Research on Manufacturing Readiness Level Improvement of Hybrid Integrated Circuit Based on Intelligent Manufacturing

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Abstract. This paper takes Hybrid Integrated Circuit (HIC) as research object, on the basis of fully understanding the concept and connotation, grading requirements and evaluation process of Manufacturing Readiness Level (MRL), aiming at the manufacturing risk factors and its sub factors in MRL, based on intelligent manufacturing technology, several ways to improve MRL of HIC are discussed, including intelligent upgrading of manufacturing equipment, intelligent management system, intelligent warehousing and logistics, intelligent interaction of Internet of Things (IOT), big data analysis and mining.

1. Introduction

Hybrid Integrated Circuit (HIC) is an integrated circuit which is made by combining semiconductor integrated process with thin (thick) film process. Compared with discrete component circuits, HIC has the advantages of high assembly density, high reliability and good electrical performance. Compared with monolithic integrated circuit, HIC has the advantages of flexible design, convenient process, convenient for multi variety and small batch production, wide parameter range, high precision, good stability, and can withstand high voltage and high power, especially in the field of microwave.

Manufacturing Readiness Level (MRL) is a new management tool used in the development of U.S. space system. It is an extension of the concept of technology readiness level, mainly to make up for the lack of technology readiness level in evaluating the economy and effectiveness of equipment manufacturing system. By setting MRL, it can effectively control and track the technology readiness state before the key technology is transferred into the manufacturing process.

If HIC manufacturing technology is not mature, it may lead to a series of problems, such as increased production costs, increased product quality problems, unstable performance, poor product consistency, reduced reliability and extended lead time. MRL is an important link in the development and application of HIC. Improving MRL plays a very important role in building a professional development model of products, supporting users to select mature products, and in product development, cultivation and application.

In recent years, the rise of a new generation of information technology, such as industrial internet, artificial intelligence (AI) and big data, has brought important opportunities for the upgrading of manufacturing technology to intelligent manufacturing [1-3]. Intelligent manufacturing is the product of the deep integration of advanced manufacturing technology and advanced information technology [4], involving the digitalization, networking and intelligent technology of manufacturing industry [5-6], which runs through every link of the whole value chain of manufacturing design, production and service [7]. Based on intelligent manufacturing technology to improve MRL of HIC can effectively
shorten the development cycle of HIC, reduce the development cost, and promote the improvement of HIC manufacturing capacity and industry development level.

2. Evaluation Method of MRL

2.1. Concept and connotation
MRL was first proposed by the Joint Defense Manufacturing Technology Panel (JDMTP) of U.S. in 2001. MRL evaluation method is a systematic management method for manufacturing risk and manufacturing capability. It establishes a quantitative evaluation mechanism of manufacturing capability in the whole cycle of engineering project by comprehensively combing the manufacturing factors that affect the development process of engineering project, which is used to determine the readiness of key manufacturing capability in engineering project and quantitatively reflect the satisfaction degree of manufacturing capability to project objectives So as to realize all-round management and manufacturing risk control in the early stage of engineering development [8]. In 2010, the U.S. department of defense issued the latest edition of MRL evaluation guidelines, which divides MRL into 10 levels, among which level 1 is the lowest and level 10 is the highest, which are MRL1 and MRL2 respectively MRL10, the definition of each grade is as follows:

MRL1: Basic manufacturing implications identified;
MRL2: Manufacturing concepts identified;
MRL3: Manufacturing proof of concept developed;
MRL4: Capability to produce the technology in a laboratory environment;
MRL5: Capability to produce prototype components in a production relevant environment;
MRL6: Capability to produce a prototype system or subsystem in a production relevant environment;
MRL7: Capability to produce systems, subsystems, or components in a production representative environment;
MRL8: Pilot line capability demonstrated; ready to begin low rate initial production;
MRL9: Low rate production demonstrated; capability in place to begin full rate production;
MRL10: Full Rate Production demonstrated and lean production practices in place.

MRL is to evaluate the readiness of technology, components and systems from the perspective of manufacturing. The introduction of MRL can promote the maturity of technology, the stability of design and the improvement of controlled level of production system. In the immature manufacturing environment, the manufacturing cost of products will increase, and it is easy to produce quality problems, and the performance of product performance index is also unstable.

2.2. Grading Requirements
MRL is the judgment index used to measure whether a technology or process has reached the transformation to equipment production, or to determine whether an equipment development project has reached entering the next stage.

In order to fully and completely identify the risks caused by product manufacturing, the existing equipment MRL standards divide the risk factors involved in manufacturing into ten major manufacturing risk factors: industrial foundation and manufacturing technology system, design, technology readiness level, process, materials, equipment and facilities, manufacturing staff, manufacturing management, quality management and cost management. Each risk factor usually includes several sub factors are shown in Figure 1. By comprehensively considering the ten major manufacturing risk factors and their sub factors, the evaluation criteria corresponding to each level of MRL are formed as the basis of MRL evaluation.
Figure 1. Ten major manufacturing risk factors and their sub-factors

2.3. Evaluation Process

Based on the definition of MRL, MRL evaluation uses the attributes of MRL to reflect the characteristics of different levels and the key differences between them. According to the realization of manufacturing risk factors in each attribute, the readiness of each major factor is evaluated. The general process of MRL evaluation is as follows: ① making evaluation plan; ② determining the products to be evaluated; ③ compiling evaluation criteria; ④ self-evaluation of the evaluated party; ⑤ expert group evaluation; ⑥ writing evaluation report.

In the process of self-evaluation and expert group evaluation, the specific judgment process of MRL is to initially determine the level of the products to be evaluated according to the definition of MRL and its basic conditions, and the development and production status of the products to be evaluated. Then select the corresponding level conditions according to the evaluation criteria, and determine the satisfaction one by one. If it meets the requirements of the initial judgment level, it will be evaluated to a higher level until it is not satisfied; if it does not meet the requirements of the initial judgment level, it will be evaluated to a lower level until it is satisfied, as shown in Figure 2.

Figure 2. Determination process of MRL
3. Improve ways of MRL

MRL of HIC is affected by many factors, such as process, materials, equipment and facilities, manufacturing management, quality management and cost management. Intelligent manufacturing uses the combination of new generation information technology and traditional manufacturing, which can realize the effective use of its own intelligent equipment and resources, and make the whole manufacturing process more flexible and intelligent. Therefore, intelligent manufacturing ways such as intelligent equipment, intelligent systems, intelligent warehousing, intelligent Internet of Things (IOT) and big data utilization can effectively improve MRL, as shown in Figure 3.

![Figure 3. Improve ways of MRL](image)

3.1. Intelligent Upgrade of Manufacturing Equipment

The popularization of intelligent equipment and intelligent terminals, as well as the use of various kinds of intelligent hardware such as sensors and intelligent instruments, are the hardware basis for the interconnection of intelligent production lines, intelligent workshops and intelligent factories. Based on the functions of common equipment, intelligent equipment must have the functions of data acquisition, storage, analysis, processing, control, reasoning, decision-making, transmission and management. Intelligent equipment has the functions of data storage, operation, logic judgment and automatic operation, which is the basis of intelligent manufacturing.

Machine vision and perception processing equipment is the core of intelligent equipment. Through the scanning acquisition and analysis of the sample image in the manufacturing process, combined with the background knowledge base to determine the feature state, the quality state of the sample can be confirmed, the efficiency of complex feature detection can be improved, and the manual operation can be reduced. The state data can be collected and analysed by visible light, infrared, laser and other ways to meet the intelligent perception in different application environments and working modes.

Intelligent upgrade of manufacturing equipment also needs to customize flexible, efficient and automatic transmission track, design standard fixture, realize the whole process of track transmission between equipment, and complete the hardware connection and data communication of HIC automatic assembly equipment, chain curing furnace, plasma cleaning and automatic bonding equipment. The new production mode can eliminate the steps of manual transfer, fixture and program replacement in the original process, significantly shorten the production cycle and reduce the number of personnel.

The use of intelligent manufacturing equipment and the effective interconnection between the equipment can effectively promote the realization of data acquisition and intelligent perception in the intelligent manufacturing system, and provide effective data resources for the intelligent decision-making of the overall manufacturing process. Through the intelligent upgrade of manufacturing
equipment, the production efficiency of HIC micro assembly can be greatly improved, the influence of human intervention can be reduced, the quality stability can be improved, and MRL can be improved.

3.2. Intelligent Management System
The intelligent management system integrates HIC manufacturing technology with digital technology, intelligent technology and network technology in the whole manufacturing process, and realizes the perception, analysis, decision-making and control in the manufacturing process. Intelligent management system usually includes Manufacturing Execution System (MES), process management system, equipment status acquisition system, etc.

The main purpose of MES is to realize the communication management and data real-time display between equipment. Through data acquisition, instruction transmission and parameter management, the efficient management, monitoring and effective information feedback of the process are realized. Through MES, the equipment operation can be observed in real time, the process parameters can be monitored and traced, the tasks can be displayed and switched automatically, and programs can be managed remotely and centrally, so as to ensure the stability of the work program.

The process management system is mainly oriented to the production, debugging, maintenance and other links of large and complex equipment. Combined with the actual business needs, it realizes the design, monitoring, scheduling and optimization of key process links. At the same time, combined with the feedback data of the underlying equipment, the real-time analysis of the process state is carried out. Based on the process information, an intelligent decision-making system is constructed to ensure the efficiency and quality of the process execution in the production process.

The core of the equipment status acquisition system is the interconnection of single intelligent equipment. The interconnection of different types and functions of single intelligent equipment constitutes an intelligent production line. Based on the requirements of workshop process management, it realizes the real-time acquisition of workshop equipment status during process execution, and provides the underlying data support for the execution and adjustment of workshop process.

Therefore, the use of intelligent management system can greatly improve the efficiency of manufacturing management and quality management, and effectively improve MRL.

3.3. Intelligent Warehousing and Logistics
The intelligent warehouse and logistics system covers the whole process from sorting to distribution. It uses intelligent machinery and robot technology to realize the automatic sorting and intelligent distribution of samples, effectively improves the internal logistics productivity, reduces the risk of material factors, and improves MRL.

Intelligent sorting system is usually a multi module collaborative system, including image acquisition module, image processing module and robotic arm control module. Intelligent distribution system usually uses robot technology to solve the problem of task description and task allocation of large-scale multi machine system and robot autonomous path planning, and find task allocation algorithm and path planning algorithm of multi robot system with strong adaptive ability.

3.4. Intelligent Interaction of IOT
If the intelligent management system needs to call many big data information of manufacturing process, it must use the new technology of IOT. Build the IOT platform as the perception element of the whole intelligent manufacturing platform, which can realize the collection of intelligent equipment data, environmental data, test data and other data, and the integration of logistics information in the intelligent warehouse and logistics system.

Whether the data information used by the intelligent management system is comprehensive depends on whether the complete information can be collected. Interaction technology of IOT can provide the system with comprehensive full cycle information. Through 5G IOT access technology, using the ultra-high computing power of cloud platform to complete large amount of computing tasks such as real-time image processing and quality detection, realize the ultra-high speed transmission
from terminal equipment to big data platform. At the same time, in order to achieve state awareness and automatic control, all intelligent equipment need to design a data architecture that can realize the automatic collection and transmission of operation data, and provide the "people, machines, materials, methods and environment" in the manufacturing process to the management system in real time to realize intelligent management and control.

3.5. Big Data Analysis and Mining
Based on the hardware of intelligent equipment and intelligent IOT, the process data, test data, quality information and usage information in the manufacturing process of HIC are integrated, the structured data and unstructured data generated by each device are collected, cleaned and mined, and the unstructured data is transformed into structured data. Through data interface, structured data file utilization and image recognition, structured data is gradually incorporated into big data analysis system to analyze and mine the data in the whole manufacturing process.

By extracting and analysing the data in the intelligent management system, the saturation of production tasks, the use of key equipment, and the timeliness index are analysed and predicted to provide decision support for decision-making management. Through the interaction of IOT, obtain the basic data of manufacturing resources, equipment sensor collection data, product status data and product logistics information of intelligent management system and intelligent warehouse logistics system, and deeply mine transaction data, data association rule information, global unified format data, business application optimization knowledge, etc., so as to provide accurate and efficient information for intelligent management system and decision makers.

Through big data analysis and mining, the manufacturing risk of technological process and other factors can be directly reduced, the risk of cost management and other factors can be indirectly reduced, and finally the level of manufacturing readiness can be improved.

4. Conclusion
Intelligent manufacturing comprehensively uses advanced technologies such as cyber-physical systems, IOT, intelligent sensor, big data analysis, cloud manufacturing, and artificial intelligence, it realizes the intelligent upgrading of traditional manufacturing, which is the inevitable direction of future manufacturing development. Through intelligent upgrade of manufacturing equipment, intelligent management system, intelligent warehousing and logistics, intelligent interaction of IOT, big data analysis and mining, etc. for HIC, it can effectively promote the improvement and upgrading of manufacturing risk factors and their sub factors in process, materials, equipment and facilities, manufacturing management, quality management and cost management, so as to improve MRL.

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