Design and Fabrication of a Low-cost Inkjet Printer for Selective Diamond Growth

Design Team 2
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Sponsor: Fraunhofer USA, Dr. James Siegenthaler

Abstract

This project developed a low-cost inkjet printing system for selective diamond growth by modifying a 3D printer to dispense diamond nanoparticle solutions onto silicon wafers. Using custom software, Arduino-controlled motion, and an HP C6602A inkjet cartridge, the system successfully printed patterns and enabled diamond growth on wafers. The results demonstrate a cost-effective, replicable approach for manufacturing diamond-based electronics. Future improvements could include refining drop spacing to increase print resolution and exploring more precise cartridges to overcome the limitations of the HP C6602A nozzle width.

Introduction

Diamond's exceptional thermal conductivity, mechanical strength, and adaptability as a semiconducting material make it a critical component in advanced electronics, particularly for high-temperature and corrosion-resistant applications. Traditional diamond manufacturing methods are costly and labor-intensive, relying on cleanroom environments and post-processing techniques.

This project builds upon the previous efforts of an ECE 480 Design project to develop a cost-effective solution for diamond lithography. The team prioritized accessibility and practicality by utilizing 3D printer and inkjet cartridge infrastructure to deposit diamond nanoparticle solutions in precise patterns. This approach aims to simplify the manufacturing process and advance the development of next-generation diamond-based electronic devices. The team kept product scalability and documentation in mind throughout the design and implementation stages of this project.

Design Constraints

Key constraints include ensuring the printer head does not contact the silicon wafer to prevent deformation. The system must achieve 50µm accuracy and 750 drops per inch resolution, based on patterns defined by standard image files. The printer requires precise x and y-axis movement with an adjustable z-offset. Modifying the inkjet cartridge presents challenges, as precise electrical pulses and timing are needed to avoid damaging the internal electronics. The chosen cartridge must dispense diamond seeding solutions without clogging or excessive wear. Additionally, creating a custom diamond nanoparticle solution with ink-like properties and preventing particle settling after evaporation presents further challenges. Thorough design and documentation are essential for future development and testing by the sponsor.

Technical Approach

The printer is primarily controlled using an Arduino communicating with a host computer via serial. The host computer reads an image, calculates the luminance value for each pixel, and generate print commands that are sent to the Arduino. The Arduino then parses these commands to control the stepper motors and inkjet cartridge. The printer works by sequentially dispensing ink in rows of 12 pixels, utilizing all nozzles on the HP C6602A cartridge.

The stepper motors are disconnected from the printer's mainboard and are controlled directly with DRV8825 stepper drivers using the Arduino. A homing sequence is implemented using limit switches to ensure positioning consistency. The printer hotend was replaced with a 3D printed mount for the C6602A inkjet cartridge. The 12 nozzles on the HP C6602A inkjet cartridge can be controlled individually with 19V pulses. This was achieved by amplifying 5V outputs from the Arduino to 19V using two ULN2803A Darlington transistor arrays. The entire system is powered using the printer's 24V internal power supply and an LM2596 buck converter to step down to 19V.

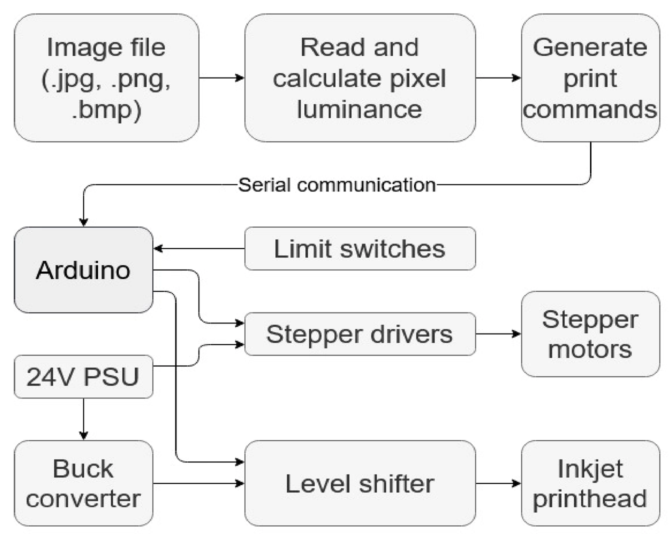

Figure 1: Project control flow

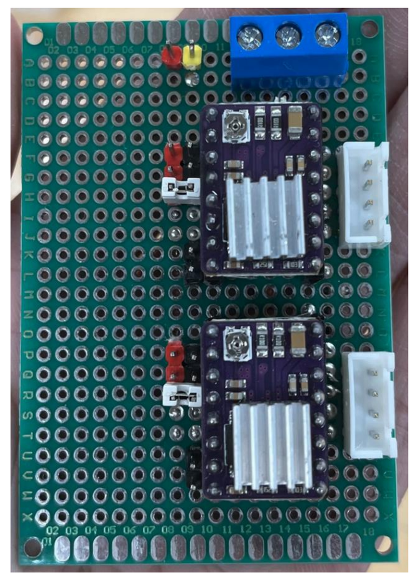

Figure 3: Stepper drivers circuit board

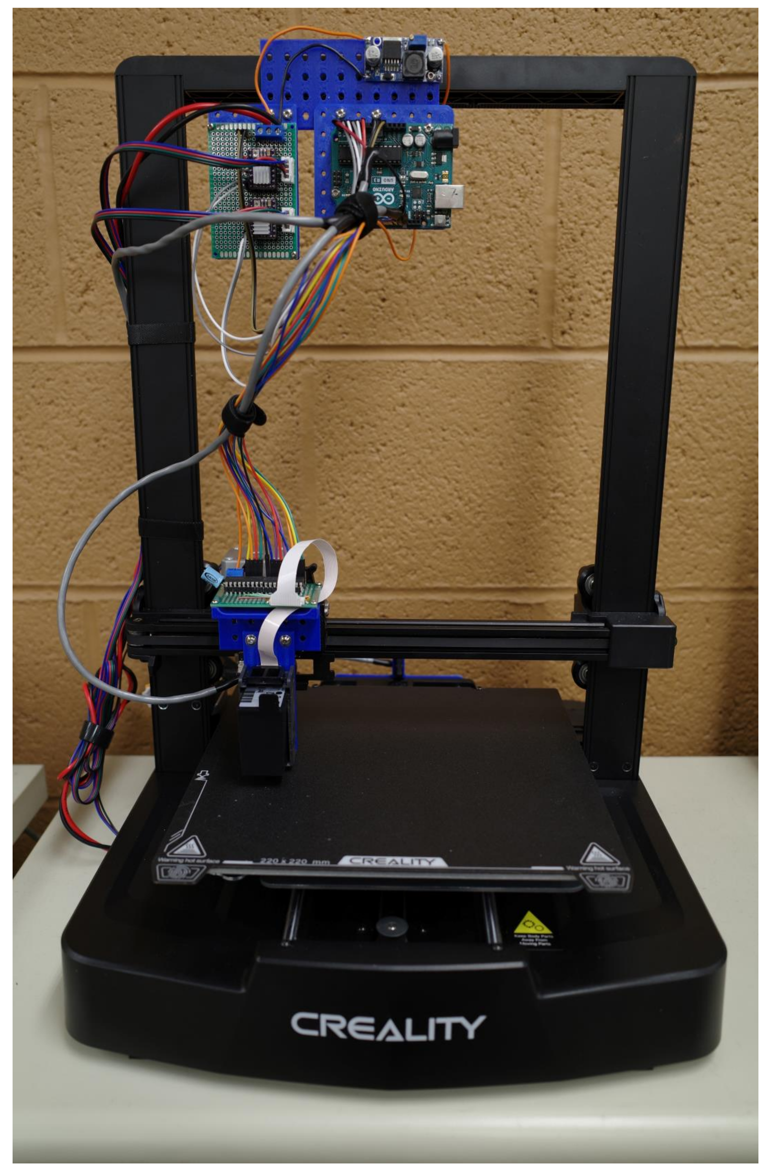

Figure 5: Final printer

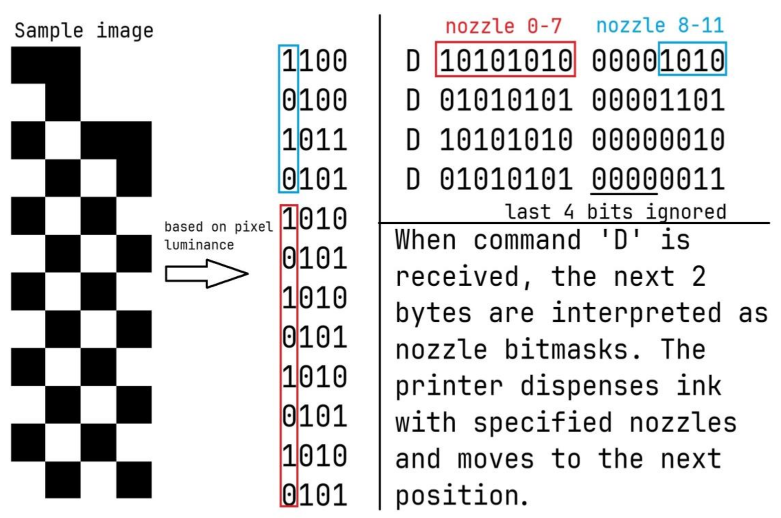

Figure 2: Sample print commands. This illustrates the structure of the dispense command

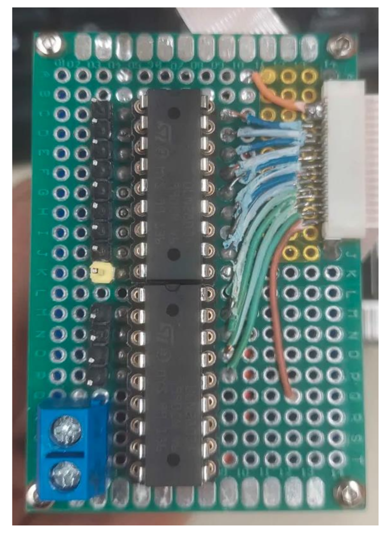

Figure 4: Logic level shifter circuit board

Testing Approach

Verification and validation were critical to developing the printer's control hardware and software. Hardware components were tested under various conditions to ensure functionality, and similar protocols were applied during integration to address potential incompatibilities. Arduino software development involved gradually replacing external signals with Arduino-generated signals to verify hardware interactions, while the host printer command software underwent parallel testing for seamless integration. This systematic approach ensured a reliable final design.

Testing with a custom diamond seeding solution began with ink to confirm functionality, followed by cleaning the cartridge using a sonication bath and testing with deionized (DI) water to observe droplet formation. Custom solutions were then synthesized and tested, using 0.5% wt. and 5% wt. of 5 nm pretreated diamond powder suspended in 2-propanol and DI water. Settling rates of the solutions were monitored over time to ensure suspension stability. Optical and SEM microscopy evaluated droplet spread and nanoparticle agglomeration before final prints were made. The wafers were placed in the reactor, successfully growing diamond in desired patterns. Additional imaging documented accuracy and resolution characteristics.

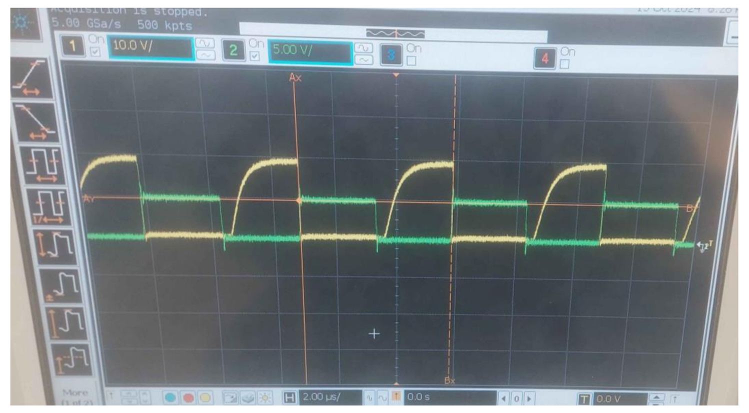

Figure 6: Logic level shift I/O waveforms. Green is Arduino 5v pulse, yellow is 19v transistor output

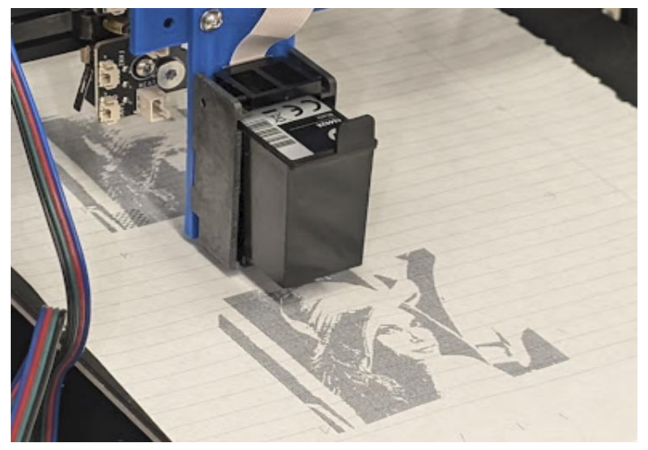

Figure 7: Successful ink test print

Figure 8: Settling behavior of both diamond seeding solutions observed after six days.

Results

The final design integrates a modified 3D printer with an inkjet cartridge to dispense custom diamond nanoparticle solutions. Custom software and hardware streamline the system, reduce redundancies, and ensure scalability, enabling adaptation to alternative cartridges and components. The system operates from a single power supply and features an intuitive interface for generating navigation commands to print custom patterns. While the design meets most customer requirements, the resolution and accuracy did not fully meet target specifications. Future improvements could focus on adjusting drop spacing to increase resolution and refining cartridge durability, as current models may face wear and clogging issues. Further testing is needed to evaluate long-term performance and explore enhancements such as piezoelectric cartridges or custom printheads.

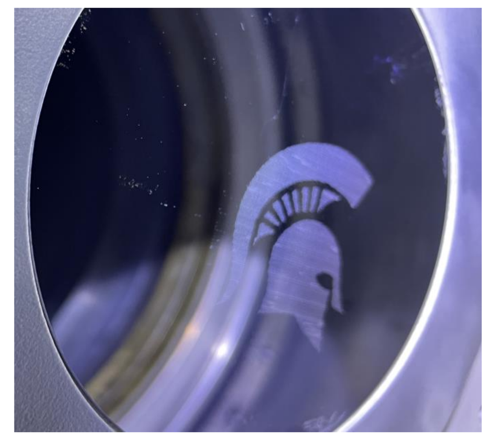

Figure 9: Full spartan head grown on silicon wafer

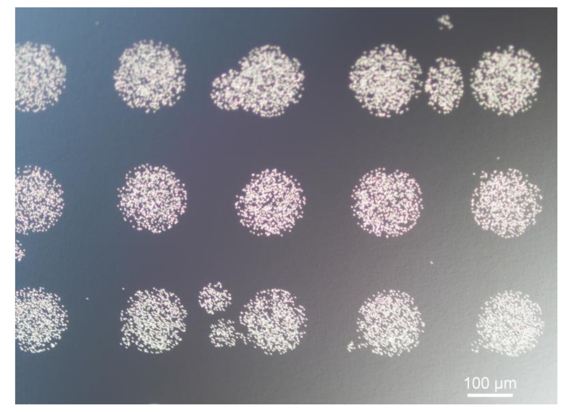

Figure 10: Grouping of grown droplets at 10x optical, homogeneous settlement

Budget

The design team was allocated a $500 budget for this project. Notably, the Ender 3 v3 SE 3D printer was purchased by the previous design team. The purchased materials are listed below; other smaller components were accessible by the ECE design lab.

Part List & Cost	Cost:
HP C6602A Cartridge (x5)	$93.65
HP Q2299A Carriage Assembly	$10.72
Glass Print Bed	$12.99
Ultrasonic Cleaner	$34.99
ULN2803A Transistor Array (x8)	$21.68
DRV8825 Stepper Driver (x5)	$9.99
Misc. Electronics	$22.95

Total Spent: 206.97
Remaining Budget: 293.03

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Fall 2024 Design Team 2

From left to right: Pritham Kura, Andrew Barton, Noah Sanders, Maté Narh, Tuan Nguyen