Method for Evaluating the Corrosion Resistance of Aluminum Metallization of Integrated Circuits under Multifactorial Influence

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Abstract. The influence of complex influence of climatic factors (temperature, humidity) and electric mode (supply voltage) on the corrosion resistance of metallization of integrated circuits has been considered. The regression dependence of the average time of trouble-free operation \( t \) on the mentioned factors has been established in the form of a modified Arrhenius equation that is adequate in a wide range of factor values and is suitable for selecting accelerated test modes. A technique for evaluating the corrosion resistance of aluminum metallization of depressurized CMOS integrated circuits has been proposed.

1. Introduction

Integrated circuits (IC), manufactured on the basis of complementary transistors with the structure of metal-oxide-semiconductor (CMOS IC), found an exceptionally wide application in products of industrial electronics and computer engineering. The main advantages that have determined their wide application are extremely low power consumption and a wide range of supply voltages (up to 15 V). However, these advantages, on the other hand, also determined the low corrosion resistance of CMOS IC metallization, that required the development of special technological measures to increase it, as well as methods of extreme tests for evaluation of the effectiveness of these measures.

For assessment of the corrosion resistance of IC metallization, determined directly by the design and technological features of the IC manufacturing process, the focus should be on corrosion processes in the IC metallization having a free internal chamber. For this purpose it is reasonable to apply extreme tests methods in conditions of the influence of high temperature and humidity, which, combined with the supply voltage [1], make it possible to reproduce the electrolytic corrosion mechanism typical for the majority of corrosion failures of CMOS IC during operation.

2. Methods

As an indicator of the IC resistance to electrolytic corrosion of aluminum metallization, as a rule, the average time to failures \( t \) is used [2]. For the optimal selection of test conditions, it is of great interest to detect the quantitative relationships between the time \( t \) and the influencing factors, i.e. the formulation and analysis of the mathematical model, for example, in the form of a regression equation [3].

\[
t = f(x_1, \ldots, x_m, \mathbf{A}),
\]

where \( x_1, \ldots, x_m \) – relevant influencing factors (\( m \) – their total quantity);
\( \mathbf{A} = [a_1, \ldots, a_m] \) – \( m \)-dimensional vector of regression coefficients.
Since the given matter is solvable, as a rule, by an experimental method, to solve the matter, it is necessary to:

1) create a plan of active tests [4];
2) select the type of the mathematical model (1);
3) conduct multifactorial tests of the IC in accordance with the plan, creating \( N \) combinations of \( m \) factors each time and determining the corresponding value of the average time between failures;
4) find the vector \( \mathbf{A} \) from the condition of minimum dispersion [5]

\[
D = \sum_{i=1}^{N} (t_i^w - t_i^s)^2 / (N-M) \rightarrow \text{min}, \quad (2)
\]

where \( t_i^w, t_i^s \) – the values of the time between failures with the \( i \)-th combination of influencing factors, determined, respectively, experimentally and according to the mathematical model (1);
5) to assess the adequacy of the model (1) using, for example, the F-criterion [6]; if the result is positive, to use the obtained mathematical model (1) in solving applied matters posed in the study, and if it is negative, to go to a new kind of mathematical model, to conduct additional tests (to increase the number \( N \)), or (and) to introduce new influencing factors (to increase the value \( m \)), then to repeat all actions again.

It should be noted that for certain combinations of influencing factors, when the time \( t_i^w \) is too long and there is no possibility to increase the duration of the tests, it is possible to use for some experiments the calculated equivalent of the time between failures [7].

3. Discussion of the Results
In accordance with the above mentioned, the matter of the model formulation (1) for the dependence of the time to failures \( t \) of the depressurized integrated microcircuits of the CMOS IC of the 564 series (the Russian analogue of CD4000A) under the influence of temperature \( x_1 \), humidity \( x_2 \) and supply voltage \( x_3 \) (\( m=3 \)), was solved, for which multifactorial tests were carried out. Their results for different supply voltages are presented in the table.

During the tests, the average values of the time to failures \( t_i^w \) were determined, and in a number of cases when the failure did not occur within 1,000 h, the value of \( t_i^w \) was estimated analytically [7].

Table 1. The time (h) of 564 series integrated circuits between failures at voltages of 5; 10; 15 V.

| \( x_2 \), % | 55 | 85 | 100 | 120 |
|----------------|------------------|--|--|--|
| 5 V           | 10 V             | 15 V | 5 V | 10 V | 15 V | 5 V | 10 V | 15 V |
| 25            | 20600            | 12200 | 7210 | 4850 | 3010 | 1850 | 2560 | 1610 | 1020 | 1190 | 762 | 675 |
| 85            | 3910             | 2320  | 1370 | 953  | 588  | 364  | 506  | 317  | 201  | 235  | 150 | 133 |
| 90            | 2680             | 1580  | 933  | 629  | 388  | 239  | 332  | 208  | 131  | 156  | 99  | 88  |
| 98            | 532              | 314   | 186  | 126  | 78   | 48   | 67   | 42   | 26   | 31   | 20 | 18  |

Assuming that the proceeding processes are largely subject to the Arrhenius law [8], the results were mathematically processed and a mathematical model was obtained:

\[
\lg t = -5.8 + 0.0725x_3 + 1.05 \lg(100-x_2) + (2,800-54x_3)/x_1 \quad (3)
\]

The Fisher test [6] confirmed the adequacy of this model with a confidence coefficient of at least 95%. Its accuracy is illustrated at figure 1.

Calculations by the model showed that the time to failure (which is proportional to the rate of corrosion processes) is mainly determined by the relative humidity and temperature of the medium. To a lesser extent, the rate of corrosion depends on the value of the supply voltage.

Methods for assessing the corrosion resistance of aluminum metallization of the CMOS IC, developed on the basis of the results of multifactorial tests, provides for accelerated testing of
depressurized IC in unsaturated water vapor at elevated temperature with simultaneous electrical voltage supply.

Figure 1. Dependences of the time between failures of 564-series integrated circuits on temperature and humidity at supply voltages 5(a), 10(b), 15V(c):

- ○ – experiment,
- x – projected equivalent,
- – mathematical model (3).

The basic modes are:
- 85% relative humidity, 85 °C temperature (it is realized using the chamber of heat and humidity);
- 85% relative humidity, 120 °C temperature (it is realized using the autoclave).

The duration of the tests is determined by their purpose, the capabilities of the laboratory base, the design and technological features of the IC, the selected modes.

4. Conclusions

The application of the theory of test planning and regression analysis has made it possible to obtain the adequate mathematical model connecting the indicator of corrosion resistance with the influencing factors and taking into account the physics of the proceeding processes. On the basis of the model obtained, the methods for evaluating the corrosion resistance of aluminum metallization of CMOS IC have been proposed, which are applicable when adjusting the technological processes for the IC manufacturing. The methods are easy to implement, have sufficient efficiency and statistical stability.

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