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LabVIEW Interfacing and Testing of an Electroplating System

ME 480 Senior Design Project
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Abstract

In this project an electroplating system for the fabrication of micro and nano structures was developed. The three important objectives of this project were LabVIEW interfacing of an electroplating power supply, design and fabrication of an electroplating jig which can accommodate three different substrate sizes, and electroforming of test patterns with micro meter size features. The final product of this project is an automated potentiostat connected to an electroplating jig to facilitate plating of a large number of micro structures on a single substrate which was tested and verified with the fabrication of micro structures.

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1 Introduction

1.1 Background

Electroforming is an age old technology which has been extensively used for the deposition of thick metallic coatings for various applications. This has recently been modified to suit the high technology applications related to Micro Electronic Mechanical Systems (MEMS) and nano technology. In this context the current project aims to develop an electroplating setup suitable for the fabrication of micro and nano structures. The goals of this project are LabVIEW interfacing of an electroplating power supply, design and fabrication of a simple jig, and testing and electroforming of test patterns.

1.2 Requirements & Specifications

1.2.1 Functional Requirements

The customer has set three mandatory functional requirements of the final product to be met strictly. These are:

1. Providing a LabVIEW interface to control between potentiostatic and galvanostatic electroplating.
2. A jig which will facilitate mounting substrates of different sizes and shapes within a given range of 1-4 inches.
3. Capability of remote operation of the electroplating setup.

1.2.2 Technical Requirements

The customer has requested the architecture of this project be based on:

1. LabVIEW for the programming of control software for the electroplating power supply.
2. Customer specified jig design based on customer set electroplating power supply and associated equipment.

1.2.3 Performance Requirements

The customer has set the required performance requirements of the electroplating setup up as follows:

1. Ability to vary current between 10 μA and 1 A.
2. Ability to vary voltage between 1 V and 5 V.
3. Possibility of using the same setup for pulse electroplating.

1.2.4 Safety and Environmental Requirements

The customer has set two major requirements in this respect which are:

1. Power, where the electroplating setup should be accident proof as the process deals with current and liquid chemicals, which suggests that the design has to be able to separate these two elements to a degree that will allow the process to go on smoothly without accidents occurring.
2. Chemicals, where materials must be handled, disposed and processed according to material safety data sheets and established procedures.

1.2.5 Summary of Major Requirements

The table below describes a summary of the customer's major requirements:

Requirements	Description
Functional Requirements	
LabVIEW Interface	To control between potentiostatic and galvanostatic electroplating.
Jig	To facilitate mounting substrates of different sizes and shapes.
Remote Operation	Capability to be operated remotely.
Technical Requirements	
Programming Language	Customer has set LabVIEW as the required programming interface for this project.
Jig Design	Customer has set the design of the jig to be constrained to fit different substrate sizes.
Performance Requirements	
Current	Ability to vary current between 10 µA and 1 A.
Voltage	Ability to vary voltage between 0.5 V and 5 V
Expandability	Possibility of using the same setup for pulse electroplating
Safety and Environmental Requirements	
Power	Accident proof setup as the process involves current and liquid chemicals which are hazardous when not separated safely.
Chemicals	The handling, processing and disposal of chemicals according to material safety data sheets.

Table 1 : Summary of Major Requirements

1.2.6 Measurable Engineering Specifications

The table below lists the customer specified measurable engineering specifications and the methods of verification:

MES	Description	Method of Verification
Current	Ability to vary current between 10 µA and 1 A.	Sensor output within data acquisition system.
Voltage	Ability to vary voltage between 0.5 V and 5 V.	Sensor output within data acquisition system.
Expandability	Possibility of using the same setup for pulse electroplating.	Final hardware setup and LabVIEW interface programming.
Flexible Substrate Sizes	Ability to plate on substrates 1 – 4 inches in diameter.	Final hardware setup.
Uniformity of Plating Thickness	A uniformity of thickness of ± 10 %.	Observation by high power optical microscope.

Table 2 : Measurable Engineering Specifications

1.3 Benchmarking

The following section discusses current competitors in the electroplating industry and focuses on their level of technology and expertise. The discussion will be wrapped up by a comparison between the electroplating system developed and the systems used by the competitors.

1.3.1 Advanced MicroSystems

Offers design, development and volume manufacturing foundry services for 3" and 6" wafer MEMS, MOEMS and thin film devices. Specialties include CMOS-compatible processing, magnetic materials, high aspect-ratio UV-LIGA microlithography, through-mask electrode position, CMP, deep-silicon Bosch ICP etching, dry and wet release etching and super-critical drying. AMS features a large, modern Class 100 clean room with Class 10 micro lithographic coating.

1.3.2 Silex Microsystems

Offers design, development and volume manufacturing of MEMS components primarily for customers in the telecommunication and life science markets. Specialties include bulk micromachining with etching, V-grove and DRIE, anodic, fusion, adhesive and solder bonding, surface micromachining with multilayer polysilicon, polyimide/BCB dielectrics for RF applications, and electroplating and electronless bumping of gold, nickel and solder tin. Components are developed and fabricated in state-of-the-art class 10-10000 clean rooms using 4", 6" and 8" diameters wafers.

1.3.3 Protron Mikrotechnik GmbH

The business area of Protron Mikrotechnik comprises design, development, and manufacturing of customer-specific micro-electromechanical systems (MEMS). The technology core competences are high aspect ratio silicon etching (DRIE) and standard MEMS technologies. Main application fields are micro-fluidic systems, micro-optical devices (e.g. glass fiber coupler), and silicon tools for injection molding and hot embossing processes.

1.3.4 Amkor Technology

Amkor Technology is the world's leader in micro electronic packaging technologies and the worlds largest outsource provider of Micro-Electronic Machines (MEM) and Micro Optical Electronic Machines (MOEM).

All of the companies listed above are major competitors in the fabrication of microstructures. However, these companies have standard procedures and processes with no room for customized systems. The electroplating system developed in this project allows the flexibility of varying critical parameters in the electroplating process. These critical parameters are:

1. Number of electrodes, where a 2 electrode system would be utilized for microstructure fabrication whereas a 3 electrode system would be utilized for nanostructure fabrication.
2. Substrate sizes, where the above mentioned companies offer standard size wafers. The system being designed will offer the flexibility of customer defined wafer sizes.
3. Setup configuration, where a potentiostatic configuration (constant voltage) would be used for the fabrication of nano wires and a galvanostatic configuration (constant current) would be used for the fabrication of high aspect ratio microstructures and metallic electrodes for micro devices.

2 Implementation/Design

2.1 Electroplating Jig Design & Fabrication

Jig design was carried out in different steps. In this process, the initial design was found to have certain deficiencies and hence a Mark-2 jig was developed. In the following section, the important features of the first design are explained with its drawings, which are followed by the details of the Mark-2 design and its features.

2.1.1 Initial Design

This design comprises of three parts that make up the complete jig. The parts include the jig base, the substrate base and the top plate. The jig base is the same for all of the sample sizes but the substrate base and the top plate change according to the size and shape of the sample being plated. Figure 1 is an assembly diagram of the jig where the jig base is part number 1.

The next part is the substrate base which attaches to the jig base. It is a threaded part that screws onto the jig base and has a step for the substrate to be placed in. It also has several female threaded holes in which the bolts mounting the top plate will be held. The substrate base is different for different substrate sizes. The substrate base is part number 2 illustrated in the assembly diagram.

The final part of this design is the top plate. The top plate is a thin plate about 0.2 inches thick that is placed on top of the substrate base. This plate secures the sample that is being electroplated and seals the conductor which is fixed on the sample. There is a hole cut out in this piece. It exposes the sample to the electroplating solution to allow electroplating to occur. There is a different plate for different substrate sizes. The top plate is illustrated as part number 3 in the assembly diagram.

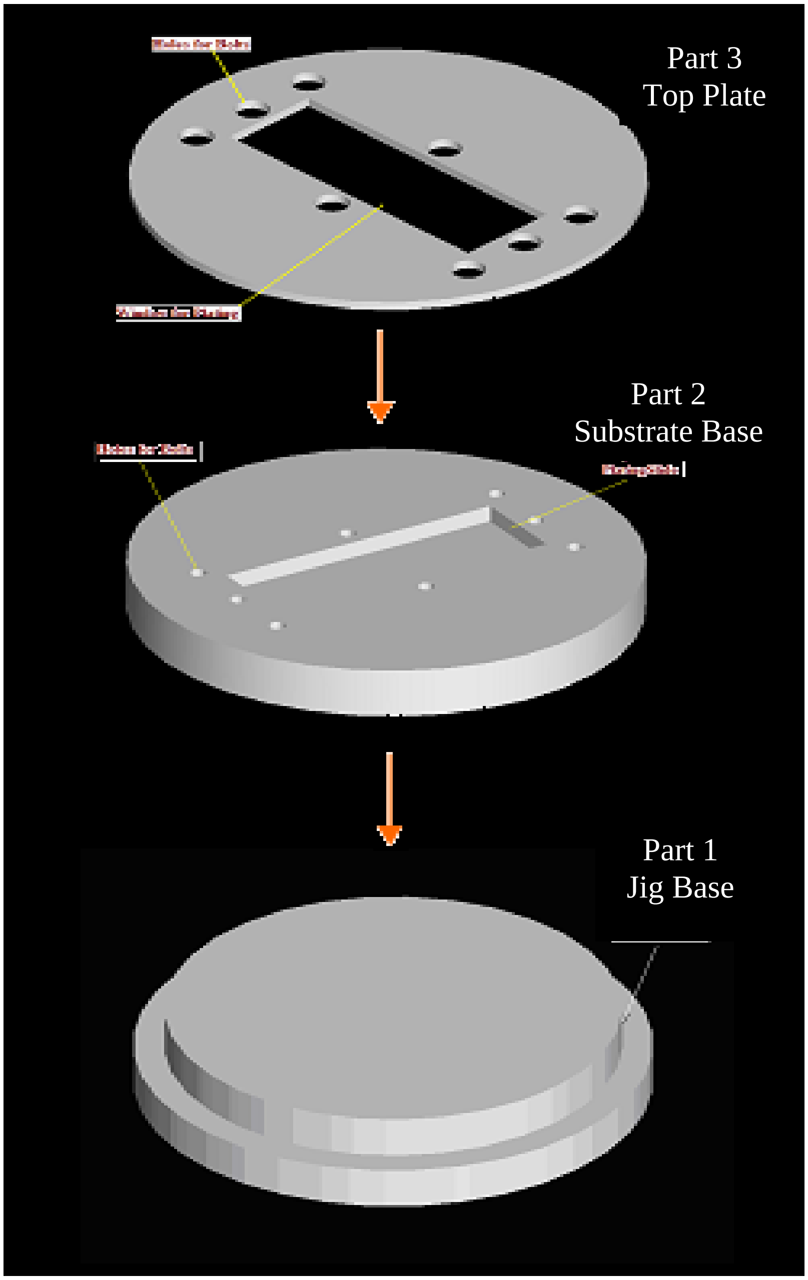

Figure 1 : Jig Assembly Diagram

The initial design was a feasible design but after some in-depth analysis, this design was abandoned. The major issues identified with this design are:

- Too many individual parts to be fabricated.
- Excessive use of material due to number of individual parts.
- Electroplating solution may leak through the outside of the top plate and this will cause the electrical contact to be plated resulting in poor conduction.
- The concentrated forces in several areas due to bolting may result in an uneven plated sample.
- The entire jig was about 5” in diameter which will not fit in the beaker used for the electroplating process. A 1 liter beaker is proposed to be used in all the experiments.

2.1.2 Revised (Final) Design

The next step was to revise the initial design. After careful revision, the final design was conceived. Although it looks very different from the first design, the second design shares several ideas from the initial design. All these changes were made based on the information from analysis of the initial design. The major change is that the 3 x 1 inch rectangular substrate has its own jig independent of the other substrates which would allow the reduction of the overall size of the jig. A circular jig will be designed to hold a 2 inch diameter, 1 inch diameter and 1 x 1 inch square substrate. A rectangular jig will be designed to hold a 3 x 1 inch substrate.

2.1.2.1 Circular Jig

This jig consists of a base and an adapter plate which will hold all three substrate sizes and a lid that attaches to the base. The base has a 2 inch diameter step that will hold a 2 inch diameter substrate. The other substrates (1 inch diameter and 1 x 1 inch square) will be held in place by an adapter plate which will be placed in the 2 inch diameter step. Figure 2 illustrates an assembly diagram of the jig. The jig base is threaded on its lower section. It also has an o-ring groove that will seat an o-ring to prevent the electroplating solution from seeping into the jig. The jig base is part 1 in the assembly diagram.

The adapter plates are 2 inches in diameter. They are placed in the jig base on the step cut out for the 2 inch diameter substrate. The first adapter plate holds a 1 inch diameter substrate and is part 2 in the assembly diagram. The second adapter plate holds a 1 x 1 inch substrate and is part 3 in the assembly diagram.

The final part of the jig is the lid. Two lids were designed to support different substrate sizes. There is a hole cut out on the top of each lid to expose the substrate to the electroplating solution. The holes are smaller than the total size of the substrates. They were designed to be smaller so that the electrical contact which is placed on the edge of the substrate is isolated from the electroplating solution to avoid it from being plated. The lid for the 2 inch diameter substrate (Part 4) has a circular opening of 1.47 inches in diameter, whereas the lid for the 1 inch diameter and 1 x 1 inch substrate (Part 5) has an opening of 0.49 inches in diameter. Sealing is accomplished by an o-ring which is placed in between the hole and the electrical contact.

Detailed technical drawings of the designed parts are located in Appendix A.

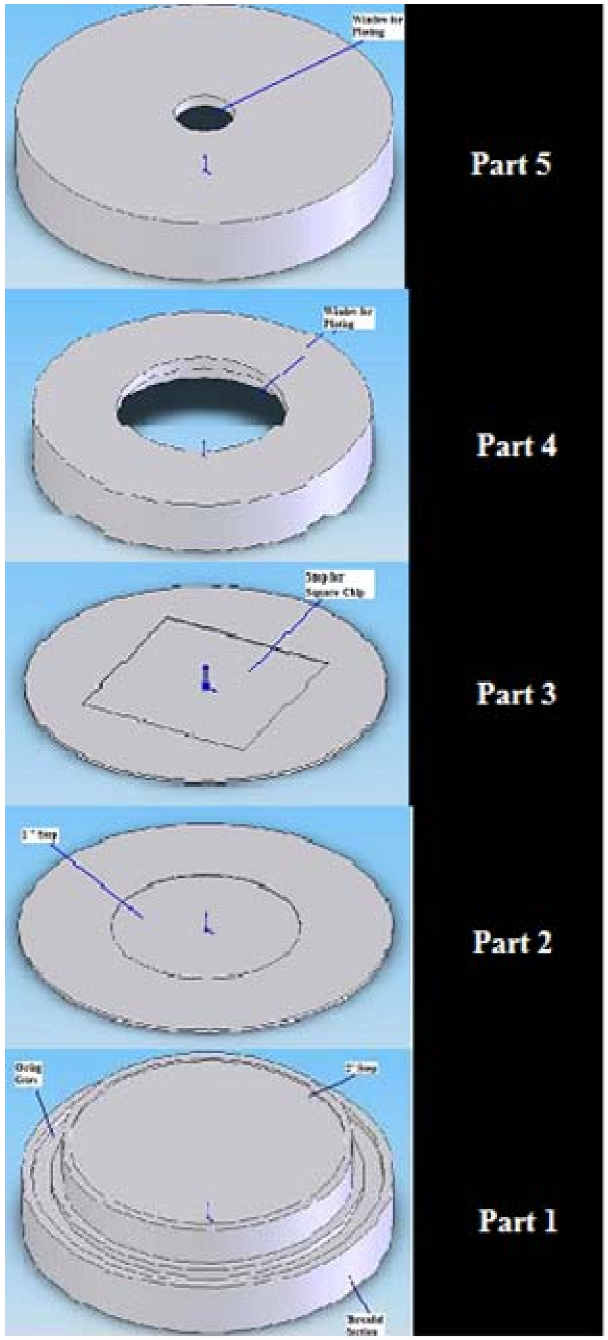

Figure 2 : Circular Jig Assembly Drawing

2.1.2.2 Rectangular Jig

The rectangular jig consists of the jig base and the jig lid. The base has a step to hold the 3 x 1 inch substrate and a groove to fit a rubber gasket. The lid has an opening of 2.59 x 0.43 inches to expose the necessary plating area. As with the circular jig, the exposed plating area is smaller than the substrate size to allow a rubber gasket to seal and isolate the electroplating contact from the electroplating solution. Figure 3 is an assembly diagram of the rectangular jig. The base is illustrated as part 1 in the assembly diagram.

The lid has a groove for a rubber gasket to prevent electroplating solution leaks from the opening on the lid. The lid is screwed down onto the base by 6 Teflon bolts spaced out uniformly.

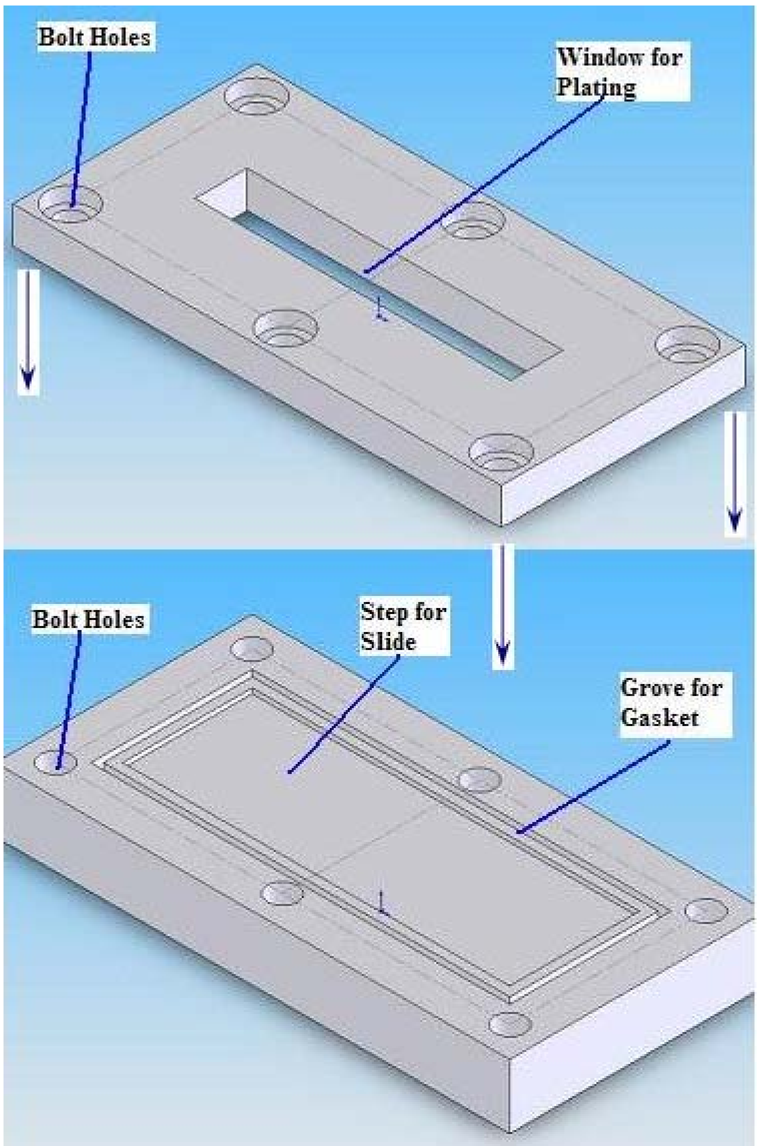

Figure 3 : Assembly Diagram for Square Jig

2.1.2.3 Design Comparison

Initial Design	Revised (Final) Design
Too many individual parts to be fabricated.	Only base and lid required
Excessive use of materials.	Less material required.
Possibility of electroplating solution leak.	Inner and outer o-rings seal the electroplating contact.
The concentrated forces in several areas due to bolting may result in an uneven plated sample.	There will be a uniformly spread force with the threaded screw on design. (for the circular jig)
Exceeds size constraints.	Meets size constraints.

Table 2: Comparison of Initial & Final Design

2.1.3 O-Ring Selection

The selection process for the o-rings to be used on the jig involved detailed calculations and is directly related to the allowable groove dimensions which is restricted by the design specifications of the jig. Detailed guidelines on o-ring selection and groove design are located in Appendix B. The table below lists the o-rings used in the circular jig and their specifications.

Intended Use on Jig	SAE Part #	Inner Diameter (inches)	Cross Section (inches)	Outer Diameter (inches)
1" x 1" and 1" Diameter Lid	114	5/8	1/8	13/16
2" Diameter Lid	130	1-5/8	1/8	1-13/16
Jig Base	141	2-5/6	1/8	2-1/2

Figure 4 : O-Rings Used for Circular Jig

2.1.4 Jig Fabrication

The entire jig is fabricated from Teflon (PTFE), which has good chemical stability against acid and base environments (as this jig is meant to be immersed in acid or base electrolyte solutions at high temperatures during the electroplating process), will not soften up to around 70°C (operating temperatures never exceed 70-75 °C) and it does not react with chemicals use din common plating solutions. An American Pacemaker tool room lathe was used to fabricate the jig. All work was done in the Western Michigan University Machine Shop. Almost 95% of the machining was done on this lathe. This huge lathe is accurate up to almost 1/1000 of an inch. The Jig was fabricated to an accuracy of about 1/5000 of an inch.

This lathe can perform several operations such as facing, turning, drilling, reaming, and boring. The threads were cut on the large cylindrical Teflon piece before it was sliced into individual parts. The threads were machined with a process called milling where the material was cut by feeding a work piece past a rotating multiple tooth cutter. To machine various types of materials, hold tight tolerances and produce good surface finish, the spindle RPM must be properly selected.

The holes on the jig were machined using two processes which are drilling and boring. Drilling was basically used for making external holes and boring was used to make internal holes. Boring is basically an operation of enlarging a hole already drilled or cored, with a single-point tool. This operation produces a close tolerance and fine finish. Finally, a grooving tool was used to machine the grooves for the o-rings.

The only time the milling machine had to be used was when the square step for the 1” x 1” adapter plate had to be fabricated. This could not be done on a lathe as the tools would not result in a square that could facilitate sharp edges. Due to the nature of Teflon, rough surface on machined parts tend to occur. To get rid of this, simple yet delicate hand sanding was done using a low grade sand paper.

2.2 Electroplating Equipment Setup & Interfacing

Electroplating at a micro level is a delicate process. It requires extreme precision in terms of equipment setup and process control as the smallest of variations in current could cause the electroplating of unwanted structures at different places. Variables controlled in the process are electrode voltage, current and plating duration.

Control of plating parameters as well as monitoring the electroplating process is done through a LabVIEW interface. LabVIEW is a graphical development environment developed by National Instruments for creating flexible and scalable test, measurement, and control applications rapidly and at minimal cost. The LabVIEW interface controls a bi-potentiostat, commonly called an electroplating power supply which was purchased from Pine Instruments a pioneer in electrochemistry research equipment. A DAQ (Data Acquisition) PCMCIA card, also developed by National Instruments provides a bridge between the bi-potentiostat and the LabVIEW interface and allows two way communications to control as well as monitor the electroplating process.

In brief, the electroplating setup consists of:

- Pine Instruments AFCBP1 Bipotentiostat (Electroplating Power Supply)
- National Instruments DAQCard-6062E
- Dell Latitude D610 Laptop
- Electroplating Jig

The figure below is a block diagram schematic of the connections between different systems used in this electroplating experiment.

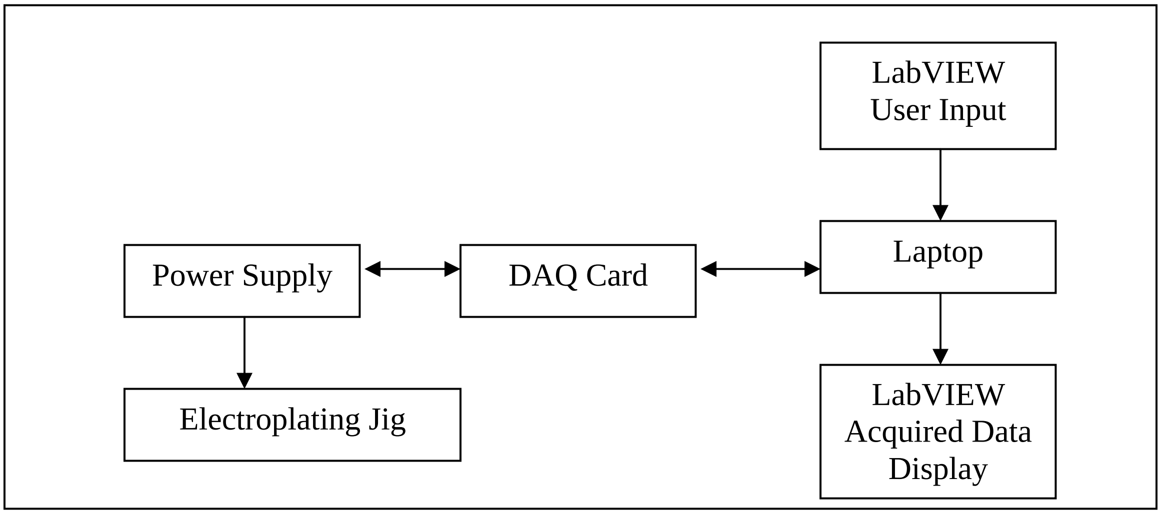

Figure 5 : Illustration of Electroplating Setup

As illustrated in the figure above, the power supply provides the required electrode voltage and current to the plated sample, which is programmable and controllable through the LabVIEW interface on the laptop. This interface also logs the operating parameters of the power supply and also incorporates error control which terminates the electroplating process in case of an abnormal operation of the power supply. The LabVIEW interface resides on a laptop from which control and monitoring is executed.

2.3 LabVIEW Interface Design

The electroplating power supply was provided with its own user interface and control software (PineChem). One of the customer requirements was to have a customized LabVIEW interface which would allow total flexibility in terms of control and output. This also allows easier implementation of upgrades in the future.

The initial requirement set by the customer was a LabVIEW interface capable of controlling electrode voltage and current. As the design phase commenced, it was discovered that only electrode voltage was controllable directly. The manufacturer of the power supply was contacted and it was determined that control for electrode current and various other miscellaneous parameters was possible but complex programming had to be implemented to incorporate those features. The customer then revised the main requirements of the LabVIEW interface. The revised requirements were that the interface needed to be able to control electrode voltage, an integrated timer which would run the interface for a set time, datalogging and error handling routines with a display of error messages.

The programming phase of the interface was straightforward. The interface was designed to be as simple as possible while providing essential control, monitoring and error handling functionality.

The LabVIEW interface was designed based on guidelines provided by Pine Instruments in the Developer's Kit for AFCBP1 Bi-Potentiostat located in Appendix C

2.4 Sample Preparation

Electroplating is the deposition of a metallic coating onto an object by a chemical reduction process using and electrolytic solution containing the salt of the required metal. The sample to be plated is maintained at a negative potential while the anode (second electrode) is kept at a relatively positive potential. For microstructures to be plated onto substrates, the substrates must be coated with a layer of polymer photoresist (Photoresist is a polymer which is sensitive to light in a given wavelength region) and patterned to expose only the area intended for electroplating.

The schematic below illustrates the processes a substrate undergoes from a plain substrate up to the final step of a plated substrate. Each process is explained in the following pages.

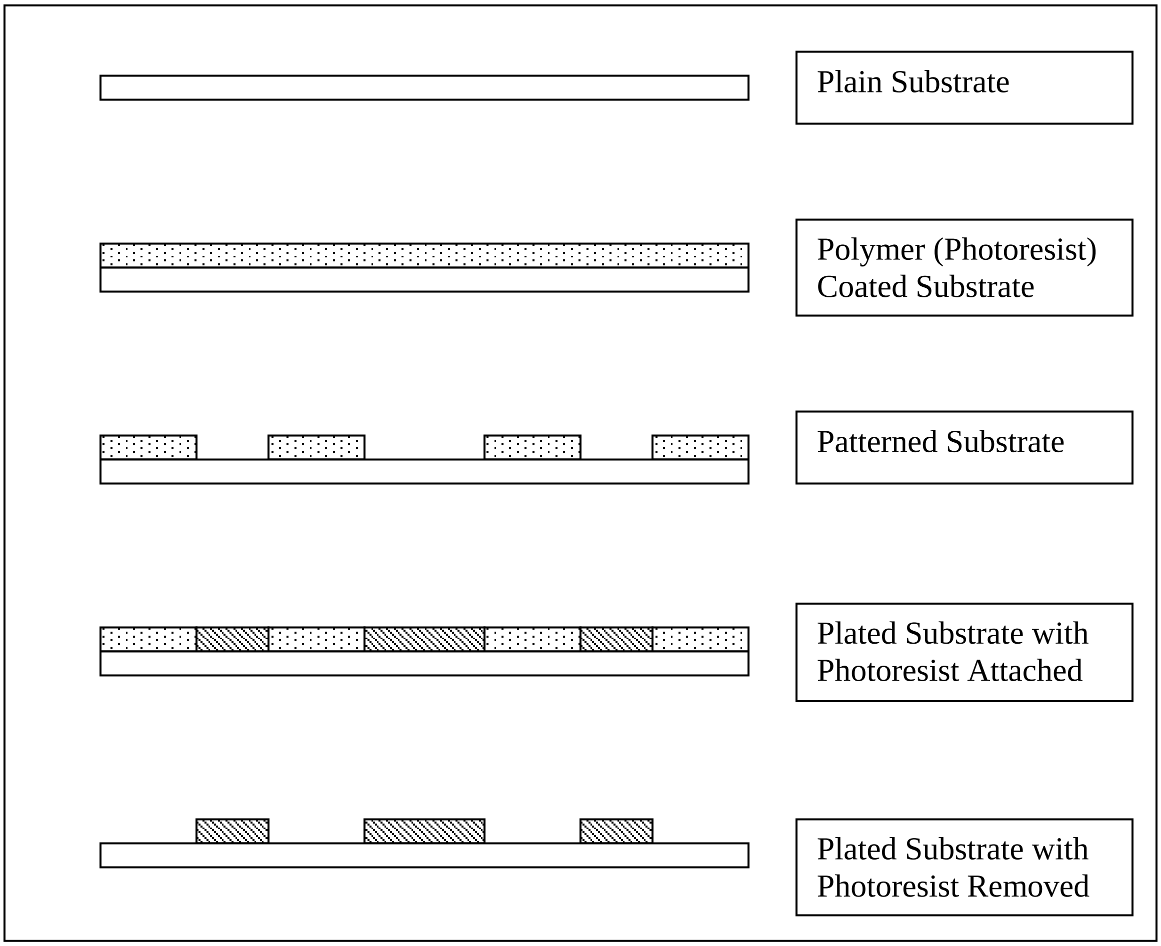

Figure 6 : Schematic of Substrate Processing

2.4.1 Substrate Cleaning

A copper clad phenol board (normally used for making printed circuit boards) is used as a substrate in this work. The plain substrate is put in a beaker and rinsed with

De-Ionized (DI) water. It is then rinsed with acetone to remove traces of impurities resulting from manufacturing and also post-manufacturing handling of the substrate. It is rinsed with DI water again to remove any traces of acetone. The substrate is now ready to be coated.

2.4.2 Substrate Coating

The cleaned substrate must now be coated with a layer of polymer photoresist. The photoresist selected is named SU-8 which was developed by IBM. It is a negative tone resist and is a multifunctional epoxy derivative of a bis-phenol-A novolac. Its basic advantages compared to other resists is that it can be spun up to a thickness of one millimeter versus two hundred to three hundred micrometers for other types of resists. It is designed for exposure at a wavelength range of 250 – 360 nm. This property suits the Krypton Fluoride laser used for patterning which has a wavelength of 248 nm. The steps in substrate coating are outlined below:

1. The first step is coating the substrate with an adhesion promoter to help the adhesion of SU-8 onto the substrate. 2 – 4 ml of Electronic Grade Adhesion Promoter is dispensed onto the substrate surface. It is spun at a speed of 3000 rpm for 45 seconds in a spinner.
2. Next, 2 - 4 ml of the SU-8 photoresist is dispensed onto the substrate. SU-8 must be dispensed carefully to avoid the accumulation of air bubbles. Spinning is carried out at 500 rpm for about 15 seconds allowing the resist to spread. It is then accelerated to the final spin speed of 2000 rpm for 30 seconds, which provides a uniform coating.

3. The substrate is finally soft baked at a temperature of 95 degrees Celsius for 20 minutes in a convection oven.

2.4.3 Substrate Patterning

The final step before electroplating the substrate is patterning it to expose areas that will be plated by removing the photoresist in these areas. There are two methods of patterning which are either lithography or laser micromachining based techniques.

Lithography in the Micro Electronic Mechanical Systems (MEMS) context is typically the transfer of a pattern to a photosensitive material by selective exposure to a radiation source such as light of a given wavelength depending on the photoresist used. A photosensitive material is a material that experiences a change in its physical properties when exposed to a radiation source. By selectively exposing a photosensitive material to radiation by masking the areas where photoresist is to be retained the pattern is transferred to the material exposed. The material is washed in a developer solution and the exposed or unexposed regions are removed depending on whether the photosensitive material is a negative or positive tone resist.

Laser micromachining, uses a laser to cut out a pattern onto the coated substrate. The laser cuts through the photoresist to expose the pattern required for electroplating. Laser micromachining was selected for this project.

The first step in laser micromachining is making sure that the laser beam is in focus. An unfocused beam can result in bad cuts that do not expose the area required for plating. This makes the sample not suitable for any plating. Figure 7 is a picture comparing a cut by a focused beam and an unfocused beam.

Figure 7 clearly shows the importance of focusing the laser beam for cutting as an unfocused beam results in the required area not being cut which renders the sample useless.

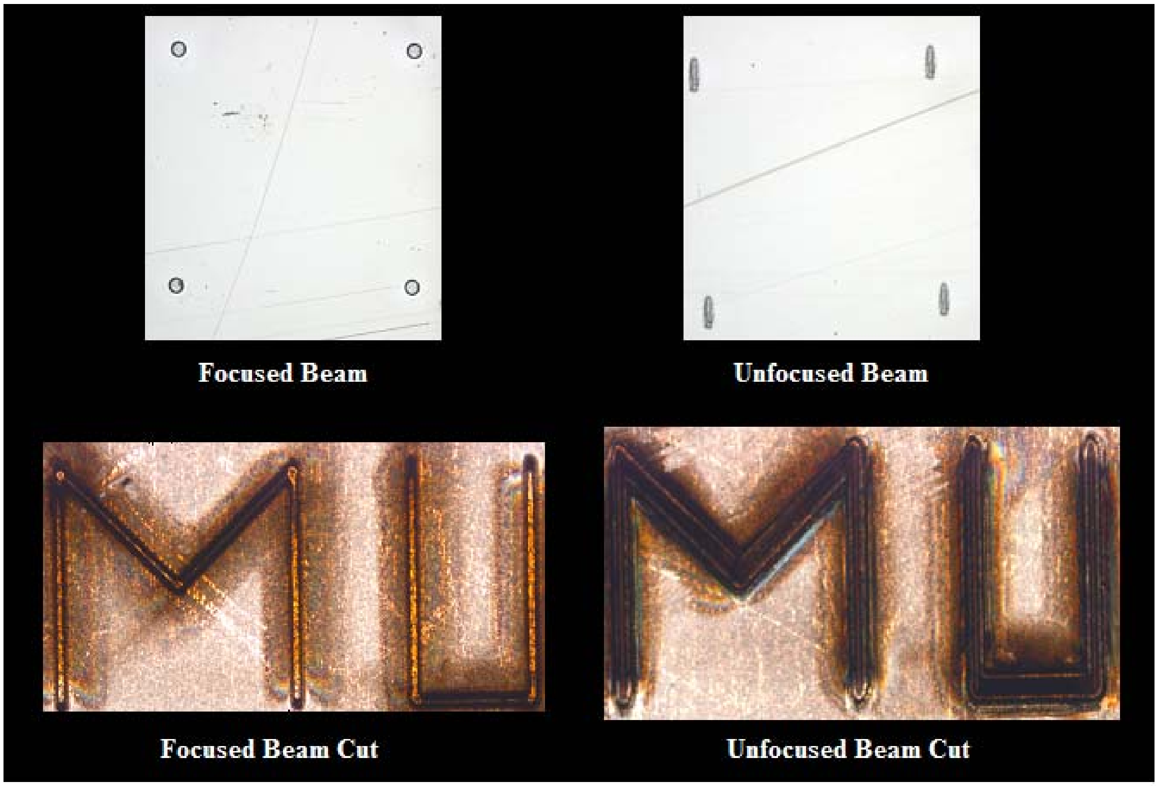

Figure 7 : Patterns of Unfocused vs. Focused Beam Cuts

Once the beam was focused, patterns were cut out and the results were positive. A serpentine structure and the words ‘WMU MICROTECH’ were cut out onto the sample. The serpentine structure was 5,000 microns in height and 10,000 microns in length. The words ‘WMU MICROTECH’ had a height of 1,000 microns. It was spread out over a length of 7,000 microns. The width of both patterns is 30 microns. Figure 8 is a picture of the patterns cut out.

Figure 8 : Laser Machined Patterns

Figure 9 : JPSA Krypton Fluoride Excimer Laser

Figure 9 shows the laser micromachining system (248 nm KrF laser manufactured by JPSA, USA) with the laser beam line along with the image cameras, which show a closer view of the sample stage when the sample is mounted for machining.

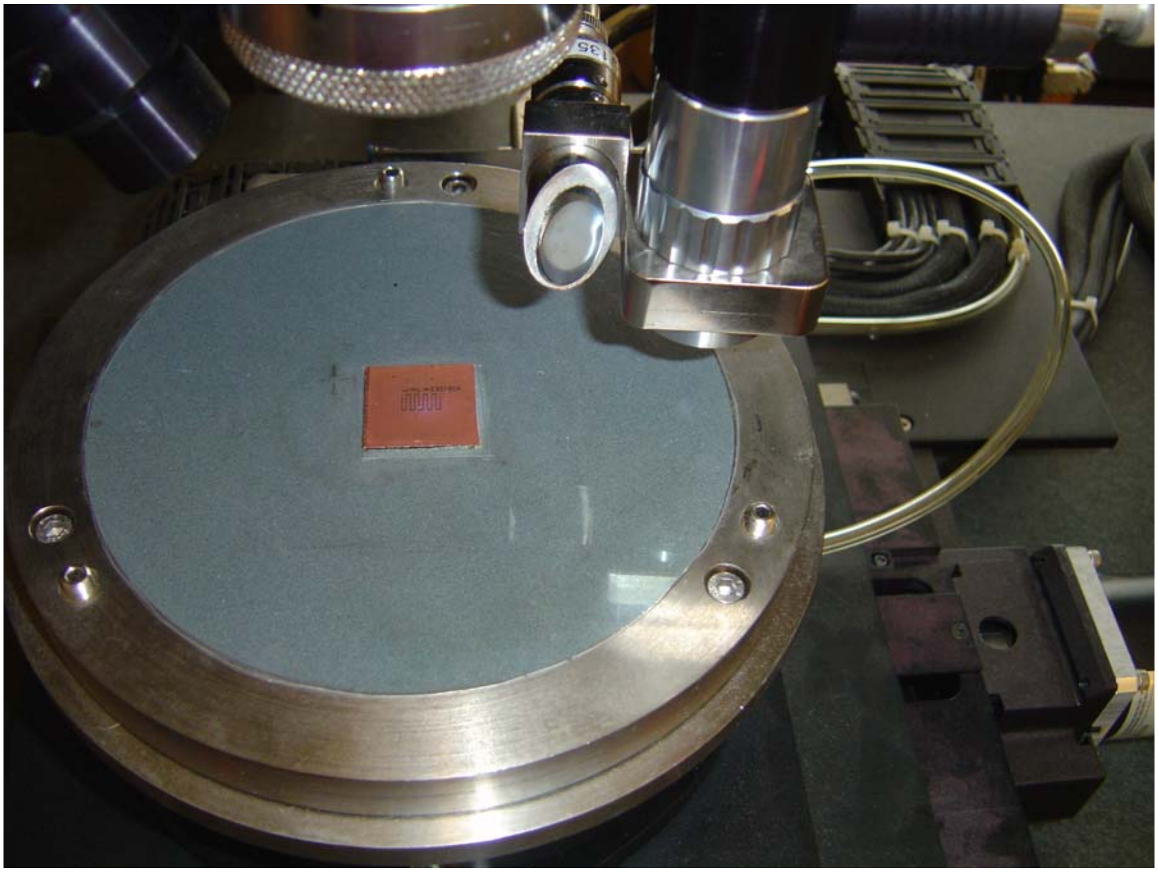

Figure 10 : Laser Machining In Progress

The sample stage can be programmed to move in the x, y and z directions to within a 1 micron resolution. The laser can be programmed to define the energy, number of shots (as this is a pulse laser, one has to decide the number of laser shots required for patterning) and the speed/acceleration of the sample movement stage. These parameters were adjusted to provide an optimized machining process.

With the patterning process complete, the sample can now be electroplated bringing the project to its completion stage.

2.5 Electroplating & Fabrication of Micro Structures

The final phase of the project was electroplating and fabrication of micro structures. Copper sulfate electroplating bath is used in this work to plate copper structures. Figure 11 is a block diagram of the electroplating setup.

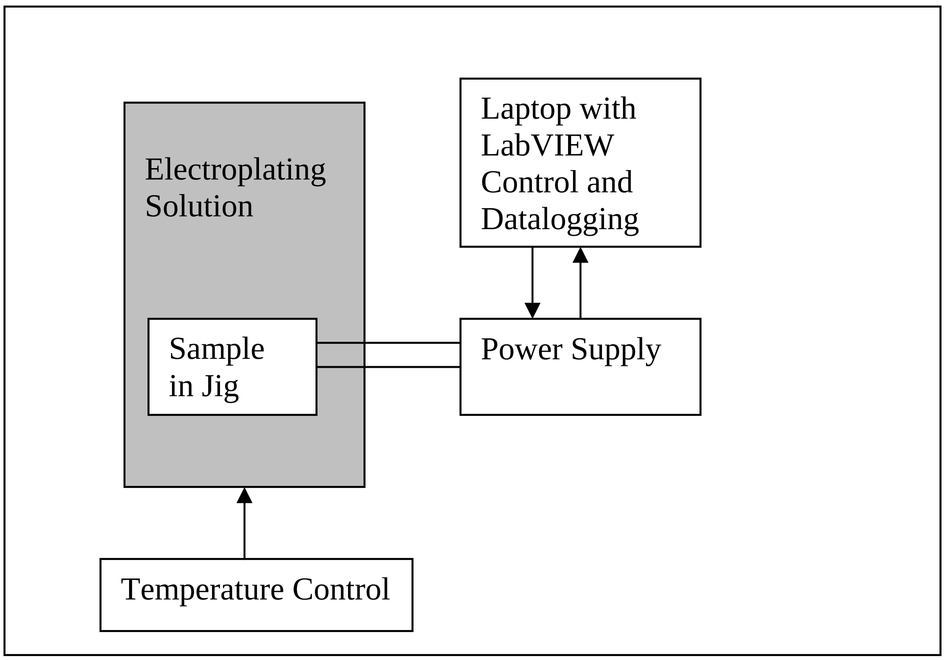

Figure 11 : Block Diagram of Electroplating Setup

The parameters needed to be set in this procedure were electrode voltage and plating duration. To set an electrode voltage we have to know the required current for the process. The required current is calculated from the area required to be plated. The optimal current density for plating copper using copper sulfate solution is 5mA/cm^2. It was determined that the total area to be plated was 0.1167 cm^2. With that a current of 0.58 mA was required. The current converter on the power supply was set to 1 mA per volt which meant that a voltage of 580 mV was required. Other important parameters were the electroplating solution temperature which was set at 26 degrees Celsius. The plating rate under the conditions is expected to be around 5-8 microns per hour. To plate the plating mould in SU-8, which is around 30 microns, requires at least 4 hours. With all these parameters set, the experiment was carried out. At the end of 4 hours the sample was taken out of the jig and rinsed in DI water. The sample was then analyzed under a microscope. Figure 12 shows the laptop with the LabVIEW interface controlling the electroplating process.

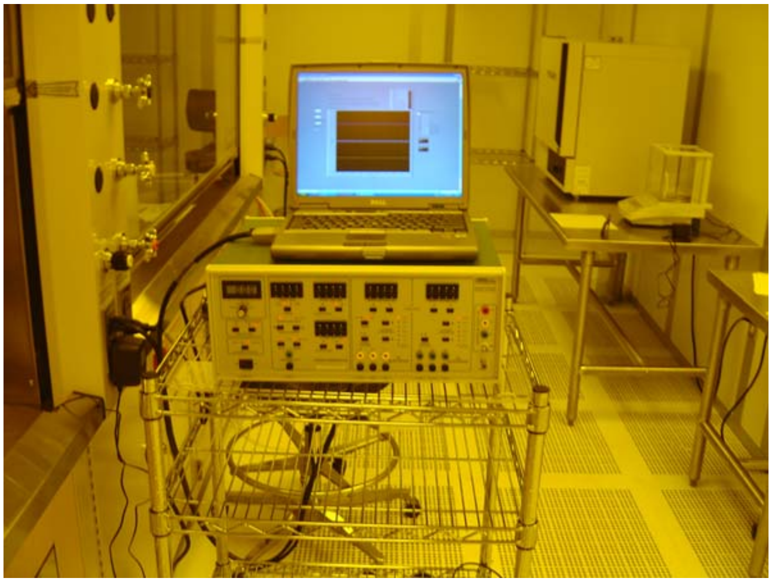

Figure 12 : Laptop with LabVIEW Interface Attached to Power Supply

Figure 13 shows the electroplating setup where the jig is immersed in the electroplating solution is arrange on a heater and magnetic stirrer system which controls the temperature of the solution, while providing a mild agitation of the solution with the help of a Teflon coated magnetic stirrer placed in the beaker.

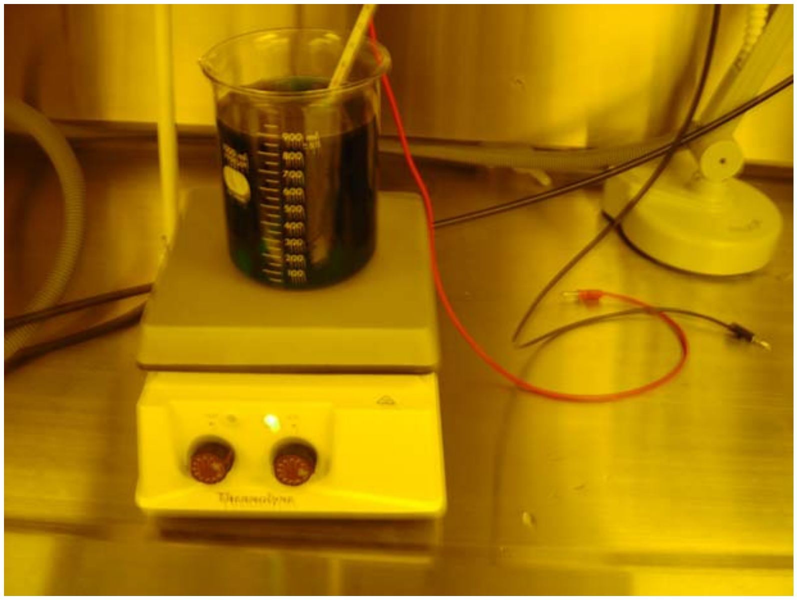

Figure 13 : Plating Setup

The performance of the system and the results obtained are further discussed in section 3.3.

3 Results

3.1 Electroplating Jig

The fabricated jig satisfied all the specifications. The only necessary revision was the thickness of the adapter plate due to material bending issues. The problem faced was that the design specifications required an adapter plate that was 0.2 inches thick. It was not possible to machine the plates to this thickness as the Teflon started to bend if too thin a section was cut out. The change in thickness still allowed the adapter plates to function as they were intended to. Figure 14 below shows the fabricated parts for the jig. The jig base and both the lids are fitted with their specific O-rings.

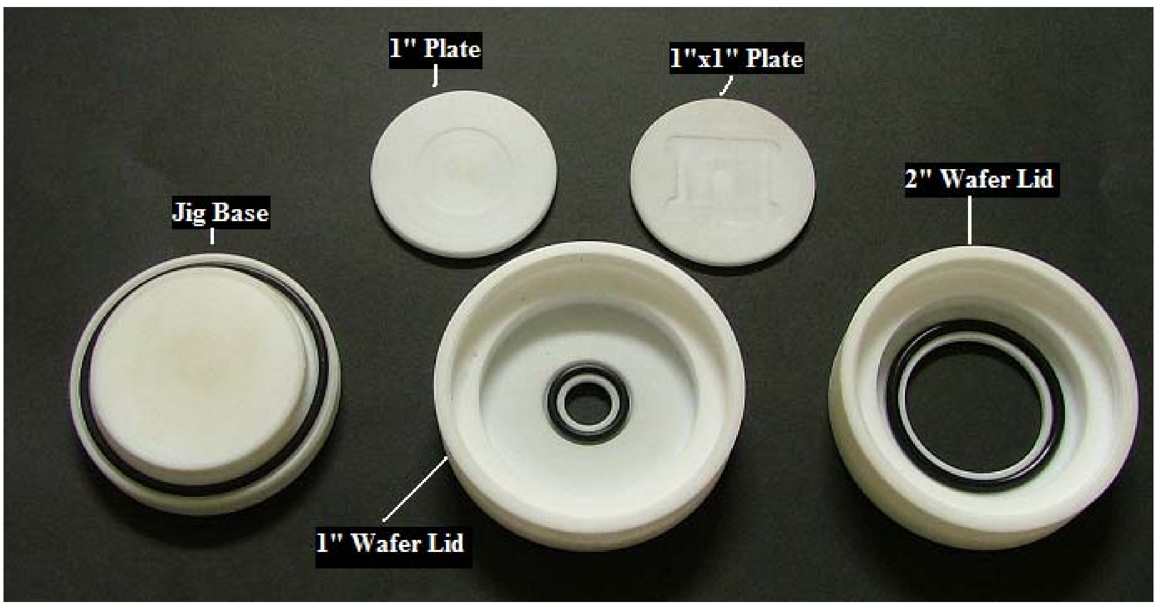

Figure 14 : Elements of the Circular Jig

Figure 15 shows a 1 x 1 inch adapter plate and a 1 inch diameter substrate adapter plate sitting on the jig base.

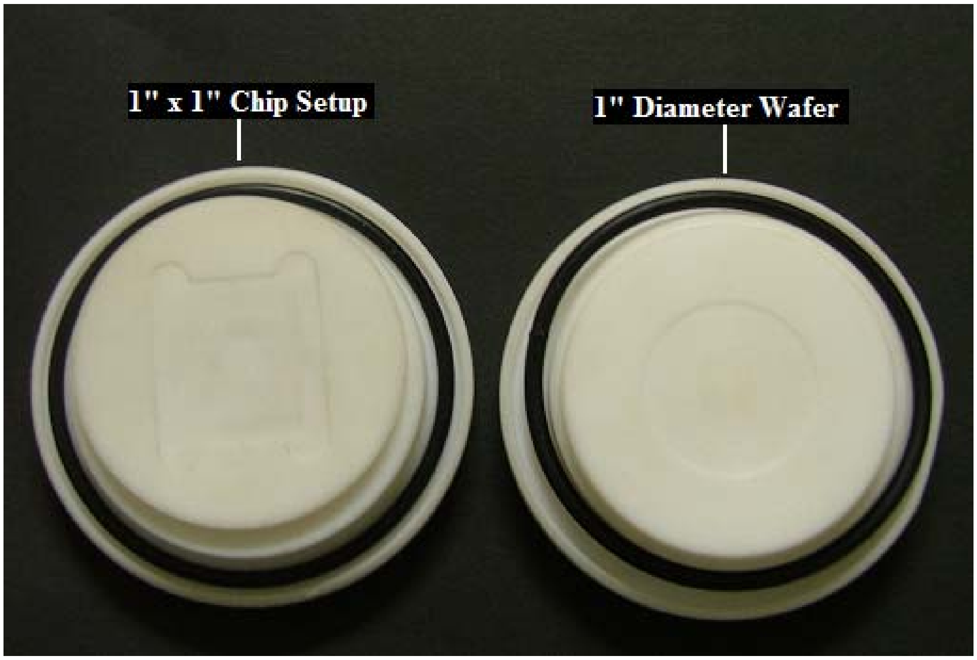

Figure 15 : Jig Base with Adapter Plates

Figure 16 below shows a 1 x 1 inch square sample placed on the adapter plate and the jig base. The setup on the left is without the lid and the setup on the right is with the lid screwed on. The round opening on the lid exposes the required plating area.

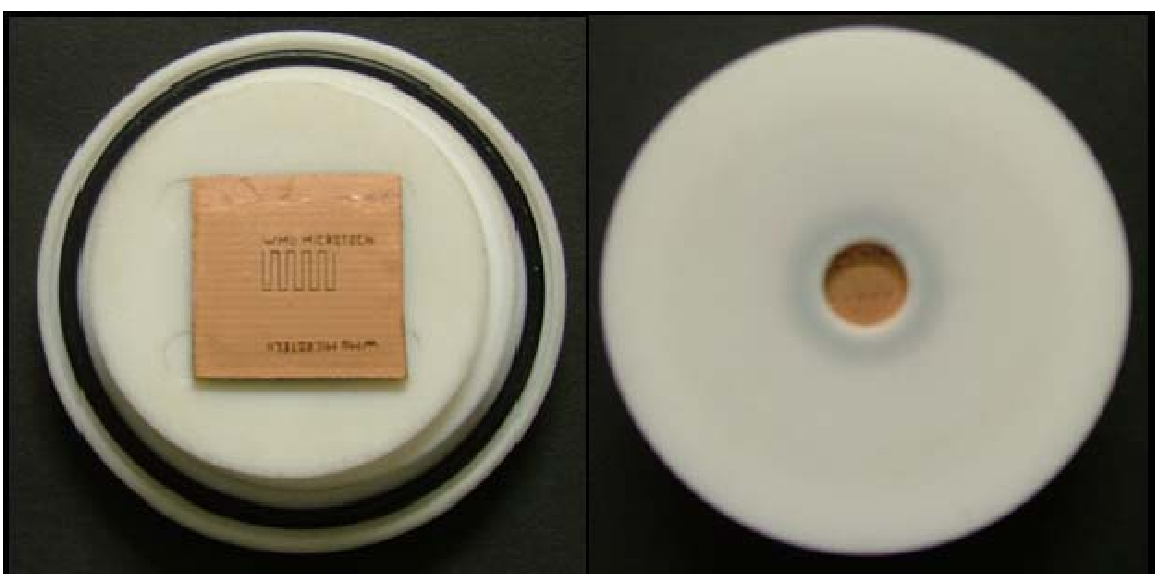

Figure 16 : 1 x 1 inch Adapter Plate & Sample

Electroplating was carried out with the setup in Figure 16. This setup was effective in that the jig performed as intended with complete sealing.

3.2 LabVIEW Interface

The LabVIEW interface designed is pictured in Figure 17 & 18. Figure 17 shows the control panel of the interface. As can be seen, controls are provided for voltage control of electrode K1 & K2 and plating duration. The control panel also provides a graph and numeric indicators on the plating parameters for the user to monitor the plating process. All of the parameters are stored in an array for convenient access at a later time for analysis. The panel also features warning lights in case of an overload condition.

Figure 18 shows the block diagram of the interface. The block diagram essentially highlights the structure of the whole program and how it works. Different modules contained in the program are shown in Figure 18. The voltage control module consists of numeric controls connected to the DAQ assistant output which sends voltage signals out to the power supply to control the electrode voltage. The process data acquisition module is a DAQ assistant input which reads input signals from the power supply and splits the signals to a graph and an array of numeric indicators.

Error handling is integrated into the interface in the form of overload control. The overload control module reads the overload signal from the power supply and terminates the experiment in the event of an overload. A voltage reset module resides outside the loop. It serves to reset the power supply voltage to zero when the program terminates due to an error or when the experiment is completed.

The timer module regulates the length of time the program runs before it terminates. It is activated on user input of the plating duration and has a numeric indicator to show the elapsed time. The final module is the user message interface which displays a message when the program terminates due to an error or when the experiment is completed.

This interface was used to perform the electroplating experiments. It functioned well in terms of controlling electrode voltages as well as monitoring operating parameters. The interface ran the experiment without any major issues and terminated the experiment by resetting the power supply voltages when the plating duration set was reached.

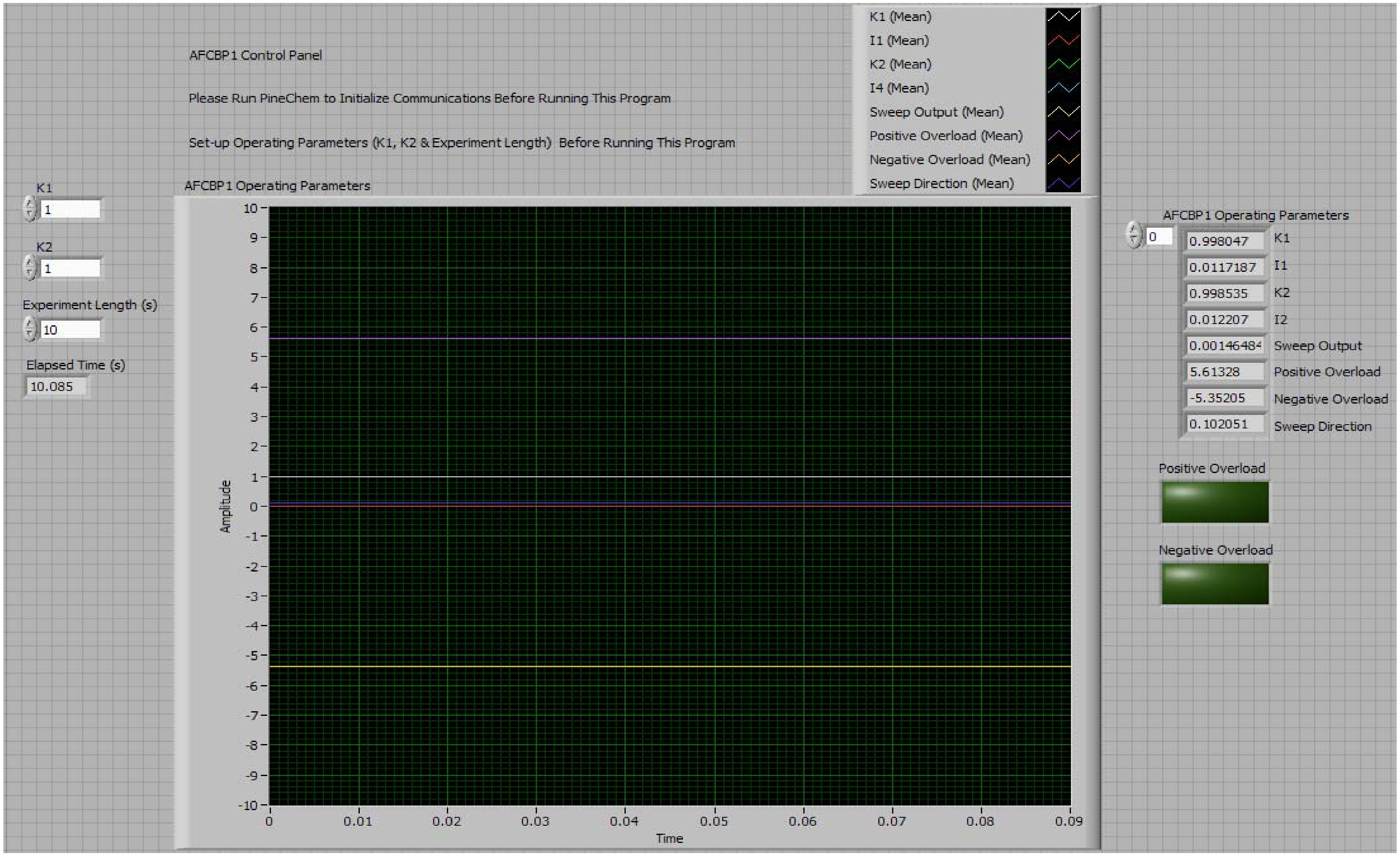

Figure 17 : LabVIEW Interface Control Panel

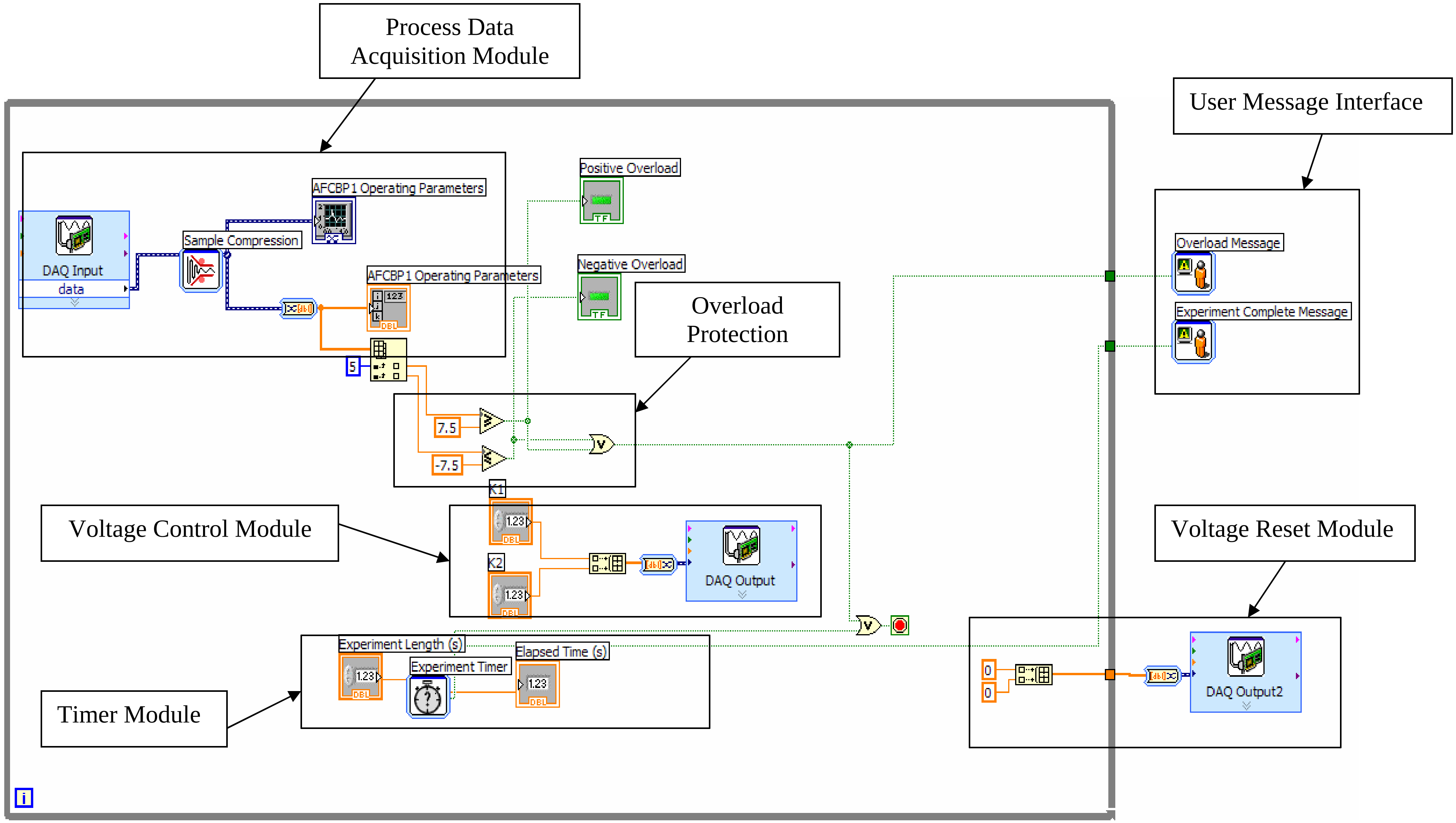

Figure 18 : LabVIEW Interface Block Diagram

3.3 Fabrication of Micro Features

Three samples were electroplated for the purpose of this project. The first sample was a plain copper board which was plated as a test sample to ensure that the electroplating system was working well. This sample turned out as expected. Electroplating was carried out on another 2 patterned samples. The first sample did not show any signs of plating. Instead there were nodules of copper ions which formed mushroom-like structures. After through analysis it was deduced that the required current had been miscalculated. Instead of setting the voltage to produce a current of 0.1mA, the voltage was set to produce a current of 100 mA which produces the abnormal plated structures. Figure 19 and 20 illustrate good and bad plating results. A good comparison can be made between good and bad plating in Figure 20.

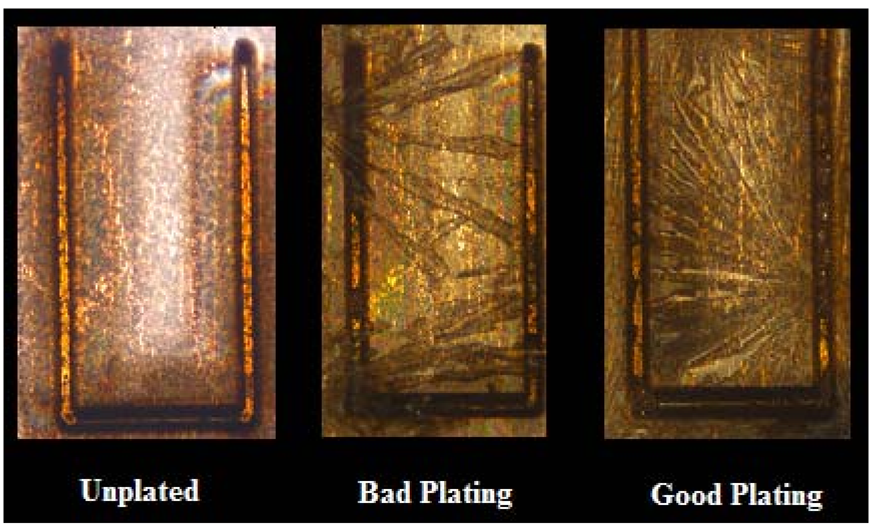

Figure 19 : Comparison of Bad Plating & Good Plating

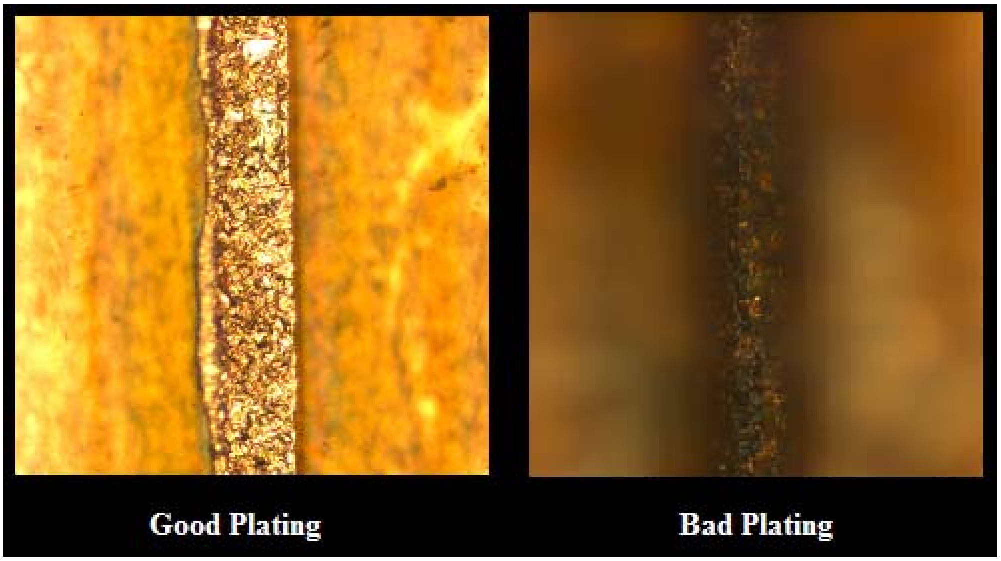

Figure 20 : Comparison of Bad Plating & Good Plating

For the second sample, precise calculations of the required current were made and implemented into the LabVIEW interface. After the process had completed structures such as those seen in Figure 20 (Good Plating), 21 & 22 were formed. Figure 21 & 22 highlight the difference between the unplated and plated samples which can clearly be seen.

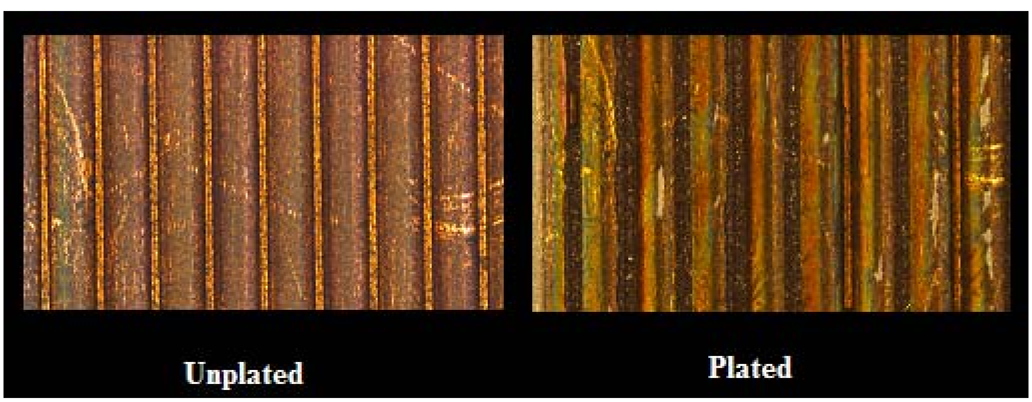

Figure 21 : Comparison of Plated & Unplated Samples

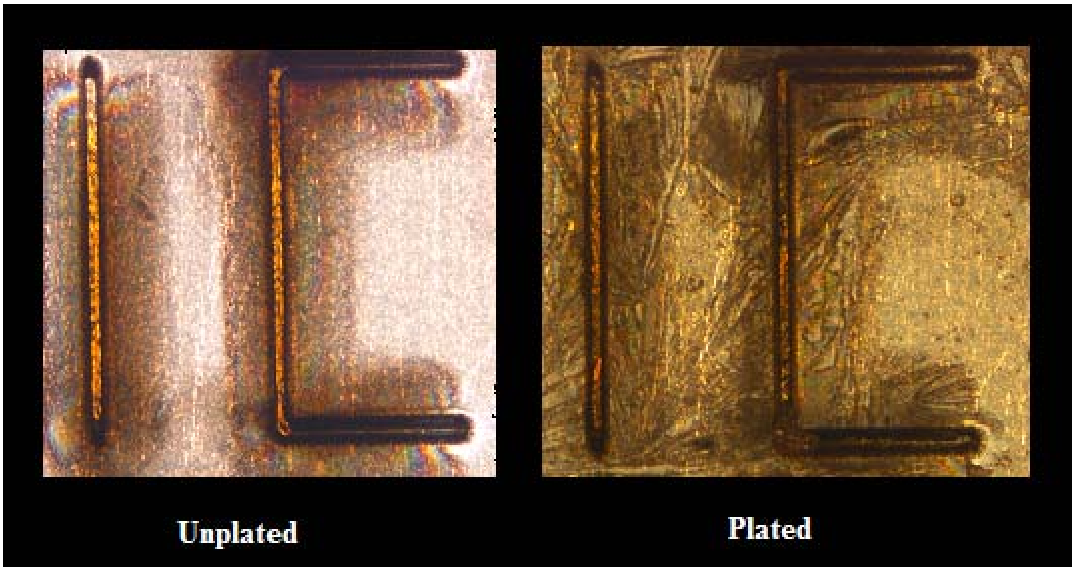

Figure 22 : Comparison of Plated & Unplated Samples

After the pictures above were taken, the samples were placed in acetone to remove the SU-8 photoresist. This was done so that more clearly defined pictures can be taken to highlight the electroplated structures. Instead of dissolving when placed in acetone, the SU-8 layer on the sample came loose and forced the plated copper off with it. Through literature research and from our experience it was found that it is not uncommon for SU-8 to behave that way. One disadvantage of SU-8 in the removal phase is that unlike other photoresists that dissolve in acetone, SU-8 tends to lift itself of the surface of the sample, sometimes forcing the electroplated structures off with it. The lifting off of the electroplated structures can be attributed to thin residual SU-8 layers nanometers thick left at the bottom of the laser micro machined mold part. This prevents good adhesion between the substrate and the electroplated copper film. Figure 23 shows the displaced electroplated structures on the sample.

Figure 23 : Displaced Electroplated Micro Structures

Overall, the electroplating setup worked as intended and that electroplating occurred. Suggestions for future work may include using lithography or making sure the complete removal of SU-8 without leaving any residual layers within the patterned area.

4 Cost Analysis

A cost analysis was done on this project to show the labor costs as well as fixed costs involved in this project.

The tables below list the labor rates as well as fixed cost for this project:

Job	Rate
Design Engineer • Hourly Rate • Overtime	 • $80.00/hr • $90.00/hr
Machining	• $60.00/hr
Clean Room	• $50.00/hr
Substrate Analysis	• $50.00/hr

Table 3 : Labor Rates

Job	Rate	Hours Calculated	Total
Design Engineer • Hourly Rate • Overtime	 • $80.00/hr • $90.00/hr	<u>Hourly</u> 60 x $80.00/hr <u>Overtime</u> 20 x $90.00/hr	 $4,800.00 $1,800.00
Machining	• $60.00/hr	35 x $60.00/hr	$2,100.00
Clean Room	• $50.00/hr	45 x $50.00/hr	$2,250.00
Substrate Analysis	• $50.00/hr	5 x $50.00/hr	$ 250.00
		TOTAL	**$11,200.00**

Table 4 : Calculated Labor Costs

Item(s)	Fixed Cost
DAQ Card	• $1,050.00
Materials for Jig • Teflon Rod for Circular Jig • Teflon Sheet for Square Jig • O-Rings	 • $120.00 • $100.00 • $30.00
Electroplating Power Supply	• $7,000.00
Electroplating Substrates	• $ 50.00
Electroplating Chemicals (Copper Sulfate, Hydrochloric Acid, Surfactants, etc)	• $ 150.00
TOTAL	**$8,500.00**

Table 5 : Fixed Costs

The actual cost incurred in the implementation of this project at this level is the fixed cost outlined in Table 5. If the project were to be implemented at a professional level the labor cost would be factored in which would almost double the total cost of the project. Overall the total cost of the project is reasonable, with the power supply being the major item in total cost.

5 Recommendations / Conclusion

5.1 Recommendations

After an in-depth analysis of the project on a macro level, the engineering team concluded that the project was successful and all requirements were met. The engineering team does have some reservations on 2 issues and recommends that:

1. The LabVIEW interface be upgraded and enhanced to enable current control although it would require some complex programming structures. This would make the electroplating power supply a completely standalone unit able to operate on just the LabVIEW interface.
2. Another type of photoresist is used for the coating of samples to avoid displacing the plated structures as in the case of the SU-8 photoresist used.

5.2 Conclusion

Micro and Nano Technology is a fairly new and complex area of engineering. A lot of the techniques and processes employed in this field are fairly experimental. The processes are very delicate and the slightest of variations cause experiments to fail. A good example would be the case of laser micromachining where the focal point of the laser beam was 1200 microns below the set zero level of the machining platform. 1200 microns is 1.2 millimeters which is a short distance. But this short distance, was the deciding factor in a well cut sample or a badly cut sample which could not be utilized.

Even though the engineering team faced a lot of difficulties in implementing this whole project, several valuable skills were learnt. These skills are:

1. Effective design procedures.
2. Operational procedures of a clean room.
3. Spin-coating substrates in preparation for patterning.
4. Patterning techniques (Laser Micromachining).
5. Fabrication of micro structures by electroplating.

The major achievements of the design team in this project are designing and implementing a micro fabrication setup and fabricating microstructures 30 microns in width.

In conclusion, the engineering team has fulfilled the requirements of this project that are:

1. A LabVIEW interface to automate the electroplating process in the fabrication of micro structures.
2. An electroplating jig to facilitate the electroplating process.
3. Fabrication of micro structures.

and with that the project was successfully completed.

6 Bibliography

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4. Muralidhar K Ghantasala (2003). Electroplating

Appendix A: Electroplating Jig Technical Drawings

Appendix B: O-Ring Design Guidelines

Appendix C: AFCBP1 Bi-Potentiostat Technical Reference Manual for Control Software Development