**White Paper**

# Removing the Threat of Sulfuration to DRAM Modules


## Executive Summary

Pollution from fossil fuels and volcanic activity are the main sources of sulfur contaminants in the air. Sulfur in form of hydrogen sulfide will react with silver located in DRAM resistors in a corrosive reaction that lowers conductivity and eventually causes module failure.

A protective layer can be added to ensure that the silver does not come into contact with hydrogen sulfide, thus preventing corrosion. Alternatively, the silver alloy can be altered to increase sulfur resistance.

Tests using the ASTM B809-95 standard show that switching to anti-sulfuration resistors provides full protection against hydrogen sulfide in the air.

## Introduction

Embedded operators are facing increasing difficulty with high sulfur content in their surroundings. This can be attributed to the trends of IoT and edge computing where devices are moving out into the field where environmental risks are greater.

Sulfur contamination will cause corrosion damage to DRAM modules and other sensitive equipment. DRAM resistors use silver due to its high conductivity and stability. It is, however, susceptible to corrosion from sulfide, especially in the form of hydrogen sulfide gas. Once the silver corrodes, it loses all conductivity. This will eventually lead to module failure and consequently the whole system crashing.

Hydrogen sulfide gas exists in minuscule amounts in the atmosphere, but elevated levels are found in areas with volcanic activity and areas with pollution from fossil fuels.

Other than the more obvious scenarios where one can encounter sulfur contamination, it is also seen as a hidden danger in data centers. Data center air intakes can carry contaminants into the building, and urban areas will have higher hydrogen sulfide levels due to traffic and other forms of pollution.

Protecting DRAM modules can be done with different methods but the main two contenders are:

1. Adding a Protective Layer across the sensitive area
2. Replacing the silver with a more resistant alloy

Furthermore, DRAM modules can be tested for sulfur resistance through the ASTM B809-95 testing standard.

This paper will expound on the problem of sulfuration and further discuss the two main methods of solving the issue, as well as how to verify the quality of the sulfuration protection.

# Background

### How does silver corrode?

Elemental/pure silver is relatively stable and non-reactive in air. However, hydrogen sulfide gas will cause silver to oxidize, even when only present in low quantities. This is a form of corrosion (also called tarnishing) that leaves a thin layer of black silver sulfide on the surface of the metal, and can typically be observed on silverware and silver coins that have been exposed to sulfides in water or air.

The balanced chemical reaction is as follows:

$$2Ag_{(s)} + H_2S_{(g)} \longrightarrow Ag_2S_{(s)} + H_{2(g)}$$

Where silver (Ag) is oxidized and sulfur (S) is reduced to create silver sulfide ($Ag_2S$). The hydrogen (H) from the hydrogen sulfide ($H_2S$) forms hydrogen gas ($H_2$). Salts and higher levels of humidity will act as catalysts and increase the rate of the reaction.

Pure silver is one of the best conductors of electricity, but once it oxidizes and forms silver sulfide it loses all conductivity. This means that silver that is in contact with hydrogen sulfide will steadily lose conductivity as long as the reaction is allowed to happen.

**DRAM Resistors**

The resistors used on DRAM PCBs (Printed Circuit Board) are called SMD resistors (Surface Mount Device). These resistors have an electrode placed on top of a ceramic substrate (see figure 1). The electrode has to be a good conductor of electricity and is placed above the non-conducting ceramic material.

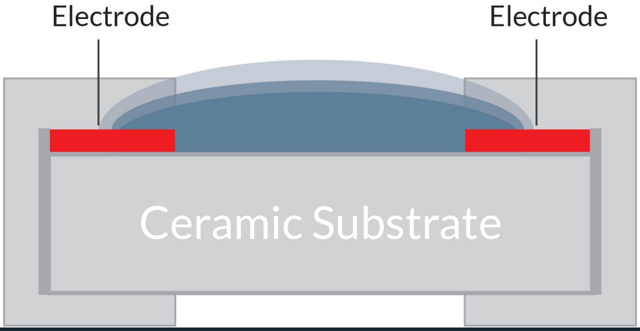



Figure 1: DRAM resistor showing electrode above the ceramic substrate

**The ASTM B809-95 Testing Standard**

ASTM International, formerly known as *The American Society for Testing and Materials*, provides testing standards on a world-wide basis. The most suitable standard for testing anti-sulfuration is ASTM B809-95, which is also the most commonly known among suppliers of resitors. This standard is also called *Standard Test Method for Porosity in Metallic Coatings by Humid Sulfur Vapor ("Flowers-of-Sulfur")* and is designed to recreate a high-humidity, high-temperature environment with elevated hydrogen sulfide levels.

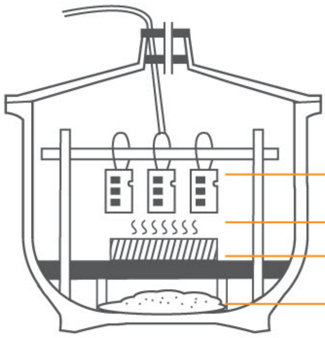


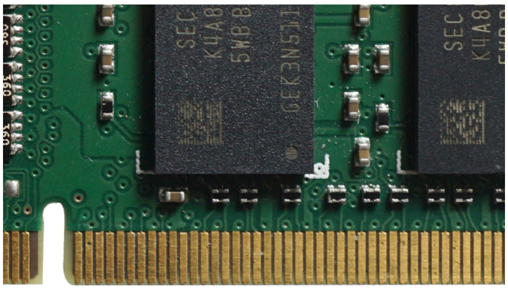

Figure 2: Basic setup of ASTM B809-95

DRAM modules are suspended above a container of pure sulfur and potassium nitrate ($KNO_3$) that is continuously releasing hydrogen sulfide gas. The test described in this paper was run significantly longer than stipulated by the testing procedure, thus ensuring that all susceptible metals that are in contact with the air will have undergone corrosion.

## Challenges

The main issue with sulfur contamination and DRAM modules is when the silver electrode comes into contact with air holding higher levels of hydrogen sulfide. Once the hydrogen sulfide gas starts oxidizing the silver, conductivity will slowly decrease until the module eventually fails.

The sulfuration process can be observed by noticing a color shift as seen in the picture below.



Picture 1: Resistors changing colors after test completion on standard DRAM module

## Solutions

### Protective Layer

The protective layer solution is simple and straight-forward; a layer of protective film is added around the electrode to isolate it from air contact and potential sulfuration (see figure 4). The layer also prevents any gas diffusion, as even a tiny amount of hydrogen sulfide particle is enough to affect the electrode. This method is also relatively inexpensive and easy to implement.

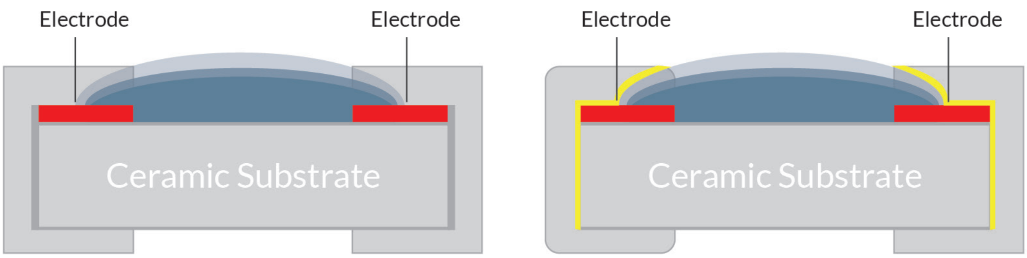



Figure 3: A standard resistor (left) and a resistor with an added protective layer (right) marked in yellow

### Altering Electrode Alloy

The issue of sulfuration can be addressed by altering the silver alloy used in the electrode. This is usually done by increasing the amount of palladium in the alloy. Palladium is less reactive compared to silver and can form alloys that are sulfur-resistant.

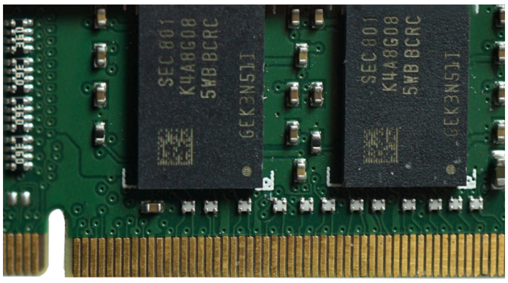
However, palladium is also significantly more expensive than silver, which means this solution will be more costly than the above mentioned protective layer.

### Testing of DRAM Using Anti-Sulfuration Resistor

Testing was conducted on several modules fitted with anti-sulfuration resistors (see below) according to the ASTM B809-95 standard.

Picture 2: Testing of DRAM modules fitted with anti-sulfuration resistors

All modules showed no signs of tarnishing after having completed the testing procedure. The resistors kept their original white-gray coloring indicating no or indistinguishable levels of corrosion.



Picture 3: DRAM anti-sulfuration resistors unaffected after sulfuration test

## Conclusion

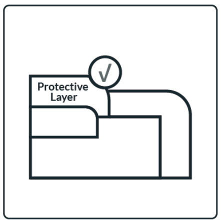
Protecting DRAM modules and other sensitive components is essential as the number of devices around us grows and the risk of sulfur contamination increases. Sulfur can be an unaccounted risk factor in many embedded environments and can cause significant damage if ignored.

Solutions are, however, readily available. Adding a protective layer inside the resistors is easily done at a comparatively low cost. While altering the silver alloy to increase sulfur resistance is a viable solution, it is also associated with a higher cost increase.

Every operator facing the risk of sulfuration should take the necessary steps to protect memory modules as any increase in cost will be far outweighed by the consequences of module failure.

# The Innodisk Solution

## Anti-Sulfuration added to all DDR4 DRAM Modules




### Extended Longevity

The robust anti-sulfuration design greatly increases the modules longevity in harsh environments

### Lower Total Cost of Ownership

Increased durability ensures longer sustained use without the need for maintenance or replacement


### Free-of-Cost Upgrade

All Innodisk DDR4 modules will be upgraded without any added cost to include robust anti-sulfuration measures

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