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Due Date -- Wednesday, October 26, 2016

Case 4: Greenfield Technologies Startup

Topics: **Microelectronics manufacturing; Integrated Fab; Material Handling Systems (MHS); Work In Progress (WIP); Scheduling; Integrated production planning and material handling**

Background

Integrated Circuits (IC), a.k.a. chips, micro-chips, or nano-chips are touching every aspect of our life. They are used in computers, cars, smartphones, robots, microwaves, TVs, toys, computer games, grocery store checkouts, production machines, material handling equipment, ATMs, etc. What are these IC devices and how are they manufactured? An IC can be defined as a collection of electronic circuits working together in accordance with the laws of semiconductor physics. Today, ICs can contain several billion transistors and components in an area as small as the size of your finger nail. The distance between them in the IC "facility layout" can be measured in several nanometers. Their development is a major driver of the information revolution, automation revolution, and digital revolution. (Read about IC generations through VLSI, up to ULSI and 3DIC.) How do we design and improve their manufacturing and production systems?

A typical Metal Oxide Semiconductor (MOS) transistor "device" is shown in Figure 1.

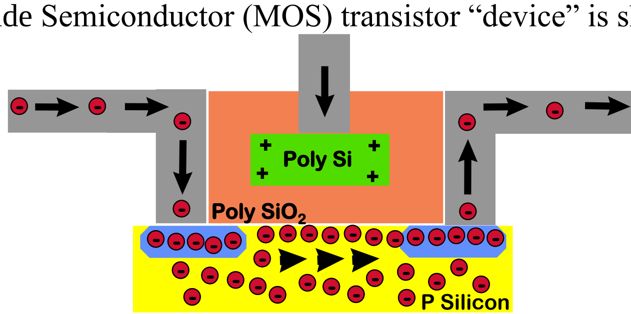

Figure 1 A MOS Transistor

The regions shown in Fig. 1 purposely have certain material properties which are generated by using a series of mechanical and chemical processes known as the *wafer fabrication*. This process is done in a "clean room" where air, temperature, personnel, process chemicals, and gases are all carefully controlled to prevent defects due to micro- and nano-contamination. A critical dimension (smallest geometry) on a transistor could be as small as less than a micron ($1X10^{-6}$ m). Just one unwanted microscopic particle could scrap the entire part. Production of Integrated circuit in high volume is typically achieved through the following main stages and processes, as shown in Figure 2.

A key difference in the wafer fabrication, compared to traditional manufacturing processes, is the high precision and repeatability of the process. Also, with the constant changes and drive for new designs to shrink feature size (hence, gain higher processing speeds), a wafer fabrication production facility layout must be highly flexible to changes in replacing older generation machines with the new advanced systems. A typical product cycle has been 3~5 years.

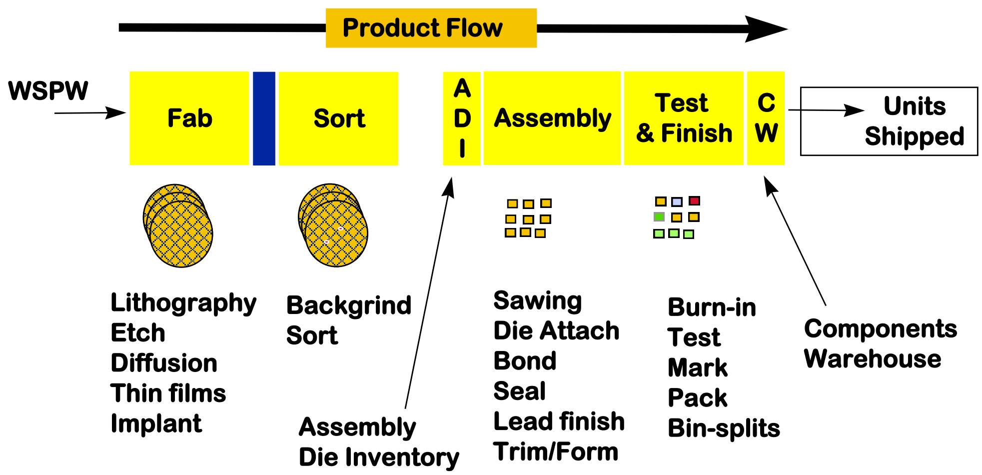

Figure 2 IC Production Flow

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Case Description

IC demand and growth has been astonishing over the last decades. Since its birth in the 1950's the annual sales have reached over $2 trillion with over 23% compound annual growth (see references on Internet.). *Greenfield Technologies* (*GREEN-T*) sees a great opportunity in this field, despites its ups-and-downs in the global market in recent years due to softness in the global economy. Nevertheless, it is preparing plans in place for launching a startup company.

GREEN-T has invented a new semiconductor design and process that can introduce a competitive microprocessor to the market 3 times faster than the best product to date. The company has a strong financial and capital venture backup to set up the factory. Therefore, fixed cost to purchase machines and set up the factory is not an issue. However, the key ingredient for success is to ensure timely delivery of products with highest possible quality at a minimum cost.

GREEN-T is asking your team to provide a recommendation on the initial setup of their "fab" by applying your Industrial Engineering techniques and quantitative analysis. An experienced employee will provide you (here) with all the information you need (?) in order to make your recommendation. Key areas of interest include:

1. Number of machines required in the fab as a function of time
2. Capacity outlook as a function of time
3. Optimal layout
4. Suggestion on the most suitable material handling system and justification ROI
5. WIP planning and control strategy
6. Indicators to track the production performance of the factory
7. Focus areas to improve "Yield" and direction on implementation.

In the following sections you will find the pertinent information and the constraints for your assumptions and analyses.

1. Key Equipment States and Definitions

Equipment states that should be used for your analysis in this case study are as follow:

Availability (A) of a machine is defined as the total uptime of a machine. During this period the equipment CAN be used to provide its intended function or purpose. Utilization (U) or "Productive time" is the duration that equipment is in the process of performing added value tasks to/on products; it is generally referred to as the time "the machine is running parts". Gap or "standby Time" is defined as A (minus) U (see Figure 3).

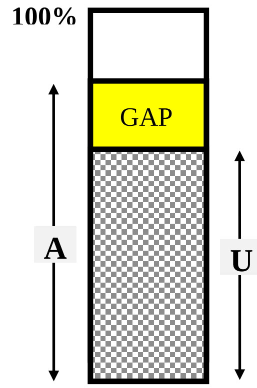


Figure 3 Equipment States

SEMI E10-96 provides the standard definition of equipment states in semi-conductor manufacturing as follow (Figure 4):

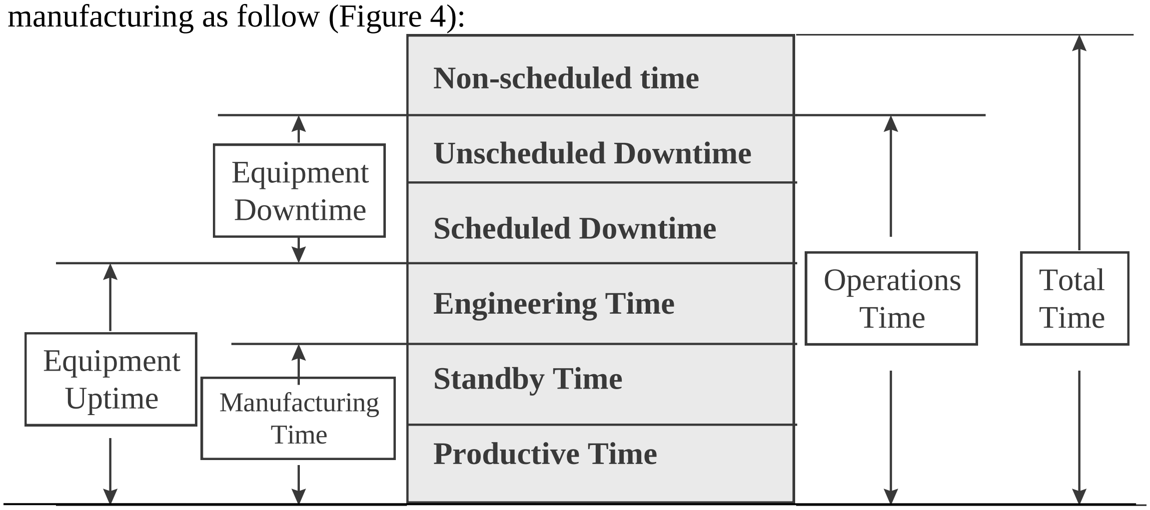


Figure 4 E10 Standard Definitions of Equipment States

- *Productive Time*: The machine is performing its intended function. This includes processing wafers, loading, and unloading.
- *Standby Time*: Machine is available, but is not being used. Reasons include no product, no operator, and host computer system down.

- *Engineering Time*: Equipment is used to conduct engineering experiments.
- *Scheduled Downtime*: Equipment is not available due to planned downtime events.
- *Unscheduled Downtime*: Machine is not available for use due to an unplanned downtime event. Events include rebooting, recycling software, changing chemicals, out-of-spec input, essentially any condition which interrupts the machine from performing its intended function.
- *Non-scheduled Time*: Time when machine is not intended to be used, including holidays and weekends.

2. Operational Environment

- The Fab (factory) operates 24/7 = for 7 days per week, 24 hrs per day.
- There are 3 shifts per day.
- Everyone in the Fab must wear a “bunny” suite before entering the clean room area.
- Safety of the people is the top priority. There must be an easy and clear exit path in case of emergency.
- Production demand is measured in terms of wafers/week. A *wafer* is the foundation that is used to build ICs. Wafers are transported in “cassettes” which are stored in a box known as a “lot”. On average, assume there are 20 wafers per lot.
- After each process the wafers are inspected for any mis-processing issues.
- Lots must be handled with gentle care (no vibration) to minimize the damage or risk to the yield (number of good parts on a wafer).
- Several experimental engineering and development projects often run as priority lots in the factory with unique process flows and machine setups.

3. Products and Processes

The company will utilize the following fabrication processes, as shown in Table 1.

Table 1 Production Process and Descriptions

No.	Process	Description
1	Oxidation	Process of growing a layer of silicon dioxide onto a wafer
2	Lithography	Process in which the pattern of the IC components is transposed onto a wafer using light
3	Wet Etch	Process of removing material from a wafer by using chemicals
4	Dry Etch	Process of removing material from a wafer by using plasma gases
5	CVD	Chemical Vapor Deposition is a process for forming a stable compound over the substrate by thermally reacting gaseous material on the surface
6	Implant	Introducing ion dopants into a wafer by “bombarding” onto the surface to penetrate
7	Sputtering	Technique used for depositing metal onto a wafer
8	Passivation	A thin layer of nitride is deposited on to the metal layers to protect it

Products and routes are described in Table 2.

Table 2 Products and Routes

No.	Product Name	Production Route	Frequency
A	Jupiter II	1,2,1,2,6,1,3,1,5,2,4,2,6,2,6,1,5,2,4,7,2,4,5,2,4,7,2,4,8,2,3	1.8 GHz
B	Saturn Lt	1,2,1,2,6,1,2,6,1,3,1,5,2,4,2,5,3,5,2,4,6,2,6,1,5,2,4,7,2,4,8,2,3	750 MHz
C	Moonlight Pro	1,2,1,2,6,1,2,4,1,3,1,5,3,5,6,2,4,1,2,6,2,6,5,2,4,2,6,1,5,2,4,7,2,4,5,2,4,7,2,4,8,2,3	3.6 GHz

Product demand outlook estimates in wafers/week are shown in Table 3.

Table 3 Product Demand Outlook

	Q1’17	Q2’17	Q3’17	Q4’17	Q1’18	Q2’18	Q3’18	Q4’18	2019	2020
A	100	200	300	400	500	650	900	1000	500	250
B	500	700	1000	1250	1500	2000	1000	900	450	100
C	0	0	0	100	850	1250	1500	1250	600	300

4. Equipment Metrics and Product Run-rates

Machine metrics and assumptions are shown in Table 4.

Table 4 Machine Metrics

Process Machine	Avail. (%)	A wfr/hr	B wfr/hr	C wfr/hr
Oxidation	85	25.3	30.2	25.5
Lithography	60	23.2	27.5	24.6
Wet Etch	80	100.5	93.2	126.5
Dry Etch	60	15.5	17.2	12.5
CVD	85	32.9	35.4	25.3
Ion Implant	60	60.0	75.3	72.7
Sputtering	70	50.2	45.8	36.2
Passivation	85	33.5	35.4	32.7

Assume:

- Gap = 15%
- Rework = 10%
- Yield = 80% (except for Litho which is 70%)
- Engineering/re-engineering time requirement = 20 hrs/wk

5. Facility Layout

AutoCAD plan view of the facility is shown in Figure 5. In addition, the block layout diagram and the process machines (1~8) are shown and labeled in Figure 5.

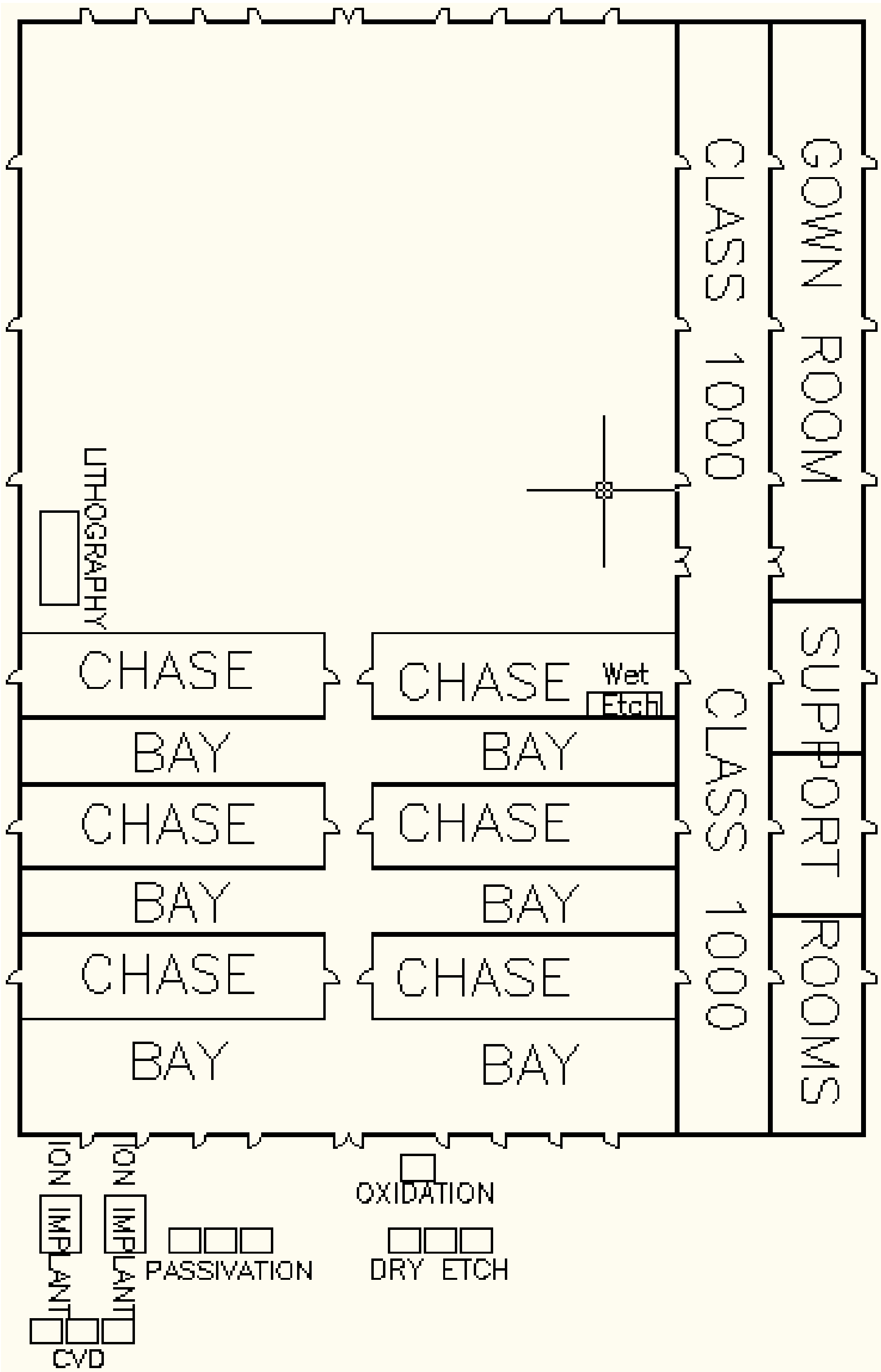
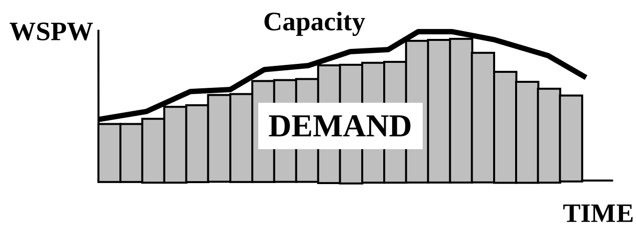


Figure 5 Plan View

Tasks

1. Our company has been advised by financial consultants to purchase and install machines only when they are needed to support production demand.
   a) What is the justification for the above advice?
   b) Apply linear interpolation to smooth out the factory demand for product A in order to obtain weekly demand.
   c) Determine the total number of process machines that are required as a function of time for product A.
   d) Draw a "Capacity outlook graph" to show total capacity and demand as a function of time. (Hint: Use Excel for calculation and graph, and for sensitivity analysis. See a simple sample below).



e) Indicate on your graph when you require the Nth machine to be up for production to support your capacity requirements.

2. Apply your IE skills to determine and recommend an optimal layout of the factory to support production of our products. Use Figure 5 for the plan view of the building. Place machine blocks in the facility layout configuration that you recommend. Explain and justify your recommended layout.

3. The company has learned that having a material handling system (MHS) to transport products will help to minimize risk to the yield.
   a) Investigate and recommend your selection for the most suitable MHS. Justify your reasoning by providing a Return on Investment (ROI) analysis. Clearly state your assumptions.
   b) Draw your design (call it "*MHS Design A*") on the facility plan view.

4. Determine another MHS design ("*MHS Design B*") that interacts with your Design A in (3) to further improve output from the process tools (Hint: Think about sources for Gap inefficiency).
   a) Present your "*MHS Design B*" and draw it on the layout.
   b) How would you justify a return on investment?
   c) Make up an example and apply to (1) to defend your proposed design.

5. Recommend a WIP policy that would be most suitable for our factory. The objective is to maximize factory output or minimize the total time a lot spends in the factory.
   a) Explain your WIP policy and identify which indicators should be tracked to monitor the factory performance.
   b) Justify your reasoning in (a) with an example.
   c) Our company will apply an ERP/MRP system to plan production and interact with suppliers and customers. Based on your MERP experience, explain specific ways your recommended WIP policy and factory performance monitoring can benefit the MERP decisions.

QUEUING MODELS / SIMULATIONS ARE EXPECTED IN THIS CASE.