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Review

Research Progress in Corrosion Protection Technology for Electronic Components

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Abstract: As a necessary part of all electronic devices, equipment and systems, electronic components play a vital role in the global economy. Since the corrosion of a single electronic component may directly affect the normal operation of the entire electronic system, the failure of electronic components has now become the most important cause of electrical system failure and has become a major obstacle to China's transformation into a scientific and technological power. Therefore, it is urgent to study the corrosion failure process of electronic components and the means of effective protection. In this paper, starting from the corrosion types and influencing factors of electronic components, especially chips, we introduce the influence of humidity, temperature, salt spray, and environmental particles, as well as the device's own surface roughness, material adhesion, semiconductor materials, metal coupling system, and lead-free solder system on corrosion performance in the environment. Subsequently, this paper summarizes how to protect electronic components during processing, and sums up the types of electronic component protections, and the specific corrosion protection process for the three commonly used types of chips, namely, the indium antimonide InSb chip, the IC chip, and the Sn–Zn solder chip, for reference. Finally, future development trends in the corrosion protection of electronic components are anticipated and summarized.

Keywords: electronic components; chip; corrosion; protection

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1. Introduction

"The 14th Five-Year Plan" emphasizes the need to "accelerate digital development and build a digital China" [1]. In the process of transformation and upgrading of the global manufacturing industry towards intelligence, the basic equipment control system, especially the electronic components, bears an unshirkable responsibility, and has become the key to structuring the digital economy. Electronic components include common electromechanical components, semiconductor discrete devices, optoelectronic devices, electric vacuum devices, microwave devices and components, and integrated circuits. Among them, the chip is the basic carrier of the integrated circuit and is also the collective name for semiconductor electronic components.

The ongoing development of electronic components towards miniaturization and a high degree of integration is now placing higher demands on the reliability of single components. The degree of corrosion of electronic components determines their electrical functional characteristics, including the safety as well as the reliability of the system. Currently, the failure of electronic components accounts for 70% of the causes of failure in electrical systems [2]. The corrosion of electronic components is mainly due to atmospheric corrosion; the corrosion types include uniform corrosion, pitting corrosion, galvanic coupling corrosion, intergranular corrosion, corrosion under stress, crevice corrosion and microbial corrosion. In hot and humid climates, such as the South China Sea islands and other special environments, high temperature, high humidity, and high salt spray together constitute harsh conditions that can cause serious corrosion effects on electronic components. The same batch of navigational equipment operating in the islands and reefs of the Cangzhou environment showed three times greater levels of corrosion than when used in less harsh environments [3]. The intensification of corrosion means that the probability of failure of electronic components increases. Zhang et al. [4] found after three years of field research that the failure rate of electronic equipment in aircraft serving in coastal airport environments was two to three times that of aircraft serving inland. As a key component of electronic components, chips play an important role in the national economy and play an important role in the country's economic development. So, in order to improve chip life and reduce product costs, chip corrosion protection technology is in urgent need of development. In view of this, the study of the mechanisms of corrosion damage of electronic components, and the taking of protective measures to improve the service life of electronic components for the development of the electronic components industry has important economic as well as social benefits.

However, at this stage, the corrosion failure and protection technology of electronic component materials has not received much research progress. In view of this, this paper summarises the existing research results in electronic component corrosion and protection, integrated circuit corrosion and other related fields [5,6]. This paper summarises the impact of different environmental factors on the corrosion of electronic components, focusing on an overview of the manufacturing process of electronic component processing and protection technology, as well as corrosion protection methods for several common chip types. This paper analyses the material properties, which provide a reference for chip corrosion protection. Finally, it looks forward to the future development trend of corrosion protection of electronic components.

2. Analysis of the Causes of Corrosion

The diversity of materials used in electronic components and the complexity of the application environment make the types of corrosion of electronic components diverse. The main type of corrosion that leads to the failure of electronic components is atmospheric corrosion. Atmospheric humidity, temperature, salt spray, environmental particles, and the surface roughness, adhesion, and welding materials of the material system of the electronic components are the main factors influencing their corrosion.

2.1. Types of Electronic Component Corrosion

The main type of corrosion leading to the failure of electronic components is atmospheric corrosion. Depending on the environmental humidity and liquid film thickness, atmospheric corrosion can be divided into dry corrosion, moisture corrosion, and wet corrosion. The relative humidity (RH) is an important factor affecting the rate of atmospheric corrosion, representing the water vapor pressure in the air and the percentage of saturated water vapor pressure under the same temperature conditions. When the humidity increases to a certain value, the amount of moisture absorption increases sharply; this certain value is called the critical relative humidity (CRH) [7].

Figure 1 in the I area image shows that, at this time, the surface thickness is δ = 10~100 Å. Because the relative humidity is very low, the material surface cannot easily form a liquid film. Many metal surfaces will form an oxide film, the corrosion rate is extremely low, and a dry corrosion process occurs. In the presence of trace gaseous pollutants, copper, silver, and other non-ferrous metals, form thin films, which are known as loss of color. Silver, for example, loses its luster in air. When the relative humidity is greater than the critical relative humidity, the metal surface liquid film thickness to meet the δ = 100 Å~1 µm; that is, in Figure 1 in the II zone location, the material is in the tide corrosion state. Aqueous films containing gases such as CO_2, H_2S and SO_2 cause severe corrosion of non-metallic materials and alloys such as steel, copper, nickel and silver. For example, silver loses its lustre on contact with hydrogen sulphide, forming a film that loses its lustre with sulphide, while copper stains and turns black. When humidity reaches 100%, a wet corrosion phenomenon is obvious; the surface liquid film thickness can be clearly observed by the naked eye, as shown in Figure 1 in the III area [7]. Under alternating wet and dry conditions, the dry corrosion product film may absorb moisture from the air and bring moisture into contact with the metal surface, thereby increasing the rate of corrosion of the metal. Green skin formation on copper, such as caliche, and structural steel corrosion, are common examples of corrosion caused by humid atmospheres.

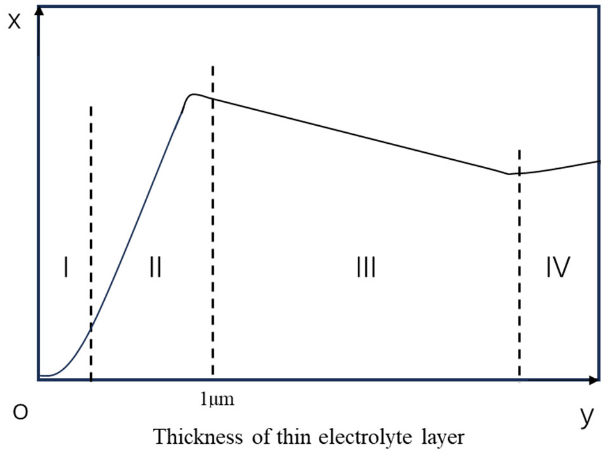


Figure 1. Corrosion rate at different liquid film thicknesses (The liquid film on the surface is divided into regions I–IV depending on the thickness of the liquid film) [7].

2.2. Study of the Influence of Environmental Factors on the Corrosion of Electronic Components

Due to the long-term exposure of electronic components to the environment, temperature, humidity, salt spray, and environmental particles influence the corrosion performance of their surfaces. Wang [8], in considering the environmental factors of chip corrosion failure, states that the corrosion mechanism is mainly affected by high humidity environment and high temperature gas environment. Related research points out that the protection of chips should start from the perspective of the degree of air contact, the ambient temperature, and the humidity in order to take relevant steps [9]. It can be seen that the impact of environmental factors on the corrosion of electronic components cannot be ignored.

2.2.1. Humidity

Environmental humidity is the basis for the classification of electronic component atmospheric corrosion. When the relative humidity of the atmosphere is greater than the critical relative humidity, water vapor from the air condenses and precipitates to form “dew droplets”, a condensation phenomenon, resulting in the formation of a liquid film on the metal surface [10].

Once the ambient humidity exceeds the critical relative humidity, the electronic components’ surface liquid film, atmospheric O_2, and other corrosion media will dissolve into the surface liquid film to form an electrolyte film. Then an oxygen concentration cell is formed and electrochemical corrosion occurs [11]. Since the atmospheric corrosion rate mainly depends on the electrochemical reaction in the electrolyte film on the metal surface, the higher the relative humidity and the higher the thickness of the surface liquid film, the easier it is for condensation to occur on its surface with increased risk of corrosion. Electronic components absorb and release moisture from the atmosphere as the local relative humidity rises and falls. Problems caused by moisture absorption include delamination and pockmarking of circuit boards, as well as blowholes, solder blowholes, and solder blowout in plated-through rectifiers. Ren et al [12] stated that when the water film forms a metal corrosion cell with separated cathode and anode, the metal on the chip surface loses electrons through oxidation, while the water film ions undergo electronic reduction and the post-corrosion polarisation slows down. Fu et al. [13], in a related chip corrosion study, also confirmed that the action of water vapor on the metal produced the phenomenon of electrochemical corrosion diffusion, which can be explained by the above corrosion mechanism. This suggests a way of preventing corrosion caused by environmental humidity, i.e., blocking electrochemical corrosion by preventing the formation of water films on the surface of electronic components.

2.2.2. Temperature

Electronic components can be classified as commercial grade (0 °C to 70 °C), industrial grade (−40 °C to 85 °C), or automotive grade (−40 °C to 125 °C) depending on their operating temperature [14]. When the humidity in the environment where the electronic components are located does not reach the critical relative humidity, wet corrosion does not occur; however, at this time, the electronic components also have the problem of dry corrosion. Li [15], in an IC plastic sealing study, proposed that dry corrosion is mainly a high-temperature oxidation phenomenon. When a metal part in a chip generates an oxide film under the action of high-temperature gases, the corrosion resistance of the metal is closely related to the characteristics of the oxide film, including the coverage and thickness of the oxide film, as well as the forming speed and morphology. In addition, temperature stresses due to temperature changes can also have an impact on the spread of corrosion defects. With regard to temperature failure, Lu et al [16] pointed out that defects diffuse to varying degrees under the effect of stresses generated by temperature changes. The parameters of the components change up and down at high or low temperatures, and return to normal only at room temperature and in the open-circuit state. The influence of temperature on the corrosion of electronic components is, on the one hand, closely related to the condition of the ambient humidity, and, on the other hand, the loss of electronic components is mainly dominated by stress corrosion.

2.2.3. Salt Spray

Salt spray environments including salt, chloride, nitrate, phosphate, and other particles, will cause electrochemical corrosion of metal leads and solder in the device, thus causing the failure of electronic components. As salt spray particles are mostly about 5 μm in diameter, the small particle size results in high permeability, so its corrosion of electronic components is obvious. Salt spray has the following effects:

(1) Chloride attached to the surface of electronic components can easily absorb water, promoting the formation of surface liquid film, further accelerating the occurrence of wet corrosion and tide corrosion, and ultimately leading to the failure of electronic components;
(2) Chloride ions in a salt spray can penetrate and destroy the surface coating of electronic components and passivation film, and form soluble compounds, eventually inducing hole corrosion;
(3) Salt spray particles accompany the atmospheric flow and settle on the surface of electronic components, which can cause blockage or jamming of electronic components' movable devices, leading to equipment failure.

2.2.4. Environmental Particles

Air contains SO_2, O_2, and H_2, which, in contact with electronic component leads, results in certain corrosion phenomenon. Al wire used for chip connection is more active and contact with air produces a corrosion-resistant oxide film, which can slow down the electrochemical corrosion effect while oxidizing the corrosion [17]. In a study on the corrosion of Al and SO_2, Han et al. [18] pointed out that the corrosion efficiency of Al increases with time, whether in dry or wet conditions. In the production of plastic sealing process of electronic components exposed to Cl- ionomer impurities will be with the continuous extension of the exposure time, so that the surface of the electronic components of the alumina film in the corrosion products gradually transformed into aluminium chloride, from chemical corrosion to electrochemical corrosion, increasing corrosion hazards [17,19].

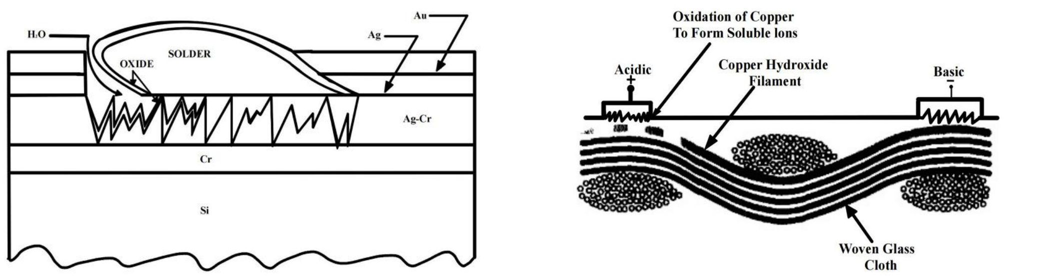
In addition, residual hydrogen atoms also have a negative impact on the performance of electronic components. As the temperature rises during the heating process of the soldering process, the hydrogen present in the air and the hydrogen carried by the chip material itself continuously penetrate into the chip semiconductor material under the influence of molecular thermal motion and enhance the dislocation movement in the semiconductor crystal structure. The lattice distortion caused by dislocations can severely scatter carriers and affect mobility, which, in turn, leads to degradation of the semiconductor properties [20,21].

2.3. Study of the Influence of Electronic Components' Own Factors on Corrosion

In addition to the environmental factors that lead to the corrosion of electronic components, the structure of the device itself and the choice of materials will have a certain impact on the corrosion effects. The structure of the electronic component itself is mainly affected by the flatness of the surface, scratches, roughness, surface welding gaps, etc.; material influences mainly include material adhesion, barrier and semiconductor materials, and metal coupling corrosion, etc.

2.3.1. Surface Roughness

The influence of surface roughness on the corrosion of electronic components is particularly prominent in chip types. Liu et al. [22] pointed out in a chip surface roughness study that, when the chip surface roughness does not meet ideal conditions when the adsorption force is enhanced, the phenomenon of adsorption of metal ions is prone to occur, resulting in increased leakage current and performance degradation. Moreover, in the chip manufacturing process, different welding methods will make the chip surface weld, resulting in increase in roughness increases, increasing the corrosion rate. Robert [23] carried out electronic materials and devices corrosion research, highlighting the chip chromium/solder interface failure process, as shown in Figure 2a. The results obtained showed that, in the porous chromium layer, after welding, surface roughness increased. In the chromium/solder interface, defects allowed water in, resulting in oxide growth, and corrosion was accelerated. Figure 2b shows a cross-sectional schematic of a printed chip circuit board, showing copper hydroxide filaments growing along the interface between resin and glass fiber, with crevice corrosion. This argues that the solder gap increases the surface roughness of the chip and has an indirect effect on chip corrosion.



(**a**) (**b**)

Figure 2. (**a**) Schematic diagram of the failure process at the chip chromium/solder interface [23]. (**b**) Schematic diagram of the cross-section of the printed chip circuit board [23].

Guo et al [24] carried out an experimental analysis on the basis of this for the problems of rough surfaces after corrosion, corrosion pits, and "bright spots" after fine polishing, and obtained that the grinding and polishing process can reduce the surface roughness of the chip, but it is easy to form irregular defects and dark damage, these conditions will accelerate the chip corrosion, so it is necessary to determine through experimental methods what speed and pressure For the surface conditions that cannot be improved by grinding and polishing, it is necessary to eliminate the dark damage that occurs on the metal surface during the grinding and polishing process by means of a corrosive solution.

The results of the study show that as the speed of grinding and polishing increases, the irregular defects and dark damage on the metal surface increase, and the speed is too fast to make the material and the polishing solution work unevenly and produce more defects. Similarly, The results of the study show that as the grinding and polishing pressure increases, the force between the material and the workpiece increases, and the surface force is not uniform, which speeds up the fine grinding rate and increases the material damage, so the pressure should be reduced.

2.3.2. Material Adhesion

Anderson et al. [25] evaluated and optimized the effect of various adhesion treatments by conducting adhesion tests on different substrates, especially poorly adhered substrates, and concluded that poly(parylene) as a coating material showed strong adhesion during chip encapsulation and a stable process during corrosion protection. In corrosion tests on material coatings, it was also concluded that poly(parylene) coatings play a crucial role in protecting copper wires from corrosion. The role of material adhesion in chip corrosion was also confirmed by Kotzar et al. [26] in their tests on material adhesion.

2.3.3. Coupled Systems of Semiconductor Materials and Metals

Semiconductor materials, as core materials for the manufacture of electronic components, play an important role in the design, manufacture, and packaging of electronic components [27,28]. Metals and their alloy materials, as the main materials used to make the internal fittings of electronic components, assume a key role in the miniaturization of chips through the continuous implementation of technologies such as small capacitance and high adhesion. However, when a semiconductor and a metal come into contact, an interface with discontinuous energy levels is formed, leading to a change in the electron energy distribution, which, in turn, causes a change in the electronic structure, with electronic structure adjustment and charge redistribution phenomena occurring and a semiconductor–metal interface effect [29,30]. This change in electronic structure affects the charge density and electric field distribution at the semiconductor–metal interface, which in turn affects the performance of the device.

In a coupled system of semiconductor materials and metals in chips, Li et al. [31] confirmed that semiconductor materials can influence or change the direction of electron transfer between the metal and the semiconductor surface, thus making the metal material easy to be corroded or slowing down the corrosion rate. This provides an idea and research basis for the study of corrosion in complex systems and environments by promoting the mechanism of corrosion in coupled systems of semiconductor materials and metal materials in chips. For systems that are not easy to passivate, Zhang [32] pointed out that the work function of N-type semiconductor materials should be lower than that of metals, and should have lower conductivity and cathodic reaction catalytic activity; for systems that are easy to passivate, the "corrosion-promoting activity" of semiconductor materials can be used to strengthen the self-healing of passivation films and achieve high efficiency of the metal The "corrosion-promoting activity" of semiconductor materials can be used to enhance the self-healing of the passivation film and to achieve high corrosion resistance. The study of "corrosion promoting activity" confirms the effect of the direction of electron transfer between the metal and semiconductor surfaces on the rate of corrosion of metals.

2.3.4. Lead-Free Solder Systems

Lead-free solder systems mainly consist of metal powders, a small amount of flux, and trace additives [33]. Considering the actual application scenario of electronic components, the lead-free solder used needs to have good electrical and thermal conductivity and should also have an ideal melting point [34], so the metal solder powder is mostly composed of a variety of metal elements [35]. As Sn melts at around 232 °C and has good wetting properties, the tin ratio in the general composition of lead-free solder is often higher than

90% [14]. Compared to the traditional lead-containing solder used, which releases toxic metal lead and may endanger human health and the environment, the lead-free solder system is more environmentally friendly and more in line with health requirements; lead-free solder is now widely used in chip packaging in the electronics industry [36]. Common types of lead-free solder include Sn–Ag–Cu, Sn–Ag, Sn–Cu, and so on [37,38]. It is worth noting that, as most of the lead-free solders used at this stage contain elements such as boron, silver, and copper, most lead-free solders have performance deficiencies compared to lead-containing solders, such as insufficient oxidation resistance [39], which makes chips encapsulated with lead-free solder systems more prone to corrosion and, thus, affects chip life.

Jaffery [39] et al. investigated the corrosion resistance of lead-free solders in different corrosive media and found that the ratio of Cu and Ag in the solder played a significant role in the corrosion behavior of Sn–Ag–Cu solders as well as Sn–Cu solders. Using FESEM photographs (shown in Figure 3) [40], the results showed that the addition of Fe and Bi exacerbated the lamellarisation of the material surface, increasing the surface area of the material and, thus, the solder corrosion. From Figure 4a [41], it can be seen that the addition of 0.05% Ti significantly increased the arc resistance of the solder, and, from Figure 4b [41], it can be seen that the impedance modulus value also increased significantly, which indicates that the corrosion resistance of the solder was significantly enhanced after the modification by Ti. The addition of 0.05% Ti to Sn–9Zn solder can form a more uniform and fine eutectic structure, reduce the number of Zn-rich phases, and, thus, improve the corrosion resistance of the solder. It has been shown that, at all temperatures, the corrosion rate of Sn is always the highest, the corrosion rate of Sn–3.7Ag is always the lowest, and the corrosion rates of Sn–3.7Ag–0.7Cu and Sn–0.7Cu are in the middle of the range (as shown in Table 1) [42]. Jaffery et al. showed that the types and proportions of elements added to different types of lead-free solders have a great influence on the corrosion resistance of the solder, which also provides a new research method for the future development of lead-free solders with high corrosion resistance.

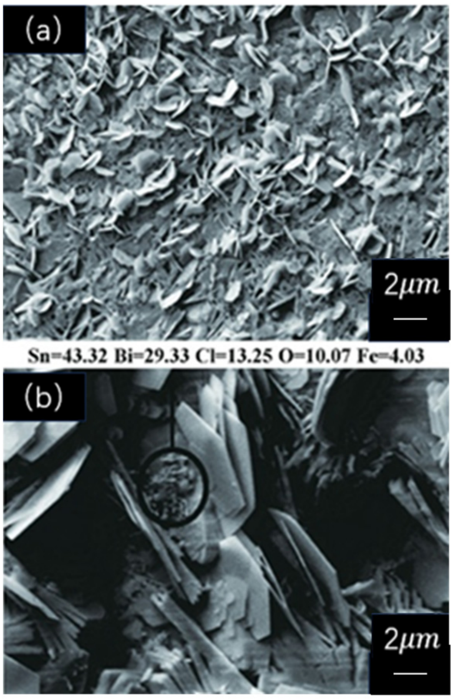


Figure 3. FESEM micrographs of solder alloys after complete polarization. (**a**) Sn–Cu; (**b**) Sn–Cu–Fe–1Bi [40].

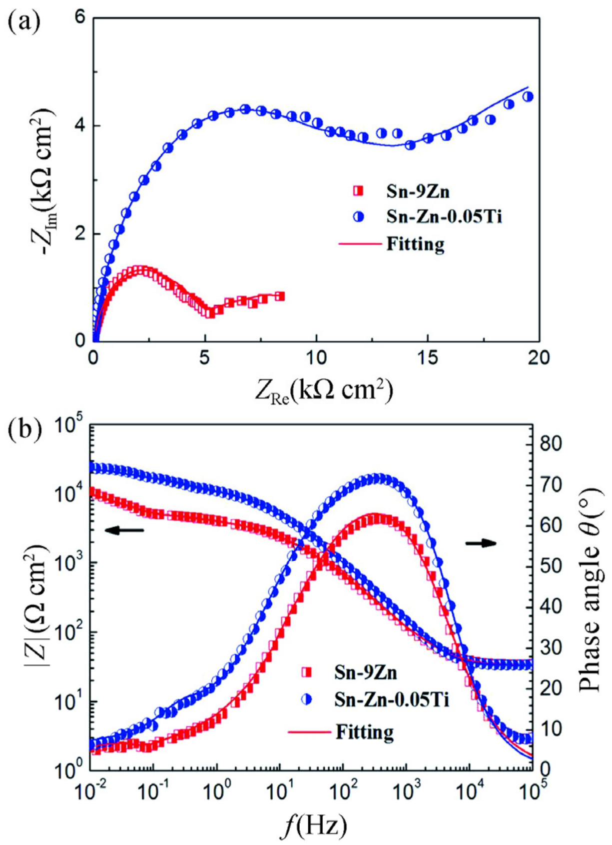


Figure 4. Spectra of Sn-9Zn and Sn-9Zn-0.05Ti solders. (**a**) Nyquist plots; (**b**) Nyquist plots [41].

Table 1. Corrosion rate obtained from 3.5% NaCl solution for Sn–3.7Ag–0.7Cu, Sn–0.7Cu, Sn–3.7Ag, Sn at different temperatures [42].

Type of Solder	Temperature (°C)	Corrosion Rate (mm/a)
Sn	25	0.0031425
	40	0.00661318
	50	0.019478
	60	0.57433
Sn–3.7Ag	25	0.000786
	40	0.00189
	50	0.002486
	60	0.006135
Sn–0.7Cu	25	0.0010375
	40	0.0032666
	50	0.0080401
	60	0.010295
Sn–3.7Ag–0.7Cu	25	0.0011062
	40	0.0023203
	50	0.0093622
	60	0.010695

3. Protection Processes

3.1. Protection Processes for Manufacturing and Packaging Processes

The protection process used in the manufacturing and packaging of electronic components determines the final corrosion resistance of the overall device. Considering the chip manufacturing process as an example, chip manufacturing is mainly divided into chip design, wafer production, packaging production, cost testing, and other major links, while crystal manufacturing and packaging manufacturing is the key to the final performance of the chip. In the manufacturing and packaging process whether the process performance is good or bad will ultimately lead to the chip corrosion effect of fast or slow; the above two processes impose certain anti-corrosion measures, which can effectively slow down the degree of chip corrosion later.

3.1.1. Manufacturing Protection

The processes of chip manufacturing are exposed to the environment, and pollutant particles in the environment can adhere to the chip surface and cause chip corrosion at a later stage, so environmental pollution control techniques need to be strictly enforced. The control technology includes indoor and outdoor air pollution control technology, pollution control technology, etc. Meanwhile, with the continuous rapid development of ultra-large-scale integrated circuit production technology, the scientific and technological community has imposed more stringent requirements for the production environment chemical pollution control index. Therefore, the following measures are focused on protection in the chip manufacturing process:

(1) When designing the passivation layer for the bonding of the chip to the packaging material, attention should be paid to improving the resistance to water vapor corrosion in the pressure zone of the IC while not affecting the bonding quality.
(2) Controlling the etching process of the aluminum layer in the bonding area, extending the chemical cleaning time after etching, and reducing the residue of fluorinated compounds on the surface of the aluminum layer [43].
(3) The storage and transportation environment of the chips in the post-etching period must not be too humid, and packaging materials must not use materials containing fluorine and halogen elements.

In industrial practice, the chip manufacturing protection process for the final corrosion resistance of the finished product plays a crucial role; however, current actual production and manufacturing factory corrosion awareness is not strong—the protection process needs to be upgraded.

3.1.2. Encapsulation Protection

As a common integrated chip protection technology, plastic-sealed chips have contributed to the size, lifetime, and functionality of chips. In a study by Zhou et al. [44] on plastic-sealed integrated circuits, it was pointed out that the non-enclosed nature of the plastic seal makes the chip subject to water vapor intrusion corrosion as well as airborne contaminant corrosion. Hermetic packages rely on a solid enclosure made of impermeable material, and are sealed to protect electronic components by keeping them in an environment with low relative humidity. Internal water content can come from stagnant water within the package before and during sealing, as well as from outgassing of adsorbed molecules. Therefore, the following controls can be implemented on the chip package:

(1) Choosing a suitable environment for placing the chip after opening the package and controlling the time it is exposed to purified air;
(2) Prevention of delamination and moisture absorption problems in the plastic seal is the key to packaging chips.

Yu et al [45] found that at the same potential, the N_{Dr} value of solder in alkaline solution is lower than that in acidic solution (as shown in Figure 5), which means that the passivation film in alkaline environment has better corrosion resistance. The environmental conditions of chip storage will affect the corrosion resistance of the solder on the chip, which in turn affects the overall performance of the chip.

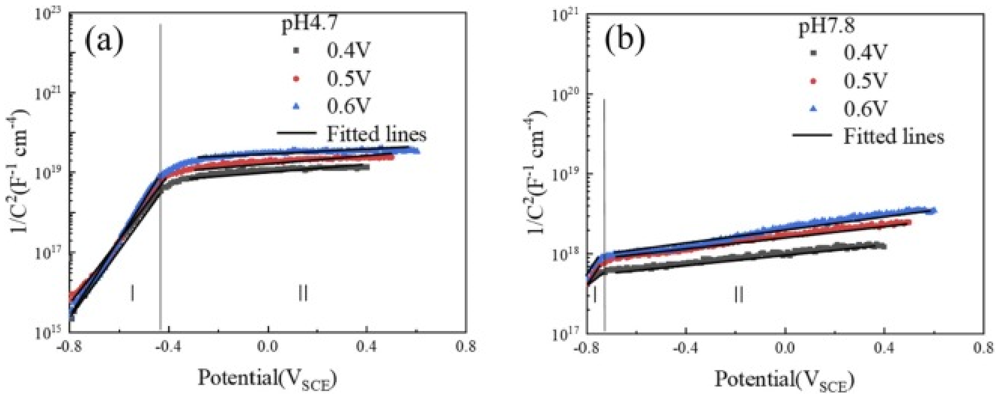


Figure 5. MS curves of solder Sn-0.7Cu in different environments (acidic (**a**) and alkaline (**b**) artificial sweat) [45].

At the same time, the packaging material serves as a barrier to isolate the chip from the surrounding environment. By choosing green, highly adhesive, low-stress, and low-moisture absorption packaging materials, the contact between the chip surface and water, dust, and other substances in the environment, can be effectively reduced, thus reducing the strength of corrosion, and extending the life of the chip [46].

For common sealing materials, the encapsulation material must have high purity to reduce the concentration of Na^+ and Cl^- plasma impurities in the plastic sealing materials to avoid the impurity ions leading to accelerated corrosion; for the filler material, higher adhesion is required to prevent corrosion of the aluminum layer in the molded area due to moisture intrusion [47]. Moreover, the addition of ion trapping agents during the production of plastic sealing materials has the same effect on the control of encapsulation materials [48].

The bio-implantability of new chips has now developed into a research "hotspot" in medicine, electronics, materials, and their interdisciplinary aspects. As implantable chips typically remain in the body for decades, their corrosion resistance needs to be further developed and tested for high-accuracy predictions to mitigate chip corrosion or adverse tissue effects. The key to improving the corrosion resistance of implantable chips is to ensure their implantation integrity (Anne et al. [49]), which must ensure that the chip functions properly for its expected lifetime and does not damage the organism after implantation. Common materials used to encapsulate biomaterials are metals, glass, ceramics, and polymers, with polymeric encapsulants, particularly poly(parylene), often used for their corrosion resistance and stability [50]. However, the containment properties of polymers are limited relative to other plastisol materials [51]. On this basis, Hogg et al. [52] proposed polymer multilayer stacks for implantable chip packaging materials, where the lack of molecular density of the polymer and the low permeability of the SiO_X layer form a stack as a means to achieve the required closure for chip protection. Therefore, for implantable chip packaging materials, the choice of polymer multilayer stacking applications is preferable.

3.2. Types of Protection Processes

Electronic component protection processes can be divided into physical and chemical-electrochemical protection, depending on the principle of protection. Physical protection is achieved by adapting the process to the characteristics of the environment in which it is used, while chemical-electrochemical protection extends the chemical or mechanical properties of the material by applying protective coatings to increase the degree of protection.

3.2.1. Physical Protection

Physical protection mainly considers the environmental effects outside the electronic components and protects them from harmful effects, such as moisture and electromagnetic radiation. In terms of physical protection, the following protective measures can be carried out:

(1) Improve the encapsulation hermeticity: choose high-quality encapsulation substrates, sealants, and filling media as encapsulation materials, and, at the same time, strictly follow the encapsulation process requirements to execute each encapsulation step, such as curing and hot-pressing welding, to ensure the stability and consistency of the process parameters. A strict inspection system should be established during the encapsulation process to screen and deal with possible defects in a timely manner to ensure that each encapsulated part is defect-free and hermetically sealed.
(2) Post-treatment of the welding and assembly process: The post-treatment of the welding and assembly process refers to the relevant treatment carried out at the end of the welding or assembly process. For example, the use of cleaning solutions, ultrasonic cleaners, and other cleaning methods to remove the surface of electronic components, such as oxides, oil, solder slag, and other impurities [53]; the need to encapsulate the components through drying, vacuum drying and other ways to ensure the dryness of their internal features, so as to extend the life of electronic components. The purpose of post-treatment of the soldering and assembly process is to eliminate impurities, such as condensation and chemical substances, that may have a negative impact, thus achieving a protective effect.

3.2.2. Chemical Electrochemical Protection

Chemical electrochemical protection mainly uses the coating of protective coatings to increase the corrosion resistance [31]. Electrochemical corrosion protection is a method of preventing or mitigating metal corrosion by applying measures to metal equipment based on electrochemical principles to make it the cathode in a corrosion cell. In the application of electronic components, chemical electrochemical protection technology needs to take into account the physical and chemical properties of the protective coatings, the device, the environment, and other factors to ensure that the protective effect is reliable. Special attention needs to be paid to the thickness of the protective coating on the surface and consideration should be given to the tolerance fit between the components to prevent the coating from being too thick, leading to component sealing failure and resulting in accelerated corrosion.

In addition, in hot and humid climates, the South China Sea islands and other special environments, taking into account the high temperature, high humidity and high salt spray environmental conditions, condensation evacuation technology, terminal sealing technology, space rust inhibitors, flow sealing technology, etc., can be used to prevent chip surface condensation and, thus, achieve the purpose of protection.

3.3. Protection Processes for Several Common Chip Materials

The corrosion protection process for electronic components needs to be determined with respect to the specific type, material selection, and application scenario of the electronic components. Considering the application range and frequency of various types of electronic components under actual circumstances, the commonly used indium antimonide chips, microelectronic devices (IC chips), and Sn–Zn solder chips are analyzed for the protection process, respectively. Indium antimonide (InSb) chips are widely used in military applications, such as infrared detectors, astronomical observation, and missile positioning, due to their unique physicochemical properties and excellent compatibility, as well as their outstanding performance in infrared detection [54]. IC chips are widely used in everyday home appliances, televisions, computers, stereos, and cameras as a type of chip that integrates a large number of miniature electronic devices in an integrated circuit. In the manufacturing process of semiconductor chips, soldering technology plays a crucial role. Sn–Zn solder is a lead-free solder, which is widely used in the manufacture of Sn–Zn solder chips in electronic products because of its low melting point and good fluidity [37].

3.3.1. InSb Chips

Considering PCB failure analysis techniques, Zhou et al. [55] conducted a study of the surface after corrosion. When a chip undergoes corrosion, its surface becomes uneven. Similarly, when an InSb chip undergoes corrosion, the roughness of its surface makes the current on the chip cause an increase in leakage current and a decrease in chip performance. Using the opposite idea, the surface roughness of the chip can be repaired as a way of implementing a re-healing technique for corroded chips [17]. However, due to the low hardness of the material of this chip, it is not easy to master the strength required when performing polishing [56]. Bouslama et al [57] experimentally verified that the repair of corroded chips can be solved under the following conditions: when the pressure is lower than 4.5 N, the speed is lower than 80 r/min, the feed ratio is 1:1, the drop rate is less than 1 drop/s, or the addition of oxidising agent H_2O_2 repairs the corroded bumps on the InSb chips.

3.3.2. IC Chips

With regard to the corrosion of IC chips, Fu et al. [13] pointed out that it is often related to the ambient humidity and temperature as well as the chlorine and copper plasma in the air. Therefore, the protection of IC chips should start from these points:

(1) Adjusting the reflow soldering oven temperature profile to appropriately increase the initial pre-treatment time and temperature and reduce the amplitude of temperature change on the components;
(2) Strengthening the sealing effect on the chip to prevent electrochemical corrosion of airborne ions with the chip [58].

Although there are differences in the causes of corrosion between InSb chips and IC chips, the reasonableness of the above chip protection techniques can be seen in the protection measures for both.

3.3.3. Sn–Zn Solder Chips

Sn–Zn-based, Pb-free solders have poorer corrosion resistance than other Sn-based, Pb-free solders due to the extremely high chemical activity of Zn in Sn–Zn solders and the susceptibility of Sn–Pb alloys to oxidation and corrosion [37]. For Sn–Zn solders as a class of Pb-free solders, alloying is the most common means of improving the corrosion resistance of Sn–Zn solder chips. The results of Zhao et al. [59] showed that the addition of trace amounts of Ag to Sn–Zn solders can generate Ag–Zn IMC, which inhibits Zn chemical activity and, thus, improves its corrosion resistance. In addition, once corrosion products are generated on the surface of Sn–Zn solder chips, the pores, pits, and cracks on the surface will lead to further contact with the corrosive medium, thus accelerating corrosion. The addition of trace amounts of Ti can slow down electron transfer and stabilize the surface area of the solder by means of a uniform, dense passivation film formed on the surface of the alloy, thereby enhancing its corrosion resistance [41]. It is worth noting that, when too much Ti is added, exceeding 0.1% of the alloy mass fraction in the Sn–Zn solder, the continuous arrangement of corrosion products will be broken due to the generation of Sn3Ti2 and Sn5Ti instead, expanding the contact surface area and leading to accelerated corrosion [60].

4. Future Perspective

With the development of the global semiconductor industry, chip manufacturing technology ushered in a golden period of rapid development, and moved the electronic components industry into a new period. The rapid development of electronic component manufacturing is closely related to the success of high-end and small component manufacturing [61–63]. Based on the market development in recent years, the following development directions for improving the corrosion resistance of electronic components are proposed:

(1) Research into the development of semiconductor packaging materials towards higher adhesion, containment, and corrosion resistance;
(2) In the process of shrinking the size of electronic component manufacturing, key properties, such as low resistance and high adhesion of metals in chips and other critical materials, need to be improved;
(3) Considering the polluting and highly toxic nature of lead, conventional Sn–Pb solders are in urgent need of environmentally friendly lead-free alternatives.
(4) Indoor accelerated simulation tests continue to improve through the simulation of realistic conditions of electronic component application scenarios, such as salt spray tests, to explore the mechanism of different impact factors on the role of electronic components.

The stability and reliability of electronic components not only depend on the choice of key technical materials in the research and development process, but the manufacturing and packaging process is also crucial.

5. Summary

This paper analyses the corrosion process of electronic components from the perspective of environmental factors and their own materials, focuses on an overview of the protection process of electronic component materials, introduces the anti-corrosion process used for several common chip materials, and, finally, looks forward to the future development trends in electronic component corrosion protection.

Electronic components corrosion depends mainly on the roughness of the surface and the occurrence of electrochemical corrosion and other factors, resulting in increased leakage current on the surface of electronic components, reduced performance, and other problems. Electronic components corrosion by environmental factors and due to their own materials both have performance impacts. There are many ways to protect against such corrosion, including by addressing the manufacturing and packaging process, considering packaging material selection and environmental control, and through consideration of other aspects of prevention and control.

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