WIP: Machine Learning Applications in Silicon / Wafer Manufacturing

Leon Knorr[1]
[1]Mannheim Master of Datascience

Student ID:1902854
Keywords: Manufacturing, AI, Silicon, Waver
21st May, 2023

1 Introduction

The semiconductor industry plays a pivotal role in driving technological advancements across various sectors, including electronics, communications, and computing. The production of high-quality semiconductor wafers is a critical step, as these wafers serve as the foundation for manufacturing integrated circuits and microchips [1]. As the demand for smaller, faster, and more powerful devices continues to grow, the need for efficient and accurate wafer manufacturing processes becomes increasingly important. In recent years, Artificial Intelligence (AI) has emerged as a transformative technology, offering unprecedented opportunities for enhancing the semiconductor manufacturing workflow [1, 2]. Especially machine learning (ML) algorithms, have the potential to revolutionize semiconductor wafer manufacturing by providing intelligent solutions for quality control and process optimization. For example, traditionally, wafer inspection and defect detection have been labor-intensive and time-consuming tasks performed by human operators, leading to potential errors and inconsistencies. In addition, human operators operate without using every bit of the vast amounts of data available in a wafer manufacturing fab. Each machine of the manufacturing process is equipped with hundreds of sensors, that measure the conditions of the current process [3]. However, the integration of AI into the manufacturing process can significantly improve these aspects, enabling real-time, automated, and highly accurate detection and classification of defects [4]. Aside from defect detection, semiconductor manufacturing poses a lot of potential applications where AI can thrive and enhance the capabilities of a manufacturing plant. This paper aims to explore various applications of AI and machine learning in a semiconductor manufacturing process by explaining them and discussing their impact on the industry.

2 Approach

First, the manufacturing process of semiconductors is defined and the performance indicators for semiconductor manufacturing factories are laid out. Afterwards, a survey of current applications of AI in the manufacturing process is presented. During the survey, each field of application is explained, and different approaches are laid out and discussed.

3 Semiconductor Manufacturing

In this section, an overview of the process of semiconductor manufacturing, as well as important definitions are presented.

3.1 The Manufacturing Process

The manufacturing of semiconductors is a highly delicate and complicated procedure [5]. It consists of hundreds of processes, where the input materials are processed according to the given recipes. These processes can be summarized into four stages:

- Wafer Formation
- Front End Processing
- Testing
- Packaging

Each of these stages is presented in detail in the following section.
It is important to note, that this section only presents the basics of the manufacturing process and that it could've been altered or optimized for different recipes or to improve yields. As a result, some steps mentioned later on during the discussion of AI applications in this industry may not be listed here but are explained as needed.

3.1.1 Wafer Formation

During Wafer Formation, a so-called wafer is created. A wafer is a thin slice, often of a round shape, of extremely pure crystalline material. Usually silicon crystals are used. These wafers serve as the foundational material for microelectronic devices [2]. Each Wafer will hold multiple dies, where a die refers to one specific microchip. After a wafer is formed, it is organized into "Lots". Each lot contains up to 25 wafers, which are processed together, using the same recipe and configuration at each step in the applied recipe [2]. After Wafer Formation, the formed wafers will continue to Front End Processing.

3.1.2 Front End Processing

Front End Processing, encompasses the creation of transistors on a silicon wafer. It is performed in special "clean rooms", where dust, vapor and other pollutants are kept at a minimum. This is achieved through air filtering and strict access policies [2]. Each step in the Front End Process is repeated multiple times, to produce multiple interconnected layers on a wafers surface.
First, a Lot of wafers runs through *Wafer-cleaning*. In this step, each wafer is cleaned, such that is has a surface which is as smooth as possible. This is important, as following processes have strict requirements concerning surface smoothness and particle contamination. If one of these requirements are not fulfilled as good as possible, it can lead to defective dies later on in the process and reduce yields [2].
After Wafer-cleaning, each wafer is run through a process called *deposition*. During deposition, a dielectric and polysilicon film is applied to each individual wafer [2]. This film serves as the foundation for *Photo Lithography*. During Photo Lithography, an ultraviolet radiation is transmitted through a *photomask* to create circuit patterns according to the recipes. The radiation travels through the non-opaque parts of the mask and reacts with the previously applied film, which is coated onto the wafers surface as a result [2]. As this mask essentially burns in the required circuits into the film, the mask has to be aligned as accurately as possible, with only very small tolerances.
After Photo Lithography, the lot of wafers are passed on to *Etching*. During Etching, unused chemicals and layers are removed from a wafer. In the etching process, the circuits patterned onto the wafer using the resistant film, during Photo Lithography, serve as a masking material

which resits the etchant. As a result, the patterned circuits are transferred onto the wafer by removing unnecessary material, layers and chemicals [2].
After Front End Processing is complete, and all needed circuits are transferred onto the actual wafers, each wafer lot proceeds to Testing.

3.1.3 Testing

During Testing, each circuit is tested for functionality and defects. Two different types of tests are carried out:

Parametric Tests Parametric Tests are performed to monitor the efficiency of the process and the quality of the design. It is measured on ad-hoc structured prepared onto the device, and consists of electrical measurements of physical quantities, such as impedance, capacitance and resistance [2].

Electrical Tests Electrical Tests, verify that each die works within specifications, and that its behavior is consistent. If a die performs out of spec, it is marked with a small dot of ink and the passing / non-passing information is stored in a *wafermap* [2].

After testing, the manufactured wafers proceed to *Packaging*.

3.1.4 Packaging

In Packaging, the wafers are sawed into pieces, which only include one die at a time. Then, electrical connections, such as Pins etc., and Integrated Heat Spreaders (IHS) are added to the chip to protect it from mechanical and environment stress, as well providing a proper thermal path for the heat the chip generates under load [2].

3.2 Performance Indicators of Semiconductor Fabs

As with any manufacturing process, semiconductor factories have certain indicators, that represent their efficiency, competitiveness and success. The two main Indicators are the Yield and costs of the manufacturing process [1, 4]. The yield of the process refers to the total amount of chips produced for a given recipe. Yields of a certain ordered chip can vary a lot depending on the state of the equipment, the raw materials, procedures applied etc. Improving Yield, will also decrease costs, as the process gets more efficient and less material has to be used to produce the same number of chips, or if seen the other way around, more chips can be produced for the same amount of material and costs. Improving yield, will also increase the competitiveness of a given factory, as offered pricing can be adjusted accordingly [1]. As yield is influenced by a lot of measurable factors, which in return involves a lot of data, applications around yield optimization are the primary ares of use for AI applications [6]. In reality however, a lot more indicators are present to define the competitiveness of a semiconductor factory, such as the smallest available node size, which influences the power efficiency of a chip and allows the packaging of a lot more transistors onto the same die size.

4 AI Applications

4.1 Virtual Metrology

4.2 Defect Detection

4.3 Yield Management

4.4 Cycle Time Optimization

4.5 Predictive Maintenance

5 Conclusion

6 References

1. Batool, U., Shapiai, M. I., Tahir, M., Ismail, Z. H., Zakaria, N. J. & Elfakharany, A. A Systematic Review of Deep Learning for Silicon Wafer Defect Recognition. *IEEE Access* **9.** Conference Name: IEEE Access, 116572–116593 (2021).
2. Susto, G. A., Pampuri, S., Schirru, A., De Nicolao, G., McLoone, S. F. & Beghi, A. *Automatic Control and Machine Learning for Semiconductor Manufacturing: Review and Challenges* en. in *Proceedings of the 10th European Workshop on Advanced Control and Diagnosis (ACD 2012)* (Technical University of Denmark, Kgs. Lyngby, Denmark, 2012).
3. Kim, D., Kang, P., Cho, S., Lee, H.-j. & Doh, S. Machine learning-based novelty detection for faulty wafer detection in semiconductor manufacturing. en. *Expert Systems with Applications* **39,** 4075–4083 (Mar. 2012).
4. Yuan-Fu, Y. *A Deep Learning Model for Identification of Defect Patterns in Semiconductor Wafer Map* in *2019 30th Annual SEMI Advanced Semiconductor Manufacturing Conference (ASMC)* ISSN: 2376-6697 (May 2019), 1–6.
5. *A machine learning approach to yield management in semiconductor manufacturing* en.
6. Jiang, D., Lin, W. & Raghavan, N. A Novel Framework for Semiconductor Manufacturing Final Test Yield Classification Using Machine Learning Techniques. *IEEE Access* **8.** Conference Name: IEEE Access, 197885–197895 (2020).