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A Survey of Reliability Methods for Integrated Circuits

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ABSTRACT

Nowadays, the integrated circuit industry is developing rapidly, and the problems of the reliability of integrated circuit products have become increasingly apparent. In order to make integrated circuit products better put into use, the most important thing is to improve the reliability of the product. This article briefly introduces the related concepts of reliability and the methods of reliability. Among them, the reliability method roughly introduces failure analysis methods, reliability modeling methods, and reliability test and assessment methods. As the basic components of various types of electronic equipment, only by improving the reliability of integrated circuits can we further ensure the normal operation of various types of electronic equipment. Therefore, it is very important to improve the reliability of integrated circuits.

1. Reliability

1.1 Background significance

As a national strategic emerging industry, the integrated circuit industry has been widely used in various major fields, especially as the basis of social informatization, and its role in information security cannot be ignored. Especially the current development of the integrated circuit industry is in a critical period. The country attaches great importance to the development of the integrated circuit industry and has issued a series of policies, which shows the important position of the integrated circuit industry.

As a kind of product widely used in various electronic equipment, the service life of integrated circuit is very important for all kinds of electronic products. As the basic components of various types of electronic equipment, the normal operation of various types of electronic equipment can be further ensured only by increasing the service life of integrated circuits. And if you want to improve the service life of integrated circuits, you need to study the reliability of integrated circuits. Only by ensuring their reliability can the safety and practicability of electronic products be guaranteed.

Nowadays, the research on the reliability of integrated circuits is more important and urgent. This is because in recent decades, integrated circuit technology is in a stage of rapid development. At the same time, its performance and integration are improving. Therefore, the introduction of new materials and processes is essential. But in the future, there will be new failure mechanisms for integrated circuits, which will bring people's concerns about the reliability of such new products. This shows that the research on the reliability of integrated circuits is of great significance.

Next, briefly introduce a few contents in the research of integrated circuit reliability. Of course, this is not the whole content, but only a few of them. First, it is the design stage of integrated circuit products. In the product design stage, reliability modeling, reliability allocation and reliability prediction are relatively important parts. Let's talk about reliability modeling first, in fact, the so-called modeling is also the same as most product designs, but also requirements analysis. After fully understanding the requirements, an early failure analysis can be performed on the product through various factors such as the material of the product and the use environment. There are many failure analysis methods, but they are roughly divided into two categories, namely, lossy analysis and nondestructive analysis. The following six methods are introduced here: scanning acoustic analysis inspection, X-ray analysis inspection, and appearance inspection; package opening, electrical technical analysis, and physical technical analysis. At this point, after completing the requirements analysis and failure analysis, the preliminary preparation for reliability modeling is roughly completed. The next step is to choose a modeling method. Common modeling methods include RBD model, FTA model, GO methodology, Markov model, and then use the appropriate modeling method to combine the results obtained from the requirements analysis and failure analysis to obtain the desired model. The next step is to complete the reliability allocation and reliability prediction. The next thing to talk about is the manufacturing stage of integrated circuit products, during which a corresponding reliability analysis will be carried out. Some products

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need to be packaged and tested after the manufacturing is completed. At this stage, some reliability tests and evaluations are also required. Among them, the life tests and environmental tests are more important. Reliability testing and assessment can be said to be the top priority in the entire integrated circuit industry chain. This step can fully guarantee the quality of the product, and further improve the reliability of the product based on the test results. And in this series of tests, the most important is the life test. Because no matter what type of product, the ultimate goal is to put it into use. Since it is actually used, it will involve the life span, and the life of the product is affected by many factors, so it is essential to carry out a life test on the product before putting it into use. By conducting corresponding tests and evaluations at different stages, different effects can be exerted, but they are all for further guarantee of product reliability. The purpose of reliability analysis at different stages is often different. For example, some reliability analysis is to optimize the reliability model, and some reliability analysis is conducted for the process or quality of the product. All in all, the reliability research of integrated circuits is actually a very wide range, not only exists in a certain stage, so in the process of integrated circuit products from scratch, reliability analysis is very important.

1.2 Related concepts of reliability

Just mentioned that for integrated circuit products, the reliability of the product directly affects the actual use of the product, so before discussing the reliability of integrated circuits, it is natural to understand some related concepts of reliability. First, what is integrated circuit reliability? In fact, the reliability of integrated circuits refers to how high the product's ability to function properly in actual use. As a qualified integrated circuit product, it needs to work normally within the required working time, so that it can be said that this product has a certain reliability. For a product, the higher the reliability, the better[1].

Although reliability seems to be just saying "reliable", reliability is not defined casually, it also has its own requirements. Generally speaking, the designed product must first ensure that its service life meets the requirements, followed by the ability to troubleshoot when the product fails, and finally the designer must fully consider the needs of the user, and the actual environment of the product should be considered when designing the product. For the user, the operation method should be as simple as possible. Therefore, when designing a product, the designer must fully consider these three aspects to ensure that the designed product has sufficient reliability. But reliability is not only affected by the designer, to a certain extent, the product is also affected by the user. For example, factors such as whether the user's operation is reasonable and whether the environment used meets the requirements will have a certain impact on the reliability of the product. So in fact, in the process of a product from scratch, designers and manufacturers can only guarantee part of the reliability of the product, but nevertheless, improving the reliability of this part of the product is also the most important thing for designers and manufacturers.

In addition to this, reliability analysis does not only exist in a certain stage of the entire integrated circuit production process. Improving product design by studying reliability is only one of the functions of reliability analysis. In addition to the product design stage, reliability research is also required many times in other stages. For example, one of the functions of reliability analysis at the design stage is to optimize the reliability of the product design at this stage, and reliability analysis will be performed at other stages. However, the reliability analysis performed at other stages may not be for the initial design of the product, and the reliability analysis at this time may have other purposes. Therefore, in general, reliability analysis is a very wide-ranging study, and the role played by reliability analysis is different in different stages of the research.

In the study of reliability, a series of reliability tests will be involved. Just mentioned that in different stages of product reliability research, the purpose of reliability analysis is different. Therefore, based on different purposes, the reliability test conducted is also different, and then based on the experimental results of the reliability test and then targeted analysis and research. In other words, the choice of reliability test method is sometimes determined according to the purpose of reliability analysis.

The above are some concepts that may be involved in reliability research. Next, we will briefly introduce some techniques and methods that may be used in reliability research.

2. Reliability method

2.1 Failure analysis method

The so-called failure analysis is to test the sample, obtain the test results through certain technical means, and use the results to determine what caused the product failure, and then make up for the defects and improve the product. Generally speaking, integrated circuit failure analysis methods are roughly divided into lossy analysis and nondestructive analysis. As the name implies, the so-called lossy analysis refers to the damage to the test sample during the analysis process, and the nondestructive analysis refers to the analysis method that causes less damage to the test sample than the lossy analysis. The degree of sample damage is often by nondestructive analysis with less damage.

Lossy analysis methods for integrated circuit products include package opening of integrated circuits, electrical technical analysis and physical technical analysis[2]. Package opening refers to unpacking the product that has been packaged. In this process, it can only be guaranteed to not cause damage to the sample, but it cannot be completely guaranteed. Therefore, this method of opening the package is a kind of lossy analysis. The electrical technical analysis uses some specific technical methods to determine the cause of the failure of the test sample. Only after the problem is identified can the targeted failure analysis be performed. Finally, the physical technical analysis in the lossy analysis, as the name implies, is to use physical technology to analyze, and further determine the cause of sample failure based on the test results.

There are three main methods of nondestructive analysis: the first method is the appearance inspection of integrated circuits; the second method is X-ray analysis inspection; the third method is scanning acoustic analysis inspection[3]. First of all, the appearance inspection of the integrated circuit is actually the simplest analysis method, which is to let the inspector observe the sample with his own eyes and judge whether the sample has obvious damage from the appearance. The X-ray analysis and inspection refers to the application of X-ray irradiation, and according to the X-ray irradiation results to determine whether there are problems such as failure in the line. Finally, the scanning acoustic inspection mainly uses ultrasonic waves to inspect the test sample to determine whether there are problems such as failure inside the test sample.

Failure analysis is also an important part of reliability analysis.

Sometimes, when we know the cause of product failure, we can be more targeted when you perform reliability analysis. Nowadays, as people pay more and more attention to the reliability of integrated circuits, the causes of failure of some products have been discovered, but more causes of failure still require analysts to continue in-depth research and experiments to discover. There are still many failure analysis technologies in practical applications. For different products and different application environments, the most suitable failure analysis technology method is selected and appropriately optimized, so that the product can be analyzed more accurately. Lay the foundation for further improving product reliability.

2.2 Reliability modeling method: GO methodology

In system-level reliability research, there are several more common modeling methods. GO methodology is one of them, and it is also a method often used.

Before studying the GO methodology, we must first understand its basic principles. The most important thing in the GO methodology is the drawing of the GO diagram, the accurate drawing of the GO diagram can help the analyst to perform the reliability calculation to a certain extent. In the GO diagram, the GO model and operation code are mainly involved. The so-called GO diagram represents the logical relationship between the model's operation code, most of the time, the actual system unit and operation code are almost one-to-one correspondence[4]. The maps obtained in this way are clear and intuitive, which makes it easy to have a clear grasp of different parts when performing reliability analysis.

The GO methodology is a commonly used reliability modeling method. Generally speaking, in the application of this method, the drawing of the GO diagram is very important. In addition, careful calculation is also essential. Based on the study of the GO methodology, someone once improved it, and proposed an improved calculation method compared to the ordinary GO methodology. Formulas (1) and (2) are some of the formulas involved in the improved method, and they represent the state cumulative probability of the input signal and the output signal, among them, $P_S(i)$ and $P_R(i)$ represent the state probability of the input and output signals of the operator, i represents the state value of the signal flow, and $A(i)$ represents the sum of the probabilities of all states whose signal flow state value is 0 to i [5]:

$$A_S(i) = \sum_{j=0}^{i} P_S(j),\ i = 0, \cdots, N-1,\ A_S(N) = 1 \quad (1)$$

$$A_R(i) = \sum_{j=0}^{i} P_R(j), i = 0, \cdots, N-1,\ A_R(N) = 1 \quad (2)$$

From this, the state probability of the output signal can be obtained, and then the probability of the successful state and the fault state is compared and analyzed, thereby further optimizing the model. Here are just some of the formulas involved in this method. If you need to get detailed analysis results, you need to combine different types of calculation formulas for further calculation and analysis.

The reason why GO methodology can become one of the more common modeling methods has a lot to do with the clear and intuitive GO diagram. Because the GO diagram can more intuitively reflect the logical relationship between the various components in the actual project, it is also convenient for the analyst to perform the reliability analysis and quantitative calculation of the system, which is also the advantage of the GO methodology. But at the same time, there are some factors that limit the development of the GO methodology, and these factors are also derived from the GO diagram. This is because in order to reflect the logical relationship in the actual project when drawing the GO diagram, a series of operators are involved, but some of these operators are more complicated, which adds a certain degree of difficulty to the drawing of the GO diagram. Therefore, this method requires analysts to be proficient in the use of operators. And it is conceivable that when the system is more complicated, the GO diagram that need to be drawn will be more complicated, and the too complicated GO diagram may not accurately reflect the actual engineering situation. This is also the flaw of GO methodology. These factors have restricted the use and development of GO methodology to some extent.

2.3 Reliability modeling method: GO-FLOW methodology

The GO-FLOW methodology is actually an improvement to the GO methodology. Although its basic concepts and algorithms are different from the GO methodology, it is also a success-oriented method that can quantitatively calculate system reliability performance[6]. Some uses of the GO-FLOW methodology are similar to the GO methodology. There are specific operators in the GO methodology, and there are also corresponding operators in the GO-FLOW methodology. The GO-FLOW methodology can be better understood by understanding the GO methodology. Same as the GO analysis method, the GO-FLOW methodology is also success-oriented. And it uses the method of graphic deduction to map the functions of the components in the system to the model diagram by operators, and then calculate the probability of various states in the system[7].

As an improved method of GO methodology, GO-FLOW methodology may have certain advantages when dealing with and analyzing problems. For example, when dealing with the problem of common cause failure in the system, several calculation formulas may be involved. It may be easier to perform calculation and analysis through the calculation formulas. Equations (3), (4) and (5) are formulas that may be applied when dealing with such problems, where the independent failures of A and B are represented by A_i and B_i, the common cause failure is represented by C_{AB}, and $P[T(A_i, B_i)]$ represents the probability of system failure caused by independent failure[8]:

$$A = A_i + C_{AB} \quad (3)$$

$$B = B_i + C_{AB} \quad (4)$$

$$P[T(A,B)] = P[T(A_i, B_i)] + P[C_{AB}] \cdot \{P[T(1,1)] - P[T(0,0)]\} \quad (5)$$

According to the above expression, combined with the specific analysis of the actual problem, we can analyze how much the common cause failure problem in the system has on the system reliability, and then eliminate the fault in a targeted manner. The above expression is mainly involved in dealing with the problem of common cause failure, but when analyzing different system problems, the system needs to be analyzed to choose the appropriate method.

As an improved version of the GO methodology, the GO-FLOW methodology is more suitable for more complex systems. Compared with the GO methodology, the operators in the GO-FLOW methodology have increased, and the functions that can be implemented are more comprehensive. Compared with the GO analysis methodology, the GO-FLOW methodology seems to be more applicable when faced with more complex systems, such as the reliability analysis of the above-mentioned systems with common cause failures. More intuitive and wide application are the obvious advantages of GO-FLOW methodology. Comparatively speaking, GO-FLOW methodology is a new reliability analysis method. With the continuous improvement of this method, its application range is becoming more and more extensive. However, this method has more operators and is generally used to analyze more complex systems, so it is still necessary for analysts to have a good foundation to avoid errors when analyzing complex systems. In particular, analysts need to have a good grasp of the complex operators involved in the GO-FLOW methodology, so that it is possible to reduce errors as much as possible during analysis and preparation and make the analysis results more accurate.

2.4 Reliability modeling method: Fault tree analysis

Fault tree analysis (FTA) is a common fault analysis method and one of the earlier reliability analysis methods. It is often used to improve system reliability.

The basic principle is as follows[9]: First establish the top event and the bottom event, and then use the logic gate to connect, we can get an inverted tree diagram, and then through this tree diagram can be analyzed layer by layer, and finally determine the cause of the underlying fault. Therefore, the tree diagram can clearly show the logical relationship between the faults existing in the system, and it is also very beneficial for the analysis of the causes of the faults later.

The above is the basic idea of the fault tree method. It can be seen that the overall idea is very clear when using the fault tree method for reliability analysis. Next, two formulas are introduced, which can be regarded as a mathematical description of the fault tree. Formulas (6) and (7) are the structure functions of AND gate and OR gate, respectively, where x_i represents the state variable of the bottom event i, $\emptyset$ represents the state variable of the top event, and $\vec{x}(x_1, x_2, \cdots, x_n)$ is the base event state vector, n is the number of base events[10]:

$$\emptyset(\vec{X}) = \cap_{i=1}^{n} x_i = \prod_{i=1}^{n} x_i \qquad i = (1,2,\cdots,n) \qquad (6)$$

$$\emptyset(\vec{X}) = \cup_{i=1}^{n} x_i = 1 - \prod_{i=1}^{n}(1 - x_i) \qquad i = (1,2,\cdots,n) \qquad (7)$$

When analyzing some simple systems, according to the above assumptions and formulas, the state variables of the top event can be obtained, and the faults that may exist in the system can be analyzed based on the fault tree, so as to further analyze the causes of the faults and improve them.

With the development of integrated circuits, the degree of integration has become higher and higher, thereby increasing the user's requirements for the reliability of integrated circuits. The so-called improvement of integrated circuit reliability is to reduce the possibility of failure of integrated circuit products in actual work, and FTA is a relatively intuitive method to solve such problems. It can be seen that intuition is a very important feature of FTA. Through the analysis of the tree diagram, the analyst can clearly understand the logical relationship between the various components. And it is precisely because of the hierarchical characteristics of the tree diagram that when analyzing the cause of the failure, the analyst can further analyze the possible causes of the failure along the shape of the tree diagram. From this point of view, the fault tree analysis method is not only intuitive but also has a wide range of fault types. At the same time, the difficulty of FTA is to construct the fault tree. When constructing a fault tree, it is important to determine the top and bottom events, and to determine the logical relationship between the levels also requires the analyst to have a good logical thinking ability. In addition, in the analysis of complex systems, even if a fault tree is successfully constructed, it may be because the tree diagram is too large and complicated, which makes this method unsuitable. These problems have limited the development of FTA to some extent.

2.5 Reliability modeling method: Markov model

The Markov model is a more common statistical model. If we want to understand this model method, the first thing we need to understand is the Markov process. In this process, the change at time t depends only on the state value at the same time t, and has nothing to do with the state of the previous time[11]. It can be seen from its nature that when using Markov model for reliability analysis, the main research is the state of the system at a certain moment.

If we want to use the Markov process model method to analyze the reliability of the system, we need to have a deeper understanding of the Markov process. In order to better understand the Markov process, here, we can deepen its learning through mathematical description. When a random process satisfies the formula (8), the process is called a continuous-time Markov process on the discrete state space E, where $p_{ij}(t)$ and $P(t) = [p_{ij}(t)]$ in the formula (9) represent transition probability function and transition probability matrix, respectively, So the transfer probability is only related to the time difference [12,13]:

$$P\{X(t_n) = i_n | X(t_1) = i_1, \dots, X(t_{n-1}) = i_{n-1}\}$$
$$= P\{X(t_n) = i_n | X(t_{n-1}) = i_{n-1}\} \qquad (8)$$

$$P\{X(t+u) = j | X(u) = i\} = p_{ij}(t)\ i, j \in E \qquad (9)$$

Through the above mathematical description, we can know that in fact, the most important point of using the Markov process model method is the need for probability calculation, and its function is also played out on the basis of probability analysis and calculation. The above formula is just to let everyone better understand the Markov process. When performing actual analysis, it is necessary to combine different conditions to define the state differently.

From the above Markov process definition, it can be known that when the state of a certain moment in this process is researched and analyzed, the development after that moment has nothing to do with its previous state. That is to say, using the no aftereffect of the Markov process, the state of development of the event can be obtained by analyzing the current state of the event. Therefore, it can also be said that a very important role of the Markov model is prediction, which is also the advantage of the Markov model method. However, if you want to make a better prediction of the state at a later time, you need to have a good understanding of the changes between the states at different times in the research process. Therefore, analysts need to grasp the various probabilities of state changes, which requires analysts to have a good mathematical theoretical foundation, which also adds a certain degree of difficulty to the reliability analysis using the Markov model. Although these problems limit the development of Markov model method to a certain extent, the predictive function of this method is still very popular.

2.6 Reliability modeling method: RBD model

The RBD model is the reliability block diagram model, which shows the logical relationship between the various unit factors that cause the system to fail by means of a block diagram, and the system failure at this time may be caused by a failure of one unit, or it may be caused by a common failure of multiple units. The role of the RBD model is to find the logical relationship between various factors that cause the system to fail. The so-called RBD model modeling is to represent each element or subsystem in the system in the form of a block diagram to express the internal logical relationship of the system, and it is divided into two types: series and parallel[14]. The so-called series model refers to the failure of one unit in the system to cause a failure of the entire system, and parallel model refers to the failure of all units in the system to cause the entire system to fail.

It can be seen that the advantages of the RBD model are simple and intuitive, easy to understand, and relatively simple to draw. But its shortcoming is that when faced with a complex system, especially when there are many and complicated reasons that cause the system to fail, it cannot be described in a block diagram. Different reliability modeling and analysis methods have corresponding characteristics, and the problems addressed are often different. Therefore, when choosing a modeling method, we must choose a suitable modeling method according to the characteristics of the system to be studied and according to actual needs[15]. Of course, if we want to choose the right method accurately, we must learn more about the basic concepts and applicable conditions of these methods.

2.7 Reliability test and assessment method: Environmental test

Reliability test refers to carrying out a series of tests on the product to check the existing faults, so as to infer the reliability of the product, and use it to optimize the next step. At the same time, there are many types of reliability tests. Generally, various types of tests such as environmental tests, screening tests, qualification tests, life tests, and field use tests may be involved in reliability analysis. The more important ones are environmental tests and life tests. Because no matter what type of product we need to let users know its life span, and different products may have their own different use environment. Therefore, from the practical point of view, these two tests will be carried out frequently, and both are more important. Next, let's understand the environmental test.

The so-called environmental test is to consider the problems that will occur in the actual use of the product in the future, so as to simulate the actual use environment of the product. Experiments in this simulated environment can improve problems by exposing possible problems in a short period of time. In the actual use environment of the product, temperature, humidity, vibration, and shock are very common influencing factors. Therefore, let the product test in these environments in advance, and then improve the product with a large amount of test data, so as to provide more reliable guarantee for future actual use[16]. When conducting environmental tests, it is necessary to simulate the environment in which the product is actually used in the future, but after all, it is simulation. Sometimes there may be no way to make the test environment consistent with the actual environment. Therefore, when conducting environmental tests, specific analysis can be carried out according to specific research problems, so as to find a suitable test condition and method to conduct the test, so as to achieve the purpose of the experiment. In particular, there are many influencing factors involved in environmental testing, so before conducting the experiment, it is necessary to know the purpose of the experiment, so as to reduce the difficulty of the test as much as possible.

2.8 Reliability test and assessment method: Life test

In addition to the use of environmental tests to simulate the actual use environment for testing, the life test also provides assistance for reliability analysis. Life test is a kind of test that is often used in reliability test, and its importance can be seen. As the name suggests, the life test is to test the life of the test product. Since any kind of product needs to have a service life, the life test is one of the tests that are frequently carried out.

After many tests and studies on the service life of the product, traditional life test methods have also been produced. But life test nowadays generally does not use the traditional life test method. Because the traditional life test method has a long test cycle and is expensive, which has greatly affected the development cycle of highly reliable integrated circuits[17]. Therefore, general researchers will use more advanced test methods. The main purpose of the life test is to test the service life of the product, so that the user can know how long the product can be used. Although the life test is only one of many reliability tests, this test is often more important, and the life span of the product can be known through the life test, which provides corresponding assistance for the implementation of subsequent stages.

It can be seen that whether it is the environmental test, the life test, or other reliability tests, they have their corresponding experimental purposes, which are to provide corresponding assistance for further analysis of product reliability. However, due to the wide variety of reliability tests, all reliability tests may not be involved in actual operation, so specific analysis should be made on specific issues, and the required reliability tests should be selected for test analysis according to their corresponding influencing factors and experimental purposes .

3. Summary

The above is a brief overview of integrated circuit reliability concepts, failure analysis methods, and common modeling methods. After a simple understanding of reliability, the understanding of integrated circuit reliability was deepened. It is found that with the development of integrated circuits, reliability technology is constantly innovating. The purpose of innovation is to meet the needs of products. Therefore, when conducting reliability research, pay more attention to the application requirements of the latest products. And reliability analysis is a very wide range of research, not only for a certain stage in the product production process, but permeated in multiple stages. And when analyzing the actual problems, some of the knowledge content involved is also very extensive. For example, when performing different failure analysis on different products, the knowledge that may need to be mastered is different. Therefore, when faced with such a wide range of research, we must first determine the purpose of reliability research, and then know which stage of reliability the problem to be studied belongs to. Only in this way can we conduct targeted research. Therefore, the research on the reliability of integrated circuits is a multidisciplinary discipline, especially in the two stages of failure mechanism research and reliability test. There are many methods that need to be applied. For specific methods, detailed understanding and analysis of actual use conditions are also required.

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References

[1] Song, X. and T. Liu. Adaptive Tracking Control of Wheeled Mobile Robot Based on Neural Networks and Slip-compensation. International Journal of Applied Mathematics in Control Engineering, 2019, 2(2): 118-126.

[2] Gao Chengyuan. Failure analysis method of integrated circuit and corresponding technical analysis [J]. China New Technologies and Products, 2016 (17): 83.

[3] Zhou Jincheng, Li Yabin, Li Xizhou. Application and example analysis of SEM & EDS technology in integrated circuit failure analysis [J]. Equipment for Electronic Products Marufacturing, 2018, 47 (06): 47-51.

[4] Liu Guangfa. GO methodology and FTA and comparison (on) [J]. Nuclear Standard Measurement and Quality, 1999 (02): 46-54.

[5] Shen Zupei, Gao Jia. GO methodology principle and improved quantitative analysis method [J]. Journal of Tsinghua University(Science and Technology), 1999 (06): 16-20.

[6] Li Fengjun. Design and development of quantitative analysis program for GO-FLOW methodology [D]. Harbin Engineering University, 2015.

[7] Fu Zhiwei, Yang Ming, Song Wei, Zhan Wenhui, Mao Huan. Research on reliability analysis of passive safety injection system based on GO-FLOW methodology [J]. Chinese Journal of Nuclear Science and Engineering, 2018, 38 (06): 1035-1039.

[8] Yang Jun, Yang Ming. Common cause failure analysis of waste heat removal system based on GO-FLOW methodology[J]. Nuclear Power Engineering, 2014, 35 (S1): 156-160.

[9] Yuan Xiuli. Fault tree analysis method for effectively improving semiconductor device reliability [J]. Semiconductor Technology, 2010, 35 (07): 647-649.

[10] Xu Rong, Che Jianguo, Yang Zuobin, Zuo Xiaoyong. FTA and its application in system reliability analysis [J]. Command Control & Simulation, 2010, 32 (01): 112-115.

[11] Hu Kang. Reliability modeling and simulation of multi-State repairable system based on Markov process [D]. Jiangxi University of Science and Technology, 2013.

[12] Cao Jinhua, Cheng Kan. Introduction to Reliability Mathematics[M]. revision. Beijing: Higher Education Press, 2006.

[13] Tan Qingnu. Research on reliability modeling, analysis and comprehensive evaluation of complex systems [D]. Beijing Jiaotong University, 2013.

[14] Zhang Xuan, Geng Jiayong, Zeng Deyin, Han Zongyao, Wei Taotao, Wang Xin. Overview of Power Electronics System Reliability Models [J]. Journal Of Power Supply, 2016, 14 (06): 99-107.

[15] Wang, H. and X. Jin. Pedometer for Obtaining Sensor Information of Android Phone Based on Matlab. International Journal of Applied Mathematics in Control Engineering, 2019, 2(2): 210-216.

[16] Zhao, X. and H. Du. Research on Human Walking Feature Extraction and Identification Recognition System. International Journal of Applied Mathematics in Control Engineering, 2019, 2(1): 81-86.

[17] Sun Xupeng, Zhang Dong, Ha Wenhui, Gao Xudong, Yang Hui. Research on New Accelerated Life Test Method for Integrated Circuits [J]. Electronic Technology & Software Engineering, 2015 (03): 121.

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