically when the resistive thin film track is opened or damaged. Resistor values  $\leq 55$  ko failed in open mode under ESD stress  $\geq 1000$  V. In contrast, higher-value resistors failed under higher ESD stresses, such as 1500 V and 2000 V. Therefore, the type of thin film resistors can be classified as Class-1 ESD-sensitive devices. Although the resistive elements for both discrete-type and die-type thin film resistors are the same, i.e., Nichrome, the ESD sensitivity differs between them. The reason for the above can be explained in terms of the conductivity of their base substrate; further experiments are in progress for an in-depth understanding.

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