Research on Failure Mechanism of a Digital to Analog Converter Induced by Electrochemical Decay

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Abstract. This paper focus on mechanism of a digital to analog converter induced by electrochemical decay. The electrical parameters and the I/V characteristics of the digital to analog converter are abnormal, and the 11-pin of the device are open because of the decay. By the scanning electron microscope inspection and the energy spectrum analysis to the decay, the carbon and the oxygen of the decay are relatively high, and there exists decaying elements chlorine. The mechanism of the electrochemical decay is analysed, the reason of the electrochemical decay contains three elements: moisture, decaying elements and electric field. Moreover, the 11-pin has the worst decay resulted from the strongest electric field, inducing the opening of 11-pin and the failure of the digital to analog converter.

1. Introduction

As the connection of the digital circuit and the analog circuit in the system on chip, the digital to analog converter are widely used in many fields such as image processing, wireless communication, measurement, control system, audio, multimedia display and so on [1, 2]. The manufacturing process of the digital to analog converter have been developed from bipolar process to many other process that contains polysilicon gate complementary metal oxide semiconductor(CMOS) process and bipolar-CMOS process. Because of the advantage of high integration, low power consumption, high yield, high reliability, short design cycle and low price [3], the CMOS process is used in not only digital to analog converter but also the other integrated circuits. Currently, more and more digital to analog converter are embedded into the integrated circuits as the components. This trend demonstrates that the need of electronics markets for the digital to analog converter is developing to high integration, in another words, system on chip [4].

This paper focus on mechanism of a digital to analog converter induced by electrochemical decay. Using internal inspection, scanning electron microscope inspection, energy spectrum analysis and electrochemical decay mechanism analysis, the failure reason of the digital to analog converter is confirmed. The failure reason of digital to analog converter is the opening of 11-pin, which is induced by electrochemical decay. For the significance of the failure analysis of the similar integrated circuit, this paper has an important value in engineering.
2. Failure phenomenon
A digital to analog converter is used in an aerospace system, and the port of the device has no output after 40 minutes power-on. The pins definition of the device is shown in figure 1 and 11-pin is power pin of the digital to analog converter ($V_{CC}$).

![Figure 1. Pin layout diagram of the DAC](image)

3. Failure reason
The I/V characteristic is tested between pins of the sample, 11-pin of the failure sample is open and is different from the good sample. By parameters test, the sample has a function failure. There are no abnormal features of the X-ray as is shown in figure 2.

![Figure 2. Image of the X-ray detection](image)

Destroying no internal structure, the internal inspection is performed by the super field microscope. The first bonding region of 11-pin has an obvious decay feature, and the bonding wire of 11-pin are open resulted from decay. Moreover, the second bonding region of 11-pin also has a decay feature, the internal photo of the digital to analog converter is shown in figure 3.

![Figure 3. Inner image (left) and enlarged first bonding region of pin 11 (right) of the DAC](image)
Using confocal microscope, the first bonding region of the other pins except 11-pin has a decay feature, which is better than 11-pin. The chip photo of the digital to analog converter is shown in figure 4.

![Figure 4. Chip of the DAC](image)

By the scanning electron microscope inspection and the energy spectrum analysis to the decay, the carbon and the oxygen of the decay are relatively high, and there exists decaying elements of chlorine. The scanning electron microscope photo of the first bonding region of 11-pin is shown in figure 5, and the energy spectrum analysis of the bonding wire is shown in figure 6.

![Figure 5. Scanning electron microscope of first bonding region of DAC pin 11](image)
4. Failure mechanism analysis

Electrochemical decay means an electrochemical reaction by metal and dielectric. During the reaction, there are charge transfer between anode and cathode. For mental, the anode reaction is shown in formula (1) and the cathode reaction is shown in formula (2).

\[
\begin{align*}
\text{Al} + 3\text{OH}^- & \rightarrow \text{Al(OH)}_3 + 3\text{e}^- & (1) \\
2\text{H}_2\text{O} + 2\text{e}^- & \rightarrow \text{H}_2 + 2\text{OH}^- & (2)
\end{align*}
\]

The reason of the electrochemical decay contains three elements: moisture, decaying elements and electric field. Moisture is the necessary condition of electrochemical decay. At room temperature, the surface of bonding region and bonding wire have the higher moisture content and higher probability to occurring electrochemical decay. The decaying elements of the failure digital to analog converter is chlorine, the chlorine has three functions: destroying oxide film of the surface of the aluminium, stopping passivation procedure of the aluminium, reacting with aluminium to accelerate the dissolution of aluminium. The electric field make the decaying elements concentrates, accelerating the dissolution of the aluminium ions.

Analyzing the failure mechanism of the electrochemical decay, the failure reason of the digital to analog converter is not cleaning the chloride ion before bonding. The electrochemical decay occurs because of the chloride ion, the moisture, and the aluminum. The chloride ion concentrates near the bonding region. As the power pin, 11-pin has the strongest electric field and the worst electrochemical decay, inducing the opening of the bonding wire.

5. Conclusion

This paper focus on mechanism of a digital to analog converter induced by electrochemical decay. The electrical parameters test and the I/V characteristics test demonstrating the digital to analog converter fails. The decay phenomenon is observed by internal inspection, and chloride ion is confirmed by the energy spectrum analysis. Combining the failure feature and the mechanism of electrochemical decay, failure mechanism of the digital to analog is confirmed.

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