Core semiconductor components and related processes

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Abstract. This article systematically reviewed the core components, key technologies, and application directions in the field of microelectronics and micro - nano manufacturing. First off, it introduced the classification, parameters, and functions of substrates (like single - crystal silicon), masks, and thin - film materials. Then it explained the basic process of photolithography, exposure methods, and the control of its key parameters, as well as thin - film preparation methods such as physical and chemical vapor deposition. In terms of applications, it covered typical scenarios in the microelectronics field, like MEMS sensors, and in the biochemical field, such as PCR and gas sensing. Finally, taking the design of pressure sensors as an example, it showed the systematic design process from requirement analysis, structural design to process planning. And it came up with an idea for designing a microfluidic sensor based on CO_2 concentration detection to monitor cell respiration status, which shows the potential of micro - nano technology in interdisciplinary applications.

Keywords: Micro-nano fabrication, Photolithography, MEMS sensors, Microfluidic CO_2 sensing, Semiconductor

1. Core Components

Substrates

Common materials: monocrystalline silicon, quartz, glass, gallium arsenide, etc. Among them, monocrystalline silicon is the mainstream choice due to its strong compatibility with microelectronic processes [1,2].

Classification of silicon wafers: classified by crystal orientation into (100), (110), and (111) types. The (100) type is often used in MOS technology, and the (111) type was used in bipolar transistor technology; classified by doping type into n-type and p-type, which is achieved by adding group III (such as boron) or group V (such as phosphorus, arsenic) impurities [3,1].

Key parameters: diameter (common 100mm, 150mm, 200mm, 300mm), thickness (e.g., the thickness of a 100mm diameter silicon wafer is about 500μm), purity (e.g., heavy metal content ≤ 1ppb), defect density (e.g., extremely low dislocation density), etc [2].

Masks

Manufacturing materials: chromium layer and photoresist coated on a fused quartz substrate, or photosensitive emulsion used [1].

Manufacturing methods: optical pattern generators (manufactured by exposing rectangular areas through shutters), electron beam lithography (capable of manufacturing complex patterns such as curves); low-cost solutions can print patterns on transparent films through high-resolution laser printers [1,2].

Function: define patterns during the lithography process and transfer circuit or microstructure patterns to the photoresist on the wafer surface [1].

Thin-Film Materials

Conductive thin films, including metals such as aluminum, copper, tungsten, and gold, serve as essential components for forming electrical interconnects and electrodes. For instance, aluminum is extensively used in the metallization of integrated circuits, while copper is preferred for high-density interconnects owing to its higher conductivity [2,4].

Insulating thin films: silicon dioxide (thermal oxidation or CVD deposition), silicon nitride (LPCVD deposition), polyimide, etc., used for insulation, masking, and structural support. For example, silicon dioxide can be used as an oxidation mask, and silicon nitride can be used as a KOH etching mask [1,5].

Semiconductor thin films: polysilicon (LPCVD deposition, which can be used for structural layers or electrodes), epitaxial silicon (used for specific device structures), etc [1,5].

2. Application Fields

Microelectronics Field

Integrated circuits: manufacturing devices such as MOSFETs and bipolar transistors, and constructing logic circuits, memory circuits, etc. For example, the self-aligned polysilicon gate process greatly improves the switching speed of transistors [1].

Sensors and actuators: as the core of micro-electromechanical systems (MEMS), such as pressure sensors, accelerometers, gyroscopes, etc [6].

Biochemical Field

DNA amplification: micro-system-based PCR (polymerase chain reaction) devices, which realize rapid DNA amplification by precisely controlling temperature regions [7].

Gas sensing: catalytic combustible gas sensors, which use filament structures made by surface micromachining to detect combustible gases through resistance changes [8,9].

3. Lithography

Lithography process: Lithography is a key process in the production of planar transistors and integrated circuits. It generally goes through processes such as silicon wafer surface cleaning and drying, priming, spin-coating photoresist, soft baking, alignment exposure, post-baking, development, hard baking, etching, and inspection [1].

Exposure methods: Contact exposure where the mask is in direct contact with the photoresist layer, which has high resolution but has the problem of easy contamination and wear of the mask; Proximity exposure where the mask is slightly separated from the photoresist layer, which can avoid mask damage but introduces diffraction effects that reduce resolution [1]. Projection exposure uses a lens to focus light between the mask and the photoresist for exposure, and can be divided into scanning projection exposure, step-and-repeat projection exposure, and scanning step-and-repeat projection exposure. Different types are suitable for different process nodes, improving resolution, and making mask production easier and reducing the impact of defects [1].

Key parameters and control: The most important parameters in exposure are exposure energy and focal length, which affect the resolution and size of the pattern. During the exposure process, it is also necessary to track and control different parameters and possible defects, using detection control chips such as particle control chips, chuck particle control chips, and focal length control chips [1].

4. Deposited Materials

Thin film deposition methods: mainly divided into physical vapor deposition (PVD), chemical vapor deposition (CVD), sputter deposition, and atomic layer deposition (ALD), etc. PVD transfers materials from the target to the substrate surface through physical processes, including evaporation deposition and sputter deposition [5]. Its films have strong adhesion and high density, but have limitations in depositing complex structures; CVD deposits thin films on the substrate surface through chemical reactions of gaseous precursors, and can prepare high-purity and dense films. Different CVD processes such as low-pressure CVD (LPCVD), plasma-enhanced CVD (PECVD), and metal-organic CVD (MOCVD) are suitable for different application scenarios [4, 10].

Material selection: The target, as the deposition source material, has common types such as pure metals, alloys, and ceramics, which are selected according to the requirements of the film properties. Thin film materials need to have chemical stability and thermal stability [4]. For example, the transparent conductive film material ITO is used in displays and solar cells, and the insulating film material silicon dioxide is used for electronic insulation. The substrate is usually a silicon wafer, glass, ceramic, etc. When selecting, it is necessary to consider matching the thermal expansion coefficient with the film [5, 10].

5. Design and Preparation of Simulation

Demand Analysis and Specification Determination

Determine parameters such as pressure measurement range, sensitivity, accuracy, and operating temperature. For example, when designing a pressure sensor for automobiles, factors such as temperature changes and vibrations in the automobile environment need to be considered [11, 6].

Structural Design

Diaphragm design: Determine the diaphragm size (such as side length, thickness). According to the sensitivity requirements, the diaphragm thickness is usually designed to be several micrometers to tens of micrometers. For example, design a diaphragm with a thickness of 10μm to meet specific sensitivity [12, 6].

Piezoresistor design: Determine the position (usually at the edge of the diaphragm, where the strain is the largest), shape, and size of the piezoresistor. A half-bridge structure (one piezoresistor on the diaphragm and one in the non-diaphragm area) is adopted to ensure measurement accuracy [6] [13-15].

6. Conclusion: Process Design Planning

Finally, I would like to talk about a simple sensor design idea by detecting the change in CO_2 concentration produced by cell respiration to reflect the cell growth state.

Cells produce CO_2 through aerobic respiration during growth, and its concentration is positively correlated with cell activity and proliferation rate. Utilize the chemical/physical interaction between CO_2 and specific materials (such as the electrical signal change of pH-sensitive materials, infrared light absorption) to convert the concentration signal into a measurable electrical signal.

Core mechanism: A microfluidic chip is used to integrate a CO_2-sensitive unit. The cell culture chamber is connected to the detection chamber through a microchannel, and CO_2 diffuses to the sensitive area for detection.

Detection methods: Electrochemical method, CO_2 dissolution changes the pH of the electrolyte, or optical method can be selected.

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