Miniature Nutrient Plant Sensor

FINAL REPORT

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Revised: 10th , December 2019, Version 3

Executive Summary

Development Standards & Practices Used

1. IEEE-315-1975
2. IEC 60062:2016
3. Unicode 12.0

Summary of Requirements

1. Sensors must measure Nitrate levels effectively, without being affected by the presence of other nutrients in the soil.
2. Sensors must be able to last for 60 days in the field, without needing to change their batteries.
3. Cellular module must collect data multiple times a day during peak harvest period and two times a day during other seasons.
4. Data between plants, cellular module and database must be transmitted efficiently, multiple times a day.

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Definitions

1. **ADC:** A device that converts an analog signal to a digital value.
2. **IoT**: Internet of Things
3. **HTTP:** Hypertext Transfer Protocol
4. **HTTP POST:** A HTTP supported request method used by the World Wide Web. the POST request will request a specific web server to accept the payload that it is carrying.
5. **Webhook:** Can be defined as an "User-defined HTTP Callback". Typically, they are triggered when a certain event (Comment made in social media, blogs released a new post, etc) has happened on a webpage or web application. When such an event occurs, the source site will generate an HTTP request to specify URL, where it will perform certain action on it.
6. **JSON:** JavaScript Object Notation
7. **Biofilm:** A thin film of organic matter, that is formed by secretions from decaying plants and insects, in a habitat.
8. **CSV**: Comma Separated Values.
9. **Etching:** Here, the use of strong acids and bases, to dissolve parts of a silicon wafer.
10. **IP:** Ingress protection standard
11. **ISM**: Ion Selective Membrane that allows NO_3 to pass through.
12. **Lifetime:** The number of days a sensor can last in the field, without requiring a change of batteries.
13. **LoRa/ LoRaWAN**: Long Range Wide Area Network used for long range communication.
14. **Margin**: The edge or border of a leaf.
15. **MCU:** A microcontroller unit like a cellular module.
16. **Midrib**: A large strengthened vein along the midline of a leaf.
17. **mm:** Millimeter ($1/10^3$th of a meter).
18. **NaCl/KCl**: Sodium Chloride or Potassium Chloride layer on the reference electrode.
19. **Needle sensor**: A sensor that is 2.5 mm thick and 12mm long, and is inserted either at the stalk or root of the plant.This is the device that records the nutrient levels in plants.
20. **nm:** nanometer ($1/10^6$ th of a meter).
21. **Nutrient levels:** Here, we are concerned with Nitrogen, Phosphorus and water levels in a plant.
22. **PCB:** An electrical board with a circuit printed on it.
23. **ppm**: Parts per million.
24. **Sensor**: A 3 inch silicon wafer with 100 needle point sensors (of various sizes) printed on it.

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List of Symbols

1. **NO_3:** Nitrates
2. **KCl:** Potassium Chloride
3. **km:** Kilometer (1 km = 0.62 miles)
4. **mm:** Millimeter ($1/10^3$th of a meter).
5. **N:** Nitrogen
6. **NaCl**: Sodium Chloride
7. **nm:** nanometer ($1/10^6$ th of a meter).
8. **P:** Phosphorus
9. **ppm**: Parts per million.
10. **NPK:** Nitrogen, Phosphorus, Potassium (K)

1. Introduction

1.2 Problem and Project Statement

Problem Statement:

Soil conditions are never the same for any two patches of land adjacent to each other. One patch could be dense in NO_3 (Nitrates), while the other could be saturated in NO_3. For the best yield per acre, farmers need accurate data about the current nitrate levels in soil, in order to determine the right type and amount of fertilizer required for that acre. However, inaccurate data and the long waiting time on soil analysis results, often leave farmers with incomplete information about current soil conditions, which has detrimental effects on the harvest of a crop. The unknown or inaccurate measurement of nitrate levels in crops leads to excess fertilizer application which in turn also result in unnecessary expenditure. At the same time, the excess or insufficient fertilizer application may also result in the production level of the crops.

Solution Approach:

The solution is to provide farmers with a portable tool that reads and provides accurate data about the current nitrate conditions on the field at any given time. With this in mind, the miniature nutrient plant sensor and its app were made. These sensors can accurately detect NO_3 levels in soil (on a daily basis) to ensure that farmers are well informed about them. The data collected by these sensors are readily available on the database once the sensor had transmitted it and it can be viewed by the app.

Purpose of the Project:

We were tasked with optimizing the accuracy of the sensors and the functionality of the app, such that the sensors can read the nutrient levels accurately without being manipulated by their environment, and the app can perform additional functionalities like sensor tracking or expanding its data transmission range. We are also required to find a way to encase the sensors, to prevent them from being damaged by environmental hazards in the field, while ensuring that the integrity of the data is not compromised.

For this project, we were hoping to create sensors that were adaptable to their respective environments and were able to read nutrient levels the plants accurately, without hindrance from environmental factors. At the same time, we hoped to produce an app that would provide convenience to its users, such that users would be able to track the location of the sensors and retrieve the data from the sensors from without being at close proximity to the sensors.i.e. long range data transmission.

1.3 Operational Environment

Although the project is tasked with finding the nutrient levels in soil, we will insert the sensors into the stalk, roots and leaves of plants because the plant provides a more stable environment than the soil for sensor implantation. The location of the needle sensors is determined by their lengths. The shorter needle sensors are used to detect nutrient levels in the roots and leaves of the plants, while the longer needle sensors derive data from the stalk of the plant. This implies that the sensor will be exposed to environmental hazards like extreme temperatures, water and dust. Aside from that, the sensors will also be exposed to biofilms, that can develop on the surface of the sensors, and deactivate the data collection capacities of a sensor altogether. The sensor will also be subjected to work in a controlled environment, like a laboratory, for testing purposes, mainly to test the accuracy of the data collected by the needle sensors.

1.4 Functional and non-functional Requirements

Functional Requirements:
1. Improve accuracy of sensors.
2. Improve battery life of the circuit box.
3. Sensors must be able to transmit data to adapt data transmission capacity with respect to the non- harvest and harvest period requirements of data.

Non- Functional Requirements:
1. Reliable data transmission from the cellular module to the database.
2. Sensors should be waterproof but they cannot stay submerged in water for months at a time.
3. Circuit box must be tamper proof, so that external factors do not heavily influence our data.

1.5 INTENDED USERS AND USES

The intended users for our end product are farmers, scientists and researchers in biotechnology. The variety of users define the variety of applications of this project, though there are similarities in uses as well. The following are the similar and different intended uses for each users:

Farmers:
1. Measured the plant's nitrate level by attaching the sensor to it and viewing on the app.
2. Allows farmers to reduce their expenditure on fertilizers.
3. Eliminates nitrate pollution by reducing nitrate runoff to rivers and watersheds.
4. Improve the quality of crop production by providing the required amount of fertilizers based on the sensor readings.

Biotech Researchers with Seed Companies:
1. Allows better tracking of nutrients levels in test plots.
2. Helps tailor Nutrient and fertilizer recommendations to increase yield in unmonitored customer fields.

Scientists:
1. Eliminates time wastage as they are not required to perform tedious tasks to extract readable data about the nitrate content of the plants.
2. Allows scientists the ability to observe the behavior of the plant without going out into the crop field.

Similarities for all users:
1. Provides flexibility to the users where they are able to view relevant data at any location as long as they have internet connection.
2. Since the readings are stored in a database, the users are able to observe past readings without the need of keeping a record of the readings.
3. Allow the users to track the approximate location of each sensor without losing the sensor in the field.

1.6 ASSUMPTIONS AND LIMITATIONS

Assumptions:

1. Each sensor will have an average lifetime of 60 days.
2. The casing of the sensor provides protection against environmental hazards.
3. The sensors must be portable.
4. The sensor will not be constantly exposed to extreme environments. For example, we assume that the sensor will not be submerged in water for an extended period of time.

Limitations:

1. Due to inadequate resources, the configuration/build of the sensor is based on the environments experienced in the Midwest.
2. Due to the lack of time, the app is only compatible with Android.
3. Data transmission tests not performed over long ranges (from field to database), due to time constraints. Short distance data transmissions were tested in lab using a multimeter.
4. Long-Term data testing was also not completed due to time constraints and available testing periods.

1.7 EXPECTED END PRODUCT AND DELIVERABLES

The end product of our project consists of four main components. These are: the circuit box, the sensors, the database and the app.

The circuit box consists of a digital wireless data communication hardware (Hologram Dash Cellular Module), a battery and power booster circuit. The sensors are required to measure the nutrient levels accurately, such that they are within the acceptable error margins. The power supplies will remain the same, from its previous design, as they are the best possible options we have available to us. The sensors will be encased in waterproofing polymer coatings, to prevent water damage to the them.

As for the digital wireless data communication, we are expected to deliver a calibrated version of the cellular module, where it can interact with the sensor and transmit the readings to the database. The expected end product, will allow users to retrieve data from the sensors from a long distance so long as there is an available cell network nearby, without relying on the previous bluetooth module from previous design.

We are also expected to deliver an app that provides additional functionality to the users to grant additional conveniences. These functionalities include a sensor tracker, which displays a sensor's geographical location, and an interactive form of data retrieval from the database, which enhances users' accessibility to the data. The addition of database system will provide a much more efficient system as it provides sufficient memory allocation for storing a large amount of data. Hence, we are expected to deliver a configured database so that it will store the appropriate sensor's data correctly.

When these components are combined, the users will interact with the app, and the app will look at the latest data stored in the database and display it. As for the sensors, they will periodically measure the nitrate content and store the data into the database with the digital wireless data communication acting as a medium for transmitting the sensor data to the database.

2. Specifications and Analysis.

So far, we have:

1. Precisely deposited an epoxy used for waterproofing the sensor that is also compatible with biological material. The ISM deposition has been refined so it can be reliably placed upon a sensor with minimal variation in results. The overlap is approximately the desired size and the epoxy sufficiently covers the edge of the ISM.
2. A cellular module that is acting as the main MCU of the design. It is responsible for periodically transmit data into the database and called the sensor to measure the nitrate levels.
3. A database that stores all of the transmitted data.
4. An app that will retrieve the readings of the sensor from the database and display it to the users.
5. Reduced the power consumption as the bluetooth module is removed and only the cellular module and sensors is being powered.

Further Modification or Improvement for the Future

Sensor:

1. Improve the profile of the ISM, adjusting the viscosity of the solution may aid in reducing the bubble up of the deposit.

Circuit Box:

1. Improve the system's operational time by implementing a different power alternatives (Solar panels, etc) instead of relying on rechargeable battery pack.

Database:

1. With ransomware being common, it would be beneficial to implement additional security algorithm (Data Encryption, etc) to protect users' data.

App:

1. More methods for visualizing data, such as charts, graphs and map overlays
2. User Accounts and related data security

Strengths:

1. The communication between plant, sensor and database works effectively. No glitches have been reported so far.
2. The sensor helps collect the most recent values for nutrients present in the soil, and the app ensures that the data is available almost immediately.
3. The system is self- sustainable (up to 60 days), and has a low carbon footprint.

4. The system will report its GPS location of each sensor, when it transmits data to the database. This prevents the sensor from getting lost in the field.
5. The system itself is very light, and portable. This allows it to be transported easily from one location to another.

Weaknesses:

1. For now, we have decided to use the most basic model of our nutrient sensors, the ones without temperature sensors in them. Although this helps narrow down the function of this device and test the data's accuracy, we will have no knowledge of the range of temperatures for which the sensor can work effectively.
2. The rarity of the polymers, that are compatible with our sensor and the biological matter, make them not only difficult to purchase, but also expensive. Without a good budget for this project, it will be difficult to develop a sensor for the required levels of efficiency and accuracy.
3. The database is only protected by basic security methods.
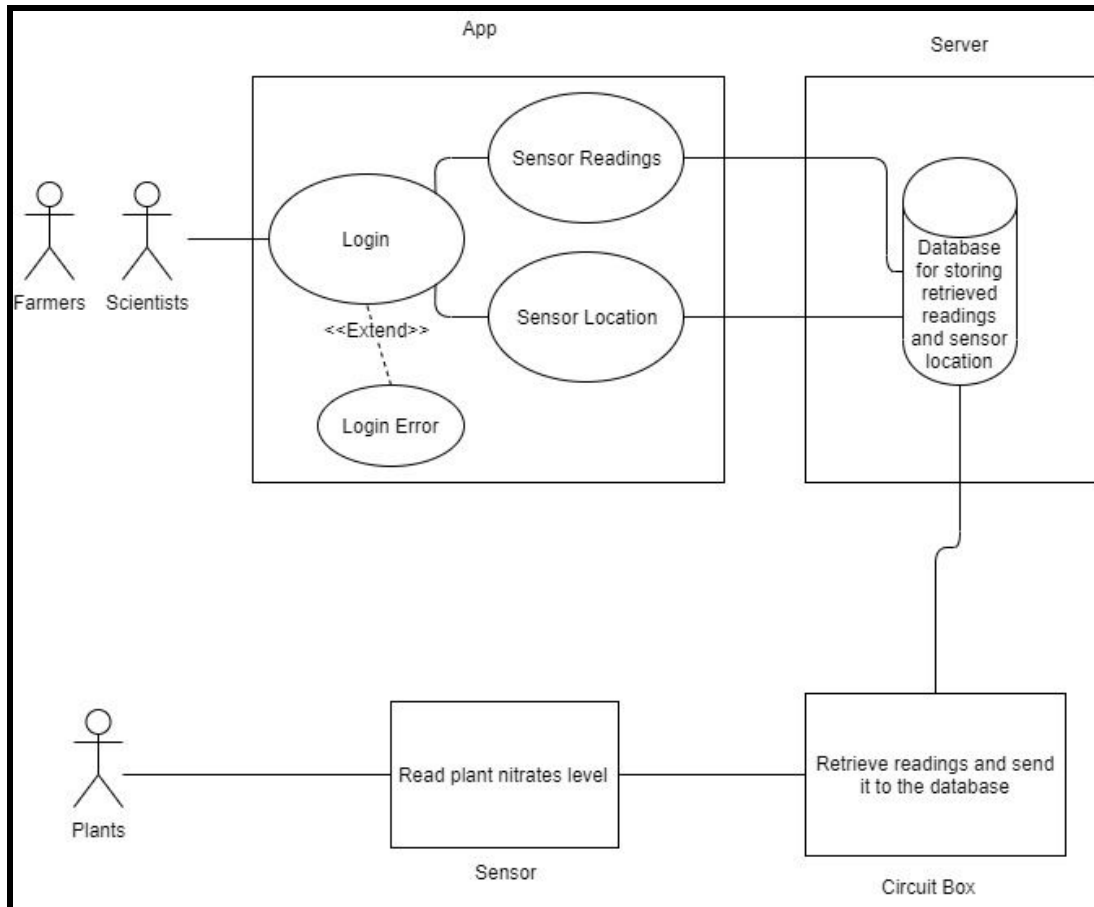
Use Case

Fig 1: Use Case Diagram of the users' interaction with both the System and the plants

As mentioned in the introduction section, our proposed solution to provide farmers and scientists with a portable tool that reads and provides accurate data about current nitrate conditions on the field, at any given time.

With that in mind, we came up with the above use case diagram to have a better understanding of the users' interaction with our system. Once the sensor has been attached to the plant and the circuit box is set up, the circuit box will wake up periodically and asked the sensor to measure the NO_3 level. Once the measurement has been conducted, it will send the data into a database to store.

At the users end, the users are able to view the sensors' reading at any location so long as there is proper internet connection. In order to view the readings, the users will login into their respective app. Once the login is successful, they will have the ability to choose which sensor they would like to view. After choosing a specific sensor, the app will go into the database and retrieve the inquired data which will then be displayed on the app for the users.
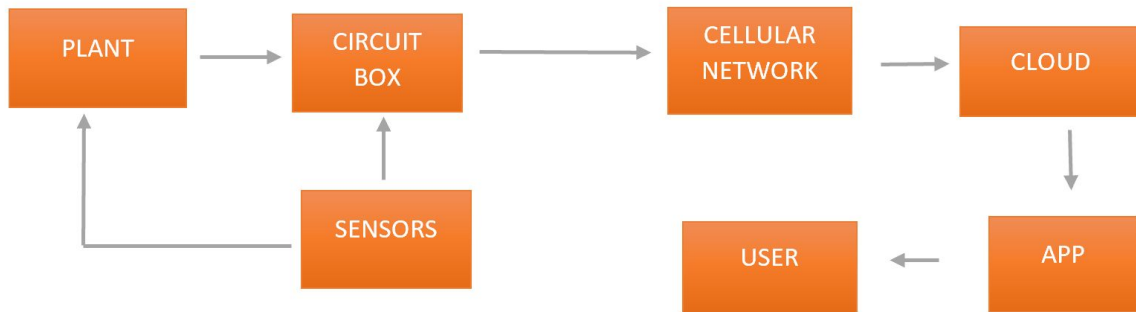

Fig 2: System level diagram

<u>**Structure of the Sensor**</u>

The sensor consists of a 3 inch silicon wafer, which is treated with ions to reduce its resistivity (within acceptable limits) . To make it compatible with biological materials, the wafer surface is coated with 115 nm thick layer of Gold, 250 nm thick layer of Silver and 22 nm of Silver Chloride. The gold dot working electrode is then coated in a waterproof polymer around the edges. Needle point sensors of varying lengths (between 5mm and 12mm) are etched into the sensor. Shown below in Fig 2 is the sensor and all its basic components. The purple layer on the bottom is the silicon substrate with the gold and silver layers printed onto it. The black pads and lines are the conductors that act as connectors or vias to the circuit box. Wires are attached to the three pads. The blue pads represent the ISM that is deposited onto the gold pads. This is a selective membrane that filters out all ions that are not nitrates. The orange pad represents a NaCl/KCl that is added on top of the silver chloride pad. These pads are used to add extra chloride to the silver chloride layer as it is depleted. The silver chloride layer slowly depletes itself as it produces current for the circuit box. The green layer represents a watertight glue that has yet to be determined. The glue helps hold down the edges of the ISM because over a few days of constant contact with the water in the plant, the ISM begins to detach from the gold plating. The glue helps keep water from getting underneath the ISM layer. The ISM, NaCl/KCl, and glue are deposited using the Nordson Dispensing Robot and the thicknesses and surface topography of the layers are measured with a profilometer.
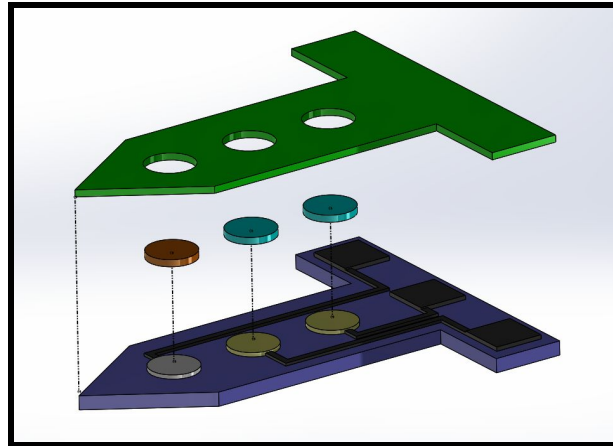
Fig 3: A diagram showing the components of the sensor

Circuit design:

Every sensor is connected to one circuit box, which transmits data from the plants to the database, using cellular data.

Working:

1. Needle point sensors are plugged into the plants.
2. Sensors receive voltage from the plants. These sensors are plugged into the circuit box using a USB port.
3. The voltage is collected by the cellular module and turned into digital values, using an ADC.
4. The digital values correspond to nitrate levels in that plant.
5. These values are then time stamped and updated to the database, using Losant's cloud storage.
6. They can be accessed by the user via the app.

Sensor Box design:

The circuit box is a 6 inch x 3 inch x 2 inch metallic box, with the top screwed on to the bottom. This provides a certain degree of water resistance and also prevents foreign entities (weather conditions, farm animals) from tampering with the sensitive equipment.
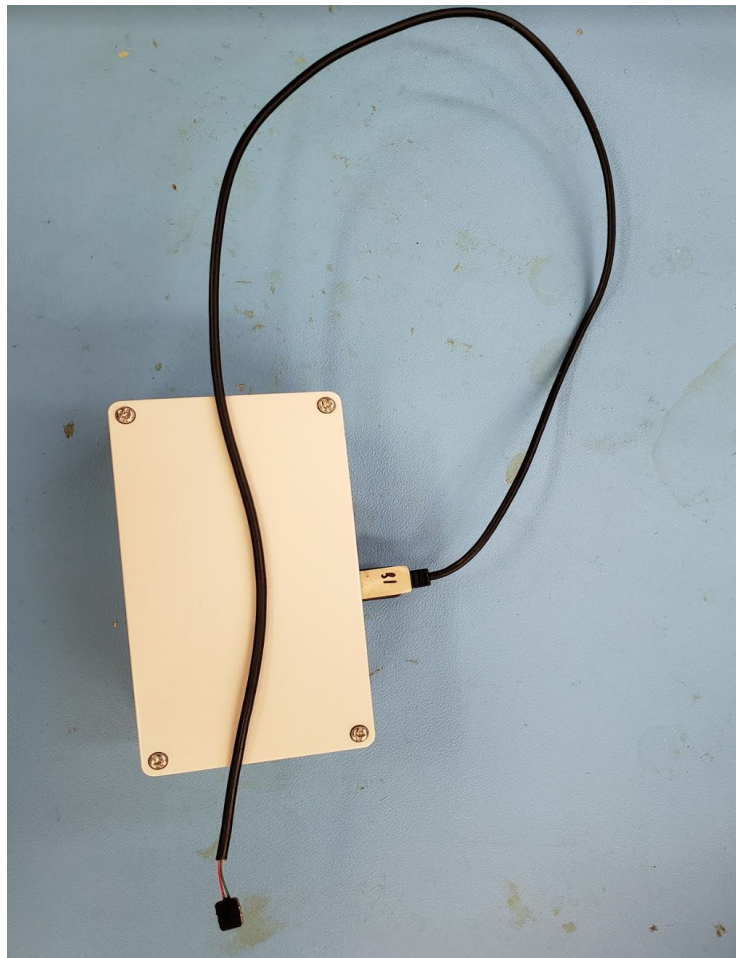
**Fig 4: Circuit box with sensor attached to the USB port on the side of the circuit box**
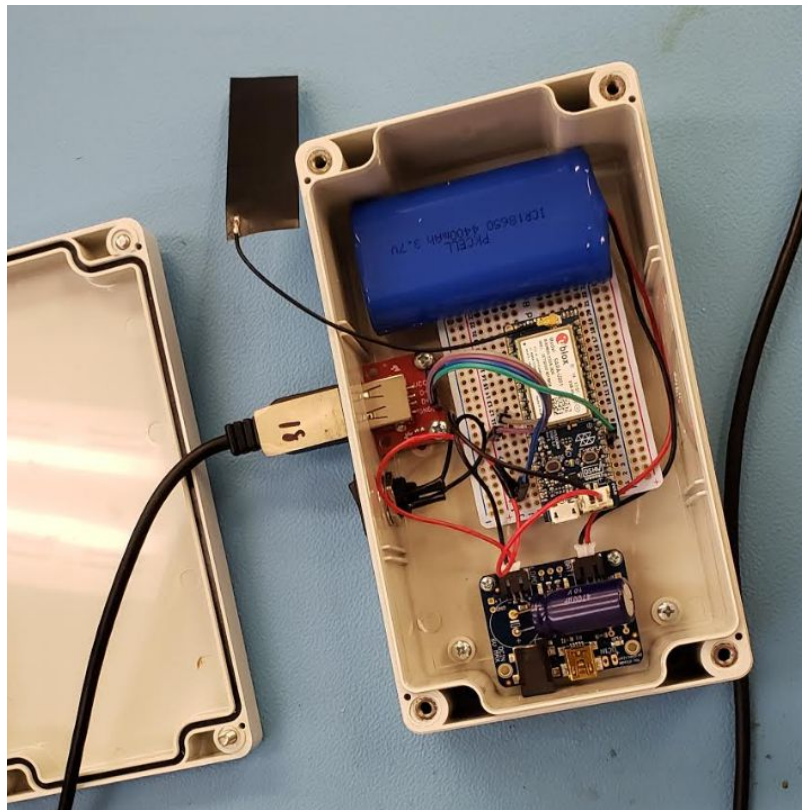
Fig 5: Circuit box design internal

<u>**Working:**</u>

1. The battery unit is two Li-on batteries connected in series, each of which provides a charge of 3500 mAh.
2. The battery powers the cellular module, which allows for data collection from plants.
3. To ensure the best battery life, the cellular module is put to sleep when not in use. It wakes up at predefined times of the day to collect and transmit data. Each transmission lasts about 10 minutes.
4. The cellular module is connected to a power booster circuit, to provide enough power to the module for data transmission.
5. During the off- season, the module sleeps for 6 hours and then collects and transmits data. This process is repeated 4x a day.
6. During peak season, the cellular module wakes up every 2 hours for data collection and transmission.This process is repeated 12x a day.
7. To determine when the sensor needs to collect more data samples, daily averages are required. If the average between two days has more than a 5% difference in values, more data points are collected for the next 3 days.

Data Transmission Design
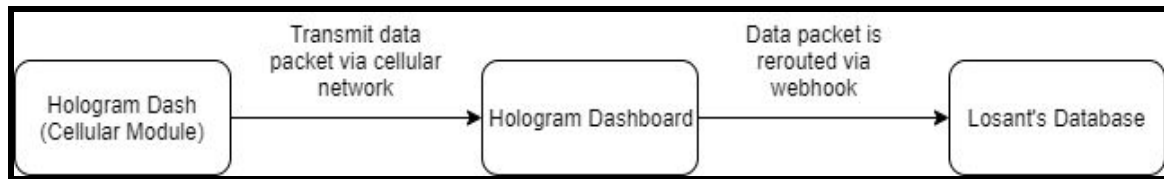
Fig 6: Data Transmission Flowchart

1. **Hologram Dash**
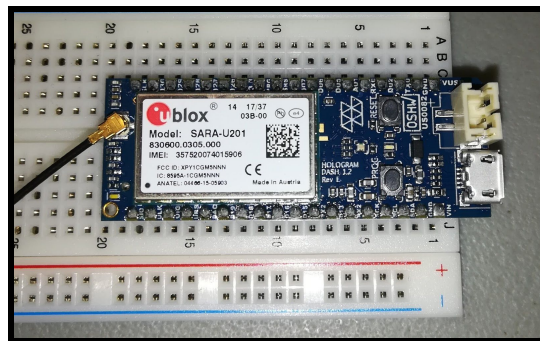
Fig 7: Hologram Dash

The hologram Dash is a cellular development kit where it is usually integrated into IoT devices or designs. The hologram dash consists of a Global SIM card and users are required to select the data plan to their liking. For the context of our design, we are using the Hologram Dash to transmit our sensor readings and it's approximate location to the Dashboard.

When the Hologram Dash wakes up after a certain period of time, it will perform a reading of nitrate level of the plant that it is currently attached to. Once the readings have been collected, the Hologram Dash will send the payload, a text string, to the Hologram Dashboard. The payload transmission is transmitted via cellular network where it will choose the cellular carries with the best network connection.

2. Hologram Dashboard
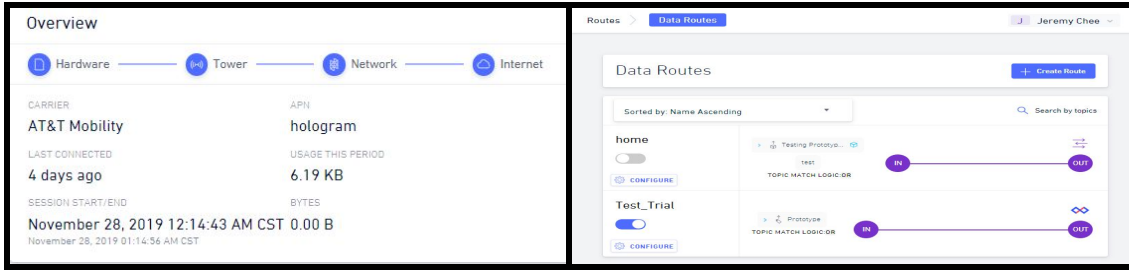
Fig 8: Statistical Overview of the latest received message (Left) and the data router manager (Right)

One of the features that the Hologram Dashboard offers is the ability to allow users to view statistical information regarding the payload that was sent to it. Besides that , it also allows users to view and upgrade their respective data plan. Compared with the mentioned features, the ability to reroute data is the most important feature. Upon receiving the payload from the Hologram Dash, the Hologram dashboard will perform specific actions based on the users' preference.

For our design, we decided to use webhook as our trigger action. Therefore, when the Hologram Dashboard receives the payload, it will generate an HTTP POST request where the request will include a payload that contains a JSON representation of the received payload. Once the HTTP POST request has been generated, it will post at the given URL which is Losant's database for our case.

3. Losant's Database (Cloud)

Fig 9: Losant's Database that is used to store the readings of sensors

The Losant platform is an application enabling platform, which offers users a variety of features like data storage, data manipulation, batch processing capabilities, real-time stream processing, and many more. For our design, we only use the data storage and workflow capabilities of the losant platform.
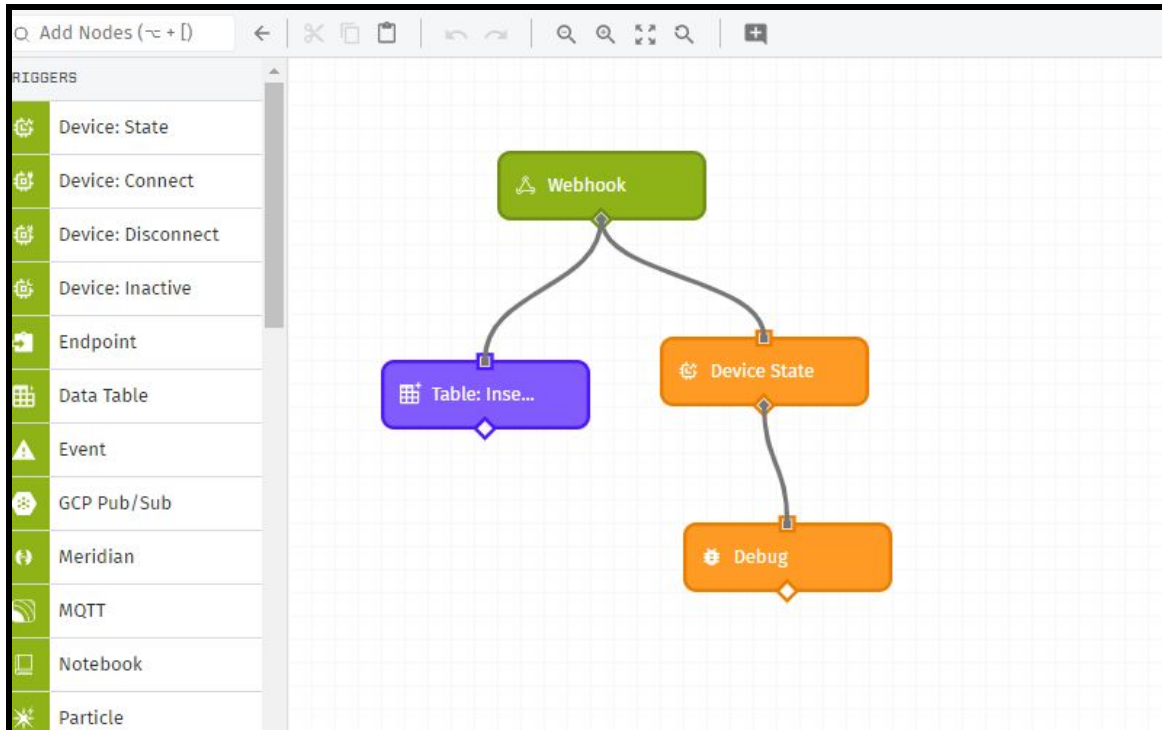
Fig 10: Workflow of the received webhook upon receiving the HTTP Request

The above picture shows the action that Losant will perform upon receiving the HTTP POST request. In the beginning, losant's URL is referenced by the data router in the Hologram Dashboard. Once the webhook has been triggered, Losant will receive the payload and insert it into the specified table in the database. The device state action shows the linked device readings while debug action plays a role in displaying the received data in a terminal. Both of this action, as shown in the picture above, are used for debugging purposes.

Android Application Design

The Application is the way data will be delivered to the user in most cases. It uses a separate webhook and workflow to retrieve data from the database and present it to the user in a variety of ways. This method of data storage allows us to display the most current readings to the

user, regardless of the status or number of sensors in use. The application has three main functions: Presenting data for individual sensors, Using GoogleMaps integration to see the locations of sensors, and providing an interface for managing sensors. The app is developed using Java and XML languages with Google Maps API and JSON for data management.

Application Flow
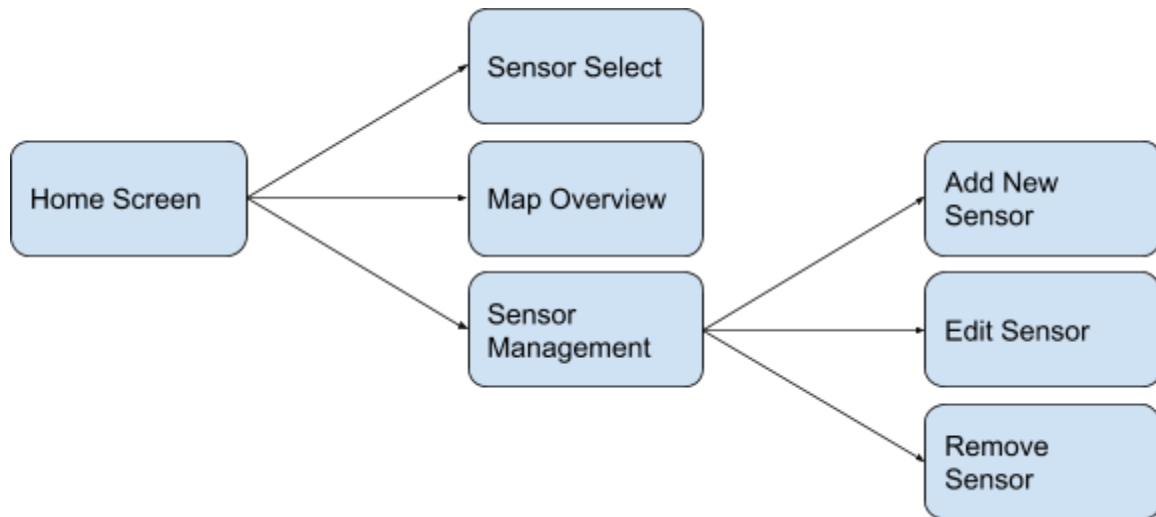
Fig 11: An overview of the UI Flow of the Application

The Application is divided into three main branches based on the main functions. Each branch is self-contained and requires no input from the other branches. The Sensor select screen will display the data for the selected sensor and relevant information about it. Map overview provides a Map with the locations of each sensor presented via the Google Maps API. The Sensor management provides the means to Add, Remove and Edit sensor properties within the database. The management functions affect the Sensor Info table in the losant database. This allows the Name or Group of the sensor to be changed without losing data already collected.

Database Integration
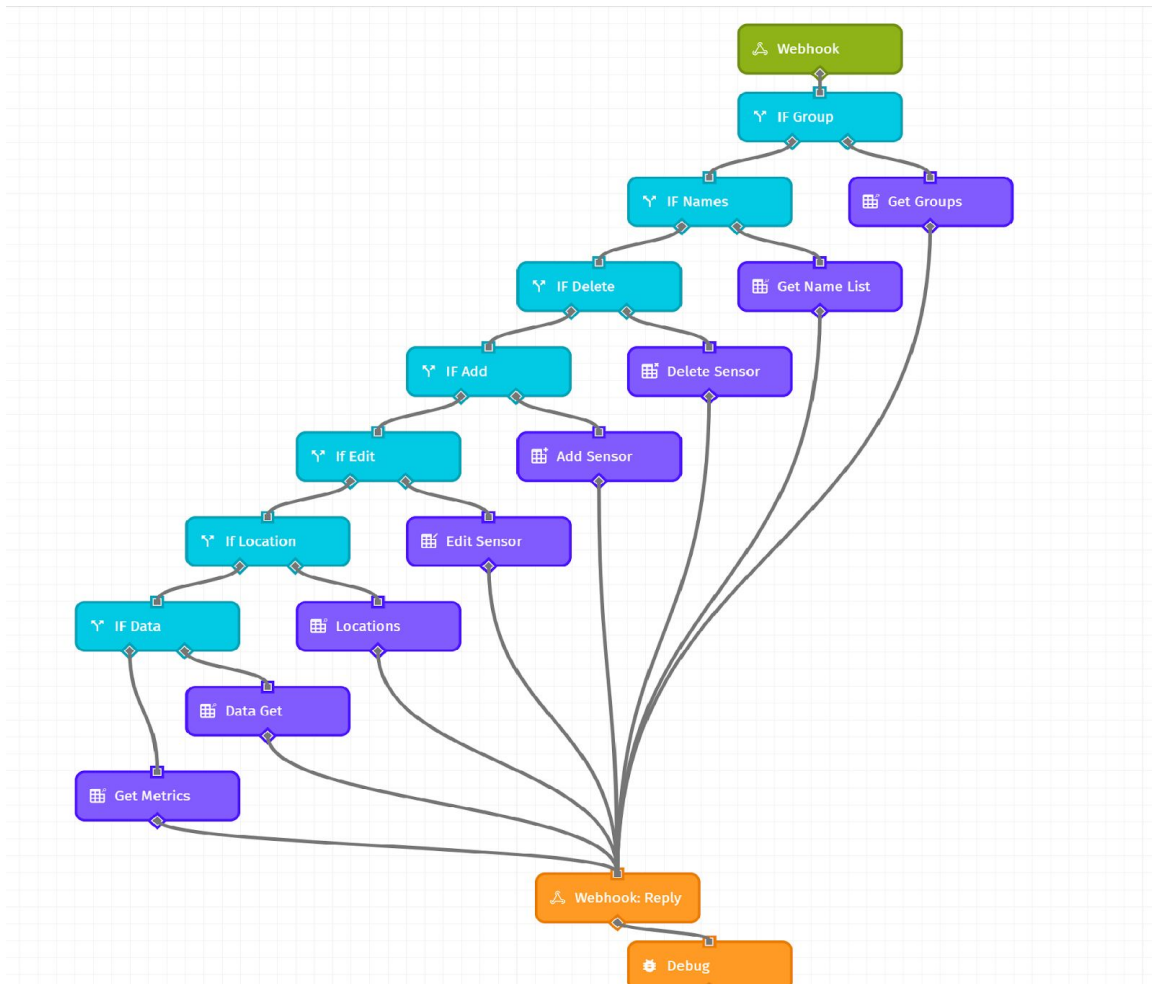
Fig 12: The Workflow started via the Application Webhook

Connecting to the database from the app is done via an HTTPS POST request with JSON as the body. The JSON object consists of a Type category with an identifier for the specific task that the request is asking for (ex. "Data" for a data request). The rest of the object consists of the specifics for that request and any needed data (the ID of the Sensor with a data request). The webhook then creates a return JSON object and sends a reply to the application with that object. The Application was developed with interfaces in mind, and as such the database class can be replaced by another class that implements its interface. This allows relatively simple integration into any database type, or other storage method.

3. Implementation Details of Design

3.1 Code Implementation of Cellular Module (Hologram Dash)

Is either one of the condition fulfilled:
1. voltagePPM is smaller than (curDayAvg-(curDayAvg/maxDelta).
2. voltagePPM is bigger than curDayAvg+(curDayAvg/maxDelta)

Yes

(curDayAvg + voltagePPM)/2-> curDayAvg

No

Is curDayAvg equal to 0?

No

voltagePPM-> curDayAvg

Yes

Is prevDayAvg is equal to 0?

Yes

voltagePPM -> prevDayAvg

No

Is either one of the condition fulfilled:
1. curDayAvg is bigger than prevDayAvg+(prevDayAvg/minTransitionDelta)
2. curDayAvg is smaller than prevDayAvg-(prevDayAvg/minTransitionDelta)

Yes

is phase equal to 1?

sleepPeriod / phase2Multiplier -> sleepPeriod,
2 -> phase,
0 -> phase2Counter

No

No

is phase equal to 2?

Yes

is phase2Counter larger than phase2Period?

Yes

Increment phase2Counter by 1.

phase->1,
sleepPeriod*phase2Multiplier -> sleepPeriod

No

Increment dayi by 1.

Is dayi bigger or equals to dayCount?

Yes

curDayAvg -> prevDayAvg,
0 -> curDayAvg,
0 -> dayi

No

Read current battery levels

Compile voltagePPM, battery readings, and location coordinates into Strings

Transmit compiled String into the Cloud

Is the transmission successful?

No

Store String into the memory address based on the value of start_address

Increment start_address by 8.

Yes

Yes

Power down the
cellular module

Put the cellular
module into deep
sleep for the
duration of
sleepPeriod

Power down the
cellular module

Fig 13: Logic flow of the software in the cellular module (Hologram Dash)

       For our design, Arduino IDE is used for implementing the software component of the cellular module. The libraries that were used in this software implementation consists of system libraries (wire.h, SPI.h, etc) provided by Arduino and libraries that is provided by the developer of Hologram Dash. As for debugging, we use the Arduino's serial function to observe the behavior of the software The above flowchart depicts the logic flow of the cellular module's software.

```
//Check if the given address is occupied. If the sector is not empty
//then proceed in transmitting the data that is stored in it.
if(DashFlash.isSectorErased(start_address) == false)
{
  String data;
  while(start_address >= 0)
  {
    data = flash_read(start_address);

    Dash.deepSleepMin(1);

    //Break from while loop if the data transmission is unsuccessful
    if(!HologramCloud.sendMessage(data))
    {
      break;
    }

    //If data has been successfully sent, erase the sector of memory that has already
    // been transmitted.
    DashFlash.eraseSector(start_address);

    data = "";

    if(start_address - 8 < 0)
      start_address = 0;

    else
      start_address -= 8;
  }
}
```

Fig 14: Screenshot of the software performing the necessary action if there's data in the flash memory.

In the beginning, the software will check whether the flash memory has any data stored on it. The address of the flash memory that will be read will be based on the global variable "start_address". If there's data being stored in that respective memory address, the software will attempt to send the data to the cloud by invoking the HologramCloud.sendMessage() function. Once the data has been successfully sent, the start_address variable will be updated. This process continues until start_address is 0.

```
//If the location string is empty, retrieve the approximate location of the cellular module
if(location.equals("") == true)
{
    HologramCloud.getLocation();
    Dash.pulseLED(100, 500);
    //Place the cellular module into sleep mode until an interrupt occurs(Received coordinates of the module)
    Dash.sleep();
    Dash.pulseLED(0, 0);
}
```

Fig 15: Screenshot of the software retrieving the approximate location of the module.

After that, the millivolts reading of the sensor will be taken. Besides that, the software will check if the approximate location has been taken. If not, the software will invoke the HologramCloud.getLocation() function. While waiting for the result, the cellular module will be put into sleep. Once an interrupt has occurred (Received the coordinates), the system will wake up and continue executing its commands.

After all of the necessary data has been retrieved, the software will compare the average data of the previous day and current day. If they differ to a certain amount, the sleep period of the cellular module will change accordingly, so increasing the sleepPeriod variable will decrease the number of transmission while decreasing the sleepPeriod will increase the number of transmission.

Once the calculation has been made, the data will be compiled into a string and the HologramCloud.sendMessage() function will be invoked. If the transmission fails, the software will store the current compiled string into the flash memory. After storing into the string, the start_address variable will be updated into the next empty memory address in the flash memory.

After the compiled string is transmitted or stored, the cellular module will be powered down to reduce power consumption and it will only wake up after the sleep period (hours) has passed. When it powered up, it will reestablish connection to the network. The software will wait till proper connection has been made, before going back to the loop and restart the entire process again.

3.2 APPLICATION IMPLEMENTATION

The Application is developed with the Android Studio IDE. Android Studio provides the most consistent and easy to use environment for Android applications that we have found. It allows us to work with the GUI directly with XML via the visualization tools, and connect that XML to our Java code on the back end.

3.3 DATABASE AND SERVER IMPLEMENTATION

Losant provides workflow based tools that allow us to create Webhooks with minimal difficulty and use JSON objects to quickly develop database interactions with the provided tools. Each Webhook has separate workflows based on what they are used by, and interface with the database separately. The database is organized into two tables. The Sensor Info table relates the Sensor ID built into the box with a user defined Name and group for ease of use. The Plant Info table contains the sensor data collected from the circuit boxes.

Sensor Info:

Sensor ID	Sensor Name	Sensor Group
String	String	String

Plant Info:

Sensor ID	Data Value	Battery Level	Latitude	Longitude	Date/Time
String	Integer	Integer	Float	Float	Date/Time

Table 1: Database Structure

3.4 MANUFACTURING

The sensor is designed to last inside the stalk of a plant and therefore must withstand moisture for prolonged periods. The ISM is a very fragile coating that easily peels off in even ideal conditions with minimal force. Water easily penetrates the ISM and therefore must also be held onto the sensor with a ring of epoxy that prevents water ingress to the ISM. The ISM must be uniformly placed on the sensor directly above the gold dot working electrode. There must also be an overlap of approximately .2 millimeters around the gold dot. This ensures that only the select nitrates are coming in contact with the working electrode. To ensure precision application of the ISM, a robotic fluid dispenser was used. This required calibration of the machine and software that allows the user to program its movements. The ISM needed to be tracked as changes were made to the program that controls the robot. The variables that could be altered included the following.

1. Line speed (traverse speed)
2. Path type (line, spiral in/out, etc.)
3. Tip height
4. Tip pressure
5. Path stepover (fill band)
6. Dwell and delay times
7. Shutoff distance
8. Tip type

A spreadsheet was used to track the changes made. Appendix 4 shows the excel sheet ase used to track progress. The ISM had some defects that would render them obsolete. Deep holes which are caused by air entrapped in the highly viscous fluid can cause non-nitrate materials to reach the working electrode. Slow filling of the dispensing syringe mitigate this problem.

Most of the tools required for inspection of the ISM deposition were optical instruments such as the stereomicroscope and contrast microscope. Figure 16 was taken using a contrast microscope. This tool allows any high frequency change in light such as a void to appear darker than under the naked eye. Porosity as shown in Figure 16 and Figure 17 must be avoided. There is little to be done to prevent this condition other than how the dispensing syringe is filled. Programming methods cannot combat this problem. Figure 18 shows the use of the stereomicroscope which was best used to look for surface defects such as wavy or uneven top coating. Lighting conditions for this type of microscope can be altered so light comes from different directions which aid in seeing a non-uniform surface. Uniformity on the surface is important because it reduces mechanical stresses in the ISM layer. Mechanical stresses can cause the material to peel off under its own internal forces. A smooth top coating is ideal.
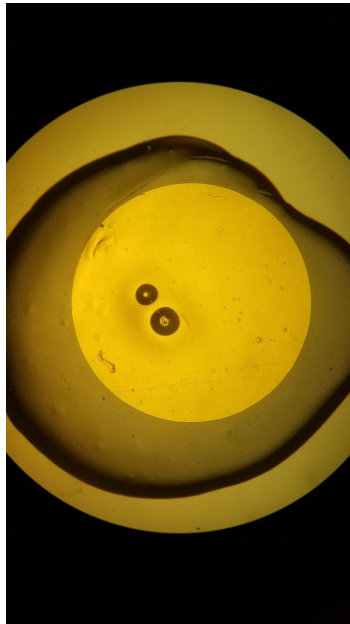

Fig 16: Sensor Image   Fig 17: Sensor Image   Fig 18: Sensor Image
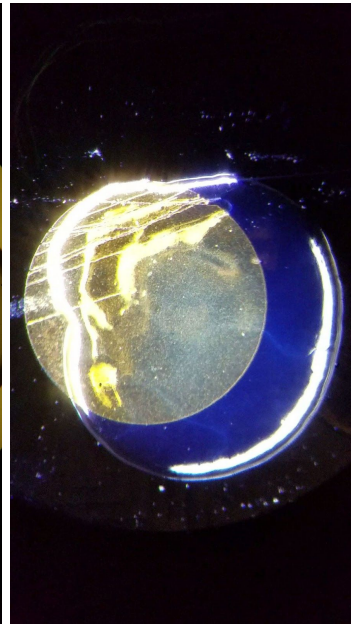
The other methods for testing the surface topography of the ISM include the atomic force microscope (AFM) and the profilometer. The profilometer is much less accurate with a range of approximately .1 mm and a resolution of approximately .0005 mm. This tool uses a small gemmed tip such as a diamond or ruby to drag across a surface similarly to how a phonograph does. This vertical displacement can be recorded and analyzed. The AFM is much more accurate with a resolution of about 20 nm but based on the results which are provided in Appendix 5, the AFM is not necessary for these purposes. The main goal for using the profilometer to obtain surface topography for the ISM was to prove that the material was wetting properly meaning the pattern that was used to deposit the ISM did not leave evidence of its path. If a spiral pattern was used, the ISM should not have a spiral pattern in its topography. Based on the profilometer results, the

surface had less than a 1500 nm toal height for surface defects which is less than 2.5% of the total thickness of the deposit. Figure 19 shows a porous sample of ISM that would likely cause a failure of the working electrode. Figure 20 shows a more ideal deposit of ISM. These images were captured during the profilometry process.
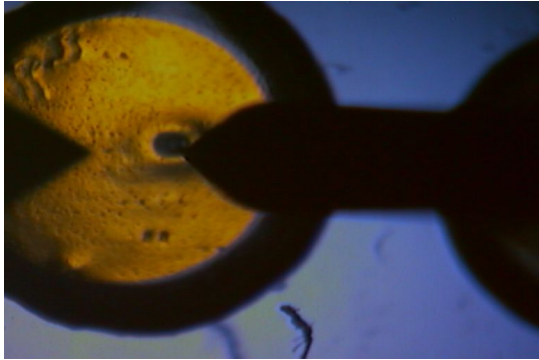

Fig 19: Profilometry   **Fig 20: Profilometry**
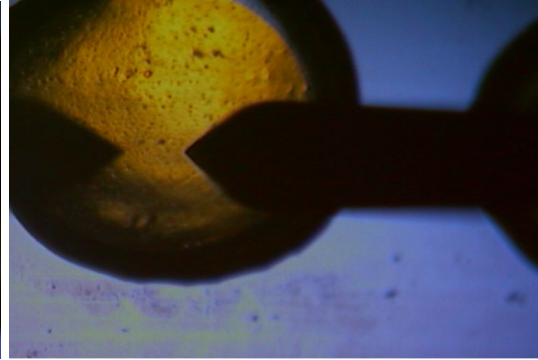
Besides mechanical stresses, the ISM had to have a consistent overlap with the gold dot electrode and it must be held in place with epoxy. The epoxy was deposited in a similar fashion to the ISM and also needed to overlap the ISM and not cover too much area of the electrode. The goal was to put a small band that overlapped with the edge of the ISM. Figure 21 shows a small test pattern for the epoxy deposition.
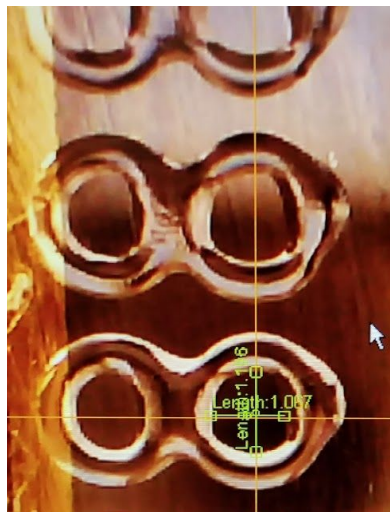
Fig 21: Test epoxy

Figure 22 shows the ideal electrode. This electrode exhibits and adequate amount of ISM overlapping the gold dot, and a layer of epoxy that covers the edge of the ISM but does not cover the electrode.
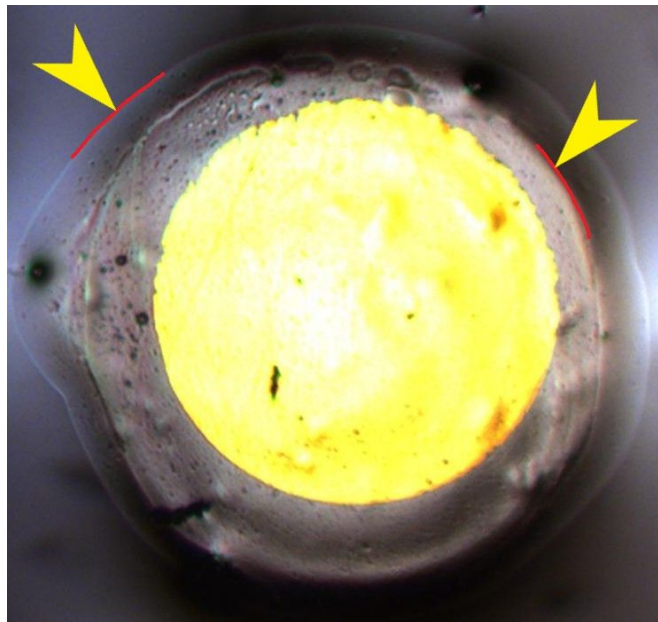
Figure 22: Ideal Electrode

4. Statement of Work

4.1 PREVIOUS WORK AND LITERATURE

There are three main methods for measuring nitrogen levels tissue analysis, optical meters, and ion selective membranes. Tissue analysis involves taking a sample of plant tissue and breaking it down to measure the nitrogen levels. Although this process produces accurate results, it requires the plants to be sent to a lab, making it impractical.

Optical meters will measure various optical properties to estimate the nitrogen levels. The method is much more convenient, but is affected by sunlight and can be unable to detect over fertilized crops.

Lastly, ion selective membranes will create a voltage based on the amount of nitrogen ions present. The method is still less accurate than tissue analysis, but provides a more direct measurement than optical sensors. [7]

Our project should be able to differentiate itself from the competitors. The lab using tissue analysis are inconvenient for farmers looking for immediate results. There are several optical sensors on the market including GreenSeeker and CropCircle. There are also some handheld ISM sensors from companies like Horiba, but they require the plant sap to be made into a solution. Our project should be the only field deployable sensor to measure nitrate levels directly from the plan using an ISM. Our sensor should provide more reliable data then sensors using optical measurements.

The sensor has a very limited life and is mostly disposable. Longevity, cost, and ease of use are the main of this project. The sensor is required to last about 60 days, and be as cheap as possible. The app will be perfected for ease of use and increased functionality. The results that are expected of the final system are listed below.

1. Data can be transmitted effectively from the field to the app, within Ames.
2. The sensor can differentiate between Nitrogen and other particles accurately and within the allowed error margins.
3. The units, when embedded correctly in plant stalks, can run for 60 days, without needing a change of batteries in between.
4. Assuming there's proper network connection, the app should be able to perform the users' request almost instantaneously.

5. Testing Process and Testing Results

5.1 Interface Specifications

1) **Cellular module-server interface:**
   a) The hologram data router functionality provides user an array of testing methods. One such option is sending the payload to an email or text message where we can view the data. Aside from that, it also allows us to use webhook where it will reroute the data into the database.
2) **Server-Application Interface:**
   a) Losant provides easy to use webhook interface testing. By using this feature we can input test results into the Database webhooks to test the resulting outputs.
   b) A Mock Database was produced with known data and structure to test the Application side of the database.

5.2 Hardware and software

1) **Sensor Testing Equipment:**
   A) Nitrate calibration and test equipment. This will be used to define and test the Sensor itself, and define the characteristic curve of the device. Similar equipment will be used for the temperature and differentiation properties.
   B) Environmental simulation. A set of devices used to simulate an environment including rain, humidity, temperature, and dirt. This will be used to ensure stability and reliability of the device in the field.
2) **Database Testing Equipment:**
   A) Mock Sensor. This will be used for testing the database input capture. It will likely be software based
   B) Database visualization software. MySql database visualization to view what is being saved and isolate the database software for testing

3) **Application Testing Equipment:**
   A) Mock Database. Used to isolate application for unit testing, hosted local to the testing machine and with known data
   B) Variety of Smartphones: Used for UI testing and to ensure wide compatibility.
4) **Additional Testing equipment:**
   A) Nordson Fluid Dispenser. This machine is used for accurately dispensing microscopic layers of polymer resins on the sensor substrate. This machine is also used for inspection of the seal that is meant to be achieved. This machine is used for both fabrication and inspection[6].

Fig 23: Nordson Fluid Dispensing Robot

   B) Contrast microscope. This tool allows porosity to be viewed by showing high contrast when high frequency shifts in light occur in a medium.
   C) Stereomicroscope. This tool allows varying lighting conditions to show surface defects in the fluid depositions that otherwise cannot be seen with the unaided eye.
   D) Multimeter. This will be used for checking various voltage outputs of the sensor and estimating power consumption.

Fig 24: Multimeter

Test Number	Test	Desired Result
1.A	Measure Nitrate Between 1 to 5000 ppm	± 10%
1.B	Differentiate From Other Nutrients(e.g Phosphorus)	± 10%
1.C	Filtering Out Data Anomalies	0 anomalies
1.D	Increasing the number of transmissions during peak season	3x increase

Table 2: Functional Testing

Test 1.A Measure Nitrate Between 1 to 5000 ppm
1. Obtain or dilute nitrate solution to between 1 and 5000 ppm.
2. Insert needle sensor into solution and connect to readout circuit box.
3. Obtain voltage value from arduino adc pin.
4. Compare value to calibration curve for nitrate concentration.
5. Repeat steps for various solutions in concentration results.
6. If data is outside error range adjust the calibration curve and repeat steps.

The goal of the test is the have the sensor box read the nitrate concentration within 10% error.

Test 1.B Differentiate From Other Nutrients(e.g Phosphorus)
Repeat test 1.A, but after preparing the solution add other plant nutrients like phosphorus. If the test isn't within 10% error the printing of the needle will need to be adjusted to only provide a voltage for nitrate ions. The goal of the test is to ensure the sensor materials are only responding to nitrate within 10% error.

Test 1.C: Filtering out data anomalies

1. Plug in the sensor to the stalk of the plant.

2. Check to see if the cellular module reads and stores data from the plant.

3. Check the bounds of the data and plot data on Excel.

The goal of this test is to see that inaccurate values (values that are not logically possible) are filtered out.

Test 1.D: Increasing the number of transmissions during peak season

1. Plug in the sensor to the stalk of the plant.

2. Check to see if the cellular module reads and stores data from the plant.

3. Calculate daily averages for two days.

4. If the difference between these averages is more than 5%, take readings more frequently.

The goal of this test is to provide our users, the most recent information about nutrient levels in soil, during peak harvest period.

5.4 Non-Functional Testing

Test 2

These tests will fulfill the user requirements for the sensor.

Test Number	Test	Desired Result
2.A	Waterproof	The sensor operates after exposure to moisture
2.B	Operational Lifetime	3 (Months)

Table 3: Non-Functional Testing

Test 2.A Waterproof

The sensor will be set up in a test field. The sensor will be setup to continuous transmit data to the server. The sensor should continue to transmit data after rainfall has occurred in the field. If the sensor fails the seal on the sensor needle will need to be adjusted. The sensor can be tested under various water conditions including a mist spraying continuously on the sensor. The sensor should have an adequate seal to prevent moisture creeping underneath the ISM and NaCl or KCl coatings located on the needle. The spray mist test will determine if the glue has properly sealed around the wires bonded to the vias. The plant will be wet for the duration of the use of the sensor and the glue will have to prevent water from penetrating underneath the ISM layer for the life of the sensor. We will also test various mounting orientations of the sensor to ensure that the sensor performs under a variety of conditions. The sensor can be mounted near the midrib of the leaf or on the margin. It can also be mounted on top and underneath the leaf.

Test 2.B Operational Lifetime

The sensor box will be deployed in a greenhouse environment. The sensor should provide continuous measurements for a three month period of time. The three month lifetime is only for ideal greenhouse environments. The sensor will also be deployed in a test field. The goal for the test field sensor is a 1-2 week operational period.

Test 3

Test3.A Reliability of Data Transmission

When it comes to testing the reliability of the data transmission, we are focused on testing the speed of the data transmission. The speed of the data transmission is tested by frequently transmitting data across the network at a fixed time interval. Throughout the transmission process, we realized that occasionally there will be a small wait time of when the data has been successfully sent and when the database has received the data. Out of the 50 attempt, 4 of the attempts have a

delay of approximately 20 seconds compared with the other 46 attempts while the other 46 attempts arrived at the database less than 2 seconds. In the end, we deduce that the delay may possibly be caused by the slow internet or cellular network connection.

6. Closing Material

6.1 CONCLUSION

The goal of the project was to improve on all the components of the sensor system. The sensor needle has been made more reliable and is relatively invariant to other stimuli. The circuit box has been made more weatherproof, energy efficient, and easier to use. The transmission is now more reliable, since data is transmitted using cellular networks rather than Bluetooth. The app has been updated to be easily accessible by the users.

6.2 References

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7. Appendices

1)Set Up Sensor and install on plant:

The first step to using the sensor is to install the sensor and circuit box into the desired plant. Each sensor is independent and should be spread far enough to capture meaningful data across the entire field. Each circuit box has an ID number printed on the box. This number is needed to properly attach the box to the application, so take note of it. When the sensor is properly fitted to the plant, switch the circuit box power switch to the on state. This completes the circuit box and Sensor installation in the field.

Fig 25: Installing of Sensor

2)Add Sensor to Database :

As stated before each circuit box has an ID number printed on the case. Once the circuit box is installed and powered on, open the Android application and navigate to the sensor management section by pressing the button labeled "Sensor Management". Next Select "Add Sensor" and reach the screen displayed below.
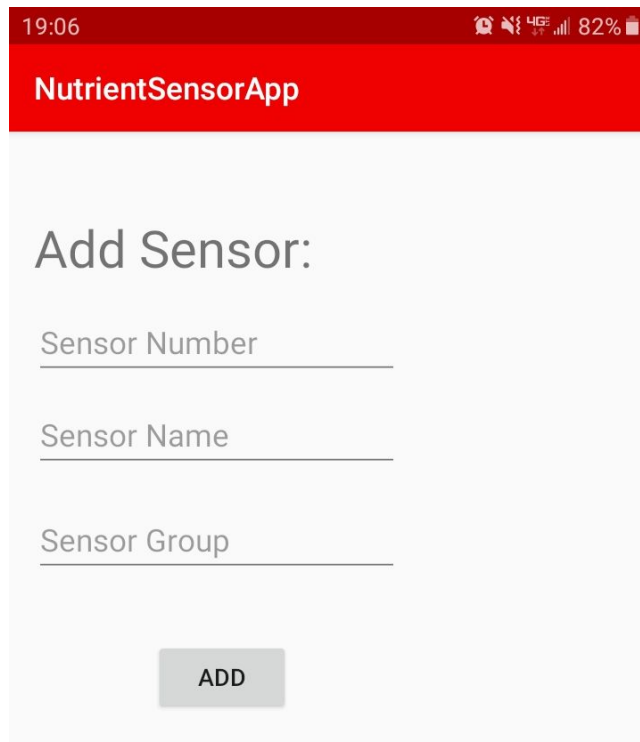
Fig 26: The Add Sensor Screen

Complete the form by adding the ID to the "Sensor Number" Field, Giving the sensor a meaningful name with the "Sensor Name" field, and adding a group to organize the sensor into. The Sensor Name will be the primary way that the sensor will be identified, so make sure it is distinct.

3)View data Using Application:

Once the Sensor is registered in the application and the sensor is installed, data will be collected automatically and stored in the database. In order to view the data that has been taken, Open the application and navigate to the Sensor View screen by selecting "View Sensor Data" on the home screen. Then use the spinners to select the group and the name of the sensor that you wish to view. This will open that sensors summary screen when "Select" is tapped. Data can be viewed on this screen, or Exported to a .CSV file for more useful analysis with a program like Excel or Sheets.
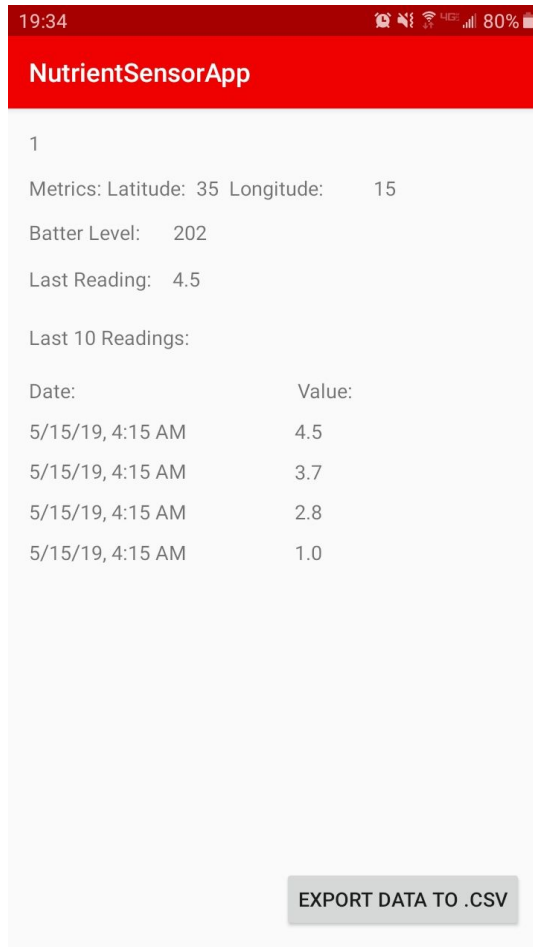
Fig 27: The Sensor View Screen

Additional App Features:

       The application has a few other features to round make sensor management easier. The Map button can be used to create maps with the location of the circuit boxes. This can be used to locate circuit boxes in large fields of crops. The other untouched sections of the Application are the "Edit Sensor" and "Remove Sensor" Buttons on the Sensor management page. These can be used to remove sensors from registry and change the Name or Group of a specific circuit box. Due to the way that the database stores Sensor names and groups, the data will not be lost when the sensor is renamed or re-grouped.

Previous Circuit box from last Sr Design:
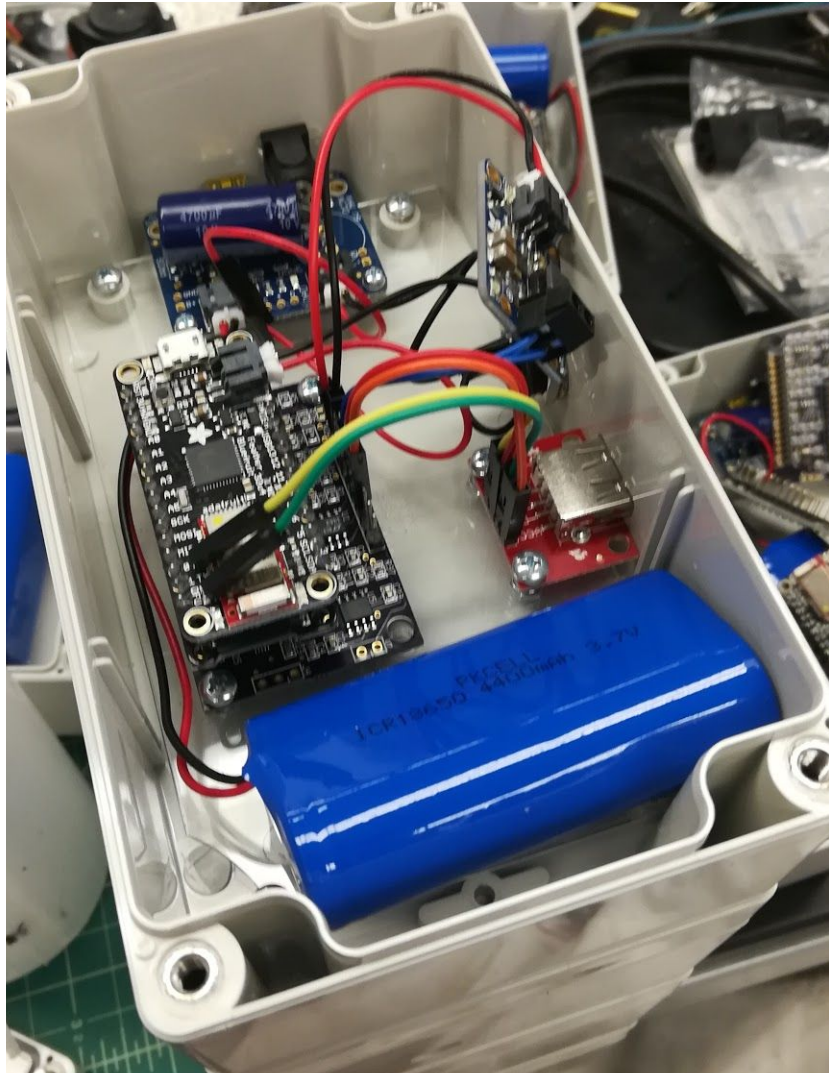
Fig 28: The Previous Circuit Box

The Previous Senior design group that Dr. Dong worked with completed a Bluetooth based circuit box design. This design was almost entirely gutted as the microcontroller, datalogger, and bluetooth shield were replaced with a single hologram dash Cellular module that had an onboard user microcontroller. The battery charging circuit and battery were used for the new sensor as well.

Previous Application from last Senior Design:

As the circuit box for the previous group was retooled to work with a regular cellular data transmission method, rather than a user driven bluetooth method, the Application that worked with that box had to be scrapped completely. A new application was devised from the ground up to work with the losant database that we designed.

Bluetooth & Cellular Combo Box:

A design that came up briefly in development was one that used both the Bluetooth module that was core to the previous group and adding our own cellular module was considered, but obvious problems of space and redundancy were seen. The client provided housing method was fairly large, but with two microcontrollers and a power system that could handle the increased load of the devices would be too large. The design was scrapped to favor an entirely new Cellular based system.

LoRaWAN Circuit Box:

When discussing Communication methods with the client, he suggested LoRaWAN as a possible solution to long distance communication. While the LoRaWAN system could handle the data transmission, it would have required extra infrastructure to deploy in a large field and was scrapped for the more flexible and well documented Cellular method.

We had to use a new MCU because the Arduino MCU (from the previous versions) used Bluetooth to transmit data between circuit box and database. Bluetooth communication is extremely ineffective over long ranges. Therefore, using a cellular module for data transmission allowed us to have a longer range of communication.

The older circuit box would be powered on continuously. There was no means of knowing the battery capacity at a given point in time, which meant that the battery would die out randomly and the sensor would stop working till the batteries had been replaced. During the harvest period, the nutrient levels of the soil provide critical information to the farmers. Having lapses in data during this critical period, would mean that the users would still have incomplete information about the soil nutrient levels. This defeated the purpose of this project.

To overcome this issue, we used a cellular module that could be put to sleep during inactive times (i.e. times of the day when there is no need to collect and transmit data). This significantly increased the battery life of the circuit box.When the user accesses this data using the app, they are not only able to view the nutrient levels in soil, they can also see the status of the battery and if it needs to be replaced, thanks to the built in battery sensor of the MCU.

Feelings vs. Fun

Appendix 4: ISM tracking spreadsheet

Spiral In	Fill Area Width (reduce change per spiral revolution)	Fill Area Band	Fill Area Type (2-circle, T-inner to outer)	LUS Pre-move Delay	LUS Settling Distance	LUS Dwell time	LUS Node time	LUS shutoff distance	LUS Shutoff delay	Line Speed	Pressure	Initial Z top height	Top height	Location	Top Type	Notes
Spiral In	0.12	0.5	2	0.5	0	0	0	0	0	1.5	2.9	35.76	35.6	1A	SS .006 DIA	Oriented Right angle is in bottom left corner. Column 1 is on left. Row A is at top. Wafer 2/4
Spiral In	0.25	0.5	2	0.5	0	0	0	0.1	0	1.5	2.9	35.76	35.6	2A	SS .006 DIA	
Spiral In	0.25	0.5	2	0.5	0	0	0	0.25	0	1.5	2.9	35.76	35.6	3A	SS .006 DIA	
Spiral In	0.3	0.5	2	0.5	0	0	0	0.2	0	1.5	2.9	35.76	35.6	4A	SS .006 DIA	
Spiral In	0.33	0.5	2	0.5	0	0	0	0.2	0	1.5	2.9	35.76	35.6	5A	SS .006 DIA	
Spiral In	0.35	0.5	2	1	0	0	0	0.2	0	1.5	2.9	35.76	35.6	6A	SS .006 DIA	
Spiral In	0.35	0.5	2	1	0	0	0	0.2	0	1	3.6	35.76	35.6	7A	SS .006 DIA	
Spiral In	0.3	0.5	2	1	0	0	0	0.3	0	0.8	3.6	35.76	35.6	8A	SS .006 DIA	
Spiral In	0.3	0.5	2	1	0	0.5	0	0.2	0	0.5	3.6	35.76	35.6	9A	SS .006 DIA	
Spiral In	0.3	0.5	7	1	0	0.5	0	0.3	0	0.8	3.6	35.76	35.6	10A	SS .006 DIA	
Spiral In	0.15	0.5	7	1	0	0.5	0	0.2	0	1.5	3.6	35.76	35.6	11A	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	6B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	7B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	8B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	9B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	10B	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	11B	SS .006 DIA	
zig zag with outer	N/A	N/A	N/A	1	0	0.5	0	0.3	0	3.2	2.6	35.76	35.6	1C	SS .006 DIA	
	N/A	N/A	N/A	1	0	0.5	0	0.3	0	3.2	2.6	35.76	35.6	2C	SS .006 DIA	
	N/A	N/A	N/A	1	0	0.5	0	0.3	0	3.2	2.6	35.76	35.6	3C	SS .006 DIA	
	N/A	N/A	N/A	1	0	0.5	0	0.3	0	3.2	2.6	35.76	35.6	4C	SS .006 DIA	
														5C	SS .006 DIA	
														6C	SS .006 DIA	
														7C	SS .006 DIA	
Spiral Out	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	8C	SS .006 DIA	
Spiral Out	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	9C	SS .006 DIA	
Spiral Out	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	10C	SS .006 DIA	
Spiral Out	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	11C	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	1D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	2D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.6	35.76	35.6	3D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0.1	0.5	0	0.3	0	2	3.6	35.76	35.6	4D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0.1	0.5	0	0.3	0	2	3.6	35.76	35.6	5D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0.1	0.5	0	0.3	0	2	3.6	35.76	35.6	6D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0.1	0.5	0	0.3	0	2	3.6	35.76	35.6	7D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0.1	0.5	0	0.3	0	2	3.6	35.76	35.6	8D	SS .006 DIA	
														9D	SS .006 DIA	
														10D	SS .006 DIA	
														11D	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	1E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	2E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	3E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	4E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	5E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	6E	SS .006 DIA	
Spiral In	0.3	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	7E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	8E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	9E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	10E	SS .006 DIA	
Spiral In	0.3	0.5	7	1	0	0.5	0	0.3	0	2	3.2	35.76	35.6	11E	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	10F	SS .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	11F	SS .006 DIA	

Spiral In	Fill Area Width	Fill Area Band	Fill Area Type	LUS Pre-move Delay	LUS Settling Distance	LUS Dwell time	LUS Node time	LUS shutoff distance	LUS Shutoff delay	Line Speed	Pressure	Initial Z top height	Top height	Location	Top Type	Notes
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	10G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	11G	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	10H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	11H	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	10I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	11I	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1A	BB .006 DIA	Notes: Oriented Right angle is in bottom left corner. Column 1 is on left. Row A is at top. Wafer 3/4
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9A	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9B	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	1C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	2C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	4C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	5C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	6C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	7C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	8C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	9C	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	1D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	2D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	3D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	4D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	5D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	6D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	7D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	8D	BB .006 DIA	
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.6	35.76	35.6	9D	BB .006 DIA	

Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	1E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	2E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	3E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	4E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	5E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	6E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	7E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	8E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.6	3.8	35.76	35.6	9E	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9F	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	1G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	2G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	3G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	4G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	5G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	6G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	7G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	8G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	1.8	3.6	35.76	35.6	9G	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	1H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	2H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	3H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	4H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	5H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	6H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	7H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	8H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	9H	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	1I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	2I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	3I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	4I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	5I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	6I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	7I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	8I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	9I	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	1J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	2J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	3J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	4J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	5J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	6J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	7J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	8J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	9J	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	1K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	2K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	3K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	4K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	5K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	6K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	7K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	8K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2	3.4	35.76	35.6	9K	88 .006 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2.7		25.46	25.35	1A	Plastic .005 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	2.7		25.46	25.35	3A	Plastic .005 DIA
Spiral In	0.2	0.5	7	0.3	0	0.5	0	0.3	0	3	3.6	25.46	25.35	5A	Plastic .005 DIA

Notes
Oriented Right angle is in bottom right corner
Column 1 is on left
Row A is at top
Wafer 4/4
Clear Plastic dispense tip very small for A-E
Switched to small metal tip for F+
Added extra half circle from 180 to 360 deg

Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.6	25.46	25.35	7A	Plastic .005 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	4.7	25.46	25.35	2B	Plastic .005 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	4.7	25.46	25.35	4B	Plastic .005 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	4.7	25.46	25.35	6B	Plastic .005 DIA
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.33	1C	PTFE .011
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.33	3C	PTFE .012
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.28	5C	PTFE .012
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.28	7C	PTFE .012
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.28	2D	PTFE .012
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.28	4D	PTFE .012
Spiral In	0.2	0.5	7	1	0	0.5	0	0.3	0	3	3.5	32.41	32.28	6D	PTFE .012
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1E	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3E	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5E	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7E	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7F	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	7J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	1K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	2K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	3K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	4K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	5K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	36.74	36.59	6K	88 .006 DIA

Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	9G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	10G	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	1H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	2H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	3H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	4H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	5H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	6H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	7H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	8H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	9H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	10H	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	1I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	2I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	3I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	4I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	5I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	6I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	7I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	8I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	9I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	10I	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	1J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	2J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	3J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	4J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	5J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	6J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	7J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	8J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	9J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	10J	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	6K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	7K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	8K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	9K	88 .006 DIA
Spiral In	0.175	0.6	7	0.3	0	0.5	0	0.3	0	3	3.5	35.74	35.59	10K	88 .006 DIA

APPENDIX 5: PROFILOMETRY