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Research status and key technology analysis of integrated circuit lead frame

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Abstract: *With the rapid development of integrated circuits, its lead frame is increasingly high precision, which puts forward higher requirements for the current research status and key technologies. In this paper, the higher requirements and innovations for the structure control of complex alloying, deformation, and heat treatment of high-precision lead frames manufactured by etching are reviewed. The relevant industrial chain at home and abroad and its current situation are introduced. The key manufacturing technology of high-precision etched lead frame is analyzed. At last, the key technology prospect and the development trend of integrated circuit lead frames in our country are discussed.*

Keywords: *Integrated circuit, Lead frame, High etching technology, Industrial chain*

1. Introduction

After decades of development, China's integrated circuit field has formed a relatively sound industrial chain consisting of chip design, chip manufacturing, packaging and testing, semiconductor raw materials, and equipment. With the continuous development of the social economy, it is always in a stable development situation. However, throughout the development of this field, we can see that the global market has been at the end of the industrial chain, limiting the rapid development of this industry field of a variety of arts, among which the most key is the corresponding problem of the lack of technological innovation [1,2]. Therefore, it is important to further improve the manufacturing technology quality and level in the field of the integrated circuit.

In the 1980s, China began to research and development and production of high strength and high conductivity copper calcium lead frame materials, but the lack of independent innovation awareness, only to introduce and copy, no in-depth systematic study of this kind of materials, resulting in a significant gap in technology and quality compared with foreign enterprises[3]. At present, the quality of high-strength and high-conductivity copper alloy materials developed and produced in China simply cannot meet the requirements of super-large integrated circuits, let alone meet the needs of the domestic market. Such materials rely on imports.

With the rapid development of modern technology and the information industry, integrated circuits are developing in the direction of large-scale and super-large-scale, which requires the lead frame material to have higher and better performance [4]. The strength of copper alloy material is 550MPa~600MPa, and the electrical strength is 75%~80%IACS; To achieve the above performance requirements, this kind of high-performance copper alloys are mostly aging strengthened alloys. It is reported that Cu-Cr-Zr alloy is the most ideal copper alloy material. At present, no domestic manufacturers can industrialize the production of lead frame materials Cu-Cr-Zr alloy. For Cu-Cr-Zr alloy, domestic in recent years, Suzhou Nonferrous metal Institute, East China electric furnace Factory, Jiang Wine Academy of Sciences Physics Institute, and other units have been for C18150 Hajin small ingot part of the test research, but from the Yue fraction design and heat treatment in strength, stress recovery and other comprehensive performance compared with foreign enterprises there is still a huge gap [5].

According to statistics, in 2022, the growth rate of the number of Chinese chip design enterprises declined for the first time in recent years, but China's integrated circuit design industry is in a stage of rapid growth. It is expected that the sales volume of the whole industry in 2022 will be 534.57 billion yuan, an increase of 16.5% compared with 458.69 billion yuan in 2021. At present, the development of China's IC design industry presents three characteristics: first, China's huge market size is strong support for the development of the IC design industry; second, the global core shortage phenomenon has boosted the IC market; third, the product technology of enterprises is not high enough and the R&D investment

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is insufficient. At present, the development of China's IC industry has made historic achievements, but it still needs hard work. Under the new development pattern with the domestic large cycle as the main body and domestic and international double cycle promoting each other, backed by the huge scale of China's IC market, enterprises should strengthen their supply chain bottom line, promote innovative technology, and reduce the dependence on foreign advanced and sophisticated technology.

2. Integrated circuit lead frame definition and function

The lead frame is the basic material of integrated circuit packaging. As the chip carrier of the integrated circuit, it realizes the electrical connection between the lead end of the internal circuit of the chip and the external lead wire using bonding materials (gold wire, aluminum wire, copper wire), forming the key structural part of the electrical circuit and playing the role of the bridge connecting with the external wire. See Figure 1. In semiconductors, the lead frame plays the role of stabilizing the chip, conducting signals, and transmitting heat, which needs to have high heat resistance, corrosion resistance, electrical conductivity, thermal conductivity, and other properties.

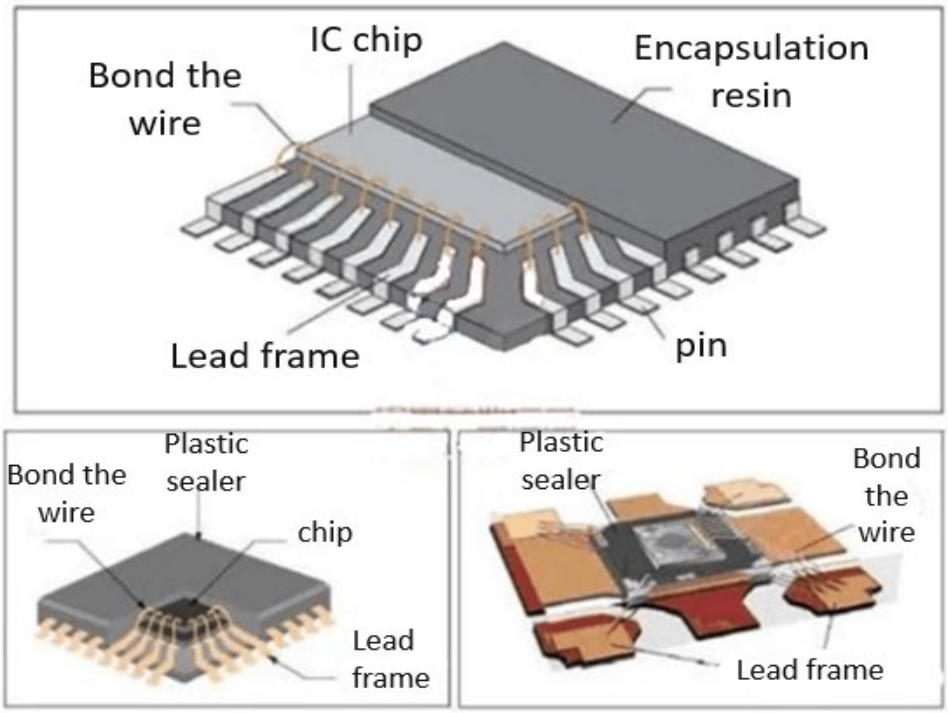

Figure 1: Example of IC lead frame

The lead frame according to the application of different semiconductors can be divided into two categories: lead frame applied to the integrated circuits and lead frame applied to discrete devices. Different types of lead frame applications, and their packaging methods are different. The detailed classification is shown in Table 1.

Table 1: Lead frame domain and package

type	Encapsulation mode
Integrated circuit lead frame	DIP
	SOP
	QFP
	BGA
	CSP
Power semiconductor, LED, Discrete devices Etc.	TO
	SOT

The integrated circuit according to the production process, lead frame can be classified as "stamping lead frame and etched lead frame", in which "stamping lead frame" belonging to low-end products, and "etched lead frame" belongs to high-end products. Among them, packaging materials play a decisive role

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in the upgrading process of packaging technology, and form the development pattern of a generation of packaging and materials. Different semiconductor packaging modes require different lead frames, so the development trend of semiconductor packaging mode determines the development trend of lead frames. Figure 2 shows the lead frame of the QFN type.

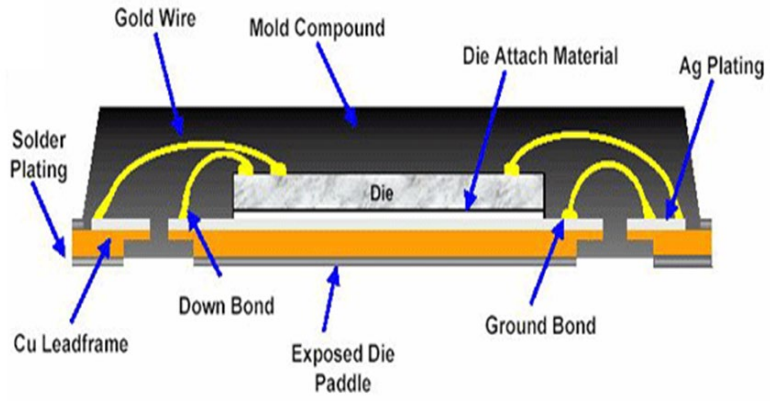

Figure 2: QFN-type lead frame

QFN is similar to traditional QFN, but with an extra circle of inner pins. This method improves the capacity of pins without increasing the package size, and its heat dissipation and reliability are superior. Firstly, based on the design summary of traditional QFN, the pin capacity of double-loop QFN was systematically analyzed, and the design scheme of cut-type double-loop QFN was proposed, including the pin arrangement scheme design, the design of enhanced lead frame binding force, and the simulation analysis of heat dissipation performance through finite element analysis, compared with the traditional QFN, and the different The main parameters to optimize the heat dissipation performance of double-loop QFN were obtained by comparison of parameter changes. After that, the problems existing in the DR-QFN packaging were analyzed, solutions were proposed for each key problem, and the solutions were analyzed and verified by experimental design, JMP analysis, and other methods, including thin lead frame transmission scheme, semi-etched area welding wire realization scheme, plastic sealing parameter selection, and quality optimization scheme.

The lead frame plays a role in connecting with the external wire. Most the semiconductors need to use a lead frame, which is an important basic material in the electronic information industry. The usual types of the lead frames are too, DIP, SIP, SOP, SSOP, QFP, QFN, SOD, SOT, etc., mainly produced by die stamping and etching.

As the lead frame plays the role of bearing an integrated circuit chip in the circuit, it also plays the role of connecting the chip and the electrical signal of the external circuit board, as well as the mechanical role of installation and fixing. At present, we are discussing the design of lead frames used in the high-power circuits, and high-power circuit chips produce high junction temperatures, so the thermal performance of the product must be taken into account in the design process. To achieve a higher heat dissipation effect, we should consider the following aspects: first, the frame structure should be suitable for the transfer of heat energy; Secondly, the heat dissipation medium (that is, the frame and the plastic sealing material) should have good heat conductivity.

The production process of high-density etching wireframe is: high-density lead frame etching method, involving the semiconductor integrated circuit technology field. The following steps are included: S1: clean the copper strip; S2: The dry film is extruded on the copper strip, which is divided into finished and non-finished areas. The copper strip in the non-finished area is bonded with the dry film, and then a corrosion-resistant protective layer is formed by ultraviolet irradiation. S3: Overlay the drawn product graphics on the protective layer of the finished product area, and then get the anti-corrosion mask after exposure and development; S4: Spray the etching liquid onto the surface of the copper strip for corrosion, remove the metal that has not formed an anti-corrosion mask, and then peel the anti-corrosion mask to get the lead frame; S5. Cut out the non-finished area around the lead frame. The flowchart is shown in Figure 3. This article discusses divides the copper strip into a finished product areas and a non-finished product area. The non-finished product area is bonded with the dry film by adhesive, and the non-finished product area is removed after the product molding so that the copper surface and the dry film can be better fitted, and the normal production of high precision and low line distance products can be realized and the product quality can be guaranteed.

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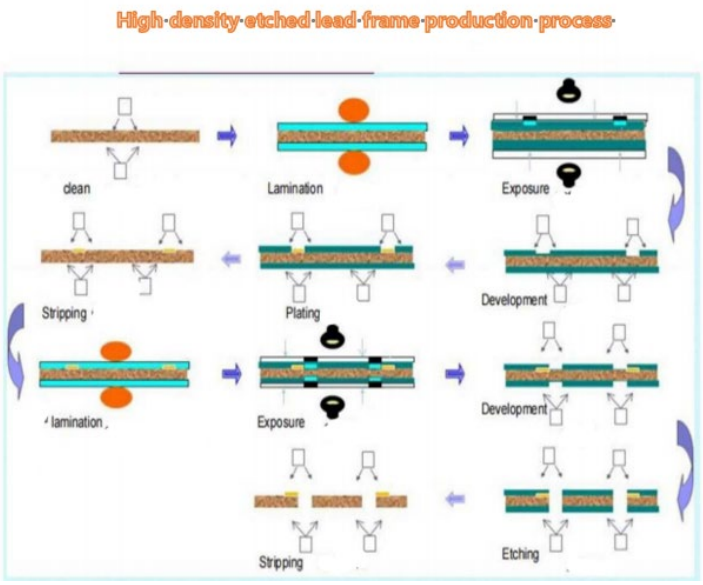

Figure 3: High-density etched lead frame production process

3. Industrial chain analysis and prospect analysis

3.1 Integrated circuit lead frame industry development

Although China's IC industry started late, after nearly 20 years of rapid development, China's IC industry has grown from scratch, from weak to strong. Since 2005, China has become the world's largest IC market economy, accounting for 56% of the global market share, and the IC industry market scale has grown steadily. Has a pivotal position in the globally integrated circuit market. According to the statistics of China Business Information Network, from 2010 to 2020, the sales of China's IC industry showed an overall growth trend, increasing from 144.15 billion yuan in 2010 to 882.19 billion yuan in 2020, with a compound growth rate of up to 20% during the period. With the wave of intelligent upgrading in the manufacturing industry, the demand for high-end chips will continue to grow.

Lead frame and gold wire are special materials for semiconductor/microelectronics packaging and play an important role in the process of semiconductor packaging. Microelectronic or semiconductor packaging, intuitively is the production of chip packaging, for the normal work of the chip to provide energy, control signals, and provide heat dissipation and protection functions.

The lead frame is a key structural component used as an integrated circuit chip carrier, and with the help of bonding wire, the lead end (bonding point) of the internal circuit of the chip is electrically connected with the external lead through the internal lead. In the semiconductor, the lead frame mainly plays the role of stabilizing the chip, transmitting signals, and transmitting heat, need to achieve higher standards in strength, bending, electrical conductivity, thermal conductivity, heat resistance, heat matching, corrosion resistance, stepping, coplanar, stress release and other aspects.

In the lead frame market, many middle and high-end technology products are still in the hands of foreign companies, especially in the field of etching lead frames. Domestic enterprises started late, the foundation is relatively weak, and the production equipment, products, and technology lag behind foreign lead frame enterprises.

3.2 Analysis of the industrial chain of the frame of cable

The upstream industry of the lead frame industry is mainly the copper alloy strip processing industry, and the downstream industry of the lead frame industry is the semiconductor packaging and testing industry. The market scale of the Chinese wire frame. According to the national IC policy and the development status of the lead frame industry, the lead frame market has been expanding in recent years, and the market prospect is broad. According to the data of the China Semiconductor Industry Association, the market size of the lead frame in 2019 was about 8.54 billion yuan, accounting for about 39.50% of the global market size. As the development speed of domestic semiconductor packaging enterprises is faster

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than that of upstream semiconductor packaging material lead frame production enterprises, resulting in domestic lead frame products in short supply, this situation promotes the semiconductor packaging material lead frame production enterprises to continue to expand production and technological innovation. The following chart shows the market size of the Chinese lead frame from 2013 to 2019(Figure 4).

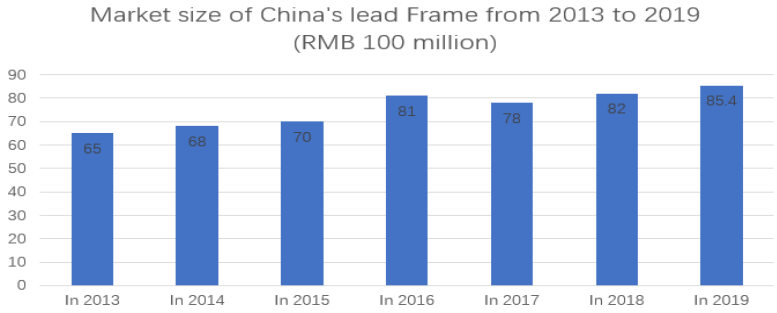

Figure 4: The market size of Chinese lead frame from 2013 to 2019

4. Key technology

4.1 Multicomponent composite alloying

The composition of copper alloy directly determines its basic properties. The composition optimization of high strength and high conductivity copper alloy has been continued for a long time. For high-strength and high-conductivity copper alloys, the influences of Ag, Zr, Y, rare earth, and other elements on the properties of Cu-Cr alloys, and the influences of Co, Al, Sn, P, and other elements on the properties of Cu-Ni-S alloys have been studied in China at present. However, to further improve the performance and realize the coordination of high conductivity and high strength, it is necessary to reveal the microscopic mechanism of the cooperative improvement of the comprehensive performance of alloy elements and the influence of trace elements based on the study of the influence mechanism of a single element on the alloy properties. To realize the strengthening of various mechanisms, the basic research should be based on the first principles, molecular dynamics theory, alloy cluster theory, and crystallographic theory considering the internal correlation between alloy elements, microstructure, and comprehensive properties, and combining theoretical calculation, physical simulation, and specific experiments. The existing form of alloying elements in alloy and its influence on the microstructure of alloy were predicted and analyzed, including the composition, microstructure, morphological characteristics, and interface structure of the strengthening phase, to realize the integrated cooperative control of alloy composition, microstructure and comprehensive properties. By changing the traditional "trial and error" mode to "theoretical prediction and experimental verification" mode, the research period can be shortened and the alloy system can meet the performance requirements can be obtained.

4.2 Complete process of structure control for deformation and heat treatment

Previous studies show that for the same alloy composition, different deformation and heat treatment processes can obtain significantly different properties of the alloy, alloy strengthening mode, processing process, deformation and heat treatment (solution, quenching, aging) combination, solution/aging temperature and time combination, It can directly affect the microstructure and properties of Cu-Cr and Cu-Ni alloys obtained. Since copper alloys used for high-precision etched lead frames have higher requirements for internal stress and surface quality, it is necessary to further study the influence of deformation and heat treatment systems on the surface quality of plate and strip, microstructure uniformity and internal stress under mass production conditions based on the existing alloy preparation technology, so that according to specific performance requirements, Develop more efficient manufacturing packages. In addition, the high precision etched lead frame requires high uniformity, stability, and consistency of copper alloy strip properties. The traditional annealing method in a furnace meets the requirements, and it needs to be carried out by high-temperature online continuous solution treatment.

4.3 Precision forming control technology

The domestic copper alloy strip used for lead frames has long existed some problems, such as excessive internal stress, high surface roughness, and serious surface defects, so it is more difficult to control the

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deformation of high-strength copper alloy. A lot of research has been carried out on the hot deformation behavior of CuCr-Zr alloy in the early stage, which provides a certain basis for optimizing the hot forming process. To further improve the forming quality of the strip, it is necessary to further study the precision rolling technology under the condition of mass production, realize the precise control of the rolling process, improve the dimensional accuracy of the strip, and effectively solve the problems of high surface roughness, a large number of surface defects and deep pits of the strip. The evolution law of residual stress, microstructure, and shape size in the process of tensile bending straightening and low-temperature tensile annealing was revealed, and the action law and collaborative control mechanism of the synergic action of tensile bending straightening and low-temperature tensile annealing on the microstructure, residual stress, shape and size of copper alloy strip were clarified, and a set of control technology of tensile bending straightening and low-temperature tensile annealing residual stress of copper alloy strip was formed. The precision control of strip flatness and shape can be realized.

5. Discussion

5.1 Key technology outlook

The production process of lead frame copper strip is complex, including batching, melting, casting, hot rolling, milling, initial rolling, edging, annealing, pickling, pre-finishing rolling, solid solution, finishing rolling, skimming, bending straightening, shearing, and packaging, etc., as shown in Figure 5. Most of these processes will affect the final performance of the strip. Therefore, important processes must be developed to solve the composition, deformation, and heat treatment, precision forming several key technical problems. The lead frame is the main structure of the integrated circuit and discrete device package, its function is to connect the circuit chip and printed circuit line. At present, the production process of the lead frame is mainly divided into two kinds: high-speed stamping and etching, among which high-speed stamping is the main way, which is suitable for mass production. The etching method is auxiliary, and suitable for new product development. Precision carbide progressive die is the key process equipment for mass stamping of the lead frames at high speed. Hard alloy progressive die requires high precision, complex processing shape, many stations, design difficulty, and manufacturing difficulty (Figure 5).

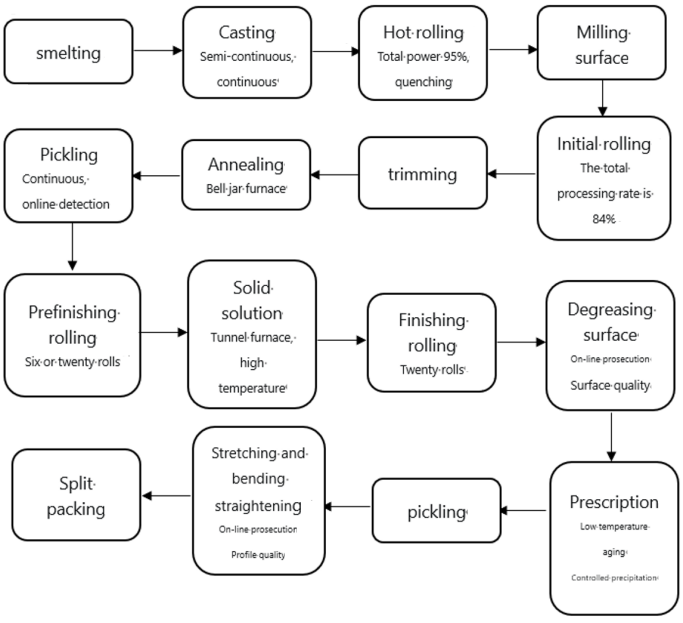

Figure 5: General production flow of copper alloy strip for lead frame

5.2 Development tendency

With the further density of integrated circuit packaging, the etched copper strips will be further thin and thin. The application of high strength and high conductivity copper alloy strips will be accelerated. It is mainly reflected in: first, the copper-nickel alloy material 7027 is further improved based on material, improves the conductivity and hardness, and improves the subsequent electroplating processing

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performance; Second, Cu-Cr 64T is a high strength and high conductivity non-magnetic high-performance copper alloy used for high-density lead frame at present, the consumption is not large, but there is no substitute variety in China. In addition, the strength needs to be further improved, and the introduction of new alloy systems into high-density etched lead frame materials will be accelerated

On the market side, domestic substitution will advance rapidly. Domestic demand for etched copper strip materials has developed rapidly in recent years, and the current environment for domestic substitution has been recognized by all levels of the market. The overall market demand for etching lead frames in China has been large, and it is still expanding. At present, it is mainly imported. The market share of domestic enterprises is still small, and there is a great space for expansion. On the other hand, the demand of etching frame customers for the domestic frame is seen from the perspective of smaller domestic customers (mainly new QFN packaging manufacturers), but up to now, large domestic packaging customers (Tonfu, Huatian, Axa, etc.) have begun to fully cooperate with domestic etching lead frame, promising development prospects.

6. Conclusion

This paper mainly describes the definition and function of IC lead frame, which uses the etching method to manufacture high precision lead frame, summarizes the higher requirements and innovation of the complete set of structure control technology of multi-component composite alloying, deformation and heat treatment, precision forming control technology, introduces the relevant industrial chain and its current situation at home and abroad and analyzes its industrial chain and its prospect. The key manufacturing technology of high precision etched lead frame and its future development and trend are analyzed.

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