A Storage Reliability Evaluation Method of Plastic Package EEPROM Based on ADT And Physical Analysis

Yucui Cao, Cheng Gao, Xiangfen Wang

School of Reliability and Systems Engineering
Beihang University
Beijing, China
caoyc@buaa.edu.cn

***Abstract*—Storage reliability estimation is critical to the electronic product in military field. EEPROM is a type of read-only memory that is widely used in some military device, but its storage failure mechanism is not considered deeply. This paper attempts to demonstrate an efficient method to predict storage reliability of EEPROM. Failure mode and failure mechanism of the plastic package EEPROM with MOS structure is given. Then the Accelerated Degradation Test (ADT) of EEPROM is designed and taken. The electrical performance is monitored over time. The degradation data are collected and modeled, which is used to predict the storage reliability at normal condition. Finally, the method of physical analysis based on non-destructive Scanning Acoustic Microscope (SAM) is employed to analyze the physical-chemical process in the Accelerated Degradation Test.**

Keywords—MOS device; EEPROM; Accelerated Degradation Test; storage life prediction; physical analysis

I. INTRODUCTION

Storage reliability of electronic components has always been a big concern for the consumer. They expect to use products stored for a certain period of time without any problem[1-3]. Much literature described estimation method of storage reliability. The storage failure mode and failure mechanism of plastic package devices are analyzed in depth, and a set of quality control methods are given [4]. Li [5] presents two methods for evaluating storage reliability suitable for sound source signals. However there are few studies on plastic package MOS IC. Zhang [6] has put forward that the gate oxide degradation is closely linked to data loss in MOS EEPROM. Dai [7] has taken the GaAs laser as an example to research the storage reliability estimation method based on pseudo-life and failure distribution through ADT. Due to the huge difference of process materials and circuit principles, this method can't apply to plastic package MOS devices. The most direct test method is long-term storage[8]. However, with the rapid development of science and technology, it becomes increasingly difficult to collect the time-to-failure data.

To solve this problem, this paper attempts to demonstrate a method, which is based on ADT and physical analysis. Without changing the original failure mechanism of the product, degradation data are collected and modeled. The model is utilized to predict the storage reliability at normal condition. At the same time, analyze the samples from a microscopic perspective to verify the value of storage life from other side.

This paper uses a new approach for analyzing devices. It is organized as follows. Section II introduces the theory behind this method in detail. Section III presents the concrete steps of the method. Section IV makes a case study. Section V ends with the conclusion.

II. ANALYSIS OF STORAGE FAILURE MECHANISM OF EEPROM

The plastic package MOS EEPROM consists of the plastic package material, internal lead, chip, substrate, oxide, etc. As shown in Fig.1, the chip, substrate, internal lead, and various coupling material that are wrapped by the packing. The plastic package material is different from the ceramic packaging and metallic packaging. It is a type of hybrid polymer material with the characteristic of moisture absorption. Therefore, during long-term storage, devices would absorb moisture constantly. When the storage environment temperature is elevated, the moisture will accelerate into the device, causing some physical-chemical process inside the device.

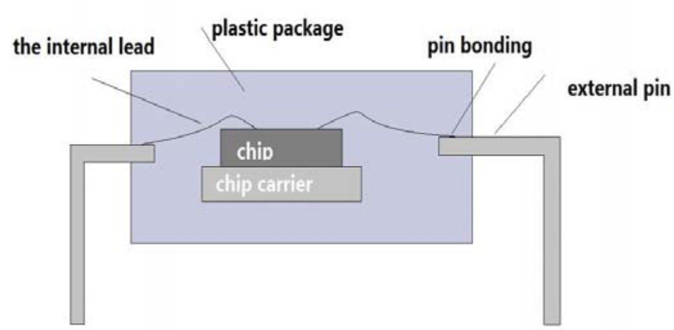


Figure 1 EEPROM with MOS structure

A. Corrosion

Packaging material contains a variety of composite resins, such as catalysts, curing agent, inert filler and so on. When moisture enters the device, it combines with impurities inside the device to form the corrosive compound. External moisture may contain free ions. Ionic impurities could be hydrolyzed and reacted with Al in the Au-Al instrumental, causing corrosion at the device chip or the inner lead. These cause parameters to drift, short circuit or open circuit. Eventually, the circuit would be turned off.

B. Delamination and crack

When temperature changes dramatically, huge thermal stress could be generated on the chip or lead frame because the different thermal expansion coefficients between the packaging material, chip, lead frame, and gold wire. Dramatic changes in temperature which results in delamination and crack. These cracks cause the device open, short-circuit and intermittent, providing access to moisture and impurities inside the device.

As the size of MOS devices gradually shrank, short circuit and open circuit are more likely to occur in the same storage condition. Table I summarized the common failure types of the plastic package MOS gate oxygen structure IC.

TABLE I COMMON FAILURE TYPES OF MOS GATE OXYGEN STRUCTURE INTEGRATED CIRCUIT

Fault Type	Fault Mode	Cause Of Failure
Sudden failure	Gate oxide short circuit	Grid-source short circuit(GSS）
		Grid - leak short (GDS)
		Grid - channel short circuit (GCS)
	Bridging faults	Wire connection
	Logic gates open internally	The network inside the logic gate is disconnected
		The gate connection of the transistor is disconnected
	Open circuit in interconnection	The input of the logic gate is disconnected from the drive wire
Degenerative failure	The parameter drift	Delamination, oxidation or corrosion occurs in the plastic

III. EVALUATION METHOD

The performance and parameters of electronic devices will gradually degenerate in the storage condition. Suppose that n devices are divided into ADT at k stress levels. The full parameters are monitored over time in order to judge the degradation of the devices. Several sensitive parameters are selected as indicators. The devices would be failed once the indicator exceeds the limit D.

From a microscopic point, parameter drift is due to the physical-chemical changes in the device, such as material aging or fatigue. When such changes accumulate to a certain extent, the internal material structure of the device will change greatly. The relevant electrical parameters will change by a considerable amount. Theoretically, the electrical parameters' drift is in line with the material aging, and both degradation rate and limit D exist. Hence, this paper puts forward a powerful analytical approach which is used to estimate the storage reliability through a micro perspective is shown in Fig.2.

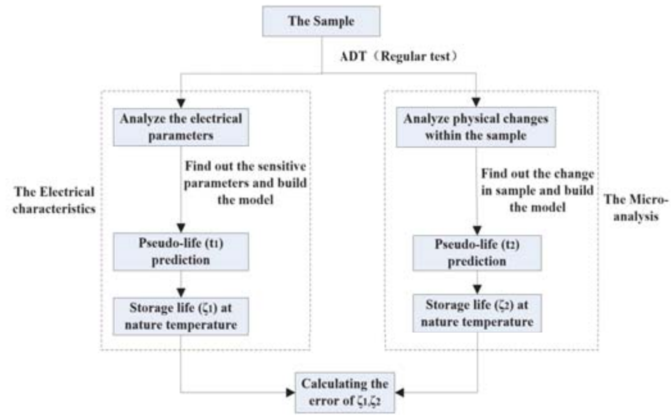


Figure 2 Flow chart of the life prediction method

A Select the sensitive parameters

Parameters with obvious degradation characteristic are usually selected as the indicator to observe the performance. Sensitive parameters' selection should follow two principles:

1)The parameter is defined accurately and can be measured;

2)The performance has an obvious degradation tendency over time.

B Regression curve fitting based on the least square method

The degradation mechanism of the plastic package MOS device is complicated, and the degradation trend is often a nonlinear function. The relationship between variation and time cannot be expressed directly. The least-square method is a mathematical optimization technique, which is a common method for the fitting curve. The principle of curve fitting using the least squares is:

Given a data set $\{(x_i, y_i), I = 1, 2, 3... m,\}$, H (x) is a known function. Find the function Ψ (x) (Ψ∈H (x)), where:

$$\sum_{i=1}^{m} R^2 = \sum_{i=1}^{m}[\Psi(x_i) - y_i]^2 = \min \tag{1}$$

TABLE II OPTIMIZATION METRIC TABLE OF SENSITIVE PARAMETER FITTING FUNCTION

device number	power		exponential		polynomial	
	R²	***SEE***	***R²***	***SEE***	***R²***	***SEE***
1	m_1	n_1	m_2	n_2	m_3	n_3
2	...	...				
...						
n						

For most electronic components with degraded performance, the degenerate trajectory is generally fitted by the model of power, polynomials, and exponential, etc. Two indicators defined by r-square (R^2) and the square of the error (SEE) are used for evaluation. As shown in table II, the regression model is selected as the optimal function model.

C The storage life prediction

Base on the above background, two steps are given below:

1) The pseudo-life prediction at each temperature point

Limit D_f is given, according to the device degradation curve obtained, the pseudo-life T_1, T_2, ..., T_n of each device is extrapolated, and then the average life of each stress level is obtained.

2) The storage life prediction under normal stress

The relationship between temperature and reaction rate can be expressed by the Arrhenius Model:

$$\xi = Ae^{-\frac{Ea}{kT}} \tag{2}$$

where Ea is the activation energy; A is a constant; K is the Boltzmann constant, $k=8.617\times10^{-5}$eV/K; T is Fahrenheit (K).

Then the formula can be transformed:

$$\ln\xi = a + \frac{b}{T} \tag{3}$$

where $a = \ln A$, $b = \frac{Ea}{k}$.

Here a, b are parameters that can be calculated from the relationship between the stress levels and pseudo-lives. Based on this formula the storage life of normal condition can be estimated.

D Physical analysis

Plastic package material would absorb moisture slowly, which may result in device delaminating. Moisture can penetrate either through the polymer or along the interface between the lead and the encapsulation resin. There are four general forms of delamination:

(1) Between the chip and the encapsulation materials;

(2) The bonding area;

(3) Between the chip and the coating;

(4) Between the lead frame and the encapsulation materials.

The physical-chemical changes would occur when the moisture penetrates into the device. Delamination affects the electrical performance of the device, resulting in the parameters drifted. Severe delamination can make the device into lead breakage, bond corrodes, chip or passivation cracking, which shows short circuit, open circuit, or intermittent. Therefore, the delamination area directly affects the electrical characteristics and storage reliability.

Scanning Acoustic Microscope (SAM) technology is a non-destructive testing method of delamination. It utilizes a noninvasive ultrasound technique to determine the integrity of the attachment of dissimilar material interfaces inside plastic encapsulated packages. As shown in Fig.3, with the transmission mode, the transducer placed at the opposite of the specimen is used to send and receive high-frequency ultrasound waves that pass through the entire thickness of the specimen. When ultrasound encounters a defect within the device, a dark shadow appears in the acoustic image.

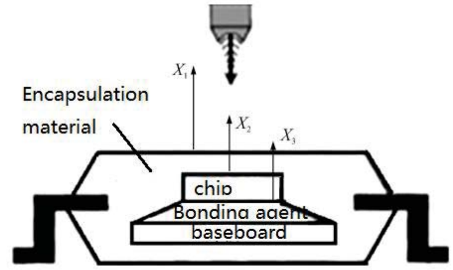


Figure 3 SAM interface reflection schematic

The transducer transmits pulses of acoustic waves through the device. At the interface of different materials inside the specimen, a portion of the pulse is reflected back to the transducer, and the remainder propagates through the interface. The degree of ultrasonic reflection from that interface is governed by the following acoustic impedance formula:

$$R = \frac{(z_2 - z_1)}{(z_2 + z_1)} \tag{4}$$

where R is the amplitude of the reflected pulse, z_1 and z_2 are the acoustic impedances of the two materials.

When a defect such as delamination or voids is encountered at an interface, practically all the pulses are reflected back. The acoustic image produced using this mode of inspection is rendered in the color code which is shown in Fig.4. The acoustic image provides information with amplitude and phase (polarity) of the gated echoes.

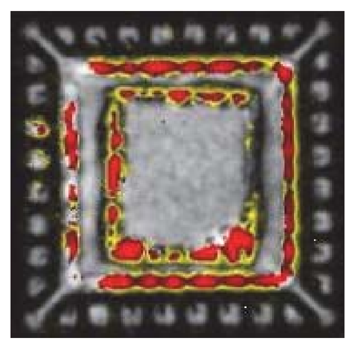


Figure 4 C-Scan Image

The relationship between the delamination area and temperature can be found by measuring the delamination area accurately. Then predict the storage life at normal condition can be estimated.

IV CASE APPLICATION

A. ADT and data processing

A type of plastic package MOS EEPROM was chosen as samples in the case. Pre-experiment has shown that temperature has a significant influence on performance. Hence, this paper selects the temperature as accelerate stress of the ADT. The samples are divided into three groups: 60℃, 85℃, 105℃. Each stress level puts six devices, and normal condition put 5 only. In this work, each sample is monitored over the same time intervals for the performance and full electrical parameters are monitored.

It is found that the leakage current I_{LO} has changed greatly, and the typical failure mode is the parameter drift. Hence, the sensitive parameter of the test was determined as I_{LO}. The changing trend of I_{LO} at three stress levels is shown in Fig.5 to Fig.7.

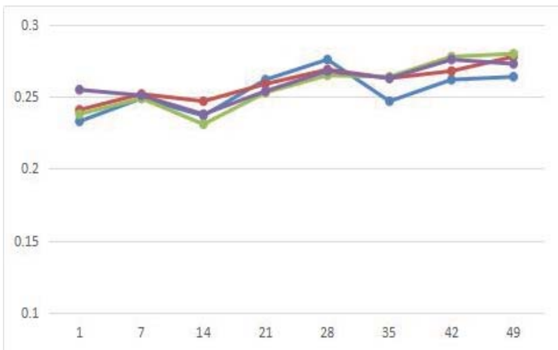


Figure 5 60 ℃

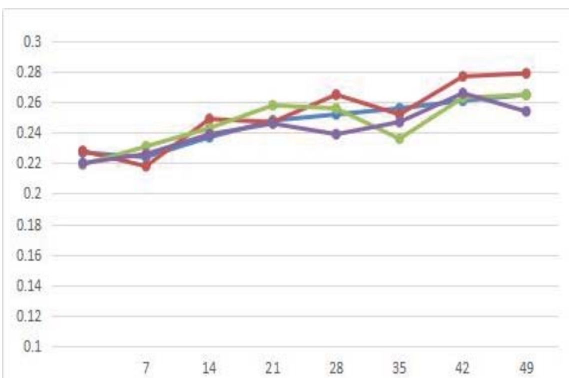


Figure 6 85℃

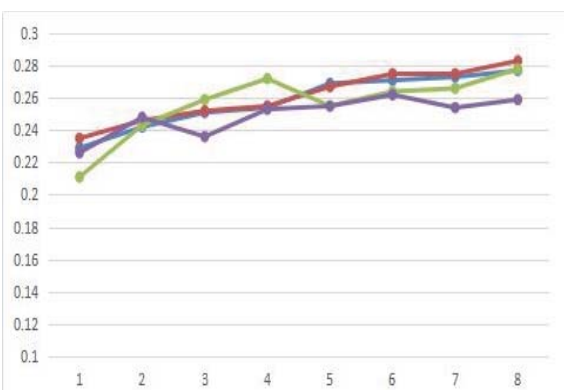


Figure 7 105 ℃

The power model, polynomial model, and exponential model are fitted with the degradation data respectively. Furthermore, The fitting fit of the model was evaluated by two indexes of R^2 and SEE. The results are shown in Table III:

TABLE III LEAKAGE - FLOW DEGRADATION TRAJECTORY FITTING TABLE

	No	polynomial		power		exponential	
		SSE (10^{-4})	***R2***	***SSE (10^{-4})***	***R2***	***SSE (10^{-4})***	***R2***
60 ℃	1	3.2	0.641	3.2	0.641	3.1	0.648
	5	6.7	0.603	6.3	0.568	5.8	0.605
	8	16.4	0.261	5.5	0.174	6.5	0.255
	10	15.8	0.034	16.2	0.008	15.7	0.036
85 ℃	12	4.3	0.202	4.3	0.193	4.2	0.202
	13	7.5	0.434	7.0	0.428	7.6	0.445
	17	5.5	0.196	5.4	0.208	5.5	0.195
	18	1.1	0.851	1.5	0.823	1.1	0.869
105 ℃	22	0.2	0.982	0.9	0.919	0.2	0.983
	23	6.9	0.324	6.6	0.274	5.6	0.316
	27	4.5	0.290	5.7	0.220	4.6	0.283
	30	1.9	0.505	2.6	0.337	1.2	0.511

When SEE is close to 0 and R^2 is close to 1, the model is consistent with the data structure and has good constructive validity. The results show that the exponential function has the best fitting.

According to the exponential model, when the stress S_K=T_K, the trajectory model of the *i*-th device is:

$$X=\alpha e^{\beta t} \tag{5}$$

where $\hat{\alpha}$ and $\hat{\beta}$ can be obtained from the degradation data of each stress level. According to the datasheet, the limit of the I_{LO} is 10μA. Then the formula can be expressed as:

$$t=\frac{\ln 10-\ln\hat{\alpha}}{\hat{\beta}} \tag{6}$$

Then, each device reaches the threshold time is obtained. The pseudo-life values at each stress level are shown in table IV.

TABLE IV PSEUDO-LIFE VALUES UNDER VARIOUS TEMPERATURE STRESSES

Stress level	No.	Predicted life（day）
60℃	1	1066.2833
	2	1138.1676
	3	1425.4288
	4	1144.479
85℃	5	576.5326
	6	586.9657
	7	528.7391
	8	495.9005
105℃	9	235.1023
	10	215.8382
	11	208.3744
	12	235.3128

Based on the methods described by the formula (3), the correspondence between the lnξ and $\frac{1}{T}$ was shown in table V:

TABLE V AVERAGE PREDICTED-LIFE OF EACH TEMPERATURE POINT

$\frac{1}{T}$	**Stress level**	**Average storage life ξ (day)**	**Lnξ**
0.003003	60°C（333K）	1193.589675	7.084
0.002793	85°C（358K）	547.033825	6.305
0.002646	105°C（378K）	223.656925	5.410

The over-time change of the storage life with temperature can be expressed:

$$\ln\xi_1=4622\times\frac{1}{T}-6.74 \tag{7}$$

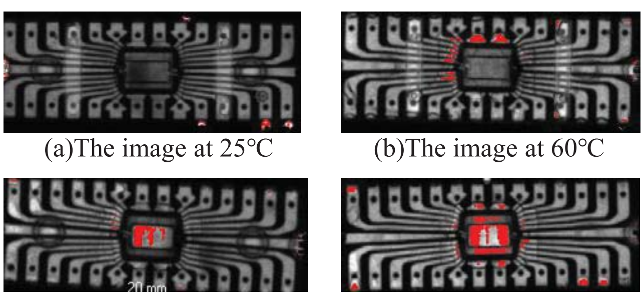
Hence, the storage life at 25°C(298K) is

$$\xi_1=e^{(\frac{4622}{298}-6.74)}=6438.17\text{ days} \tag{8}$$

that is 17.64 years.

B Physical analysis

According to the theory in Section 3, it is known that the delamination area affects the electrical performance. Hence, the storage life is proposed to be related to the delamination area. The SAM contrast images under each stress level are shown in Fig.9:



(a)The image at 25°C (b)The image at 60°C

(c)The image at 85°C (d)The image at 105°C

Figure 9 The SAM images at each stress level

When a defect such as delamination or voids is encountered at an interface, practically all the pulses are reflected back. The acoustic image produced is rendered in red code. Based on the method proposed before, the relationship between the delamination area and time at each stress level can be fitted as follows:

$$Y=Me^{Nx} \tag{9}$$

where M and N are constants, x represents the test time, and Y represents the delamination area.

In the pre-experiment, it was found that when the delamination area accounts for almost half of the total area, the sample electrical parameter drift will be close to the limit, and even sudden failure occurs.If the failure threshold is determined as 10655.93mm^2, the storage life at each stress level can be predicted and the results are shown as Table VI:

TABLE VI AVERAGE PSEUDO-LIFE OF EACH TEMPERATURE POINT

Stress level	**60°C**	**85°C**	**105°C**
Delamination content（%）	0.933	1.009	1.536
Average storage life ξ（day）	1266	505	268

The relationship between the storage life ξ_2 and temperature T can be expressed using the Arrhenius model:

$$\ln\xi_2=4351\times\frac{1}{T}-5.925 \tag{10}$$

Hence, the storage life at 25°C(298K) is:

$$\xi_2=e^{(\frac{4351}{295}-5.925)}=5858.6304\text{ days} \tag{11}$$

that is 16.05 years.

Compared with ξ_1,

$$\frac{6438.17-5858.63}{6438.17}\times100\%=9.002\% \tag{12}$$

Physically, in the process of ADT, the plastic package devices absorb moisture constantly. The moisture absorbed by the surface of the plastic package device reduces the insulation resistance between the legs of the device, which caused the I_{LO} to increase. When the devices were in a humid condition, the device surface formed a layer of water film, which resulted in the I_{LO} to increase further. Therefore, internal delamination and the I_{LO} increased there is a direct causal relationship and a certain rate exists. In this section, the comprehensive analysis is done in the electrical performance and the Physical-Chemical process, two kinds of storage life were validated respectively.

V SUMMARY

This paper sets out to demonstrate the application of the evaluation method, which combines electrical performance with physical analysis. Based on the failure mode and mechanism of the plastic package MOS device in storage, the ADT is drawn up and implemented. Degradation data are collected and modeled. This model is utilized to predict the storage life under normal condition. Then, the results of the SAM analysis show that the internal delamination leads the I_{LO} to increase. The storage life at 25°C is estimated from this way. The analysis in two ways obtains the same conclusion. The model is meaningful for avoiding redundant preventive maintenance and saving maintenance costs.

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