MIT 2.008 Design and Manufacturing II

Quiz 2 - Part B, Take-Home Component

Spring 2025

- This portion of the exam is open book/notes (since we cannot monitor you), but you are expected to work on it individually and cannot collaborate with classmates.
- All work for CREDIT must be completed in this quiz document.
- Please contact the TAs via Slack if you have any questions or difficulties.
- We will NOT be granting extensions for this portion of the exam, once you have received it. If you anticipate any difficulties with completing this question on time, please inform the TAs prior to picking this component up; within reason, we will arrange to send it to you exactly 48 hours before you need to submit it.

General Notes

- *For qualitative answers, we're not looking for long essays. Please answer using short (1-2 sentences per answer) bullet points.*
- *For quantitative answers, show your work as clearly as possible. When possible, keep answers in algebraic form until plugging in numbers at the very end; this way, it is much easier for graders to understand where you make mistakes and provide meaningful feedback* ***(and partial credit)****.*
- *Each subquestion (e.g. a, b, c) may have a few parts to it (****i, ii, iii****). Make sure you r****ead and answer all parts of the question.***

Name: ____________________________

Part A, In-Class Component		
Problem 1		Out of 14 points
Problem 2		Out of 50 points
Problem 3		Out of 16 points
Part B, Take-Home Component		
Problem 4		Out of 20 points
Bonus		Out of 5 points
Total		**105 points**

This take-home exam continues the discussion of the microLED manufacturing process from the in-class exam. Therefore, the introduction is repeated below for your reference:

Display technologies have progressed from CRT and LCD to OLED and now to MicroLED. While OLED displays use organic molecules deposited through solution-based processes to create light-emitting pixels, MicroLED displays utilize inorganic III-V semiconductor materials. These are typically grown on separate wafers for red, green, and blue emission, as each material system is optimized for a different wavelength.

In the MicroLED process, these emitter chips are **singulated** (cut into individual dies) and then **transferred onto a transistor matrix** that acts as the active backplane, controlling pixel operation—illustrated schematically in **Figure 1**.

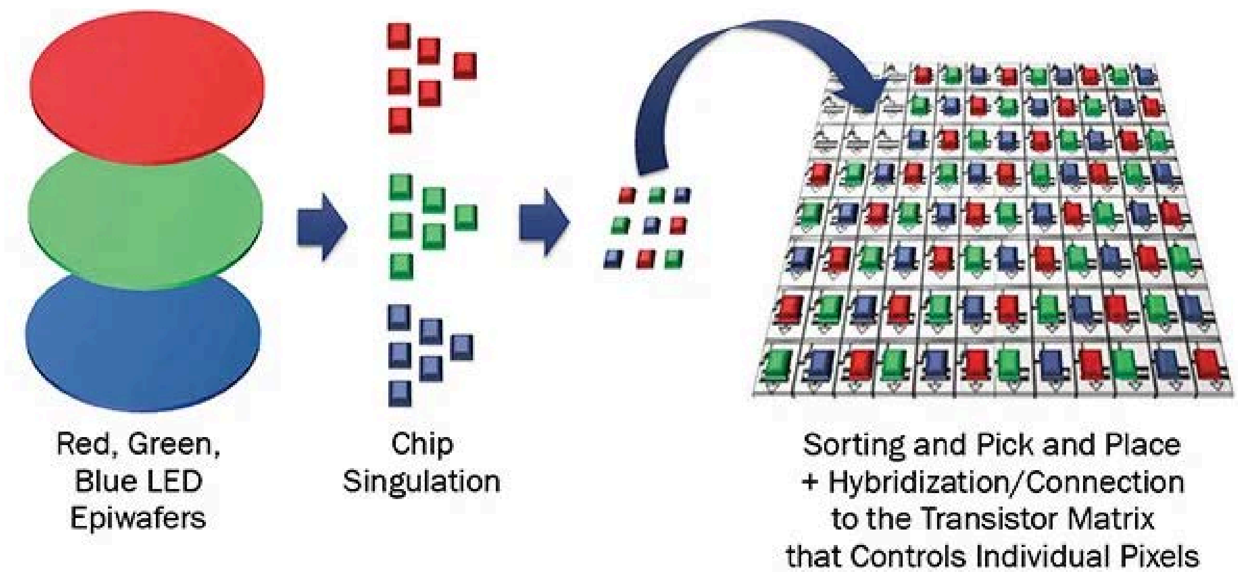


Figure 1. MicroLED pixel integration process. Singulated red, green, and blue MicroLED dies, each fabricated on separate III-V wafers, are picked and transferred onto a transistor matrix to form a full-color display.

Unlike conventional Front-End-Of-Line (FEOL) processes discussed in class, this step belongs to the **Back-End-Of-Line (BEOL) packaging**. This is an area where we **mechanical engineers can contribute**, especially in the precision mechanisms involved in chip transfer.

The **flip chip transfer process**, shown in **Figure 2**, includes a **vacuum head** that picks up singulated MicroLEDs, a **bond arm** that moves and positions the dies, and **rotating motors** that provide the necessary degrees of freedom for alignment. The MicroLED die is then flipped and bonded such that its top-side contacts align with the interconnects on the top of the transistor matrix.

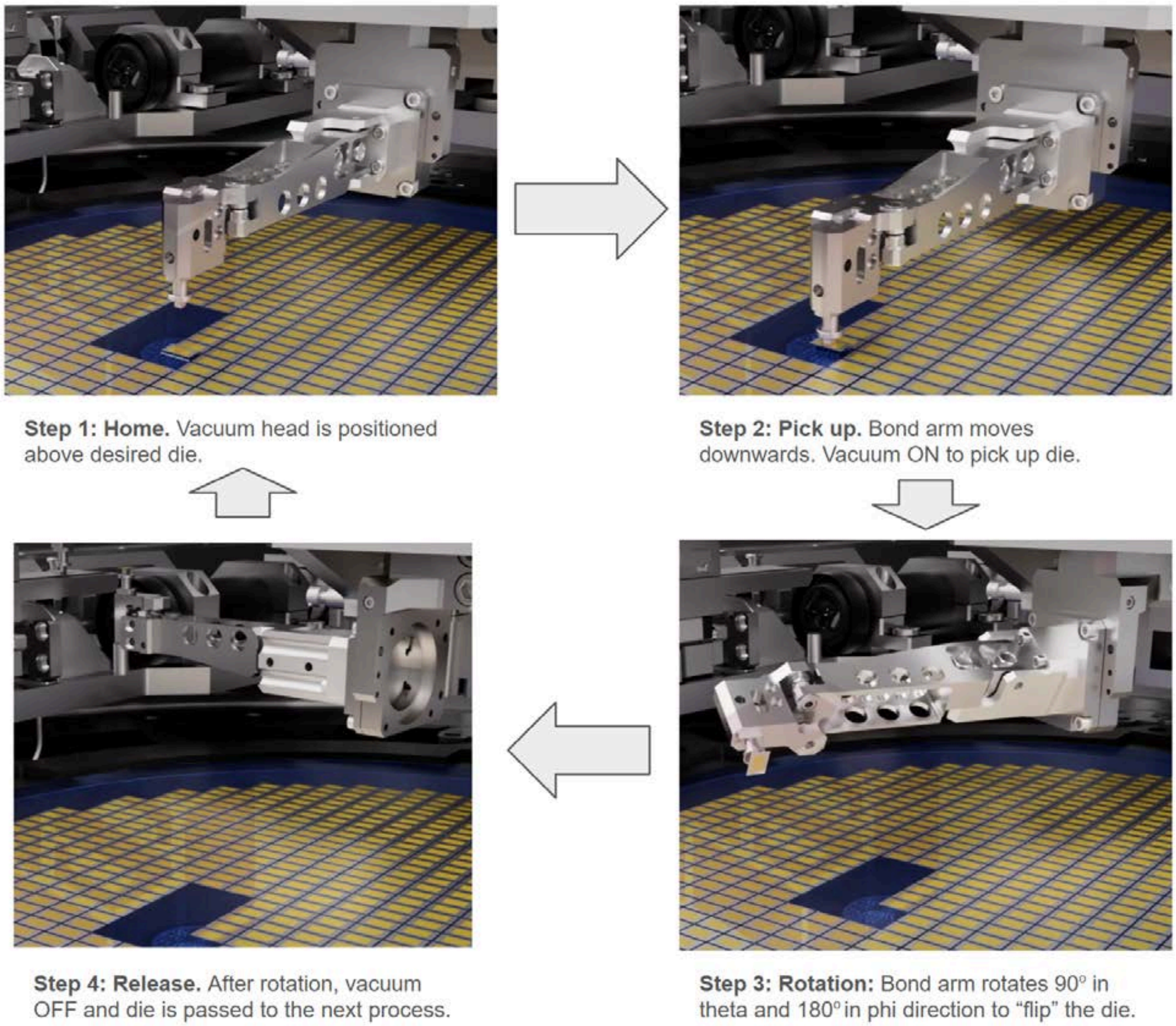


Figure 2. Schematic of the flip chip transfer process.

Problem 4 - Manufacturing Systems Analysis (20 points)

One of the biggest challenges in microLED fabrication stems from the sheer number of individual dies that must be picked and placed onto the transistor pixel matrix. Each **individual die is a single color of a single pixel.** We shall analyze the production of these microLED displays and optimize the production rate.

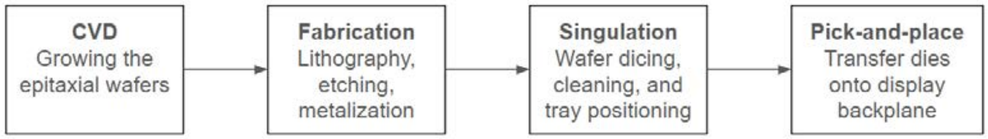
a) Meeting the required number of dies.
   i) Calculate the number of dies needed for a full HD display (**1920 pixels wide and 1080 pixels high**) with full RGB (**3 separate red, green, and blue dies per pixel**).

   ii) It takes **60 milliseconds (0.06 s) to complete a pick-and-place sequence (shown in Fig. 2) of a single die**. How long would it take for a pick-and-place machine to **assemble a single full HD display**?

   iii) Assume that each die is a square with a width of 50 microns (**0.05 mm x 0.05 mm**). Considering the die sawing line width and unusable edges, assume that **90% (yield) of the wafer area can be used as dies**. Estimate the **number of dies that can be produced from a 6-inch wafer.**

   iv) **How many 6-inch wafers** (integer number) are needed to produce the **RGB full HD display**?

b) Now, we shall consider the whole manufacturing line shown in Fig. 1, using the process diagram below for the time it takes to make 1 display:



	CVD	Fabrication	Singulation	Pick-and-place
Tau (hrs)	3	15	1	
MTTF (hrs)	300	300	100	300
MTTR (hrs)	30	60	10	60

i) **Input the operation time** for a single pick-and-place machine to manufacture one full HD RGB display panel, which you calculated in **4aii**, into the table above. Assuming a scenario with **no buffers** between operations, what is the **average time needed to produce 1 display**?

ii) You realize that the production rate is way too slow to meet demand. As such, you want to **address the bottleneck** to reduce its operation time and increase the overall production rate. What is the **minimum number of pick-and-place equipment that we need to run in parallel** to prevent it from being the only bottleneck in the system?

iii) What is the **equivalent tau of running multiple pick-and-place machines in parallel**, as you have calculated above? **Input this value into the table below** and calculate the **r and p values for each machine**

	CVD	Fabrication	Singulation	Pick-and-place (multiple parallel)
Tau (hrs)	3	15	1	
MTTF (hrs)	300	300	100	300
MTTR (hrs)	30	60	10	60
p				
r				

c) Using the long line MATLAB code to determine the production rate and optimal buffer size to maximize profit. **Paste screenshots of your MATLAB input and output, wherever appropriate.**

i) Using the values you calculated for the table in 4biii and the long line code, determine the **production rate (in displays/hour, not per cycle) of the system with no buffers**.

Determining the optimal buffer placement and size to maximize profit

Note: by default, the long line program does not include profit/cost calculations. However, you can paste in the following code beneath the long line script to compute estimates for revenue and inventory cost:

```
%Calculate hypothetical profit
pCoeff = 5000;    % Assume revenue of $5,000 per display
c = [12 8 12];      % Inventory holding cost per cycle
revenue = pCoeff*prodrate(1);
C_array = c.*nbar;
C_total = sum(C_array);
profit = revenue - C_total
```

After pasting these lines of code, your script in Canvas should look like this:

Script ?   Save   Reset   MATLAB Documentation   Open Item in MATLAB Online ?

```
% Input parameters:
% Change the values for k, r, p, and N
% Click "Run Script" to calculate prodrate and nbar
k = 0;
r = 0;
p = 0;
N = 0;

% Calculate deterministic processing time
[prodrate,nbar] = detlong(k,r,p,N)

%Calculate hypothetical profit
pCoeff = 5000;    % Assume revenue of $5,000 per display
c = [12 8 12];      % Inventory holding cost per cycle
revenue = pCoeff*prodrate(1);
C_array = c.*nbar;
C_total = sum(C_array);
profit = revenue - C_total
```

Run Script ?

ii) Suppose you can add an **infinite buffer to only one location** (i.e. between machines 1-2, 2-3, or 3-4). By inspecting the process metrics of the production line from P4biii and the holding cost from the code provided above, determine the optimal location to place the buffer.

iii) Determine the **optimal (finite) buffer size** at the same location you determined above to maximize the profit. State the **buffer size, average inventory, and profit.**

Bonus Problems - Limitations and alternatives of pick-and-place (5 points)

a) A high-end **pick-and-place** machine has a placement **accuracy of around +/- 5 micrometers**. How does this accuracy **compare to the minimum resolvable feature of the lithography** process?

b) To address the limitations of pick-and-place, there has been a push for "monolithic integration" of microLED pixels wherein wafers of different materials are transferred onto the same substrates and the microLEDs are fabricated layer by layer and aligned using lithography. Read: https://www.nature.com/articles/s41586-022-05612-1. **Discuss the advantages and disadvantages** of monolithic integration vs pick-and-place in terms of **throughput, performance, and yield**.