Sulfuration of Resistors

§0 Abstract

When flat chip resistors (Typically thick film chip resistors) are used in an environment that contains sulfur, a phenomenon known as 'sulfuration' may occur. In some cases, this may lead to a total loss of conductivity, resulting in an open circuit. This technical note explains the mechanism and causes of sulfuration, as well as its countermeasures.

§1 Sulfuration

1.1 What is Sulfuration?

Many people may have experienced that silver objects such as jewelry turn black after being left for a long time or when used in areas with seismic or volcanic activity. This phenomenon occurs when the surface of the silver reacts with the sulfur in the atmosphere or the water, forming silver sulfide. Sulfuration not only affects silver products but also a variety of products that contain silver, such as certain flat chip resistors that use silver in their internal electrodes. When the silver in these internal electrodes reacts with sulfur to form silver sulfide, that area loses conductivity. If the reaction progresses, the internal electrode loses all conductivity, resulting in a disconnection or open circuit. Figure 1 shows a sulfurated flat chip resistor. The needle-like black substances inside the red circle in the figure are silver sulfide crystals. It should be noted that "sulfuration" generally refers to the combination of a substance with sulfur. However, in the context of resistors, it refers to the phenomenon by which the silver internal electrode loses conductivity due to sulfuration, which results in the equivalent of an open circuit.

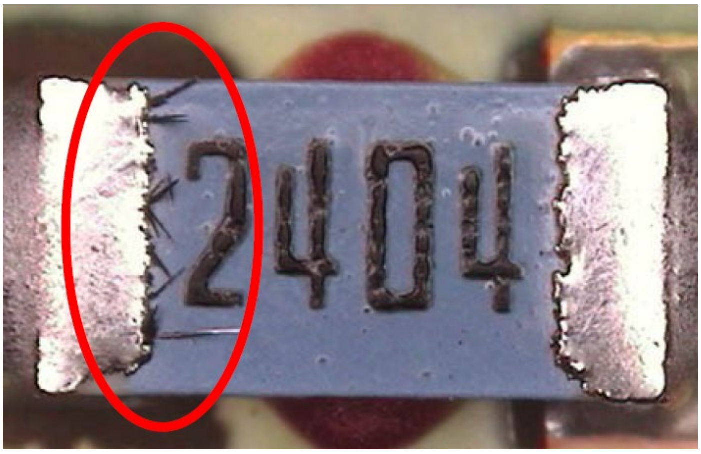
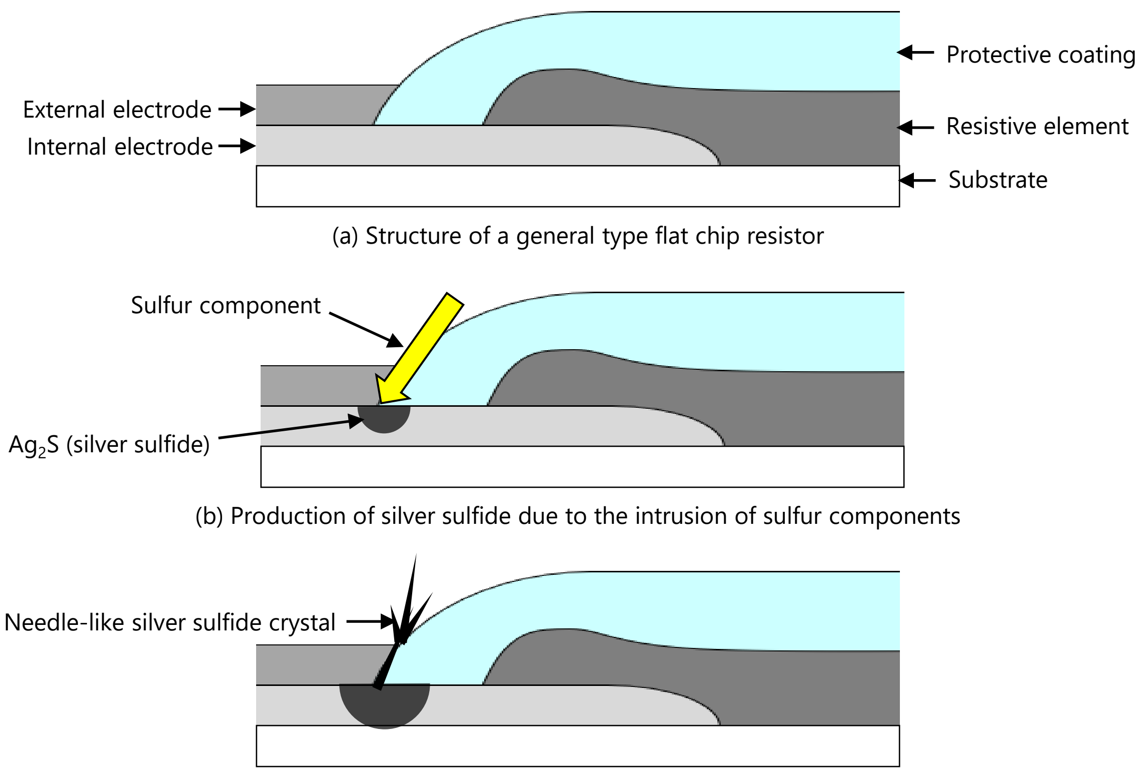


Fig. 1 Sulfurated flat chip resistor

1.2 Mechanism of Sulfuration

Figure 2 shows the structure of a general type thick film chip resistor and the process through which sulfuration occurs. When a resistor is exposed to an atmosphere containing sulfur, this sulfur penetrates the interior of the resistor through the interface between the protective coating and the external electrode. Upon reaching the internal electrode, the sulfur reacts with the silver to form silver sulfide. This sulfuring may spread from the top to the bottom of the internal electrode, resulting in the disconnection of the conductive areas.



(a) Structure of a general type flat chip resistor

(b) Production of silver sulfide due to the intrusion of sulfur components

(c) Disconnection and open circuit due to silver sulfide growth

Fig. 2 Sulfuration occurrence process

As a reference, we provide below the reaction formula for the production of silver sulfide.

Table 1 Reaction of silver sulfide

	Reaction formula
1	$Ag \rightarrow Ag^{+} + e^{-}$
2	$S + 2e^{-} \rightarrow S^{2-}$
3	$2Ag^{+} + S^{2-} \rightarrow Ag_2S$

1.3 Causes of Sulfuration

The causes of sulfuration include the use of resistors in environments containing sulfur and contact with a substance that contains sulfur. These situations are typically associated with car exhaust gases or volcanic activity. However, there are many other objects around us that contain sulfur. For example, rubber products such as elastic bands that use natural rubber undergo a process called "vulcanization", in which sulfur is added to the rubber during the manufacturing process to improve its elasticity. If such rubber is located near a resistor, it may induce sulfuration. Table 2 provides specific examples of places where sulfuration could occur.

Table 2 Specific examples of locations where sulfuration may occur

Locations	Specific examples
Natural environment	• Places where volcanic gases erupt • Hot spring facilities
Factories	• Factories for rubber-based products (when subjected to vulcanization) • Crude oil refineries • Around machinery (where oil and grease may contain sulfur)
Inside products	• Instances where nearby mounted parts contain sulfur • Where rubber-based molds are applied to substrates • Where rubber-based seals are used
Others	• Cardboard (which may contain sulfide gases) • Fabric dyes • Locations filled with car exhaust gases • Locations where biological decomposition gases occur, such as sewage and wastewater treatment facilities.

§2 Countermeasures against Sulfuration

If the resistors are not used in an environment that contains sulfur, sulfuration will not occur. However, as shown above, there are many environments where sulfuration could occur, making it difficult to completely avoid use in such environments. There are two main countermeasures against sulfuration in resistors: delaying sulfuration and preventing it. An example of a method to delay sulfuration is to add a layer between the plated terminal finish and the protective coating. This structure cannot completely prevent the intrusion of sulfur gas, so while it can delay the onset of sulfuration, the possibility of a disconnection or open circuit due to sulfuration remains. The other method involves the use of an inner electrode material that does not sulfurate as quickly or at all. Since sulfuration is caused by the reaction of the silver in the internal electrode with sulfur, this problem can be avoided by using a non-sulfurating material. In this way, the product can be used even in environments that contain sulfur. Figure 3 shows images of a general type product (not treated for sulfuration), a product with a sulfuration-delay layer added, and a product with a changed internal electrode material.

Sulfuration of resistors

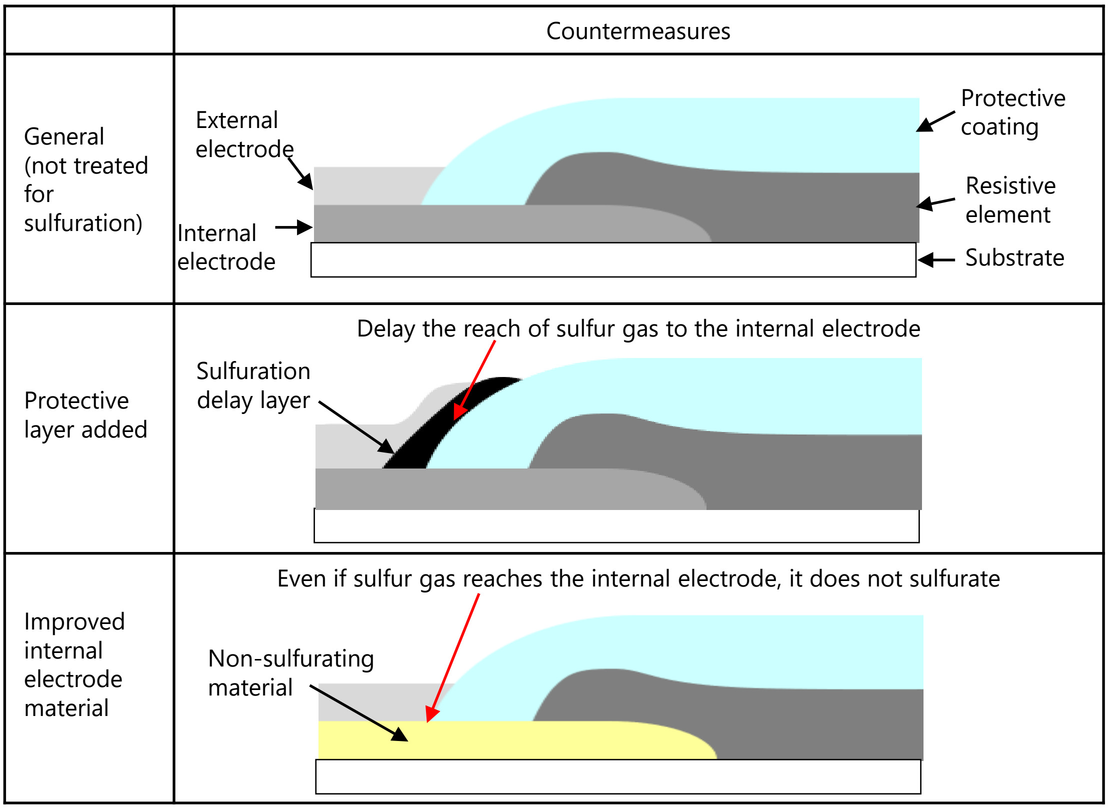


Fig. 3 Sulfuration countermeasures in chip resistors (image diagram)

KOA offers a range of countermeasure products that use non-sulfurating materials, as mentioned above. Products that have "-RT" at the end of the resistor family prefix include sulfuration countermeasures as the equivalent of many common series (for example, RK73B-RT). The sulfuration resistance tests conducted by KOA are not only tested under a sulfur atmosphere, but also, the chip resistors are soaked in industrial oil containing 3.5% sulfur components for 500 hours at a temperature of 105°C. The change in resistance measured before and after the test is less than 0.3%, indicating that there are no effects due to sulfuration.

In addition to the sulfuration protection measures within resistors, components or circuit boards may be conformally coated. In this case, it is essential to ensure that the entire surface is fully covered with the coating, as sulfur gas can infiltrate the interior if there are gaps in the coating. Additionally, we recommend using acrylic materials for the coating instead of silicone ones. This is because silicone materials tend to absorb and retain moisture and sulfur components, which could inadvertently promote sulfuration.

§3 Conclusion

When resistors with silver internal electrodes are used in an atmosphere containing sulfur, the silver in the internal electrode reacts with the sulfur to form silver sulfide. Silver sulfide is very low in conductivity, so if this reaction progresses, it could lead to the disconnection of the electrode and an open circuit. There are two types of countermeasures against the sulfuration of resistors: a method to delay sulfuration and a method that uses materials that do not sulfurate. KOA offers a range of products using non-sulfurating materials as a countermeasure, using patented technology. The use of such products is recommended in cases where chip resistors are to be used for a prolonged period in a severe sulfur atmosphere or where there is a need to prevent significant resistance changes. KOA offers technical support, including sulfuration resistance test results for these KOA products. Please feel free to contact us with any questions.