# Backend Technology

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**Wafer Test**

Wafer test, also known as wafer probe or electrical die sorting (EDS), is a quality control process in semiconductor manufacturing where each die on a wafer is electrically tested before packaging.

It helps manufacturers identify good and bad dies early—saving cost by avoiding packaging defective ones.

🔄 When It Happens

Wafer testing is performed after wafer fabrication (when all circuits are built on the wafer) and before dicing and packaging.

How It Works

1. The wafer is loaded onto a prober station.
2. A probe card with tiny needle-like contacts touches each die’s bonding pads.
3. Test patterns are applied by Automatic Test Equipment (ATE) to measure:
   * Logic functions
   * Memory access
   * Voltage/current characteristics
   * Timing
4. Pass/fail results are stored and used to create a wafer map.

Why Wafer Test Is Important

* Avoids wasting packaging cost on bad dies
* Helps detect process issues (e.g. contamination, lithography defects)
* Enables yield analysis and process optimization
* Essential for multi-chip modules and stacked die applications

✅ Summary

| Feature | Description |
| --- | --- |
| What | Electrical testing of individual dies on a wafer |
| When | After fabrication, before dicing and packaging |
| Why | To detect faulty dies early and improve yield |
| Tools Used | Prober station, probe card, automatic test equipment (ATE) |
| Output | Wafer map with good/bad die info |

**What Is a Wafer Map?**

A wafer map is a visual representation of the layout and test results of individual dies on a semiconductor wafer. It is used primarily in manufacturing and test processes to:

* Track which dies passed or failed
* Locate defects
* Guide die picking during packaging

Why It’s Important

During wafer fabrication, each wafer contains hundreds to thousands of dies. After electrical testing (wafer sort), a wafer map helps:

* Visualize die performance
* Identify patterns of defects
* Select known-good dies (KGD) for packaging

Key Features of a Wafer Map

|  |  |  |
| --- | --- | --- |
| Element | Description |  |
| Grid Layout | Each cell represents a die location |  |
| Color codes | Show die test results (e.g., pass = green, fail = red) |  |
| Bin codes | Numeric or symbolic codes indicating different test outcomes or die categories |  |
| Die coordinates | X-Y positions for reference or pick-and-place systems |  |
| Edge exclusion zones | Often show dies at wafer edges that are not tested or are marked unusable |  |

## Sawing Methods

### Laser cut:

1a.  What Is Stealth Dicing?

Stealth dicing is an advanced wafer singulation (dicing) technology used in semiconductor manufacturing to separate individual dies (chips) from a wafer without physically cutting through the surface. Instead, it uses a focused laser beam to create an internal layer of weakness deep inside the wafer, allowing the wafer to be broken along those lines later.

Key Concept

Unlike traditional blade or laser dicing, stealth dicing doesn’t cut from the top. It modifies the crystal structure inside the wafer, typically using an infrared laser that passes through the surface and focuses at a specific depth.

1b.Grooving:

1c: full cut

2: Plasma dicing: Plasma dicing is a dry etching technique used in semiconductor manufacturing to singulate (cut) individual dies from a wafer using a reactive plasma. It replaces traditional blade dicing and laser dicing by using chemical etching instead of mechanical or thermal cutting.  Key Concept

Instead of physically sawing or melting through the wafer, plasma dicing uses reactive ions in a plasma chamber to etch narrow trenches in the wafer along the dicing streets (scribe lines), cleanly separating the dies.

⚙️ How Plasma Dicing Works

1. ✅ Photolithography: A masking layer (e.g. photoresist or metal) is applied and patterned to define the dicing lines.
2. ✅ Deep Reactive Ion Etching (DRIE): The wafer is placed into a plasma etching chamber.
3. ✅ Etch Process: A reactive plasma (like SF₆, O₂, or Cl₂) removes silicon or other wafer materials along the patterned lines.
4. ✅ Wafer Singulation: Once the etching goes completely through the wafer, the dies are released.

🧪 Suitable For:

Thick or thin wafers

MEMS, CMOS sensors, power devices

Wafers on tape or carrier substrate

Materials like Silicon (Si), Silicon Carbide (SiC), GaN, and more

3. Mechanical blade:

What Are Quantization Errors?

Quantization error (or quantization noise) occurs when a continuous signal is converted into a digital (discrete) signal, and the process introduces small errors due to rounding or approximation.

In Simple Terms:

Quantization error is the difference between the actual analog value and the nearest digital value it's mapped to during Analog-to-Digital Conversion (ADC).

Example:

Suppose an analog signal value is 2.74 V. If your ADC can only represent values in steps of 0.5 V, it might round to 2.5 V or 3.0 V.  
The difference (e.g., 0.24 V) is the quantization error.

🔢 Where It Happens:

* In ADC (Analog-to-Digital Converters)  
  In digital audio, video, image processing
* In digital control systems and signal processing

🧯 Minimizing Quantization Error

* Increase ADC resolution (e.g., from 8-bit to 12-bit)
* Use dithering (adding noise to randomize error)
* Filter the signal before conversion
* Use oversampling and averaging

✅ Summary

|  |  |
| --- | --- |
| Feature | Quantization Error |
| What | Error from mapping a continuous signal to discrete levels |
| Cause | Rounding during analog-to-digital conversion |
| Effect | Loss of detail, added noise |
| Control | Use higher resolution ADCs, dithering, filtering |

Let me know if you'd like a diagram or formula for calculating signal-to-quantization-noise ratio (SQNR).

## **4: Moulding:**

Moulding is a backend semiconductor process where a protective encapsulant (usually a plastic or epoxy resin) is applied around the die (chip), wire bonds, and part of the substrate or lead frame. This protects the package from:

* Mechanical damage, Moisture and corrosion, Contaminants and chemicals
* Thermal and environmental stress

🔄 Where It Fits in the Process:

1. Wafer is diced into individual dies
2. Dies are mounted on substrates or lead frames
3. Wires are bonded between die and package leads
4. 🔹 Moulding step – encapsulation with resin
5. Final processes: trimming, marking, testing, etc.

#### Why Are Chips Called "Die"?

A "die" (plural: dies or dice) is an individual rectangular piece of silicon that contains a complete integrated circuit (IC). It's what you get after a wafer is fabricated and then diced (cut) into many small pieces.

So, each cut piece of silicon that contains one functioning circuit is called a die.

### What Are **Wire Bonds**?

**Wire bonds** are **tiny metal wires** used to **electrically connect** the **semiconductor die (chip)** to the **external leads** of a package or to a **substrate**. It is a key step in the **backend semiconductor packaging** process.

Wire bonding enables the chip to communicate with the outside world—allowing power, signals, and data to flow in and out of the integrated circuit (IC).

### Where It Happens

Wire bonding is done **after the die is attached** to the substrate or lead frame, and **before moulding** (encapsulation).

### Main Types of Wire Bonding

| Type | Description | When Used |
| --- | --- | --- |
| **Ball Bonding** | Uses a small ball at one end of the wire (common with gold wires) | For high speed and fine-pitch connections |
| **Wedge Bonding** | Wedge-shaped bond made by pressing wire onto the surface (common with aluminum wires) | Often used for power devices |
| **Ribbon Bonding** | Uses flat ribbon-shaped wire | For high-current or RF applications |

# SENSOR CHARACTERISTICS & SELECTION

## Sensor Characteristics & Terminology

In semiconductor manufacturing, sensor sensitivity refers to the ability of a sensor to detect and measure small changes in a physical or chemical parameter (e.g., temperature, pressure, gas concentration, particle count, or electrical properties) during the fabrication process. High sensitivity ensures precise monitoring and control, which is critical for maintaining yield, quality, and process consistency.

Key Aspects of Sensor Sensitivity in Semiconductor Manufacturing:

1. Detection Threshold
   * The smallest change in a parameter that a sensor can reliably detect (e.g., detecting minute temperature fluctuations in a rapid thermal processing (RTP) chamber).
2. Signal-to-Noise Ratio (SNR)
   * High sensitivity requires minimizing electronic noise to distinguish true signals from background interference.
   * Example: In plasma etch monitoring, sensors must distinguish subtle changes in optical emission spectra despite plasma noise.
3. Response Time
   * A sensitive sensor must react quickly to process variations (e.g., gas flow sensors in CVD/ALD chambers must adjust in milliseconds to prevent film non-uniformity).

Sensor resolution in semiconductor manufacturing refers to the smallest detectable change in the physical quantity that a sensor can reliably measure. It defines the sensor’s measurement granularity—how finely it can distinguish between small variations in parameters such as temperature, pressure, chemical composition, etc.

🔍 Definition

Sensor resolution is typically expressed in the same units as the measured variable. For example:

* Temperature sensor: 0.01 °C
* Pressure sensor: 0.1 Pa
* Optical alignment sensor: nanometers (nm)

Resolution ≠ Sensitivity

* Sensitivity is how much the output changes in response to a unit change in input.
* Resolution is the smallest measurable change the sensor can detect.  
  A sensor can be highly sensitive but still have poor resolution if its output is noisy or imprecise.

 Resolution vs. Sensitivity vs. Accuracy

| Term | Definition | Example |
| --- | --- | --- |
| Resolution | Smallest detectable change | A pressure sensor resolving 0.1 mTorr differences in a vacuum chamber. |
| Sensitivity | How much the output changes per unit input | A gas sensor detecting 1 ppb of a dopant gas. |
| Accuracy | How close the measurement is to the true value | A CD-SEM measuring a 10nm line width with ±0.2nm error. |

* A sensor can have high resolution but poor accuracy (e.g., detects tiny changes but with a bias).
* High sensitivity helps achieve better resolution, but noise can degrade performance.

Sensor accuracy in semiconductor manufacturing refers to how close a sensor’s measured value is to the true or actual value of the physical quantity being monitored (e.g., temperature, pressure, gas concentration, particle size, etc.). It is one of the most critical performance metrics for sensors used in the highly precise and controlled environment of semiconductor fabrication.

**Terms and Meaning**

**Silicon Epitaxy** is a process used in semiconductor manufacturing to grow a thin, single-crystal layer of silicon on a silicon substrate (wafer) with the same crystallographic orientation. The term "epitaxy" comes from the Greek words *epi* (upon) and *taxis* (arrangement), meaning the growth of a crystalline layer on a crystalline substrate.

Purpose:

* + To create high-purity, defect-free silicon layers for advanced semiconductor devices.
  + Used in transistors, diodes, and integrated circuits (ICs) to improve performance.

Plasma: The Fourth State of Matter

Plasma is an ionized gas consisting of free electrons, positively charged ions, and neutral atoms/molecules. Unlike solids, liquids, or gases, plasma contains charged particles that respond strongly to electromagnetic fields, making it electrically conductive and highly dynamic.

Key Characteristics of Plasma

1. Ionization
   * Gas atoms/molecules lose or gain electrons, creating free electrons (+) and ions (-).
   * Example: Lightning (air ionizes into plasma).
2. Quasi-Neutrality
   * Overall, plasma is electrically neutral (equal + and - charges), but locally, imbalances can occur.

**How is Plasma Formed?**

Plasma is created when a gas gains enough energy to strip electrons from atoms:

* Thermal Ionization (High temperature, e.g., stars, welding arcs).
* Electrical Discharge (High voltage, e.g., neon signs, lightning).
* Laser/Radiation (High-energy photons knock out electrons).

Applications of Plasma

1. Semiconductor Manufacturing
   * Plasma Etching: Removes material precisely (e.g., in chip fabrication).
   * Plasma Deposition: Deposits thin films (CVD, PVD).
2. Energy
   * Nuclear Fusion (Tokamaks like ITER use plasma to replicate star power).
   * Lightning Protection (Diverts strikes via ionized paths).
3. Lighting & Displays
   * Neon signs, plasma TVs.
4. Medical & Sterilization
   * Plasma scalpels (bloodless surgery).
   * Killing bacteria on medical tools.
5. Space & Astrophysics
   * Stars (including the Sun), interstellar gas, auroras.

Plasma vs. Gas

| Property | Gas | Plasma |
| --- | --- | --- |
| Conductivity | Insulator | Conductor |
| Particle Behavior | Independent collisions | Collective motion (waves, instabilities) |
| Response to Fields | Weak | Strong (shaped by E/M fields) |

Challenges with Plasma

* Containment: Requires strong magnetic fields (fusion reactors).
* Instabilities: Turbulence disrupts controlled reactions.
* Heat Management: Extreme temperatures damage materials.

### **Why is Plasma Important?**

* **96% of the visible universe** is plasma (stars, nebulae).
* Critical for **advanced tech** (chips, fusion energy, space propulsion)

**A mass separator:**  is a device that sorts ions or particles based on their mass-to-charge ratio (\*m/z\*). It is widely used in:

* Semiconductor manufacturing (ion implantation, doping).
* Nuclear physics (isotope separation).
* Mass spectrometry (chemical analysis).

**The Hall Effect**: is a physical phenomenon in which a voltage (called the Hall voltage) is generated across an electrical conductor or semiconductor when it carries an electric current and is placed in a magnetic field perpendicular to the current flow.

**How It Works**

1. Current Flow: When a current-carrying conductor or semiconductor is placed in a magnetic field, the charge carriers (electrons or holes) experience a force due to the magnetic field (Lorentz force).
2. Deflection: This force causes the charge carriers to deflect to one side of the material.
3. Voltage Build-Up: As charge accumulates on one side, an electric field builds up across the material perpendicular to both the current and magnetic field.

Sputtering is a physical vapor deposition (PVD) process used in semiconductor manufacturing to deposit thin films of materials (such as metals, oxides, or nitrides) onto a substrate, typically a silicon wafer. It works by ejecting atoms from a solid target material and allowing them to condense on the wafer surface, forming a thin film.

**How Sputtering Works**

1. Vacuum Chamber: The process takes place in a vacuum to prevent contamination and allow controlled film deposition.
2. Inert Gas Introduction (usually Argon): A gas like argon (Ar) is introduced into the chamber at low pressure.
3. Plasma Generation: A high-voltage electric field ionizes the argon gas, forming a plasma of Ar⁺ ions and electrons.
4. Ion Bombardment: The Ar⁺ ions are accelerated toward the cathode (target), which is made of the material to be deposited (e.g., copper, titanium, or tungsten).
5. Ejection of Target Atoms: When the energetic Ar⁺ ions hit the target, atoms are knocked off or "sputtered" from its surface.
6. Deposition on Substrate: These free atoms travel through the vacuum and deposit onto the substrate (wafer), forming a thin, uniform film.

An antiferromagnetic layer is a thin film of material in which the atomic magnetic moments of adjacent atoms or ions are aligned in opposite directions, effectively cancelling each other out. This results in no net macroscopic magnetization, even though the material has strong internal magnetic ordering.

Antiferromagnetism is a magnetic ordering in materials where neighboring atomic spins align in opposite directions (↑↓↑↓), resulting in zero net magnetization in the absence of an external field. Unlike ferromagnets (parallel spins) or ferrimagnets (unequal antiparallel spins), antiferromagnets exhibit cancelling magnetic moments.

**Tunnel Magnetoresistance (TMR)** is a quantum mechanical effect where the electrical resistance of a magnetic tunnel junction (MTJ) changes dramatically depending on the relative alignment of magnetic layers (parallel vs. antiparallel). This phenomenon is crucial for spintronics, MRAM, and high-sensitivity sensors.