Electrolytic Corrosion of Resistors

§0 Overview

If moisture penetrates the inside of the resistor with a thin carbon or metal film element and voltage is applied, a phenomenon called "electrolytic corrosion", during which the resistive element deteriorates or disappears due to a chemical reaction, will occur and cause malfunctions such as an open circuit. This technical note explains the mechanism and causes of electrolytic corrosion and the countermeasures that can be taken against it.

§1 What is electrolytic corrosion?

You may have experimented with water electrolysis in chemistry class at school. It is an experiment in which two electrodes are immersed in water that contains electrolytes. When electric current is passed through the electrodes, oxygen and hydrogen are produced at the anode and cathode respectively. A similar phenomenon can also occur inside a resistor.
If a resistor is used over time with damp air or moisture penetrating inside its protective film, the resistive element will dissolve into ions instead of producing oxygen. The resistive element will eventually disappear, resulting in an open circuit. This phenomenon is called electrolytic corrosion.
Figure 1 shows an example of a normal resistive element versus one that disappears and causes an open circuit due to electrolytic corrosion.

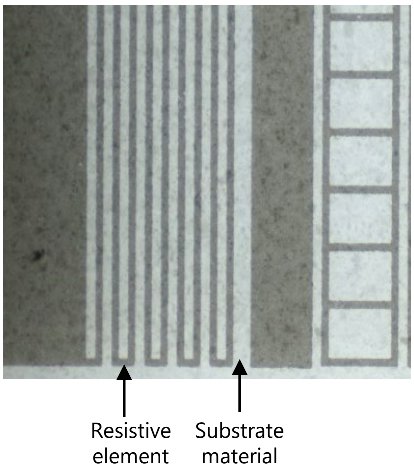
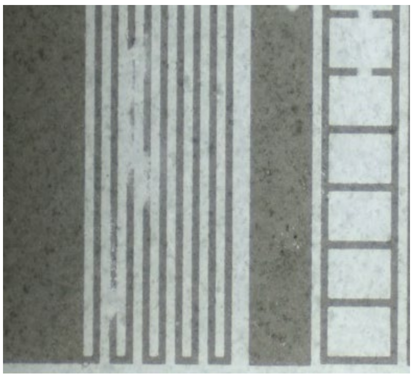
Normal state of resistive element	State in which resistive element disappeared
	

Figure 1 Example of resistive element disappearing due to electrolytic corrosion

§2 Mechanism of electrolytic corrosion

Electrolytic corrosion mainly occurs in carbon film resistors and metal film resistors. The mechanism of electrolytic corrosion is described below, using these resistors as examples.

2.1 Electrolytic corrosion of carbon film resistors

Figure 2 shows the structure of a carbon film resistor. In this diagram, the insulation coating on the surface is omitted to make it easier to see the interior.

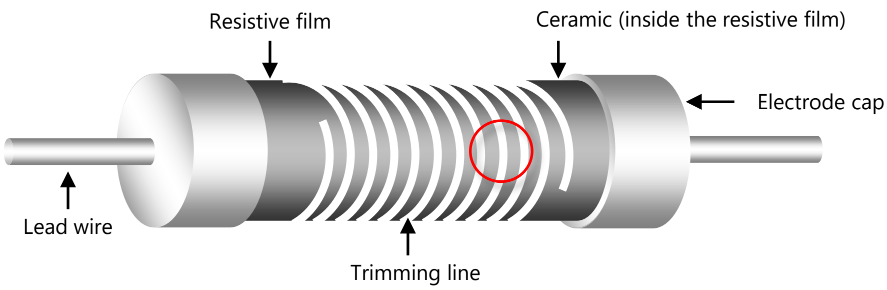


Figure 2 Structure of a carbon film resistor

Electrolytic corrosion occurs in the resistive film within the trimming lines. The process of electrolytic corrosion is described below. In addition, Figure 3 shows the cross section of the red circled area in Figure 2.

1. Due to damage to the insulation coating etc, moisture penetrates into the component and adheres between the resistive film spirals. (Figure 3(a)).
2. When voltage is applied to the resistor in this state, a potential difference is generated between the turns in the resistive film.
3. If voltage is applied continuously, the moisture is electrolyzed into hydrogen ions (H^+) and hydroxide ions (OH^-).
4. Hydrogen (H_2) is produced on the negative side (- side), while carbon dioxide (CO_2) is produced by reaction between carbon (C) in the resistor and oxygen (O) in the hydroxide ions (OH^-) on the positive side (+ side) (Figure 3(b)).
5. As this reaction proceeds, carbon in the resistive element on + side decreases over time, and eventually the resistive element material disappears (Figure 3(c)).

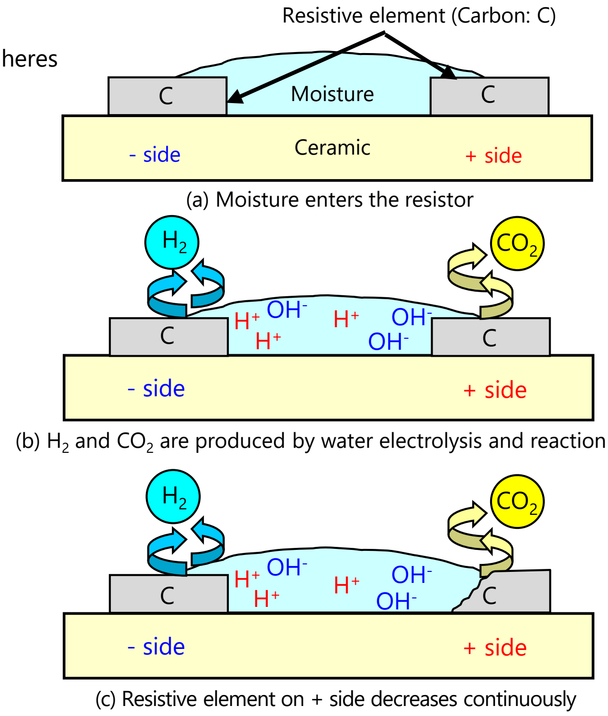


Figure 3 Schematic diagram of electrolytic corrosion in a carbon film resistors

2.2 Electrolytic corrosion of metal film resistors

Figure 4 shows the structure of a metal film resistor. In this diagram, the protective surface coating is omitted to make it easier to see the interior.

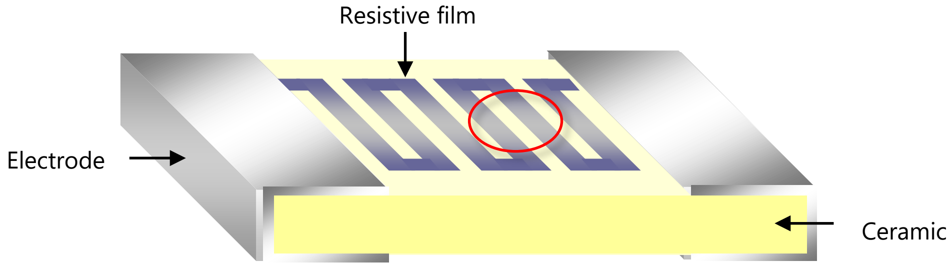


Figure 4 Structure of a metal film resistor

Electrolytic corrosion occurs between the turns in the resistive film. The process of electrolytic corrosion in resistors using a nickel-chromium alloy (NiCr) as resistive film is described below. In addition, Figure 5 shows the cross section of the red circled area in Figure 4.

1. Due to deterioration of protective coating etc, moisture penetrates into the component and adheres between the turns in the resistive film (Figure 5(a)).

2. When voltage is applied to the resistor in this state, a potential difference is generated between the turns in the resistive film.

3. If voltage is applied continuously, moisture is electrolyzed into hydrogen ions (H^+) and hydroxide ions (OH^-), generating hydrogen (H_2) on the negative side (- side).

4. On the positive side (+ side), nickel-chromium alloy (NiCr) in the resistive element reacts with hydroxide ions (OH^-), leading to the oxidization of nickel and chromium (Figure 5(b)).

   $NiCr + (OH^-)_5 \rightarrow Ni(OH)_2 + Cr(OH)_3$

   $\cdot\ Ni(OH)_2 \rightarrow NiO + H_2O$

   $\cdot\ 2Cr(OH)_3 \rightarrow Cr_2O_3 + 3H_2O$

5. As this reaction proceeds, the resistive element on the + side is oxidized and disappears, eventually leading to an open circuit (Figure 5(c)).

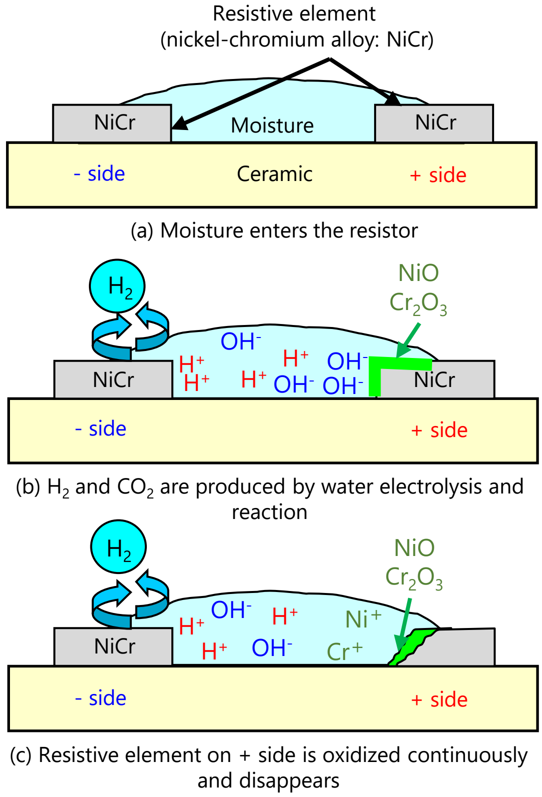


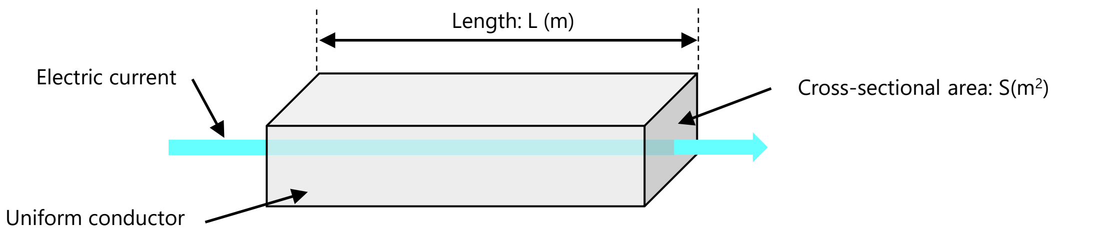
Figure 5 Schematic diagram of electrolytic corrosion in metal film resistors

2.3 Causes of electrolytic corrosion

Electrolytic corrosion is caused by moisture that has infiltrated into the resistor. When there are also ionic substances (sodium, chlorine, etc.), the moisture may induce electrolytic corrosion. Specific examples of ionic substances include flux, salt and sweat. Even the slightest amount of residue of water-soluble flux is very likely to cause electrolytic corrosion after in conjunction with moisture. In addition, salt will dissolve in moisture and induce electrolytic corrosion.

2.4 Conditions likely to cause electrolytic corrosion

As explained above, electrolytic corrosion occurs due to the penetration of moisture into the resistor. There are four conditions likely to cause open circuits due to electrolytic corrosion, which are described below:
The first condition is use in high-humidity environments. The reaction occurs easily as more moisture infiltrates into the resistor.
The second condition is the presence of ionic substances. If the moisture contains ionic substances (sodium, chlorine, etc.), they will ionize and increase the electrical conductivity in the moisture, thus accelerating the reaction of electrolytic corrosion.
The third condition is the application of high voltage. The higher the applied voltage, the faster the reaction.
The fourth condition is when the resistor has a high resistance value. Any conductor made of uniform material has a proportional constant ρ (Ω·m) called resistivity or specific resistance, which depends on the material and temperature of the conductor. The resistance value R (Ω) of an element made of this uniform material is proportional to its length L (m) and inversely proportional to its cross-sectional area S (m^2). Figure 6 shows the schematic diagram.



Formula for resistance value $R\,(\Omega) = \rho\,\frac{L}{S}$

Figure 6 Resistance value of a uniform conductor

The formula shows that a higher resistance value can be obtained by increasing the length of the conductor or by decreasing its cross-sectional area. Figure 7 shows the difference in resistive element cross section depending on resistance value in case of carbon film resistors.

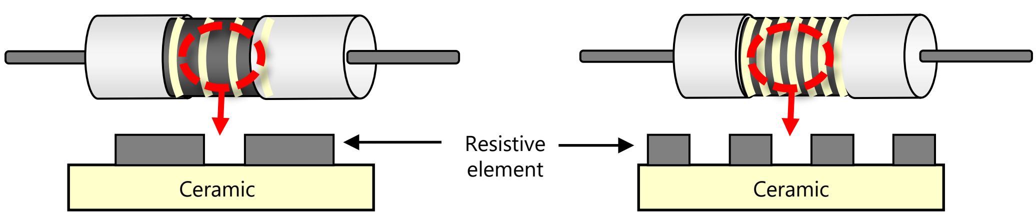


Figure 7 Schematic diagram of resistive element cross section for carbon film resistors

As carbon film resistors have a very thin resistive element, the element must be made narrow and long, as shown on the right in Figure 7, to obtain a high resistance value. The thin resistive element is more prone to an open circuit due to electrolytic corrosion.

§3 Countermeasures against electrolytic corrosion

This section describes the countermeasures that can be taken against electrolytic corrosion, which are divided into countermeasures taken by the manufacturer and countermeasures taken by the user.

3.1 Countermeasures taken by the manufacturer

Electrolytic corrosion is caused by ionic substances-containing moisture penetrating inside the resistor, so it is necessary to adopt countermeasures to prevent the infiltration of moisture. KOA's RN73H line of metal film flat chip resistors has an inner protective coat over the element and an extra protective coating on top. By increasing the adhesion between the inner protective coat and protective coating, and the inner protective coat and the ceramic substrate, moisture resistance is improved, thus inhibiting the occurrence of electrolytic corrosion. Figure 8 shows the structure.

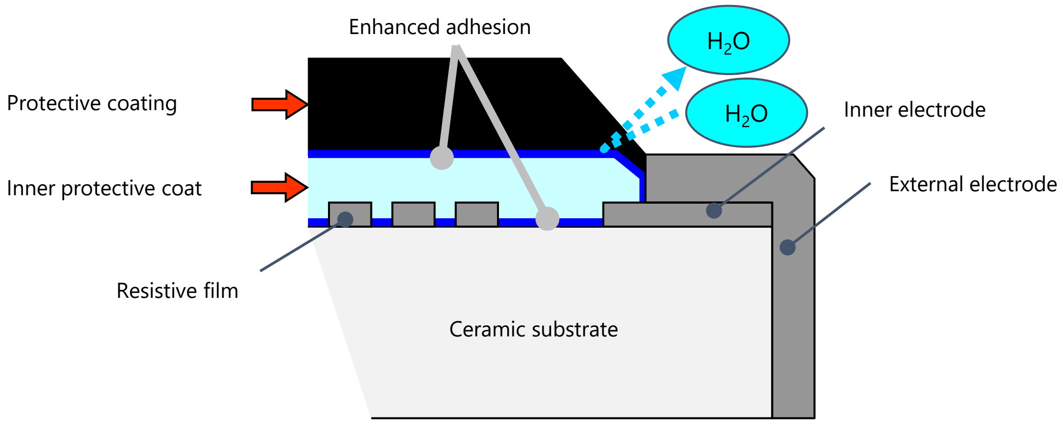


Figure 8 Countermeasures using RN73H line of resistors

Another measure that can be taken by the manufacturer is to replace the element with one that does not ionize easily, such as a metal glaze film, provided that the resistor characteristics match the application. If high precision is required, KOA's RS73 line of thick film chip resistors is a good choice.

3.2 Countermeasures taken by the user

Residual flux after mounting is an ionic substance and one cause of electrolytic corrosion, so an effective countermeasure is to use no-clean flux or to clean the flux. Another countermeasure is to avoid use in environments contaminated by ionic substances or in high humidity or condensation conditions. Circuit board coating is also effective, but care must be taken if a conformal coating is applied after the component or the circuit board has absorbed moisture, because the moisture remaining inside may induce electrolytic corrosion.

§4 Summary

Care must be taken when using resistors with a thin carbon or metal film element, because if moisture penetrates the inside of the resistor, voltage is applied, and a potential difference occurs in the resistive element, the phenomenon of electrolytic corrosion, in which the resistive element disappears or deteriorates, will occur, resulting in a malfunction such as an open circuit. Conditions likely to cause electrolytic corrosion are high humidity environments, the presence of ionic substances, the application of high voltages, and high resistance values. Countermeasures against electrolytic corrosion can be taken both the manufacturer and the user. Countermeasures taken by the manufacturer include using resistors that have improved humidity resistance (such as those with an internal protective film, etc.) or using metal glaze film resistors that do not induce electrolytic corrosion. Countermeasures taken by the user include selecting a no-clean flux type or cleaning the flux, selecting components suitable for the operating environment, and applying a conformal coating. KOA offers a variety of support services, including product test data. Please contact us at any time.