ECE 445
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Senior Design Project Proposal

Project #29: Modular Wafer Track for Semiconductor Fabrication

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1. Introduction

1.1. Problem Statement

In today's world, where semiconductors drive nearly every aspect of technological innovation, little room is left for small-scale fabrication and experimentation. Commercial wafer processing equipment ranges from tens of thousands to hundreds of millions of dollars, putting it far out of reach for hobbyists, educational laboratories, and early-stage researchers. Existing systems are not only cost-prohibitive but also lack the flexibility and modularity needed for experimentation on a smaller scale. As a result, innovation outside of large industrial fabs is limited, leaving students, independent researchers, and small labs without access to tools that enable exploration of semiconductor device fabrication.

1.2. Solution

Our team's solution to this problem is to design, build, and demonstrate a modular, cost-effective wafer track system that lowers the barrier to entry for small-scale semiconductor processing. The idea is to create a track that will:

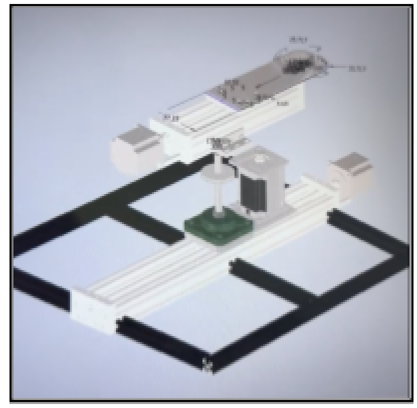
Transport wafers between the interchangeable processing modules, execute repeatable fabrication recipes that ensure process consistency, and communicate standardized instructions to each module through a defined packet interface, enabling true modularity and user-created modules.

The system architecture will be layered, with a Raspberry Pi serving as the front-end controller, providing recipe management, a user interface, and real-time monitoring. An ESP32 Microcontroller will delegate low-level instructions to each module and control the stepper motors for wafer transport. Individual modules (demonstrated through a wafer alignment station that reorients a wafer's major flat at the start of each recipe) will showcase the modular framework and mechanical precision of the track.

By defining a standardized track-module interface and releasing the system as open source, our design will empower hobbyists, students, and small research labs to reproduce, extend, and customize the platform. This solution not only addresses cost barriers but also promotes accessibility, flexibility, and innovation in semiconductor fabrication education and prototyping.

1.3. Visual Aid

[1]Tokyo Electron Limited (TEL) Track for Wafer Processing



CAD of project as of yet

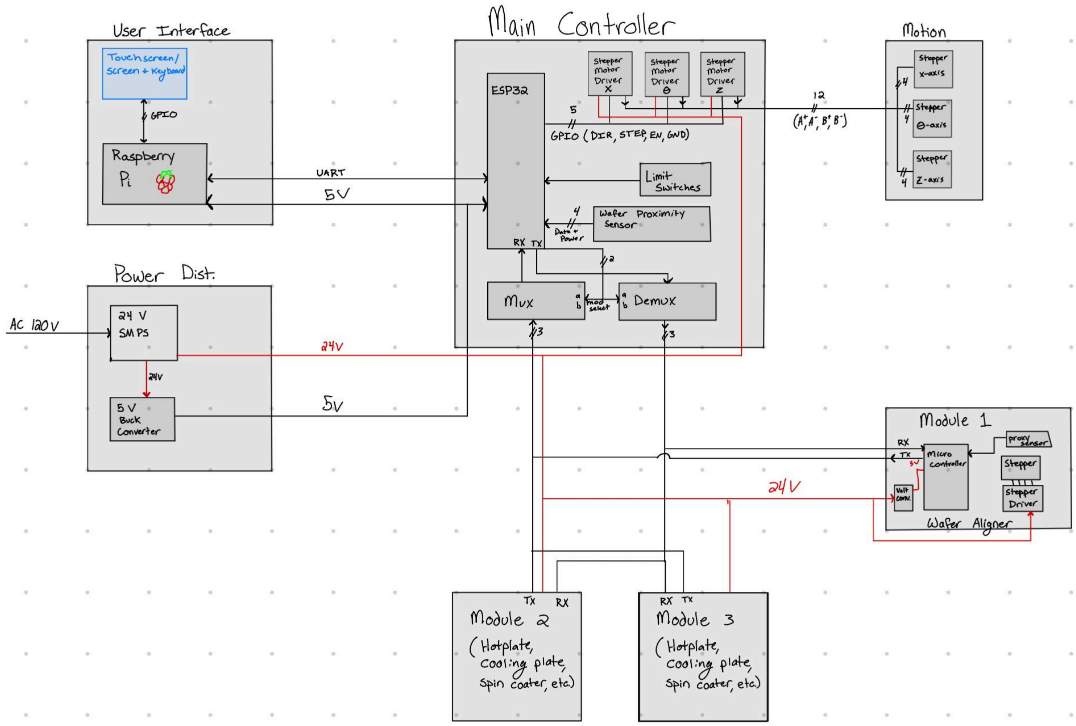
(Possibly add sketches of prototype)

1.4. High-Level Requirements

A high-level requirement is allowing the user to create and run a program on the system, which has the wafer be inserted by the user in any orientation, pulled into the main chamber, transferred to the aligner tool, which aligns the wafer by the major flat, moved back into the main chamber, and finally pushed out of the chamber. This program should be able to run more than once without any noticeable misalignment of the major flat.

2. Design

2.1. Block Diagram



2.2. Subsystem Overviews

Power Distribution Subsystem overview:

The power subsystem will be able to supply power to all of the components by stepping it down from a standard wall outlet. These components include logic ICs, a Raspberry Pi 4 model B, and linear actuators.

Main Controller Subsystem overview:

This subsystem will be responsible for receiving the wafer from the user and taking it into the system. It will feature a linear actuator on top of a stepper motor, capable of rotating 360 degrees. This would allow the wafer to move similarly to polar coordinates, except there is no phi coordinate. The wafer holder will be in the shape of a horseshoe, which can securely move the wafer around on the plane.

User Interface Subsystem overview:

The user interface subsystem will allow the user to create recipes to be executed by the modules. It will interface with the entire system to send the wafer through the steps that have been specified. Ideally, this subsystem will allow the user to save designs to be executed wherever desired by the push of a button. The user interface will consist mainly of a Raspberry Pi 4 model B, a screen, and peripherals for navigation.

Module 1 (Wafer Aligner) Subsystem overview:

This is a demonstration of a possible subsystem that can attach to the main housing. This subsystem will be able to pick up the wafer using rubber feet that approach from the bottom of the wafer and lift it while the main housing actuator retracts. It will then lower, which will bring the wafer down to the main platform. That platform can rotate such that optical sensors can detect the major flat and align it parallel to the place where the wafer entered the subsystem.

2.3. Subsystem Requirements

Power Distribution Subsystem requirements:

The power subsystem must be able to turn 120VAC from the wall to usable voltages for each component. These voltages are 24VDC rated for 5A for the linear actuators, 5VDC rated for 1A for all logic components, and a separate 5VDC system rated for 3A to power the Raspberry Pi 4 model B. These will all be buck converters. All components will work continuously within 5% of the mentioned currents and voltages for it to be considered successful.

Main Controller Subsystem requirements:

The Main Controller will be responsible for multiple high-level items. Firstly, it must control and delegate movement instructions to the stepper motors to move the wafer arm to specific modules as described by a recipe. Secondly, the Main Controller must also create files (.txt, .json, etc.) to send to the Raspberry Pi upon startup to notify it of the available modules and capabilities and store user-created recipes. The Main Controller will also be responsible for maintaining communication between each of the processing sub-modules. Finally, the Main Controller must receive signals from the proximity sensor(s) and limit switches for feedback and control. The main controller must use less than 16MB of memory for its boot code, program code, and recipe management filesystem.

User Interface Subsystem requirements:

The User Interface System will be strictly responsible for user-input and system monitoring. The screen should display the system status and allow the user to create new recipes depending on the current module(s) attached to the system. The User Interface System should be able to boot on startup and be ready to execute within 20 seconds of powering up the system. Additionally, the Raspberry Pi should be able to send data to the ESP32 in less than 100ms.

Module 1 (Wafer Aligner) Subsystem requirements:

The wafer aligner will be responsible for picking up the wafer from the main track without dropping it and lowering it down onto the main chuck in the module. It will then be able to rotate the wafer and align the major flat parallel to the door that opens to the subsystem. It should be able to correctly align the wafer within 15 seconds and have an error less than 3.6°.

2.4 Tolerance Analysis

A potential risk in determining project quality is the stepper alignment. The stepper motors must be positioned correctly to ensure transferring does not collide with the frame or other structures. To avoid this issue, we will implement two different measures. Firstly, we may include microstepping on the stepper motors for very precise movements (could 1/16 microstep, making one revolution 3200 steps, opposed to 200 steps). Additionally, we will implement limit switches on the stepper motors to home the axes at startup.

Another potential risk can come in the form of a power surge. This could result in broken electrical components and motors. This can be prevented by a simple surge protection IC chip. An example of this would be the TVS2200 which can handle current surges up to 40A.

3. Ethics and Safety

Our group promises to follow all the ethics and safety protocols mentioned in this document. We will adhere strictly to the IEEE code of ethics by pledging to follow the following statements: Public safety and welfare will be at the forefront of our development, we will prioritize the safety, health, and welfare of the public, and we will make our product/design suitable and safe for the public. Our group will hold integrity and honesty throughout our entire process, making sure we stay clear of any conflict of interest or unlawful conduct. We will create a safe and welcoming environment for all members of the team, including our mentors and advisors, and not discriminate or have any form of harassment. Along with this, we will uphold the professional development of all members of the team and hold each other to a high standard to reach our success. Lastly, our group will strive for continuous improvement of technical abilities, professional skills, products that will help humanity, and leadership skills.

Along with our pledge, our group will strictly adhere to any local laws and regulations, as well as any federal laws. If our group needs any certifications to operate machinery or any permits to continue our project, we will get them. As a part of our pledge to adhere to the IEEE code of ethics, we will make sure that anyone in our vicinity is safe and never put anyone in harm's way. These pledges and guidelines will make our group the best if we can be and have the best final project we can.

4. References

[1] Tokyo Electron Ltd., “Coater/Developer LITHIUS™ Series,” [Online]. Available: https://www.tel.com/product/lithius.html. Accessed: Sep. 18, 2025.