# Principal Analysis and Application of Laser Technology in Integrated Circuits

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**Abstract.** Since the constant development of science and technology and the popularization of electronic devices, integrated circuits are also developing in the direction of large scale and high precision. This requires the processing of integrated circuits to be constantly refined. This also prompted the laser technology has become an important processing technology in the manufacturing process of large-scale integrated circuits. Laser processing technology is a non-contact processing, its beam diameter is small, high-energy density, high productivity, stable and reliable processing quality. This paper for the laser welding, laser direct writing, laser detection and laser cleaning overview of the four-laser technology in the application of large-scale integrated circuits. And the working principle, type and process characteristics of these laser technologies are discussed. The development of laser technology has also limited the production of large-scale integrated circuits in some aspects. With the semiconductor laser, excimer laser process continues to mature, laser technology in integrated circuits will continue to expand the scope of application and break through the obstacles.

**Keywords:** Integrated circuit, Laser welding, Laser direct writing, Laser detection, Laser cleaning.

## 1. Introduction

Since the advent of integrated circuits, people have been striving to improve the precision of circuit graphics. The size Very Large-Scale Integration Circuit (VLSI) has reached 120nm, it can be said that the VISL graphics processing achieve the highest precision achieved by mankind to date. Due to the increase in the precision of graphic processing, the quality requirements for the surface of VLSI chips are becoming more and more stringent. Laser technology, as a high-precision, high-stability, non-contact, and maneuverable process, plays an important role in the manufacturing of integrated circuits. This paper mainly discusses the application of laser welding, laser direct writing, laser detection and laser cleaning of these four technologies in integrated circuits.

As the components on integrated circuits become smaller and smaller, the graphics and soldering of components on integrated circuits are constantly being challenged. Chapter 2 of this paper focuses on laser direct writing technology that uses a high-energy laser to etch the surface of a silicon wafer, creating tiny openings that form analog circuits to solve the patterning problem. Chapter 3 of this paper refers to laser welding which has a very high energy density as well as a working radius, which can lead to breakthroughs in the soldering of tiny components. In addition to the fabrication of integrated circuits, assuring their quality is also an extremely important part of the process. Therefore, laser detection, discussed in Chapter 4 of this paper, has become a key technology as well to ensure the quality of VLSI through effective real-time on-line monitoring of quality. In addition to detection, laser cleaning can effectively remove sub-micron particles adsorbed on the surface of integrated circuits, thus ensuring the quality of integrated circuits, which is also discussed in detail in Chapter V of this paper.

All aspects of science and technology are constantly improving and developing, not only integrated circuits but also laser technology. The development of integrated circuits in the direction of large-scale and high precision requires higher processing technology to manufacture integrated circuits. This has led to the research and development of laser technology. With the semiconductor laser, excimer laser process and other technologies continue to mature and develop, but also for the

integrated circuit manufacturing field will eventually come to the breakthrough as well as good prospects for development.

## 2. Laser Welding

### 2.1. Working Principle

Integrated circuits (IC), as highly sophisticated devices, require not only the use of high-heat tools to melt metallic or non-metallic soldering materials, but also a small enough focus of the soldering tool to weld small components on the integrated circuits. Laser welding, with its controlled localized heat input, allows for reduced material and heat loss and precise positioning during the welding process. In laser welding, a high-intensity laser beam is used to heat up the weld material and components. The heat generated by the laser is transmitted to the surface of the workpiece and deeper below the surface, causing the weld material to melt and penetrate the thickness of the workpiece to form a narrow cavity. As the laser welding progresses, the laser beam moves along the joint between the two workpieces to form the weld seam [1].

The absorption rate of the laser beam varies depending on the material to be welded or the temperature of the metal. The absorption of laser light by metal is inversely proportional to the wavelength of the laser light and directly proportional to the temperature and resistivity of the material. The wavelength of solid-state lasers is much shorter than that of CO2 gas lasers. Therefore, YAG pulsed lasers with shorter wavelengths, smaller heat-affected zones, and greater penetration depths are often used for welding high conductivity materials such as Ag, Cu, and Al. Therefore, laser pulse welding is used in the microelectronics industry, with YAG pulsed lasers being the most widely and commonly used.

### 2.2. Types of laser welding in integrated circuits

Pulsed laser welding in integrated circuit manufacturing is divided into three main categories.

(1) Semiconductor IC lead welding. The soldering of IC lead wires is divided into inner lead and outer lead soldering. IC inner lead welding is in the silicon wafer substrate evaporation of a few microns thick layer of aluminum film. This requires that the beam intensity, spot size, and depth of dissolution at the solder joints are all controlled within appropriate limits to avoid damaging the IC tubes. IC outer lead soldering is a sheet-to-sheet soldering of two different metals, a thin aluminum foil and a thin gold-plated phosphor bronze sheet. Since the aluminum foil is much smaller than the thickness of gold-plated phosphor bronze, and the diffusion rate is large, so the aluminum foil will be used as the upper piece of the pulse welding.

(2) IC sealing welding. The packaging of integrated circuits affects the stability of integrated circuits as well as electrical and thermal properties. In order to maintain the high reliability and stability of integrated circuits for a long time using hermetic packaging is the best program. The IC core is hermetically sealed in a metal shell using a laser. The metal cover and the bezel embedded in ceramic are made of Kovar alloy. The use of pulsed repetitive YAG laser focused spot size of 0.6 ~ 0.7mm spot overlap is about half the spot diameter. The use of laser sealing welding, it has a high airtight, high strength, high yield and easy to realize the advantages of automation.

(3) IC repairing. In the production of integrated circuits in the conventional method, often need high voltage, high current, so the production of circuits is easy to damage the adjacent components or circuits, so that the entire integrated circuit block scrap. By using pulsed lasers to form electrical connections on integrated circuits, defective integrated circuits have been successfully repaired, in addition to reconnecting aluminum wiring on integrated circuits where conduction is interrupted. Therefore, mask defect repair is an important task in the fabrication of large-scale and very large-scale integrated circuits [2].

# 3. Laser Direct Writing

## 3.1. Working Principle

Laser direct writing (LDW) is the computer-controlled scanning of a high-precision laser beam that inscribes the design circuitry onto the mask of an integrated circuit. The basic workflow of laser direct writing is to first use a computer to generate the design of the micro-optical components or VLSI mask structure data to be fabricated. Then the data is converted into a direct writing system control data, computer-controlled high-precision laser beam in the photoresist directly scanning exposure. The form of the scanning beam has a single beam, dual-beam approach: single-beam scanning laser direct writing system means that the scanning beam on the adhesive surface is only a beam, through the computer to control the intensity of the laser beam, in order to be placed in the motorized platform for the direct implementation of the photoresist cross-dose exposure, so as to carve out a continuous relief structure. Advantage is that a single beam is relatively easy to control compared to double beam, and the system structure is relatively simple, the disadvantage is that the system on the electronic control and the machine was the precision requirements of the higher and slower scanning speed. After development and etching, the design is transferred to the substrate [3].

## 3.2. Types of Laser Direct Writing Technology

(1) Femtosecond Laser Direct Writing Technology. At the present time, femtosecond laser direct writing technology is a widely used in the preparation of functionalized microfluidic chips. Femtosecond laser writing technology has a unique ultra-short pulse width and extremely high peak intensity. The processing of specific materials by femtosecond laser writing technology mainly utilizes the principle of two-photon polymerization (TPP), and the theoretical basis of TPP is the principle of third-order nonlinear effect of two-photon absorption (TPA). As a mature 3D microstructure processing technology, femtosecond laser shows great potential. The 3D processing capability, the designability of arbitrary shapes, the wide range of processable materials, and the preparation accuracy of tens of nanometers make the femtosecond laser capable of integrating all kinds of 3D microstructures in commonly used microfluidic chips, thus realizing the multifunctional applications of microfluidic chips (Figure 1) [4].

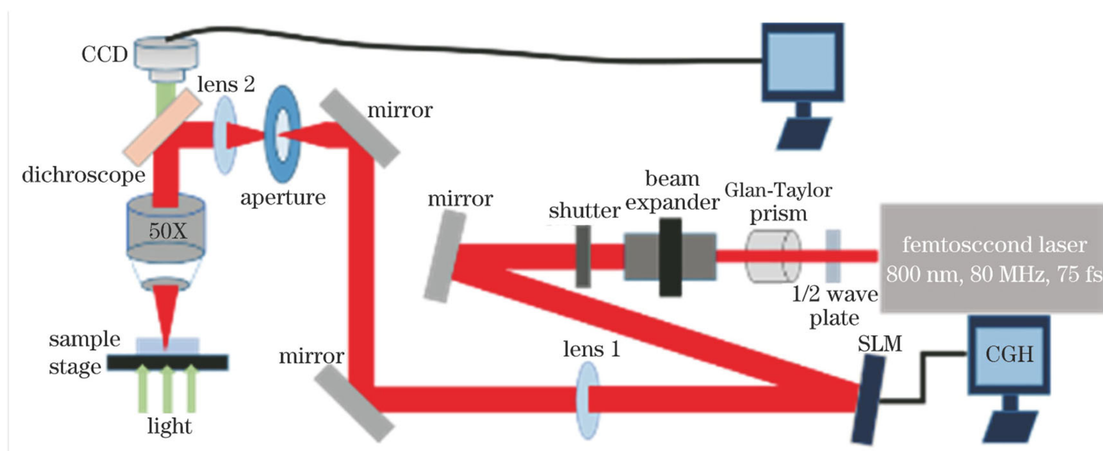


**Fig. 1** TPP processing system (Photo/Picture credit: Original)

(2) High Throughput Laser Nano Direct Writing Technique. High Throughput Laser Nano Direct Writing Technique is an advanced micro-nano processing technology with flexible three-dimensional processing characteristics, especially suitable for the current heterogeneous integration, multi-layer stacking integrated circuit development mode, especially in the development of optoelectronic hybrid devices with the incomparable advantages of step lithography. Meanwhile, compared with electron beam exposure lithography, high-throughput PPI-LDW system is simple, cost-effective, and can realize high-resolution lithography, which is expected to be used in the future for the preparation of integrated circuit mask plates [5].

# 4. Laser Detection

## 4.1. Working Principle

The quality requirements for the surface of large integrated circuits are becoming more and more stringent due to the increased precision of graphic processing. This is because in this case tiny defects on the wafer surface will lead to device failure. When a focused laser beam scans the surface of a wafer, the defects on the surface generate diffuse scattered light. The laser beam in the inspection system is directed perpendicular to the wafer surface, thus obtaining a vertical reflection in the normal area and a wide range of diffuse scattered light caused by surface defects. This scattered light contains a variety of information such as the shape, type, and location of the defect. The scattered light is collected by means of a photodetector. Parameters such as the angle of incidence of the laser beam, the type of filter, the wavelength power of the laser, and the polarization state of the light are selected and adjusted so that the data processing system enhances the detected defect signals, suppresses the noise signals, and ultimately obtains the effects of the detected defects in the observation system [6].

## 4.2. Technical Characteristics

The process of analyzing defect signals by laser defect detection technology is fundamentally different from traditional optical imaging defect detection, and this difference enables laser scanning scattering defect detection technology to achieve high detection speed and accuracy. In the image detection system, the focused beam of light irradiated to the surface of the inspected piece, its reflected light from the optical system and then focus into the photo detector. The enlarged image is decomposed into pixels by a digital camera, and the light energy collected by each pixel is the number of pixels attached to the local average reflected light energy in the irradiated area of the chip, thus the pixel size should be smaller than the object to be measured in order to obtain a high resolution. In a laser scattering inspection system, after the focused laser beam is irradiated onto the wafer surface, the scattered beam does not need to be refocused. After collecting the scattered signals from the defects by the optical components, the light will be concentrated to the photomultiplier tube, using different types of defects in the distribution of the light scattering angle of space, to select a suitable light collection space angle, to achieve a certain type of defects on the high sensitivity of the detection. Since there is no need to decompose the image, the size of the "pixel" is not limited by the size of the defect, and larger pixels can be used. As a result, the laser scanning scattering wafer inspection technique is non-destructive, has high detection speed and sorting rate, and is highly automated and computerized, making it an effective real-time on-line inspection technique for integrated circuits [7].

# 5. Laser Cleaning

## 5.1. Working Principle

Laser cleaning is able to effectively remove sub-micron particles adsorbed on the surface of integrated circuits and is an effective method to ensure the quality of integrated circuits. According to the processing of the surrounding medium and irradiation mode, laser cleaning can be divided into dry laser cleaning, wet laser cleaning and laser plasma shock wave cleaning. Dry laser cleaning refers to the dry or vacuum environment, the use of high-energy laser directly irradiated on the surface of the substrate, so that the pollutants or the substrate to produce instantaneous thermal expansion to overcome the bonding force between the two, or so that the pollutants are directly vaporized volatilization, in order to achieve the effect of cleaning. Wet laser cleaning refers to the laser irradiation before the pre-cleaning of the substrate to be coated on the surface of a few microns thick layer of liquid media film, thin liquid film absorbs laser energy to rapidly produce explosive evaporation, resulting in a strong transient force to make the pollutants loose after the splash, and with the shock wave off the surface of the substrate. Plasma shock wave cleaning refers to the laser beam through the lens focused directly above the substrate, when the energy breaks through the

breakdown threshold of the surrounding gas, the focal point of the position will be ionized, resulting in high-speed outward expansion of the plasma shock wave, when its extension and pollutant particles in contact with the particles will be rolling out of the particles [9].

### 5.2. Technical Characteristics

Dry laser cleaning process is easy to realize, and the cleaning process is easy to control, is currently the most widely used laser cleaning method, but the method of processing energy consumption is relatively large. Wet laser cleaning can reduce the thermal effect produced by the laser action, cleaning requires less energy, higher efficiency, but the thickness of the liquid film is difficult to control, in the laser irradiation produced by the high transient pressure or air bubbles easy to cause damage to the substrate. The method of processing technology requirements is more stringent, and because the laser is not in direct contact with the workpiece, the probability of damage to the substrate is minimized, mainly for precision parts surface contamination particles cleaning [8].

In terms of theory and process, although a large number of experiments have been carried out in the process research of laser cleaning, the theoretical and mechanistic research of laser cleaning is not yet perfect. Although relevant physical models have been established, but these models still have great limitations. In terms of practical application, the laser cleaning process is not mature enough, and the equipment limits the laser cleaning efficiency and precision. High-power short-pulse lasers are a major bottleneck limiting the development of complete sets of high-efficiency laser cleaning equipment [10].

## 6. Conclusion

The application of laser technology in large-scale integrated circuits (ICs) is one of the highlights of laser processing in recent years and is an indispensable tool in the manufacture of large-scale ICs. In laser welding, the laser localized heat input can be controlled, which can make the welding to reduce the loss of material, heat and other losses and achieve accurate positioning. Laser direct writing is a computer-controlled, high-precision laser beam scanning that transfers design graphics directly to the mask of the integrated circuit. The laser inspection system detects defects in the IC by detecting both vertically reflected light in normal areas and a wide range of diffusely scattered light caused by surface defects. Depending on the situation different laser cleaning can be used to remove particulate contaminants from the surface of the IC.

In addition to the application of lasers in the field of integrated circuits, laser technology itself is currently undergoing continuous exploration and breakthroughs. Laser technology is now characterized by at least one dimension in the sub-micron order of magnitude, heralding the real advent of the nano-laser era. At present, nano-lasers are mainly categorized into 2 main groups, lasers based on a variety of novel nanomaterials and nanostructures; and lasers based on plasmonic excitation modes at the interface between metals and dielectrics. Currently, excimer lasers have a wide range of applications in the field of integrated circuits. Excimer laser UV laser due to the short wavelength, single photon energy, suitable for large-scale industrial production is advantageous. However, it also brings problems such as the susceptibility of optical components to damage, and increasing the laser pulse width can effectively solve this problem.

If laser technology wants to continue to develop in the field of VLSI, on the one hand, it is necessary to improve the quality of the laser beam to make it more suitable for large-scale integrated circuits. On the other hand, it is necessary to further study the mechanism and law of the interaction between laser and electronic components and improve the application of laser beam on integrated board from the mechanism. At the same time to address the shortcomings of the laser light source, the development of a new laser light source and the maturity of the process, so that the laser in the integrated circuit to play a greater role. Although laser welding has outstanding advantages over other welding methods, but still has its own limitations: such as the requirements of the welded parts have high assembly precision material surface state is different from the laser absorption rate also changes.

It is still necessary to continue research to solve this problem. With the semiconductor laser, excimer laser process continues to mature, the application of laser technology on integrated circuits will continue to expand and break through the obstacles.

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