3-30-2004

Ultrasound Hardware Setup For CMP Pad Characterization

Bhaskar Vijay Kumar Reddy Tadi
University of South Florida

Scholar Commons Citation

Tadi, Bhaskar Vijay Kumar Reddy, "Ultrasound Hardware Setup For CMP Pad Characterization" (2004). *Graduate Theses and Dissertations.*
https://scholarcommons.usf.edu/etd/1264

Ultrasound Hardware Setup For CMP Pad Characterization

by

Bhaskar Vijay Kumar Reddy Tadi

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering
Department of Electrical Engineering
College of Engineering
University of South Florida

Major Professor: Wilfrido A. Moreno, Ph.D.
James T. Leffew, Ph.D.
Grisselle Centeno, Ph.D.

Date of Approval:
March 30, 2004

Keywords:

PID, SSR, UST, PSD, SCPI.

Acknowledgements

I would like to thank Dr. Moreno, my major professor, for his guidance and support of me financially throughout my master degree program. I would like to thank Dr. Centeno who helped me to formulate, understand and present the statistical analysis associated with this research. Dr. Leffew's review of this thesis is also greatly appreciated. I also acknowledge the contribution of journals, papers, organizations and books, to which I had occasion to refer and, which are listed in the references.

I would like thank my parents and Geetha for being with me all the time. Without their love, affection, motivation and support this thesis would not have been possible. Last but not the least I would like to thank my friends Prashant Datar, Raj and Ravi Yalamanchili.

Table of Contents

List of Tables

List of Figures

UTRASOUND HARDWARE SETUP FOR CMP PAD CHARACTERIZATION

Bhaskar Vijay Tadi

ABSTRACT

Chemical Mechanical Polishing, (CMP), pads made of polyurethane material are utilized in the Integrated Circuit, (IC), industry to planarize wafers between successive process steps. The properties of such pads and their behavior must be known in order to determine under what conditions and for how long they can be used efficiently. This research involved the development of a system to study the properties of such pads. The system developed during this research enabled the pads to be tested under varying physical conditions.

The setup used a combination of several instruments to provide excitation to the pad and acquire a measure its response. A central computer controlled the instrumentation system employed. In this research the determination of the physical properties of CMP pads was accomplished through the use of Ultra Sound testing. Ultra sound methods offer a non-destructive method of characterizing pads to be used in the production of IC wafers. Ultra sound characterization is currently one of the most widely used techniques utilized for non-destructive inspection.

This report provides a detailed account of the hardware instruments involved and the method of integration of those instruments into a system that could easily, rapidly and accurately characterize CMP pads. The pad response was measured in terms of the signal voltage transmitted through the pad to the ultrasound sensor. The software stored these readings for every set of testing conditions. Changing the temperature, humidity and depth from the pad's surface were measurements are made changed the test conditions. These data were analyzed statistically to determine the behavior of the pad. This research was part of a larger research effort that provided the statistical tool required to determine the uniformity of a CMP pad.

Chapter 1

Introduction

1.0 Research Objectives

The objective of this research was to build a system that could be used by engineers and researchers to study the effects of Chemical Mechanical Planarization, (CMP), on pads used for polishing wafers in the IC industry. Physical factors such as temperature and humidity play a major role in determining the characteristics of a CMP pad. The research required a system composed of an assembly of various devices and instruments. Each system component possessed a special functionality. A single host computer controlled all the components of the system.

1.1 Chemical Mechanical Planarization

Chemical mechanical polishing, (CMP), has been used by the wafer fabrication industry for many years. CMP is used to polish prime silicon wafer substrates and gave birth to chemical mechanical planarization as a means of micromachining thin layers deposited or grown on the substrate. Figure 1.1 illustrates the mechanization for the chemical mechanical planarization process.

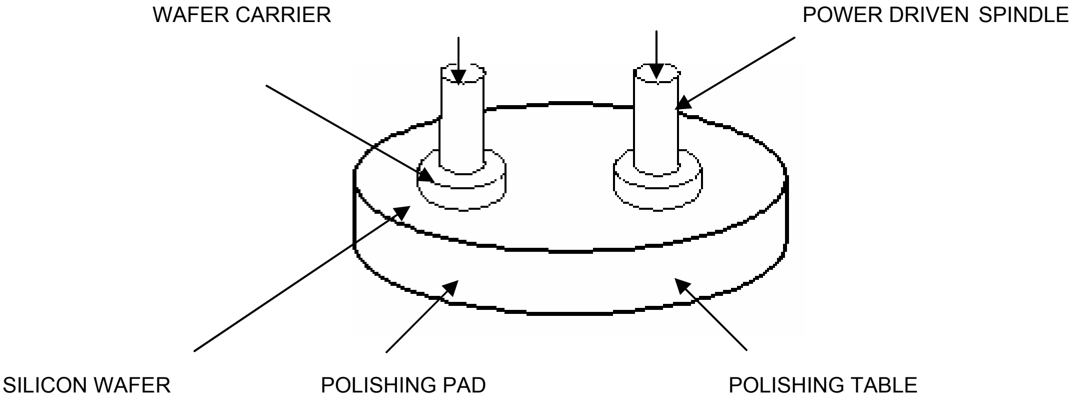

Figure1.1: Set-Up for the Chemical Mechanical Planarization Process

With the correct polishing pad slurry and planarizing machine tool, thin layers of insulting material can be removed at a rate as high as twenty wafers per tool per hour. CMP is ideal for polishing a layer when a relatively stiff polishing pad is used. During the polishing process the high spots or peak areas are polished first and brought down to a point where eventually the layer is a plane surface. “Flat” is not a very meaningful term since the wafer will tend to conform to the surface upon which it is placed. Uniformity is also desired so that the layer is equal in thickness, both locally and globally.

Changes in physical factors such as temperature and humidity produce physical effects on the CMP pads. When this happens the surface-uniformity of wafers polished using the affected pads cannot be guaranteed. Therefore, it is necessary to determine how the pads respond to ambient changes and control the polishing process in such a way as to maintain wafer quality.

1.2 Ultrasound Testing

Chemical mechanical planarization pads were used primarily in the chemical mechanical polishing of optical devices in the earlier stages. Now CMP is used to polish IC wafers. In this research, determination of the mechanical properties of CMP pads was accomplished through the use of Ultrasound testing. Ultrasound methods offer a non-destructive means to characterize pads that are to be used in the production of IC wafers. Ultrasound Testing, (UST), is one of the most widely used techniques for non-destructive inspection. Ultrasound works on the principle of sound permeability through an absorbing visco-elastic medium. The difference in ultrasound absorption in areas of varying viscosity and density is used to determine any non-uniformity within a single pad by giving an in depth idea of the physical characteristics of the given pads.

During UST, an ultrasonic wave is sent through the pad and the change in the transmitted signal with time and depth below the surface at specified frequencies, temperature and humidity are measured over the entire pad and reported. These readings allow the underlying pad structure to be determined. Material Sciences and Statistical Analysis tools are then employed to determine the various characteristics of the pad. Based on these studies, researchers can suggest improvements in the CMP process in order to enhance the quality of the pads and ultimately the polished wafers upon which they are used.

Chapter 2

Data Acquisition System Description

2.0 Basic Devices

2.1 Lock-in Amplifier 7260

A lock-in amplifier, like most AC indicating instruments, provides a DC output proportional to the AC signal under investigation. In modern units, the DC output may be presented as a reading on a digital panel meter or as a digital value communicated over a computer interface, rather than a voltage at an output connector, but the principle remains the same. The traditional rectifier, which is found in a typical AC voltmeter, makes no distinction between signal and noise and produces errors due to rectified noise components. However, the noise at the input to a lock-in amplifier is not rectified but appears at the output as an AC fluctuation. This means that the desired signal response, a DC level, can be separated from the noise accompanying it in the output by means of a simple low-pass filter. Hence, the final output of a lock-in amplifier is not affected by the presence of noise in the applied signal. The front panel of the 7620 lock-in amplifier used in this research is presented in Figure 2.1.

Figure 2.1: DSP Lock-In Amplifier 7260 [9]

A lock-in amplifier can be used for two basic purposes. To recover a signal in the presence of overwhelming background noise or to provide high resolution measurements of relatively clean signals over several orders of magnitude and frequency. Modern instruments like the 7260 offer many additional features. These instruments are used in varied fields of research such as Optics, Electrical Engineering, Fundamental Physics and Material Sciences. The 7260 Lock-In Amplifier provides the following functions:

- Precision Oscillator
- Vector Voltmeter
- Phase Meter
- AC Signal Recovery
- Frequency Meter
- Transient Recorder
- Spectrum Analyzer
- Noise Meter

2.2 Typical Lock-in Amplifier

The lock-in amplifier was a crucial instrument utilized in this research. A block diagram of the instrument is presented in Figure 2.2.

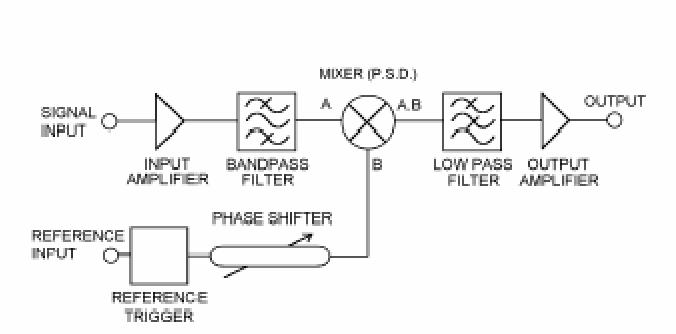

Figure 2.2: Block Diagram of a Typical Lock-in Amplifier

2.2.1 Signal Channel

The signal channel amplifies the input signal, including noise, by using an adjustable-gain, AC-coupled, amplifier in order to match it more closely to the optimum input signal range of the phase-sensitive detector, (PSD). Instruments are usually fitted with high impedance inputs for voltage measurements. Many also incorporate low impedance inputs for better noise matching to current sources. However, in some cases the best results are obtained through the use of a separate external preamplifier. The performance of the PSD is usually improved if the bandwidth of the noise voltages reaching it is reduced from that of the full frequency range of the instrument. To achieve this, the signal is passed through some form of filter, which may simply be a band rejection filter centered at the power line frequency and/or its second harmonic. The band rejection filter would be used to reject line frequency pick-up. Alternatively a more sophisticated tracking band-pass filter centered at the reference frequency could be employed.

2.2.2 Reference Channel

The reference channel provides a high-level, stable and noise-free reference input. A well-designed reference channel circuit is very important. Such circuits can be expensive and often account for a significant proportion of the total cost of the instrument. The internally generated reference is passed through a phase shifter, which is used to compensate for phase differences that may have been introduced between the signal and reference inputs by the experiment, before being applied to the PSD.

2.2.3 Mixer or Phase Sensitive Detector (PSD)

This special rectifier, called a phase-sensitive detector, (PSD), or mixer, performs AC to DC conversion and forms the heart of the instrument. The PSD is special in the sense that it rectifies only the signal of interest while suppressing the effect of noise or interfering components, which may accompany the signal. The detector operates by multiplying two signals together. The following analysis indicates how this gives the required outputs.

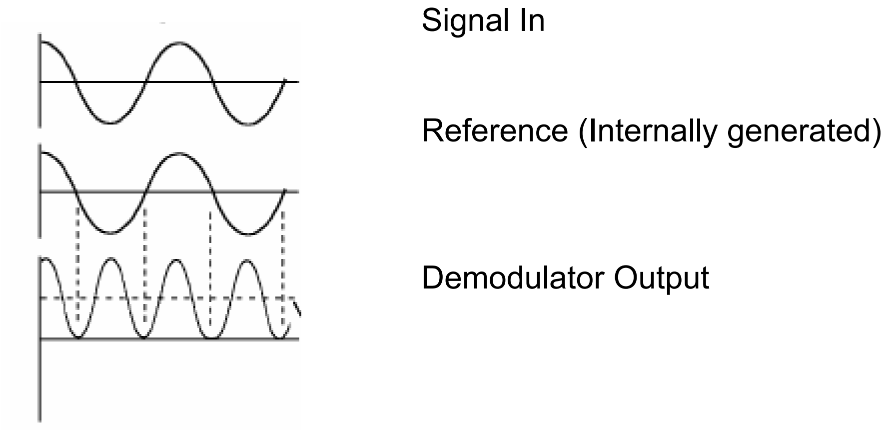

Figure 2.3: Signal In With Certain Phase

Figure 2.3 indicates that the lock-in amplifier is detecting a noise-free sinusoid, which is identified in the diagram as “Signal In”. The instrument also receives a reference signal. The reference signal is used to generate an internal sinusoidal reference, which is also shown in the diagram. The demodulator operates by multiplying the two signals together to yield the signal identified in the diagram as “Demodulator Output”. Since there is no relative phase-shift between the signal and reference phases the demodulator output takes the form of a sinusoid at twice the reference frequency with a mean or average level, which is positive.

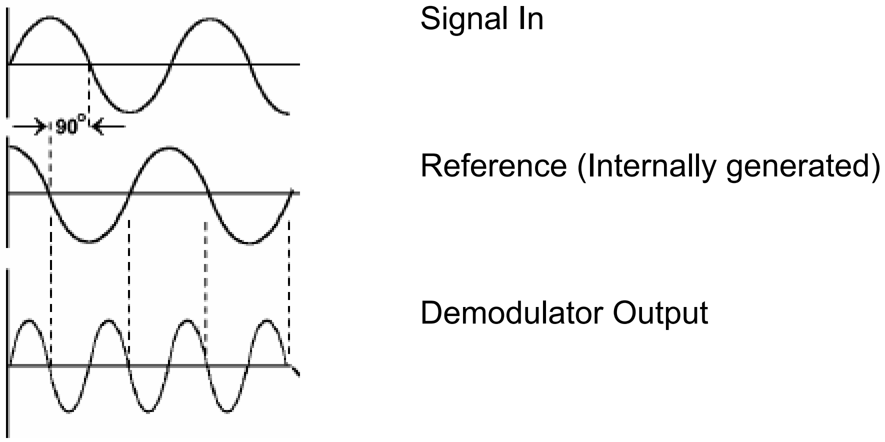

Figure 2.4: Signal-In With Delayed Phase of 90 Degrees

Figure 2.4 illustrates a similar situation where the signal phase has been delayed by 90° with respect to the reference. Although the output still contains a signal at twice the reference frequency, the mean level is shifted to zero.

This analysis indicates that the mean level is:

- Proportional to the product of the signal and reference frequency amplitudes
- Related to the phase angle between the signal and reference.

Therefore, if the reference signal amplitude is maintained at a fixed value and the reference phase is adjusted to ensure a relative phase-shift of zero degrees, the mean level the input signal amplitude can be determined. The mean level is, of course, the DC component of the demodulator output. It is a relatively simple task to isolate the DC component by using a low-pass filter. The filtered output is then measured using a conventional DC voltmeter.

2.2.4 Low-pass Filter and Output Amplifier

Practical instruments employ a wide range of output filter types, which are implemented either as analog circuits or in digital signal processors. Usually, these circuits are equivalent to one or more stages of single-pole “RC” type filters, which exhibit the classic 6-dB/octave roll-off with increasing frequency. Also, there is usually some form of output amplifier, which may be either a DC-coupled analog circuit or a digital multiplier. The use of an amplifier at the output in conjunction with the input amplifier allows the unit to handle a wide range of signal inputs. When there is little accompanying noise, the input amplifier can be operated at high gain without overloading the PSD and little gain is needed at the output. In the case of signals buried in very large noise voltages the reverse situation is required.

2.2.5 Output of Lock-in Amplifier

The output from a lock-in amplifier was traditionally a DC voltage that was usually displayed on an analog panel meter. Modern instruments, especially those instruments used under computer control, provide an output reading in the form of a digital number. The analog DC voltage signal is usually also provided. Lock-in amplifiers that employ an analog form of phase-sensitive detector use an analog-digital-converter, (ADC), to generate their digital output. Digital multiplying lock-in amplifiers use a digital to analog converter, (DAC), to generate the analog output.

2.3 Operating Modes of Lock-in Amplifier

The model 7260 lock-in amplifier is a sophisticated instrument with many capabilities. It incorporates a number of different operating modes.

2.3.1 Signal Recovery/Vector Voltmeter

The model 7260 can be used for measuring the phase of the applied signal with respect to the reference. The accuracy of this measurement is not usually paramount. This operating mode is called the signal recovery mode and is the default mode at power-up. In cases where the applied signal is essentially free of noise some of the circuitry needed for best signal recovery performance may be bypassed, which provides an improvement in the accuracy of phase measurements. However, the accuracy achieved is accompanied by an increase in noise. Selective circuitry selection is available in the vector voltmeter mode.

2.3.2 Single Reference/Dual Reference

The lock-in amplifier can measure both the signal magnitude and phase of the applied signal at a single reference frequency. This is referred to as the single reference mode. The dual reference mode in the model 7260 allows the instrument to perform simultaneous measurements at two different reference frequencies. This flexibility incurs a few restrictions such as the requirement that one of the reference signals is external and the other is derived from the internal oscillator. In addition, the maximum operating frequency is limited to 20 kHz and requires that both signals be passed through the same input signal channel.

2.3.3 Single Harmonic/Dual Harmonic

In some applications such as auger spectroscopy and amplifier characterization, it is useful to be able to make measurements at some multiple "n" or harmonic of the reference frequency "F". The only restriction is that the product "nF" cannot exceed 250 kHz. The dual harmonic mode allows the simultaneous measurement of two different harmonics of the input signal. As with the dual reference mode there are a few restrictions such as a maximum "nF" value of 20 kHz. While in the dual harmonic mode there is no advantage to the use of the vector voltmeter mode.   Therefore, simultaneous use of the dual harmonic mode and vector voltmeter mode is not recommended.

2.3.4 Internal/External Reference Mode

When the internal reference mode is selected the instrument's reference frequency is derived from its internal oscillator and the oscillator signal is used to drive the experiment. When the external reference mode is selected the experiment must include some device that can generate a reference frequency, which is applied to the lock-in amplifier's external reference input. The instrument's reference channel "locks" to the external reference signal and uses it to measure the applied input signal.

2.3.5 Virtual Reference Mode

In the virtual reference mode, the Y channel output is used to make continuous adjustments to the internal oscillator frequency and phase in order to achieve phase-lock with the applied signal. The adjustments are performed in such a manner that the X channel output is maximized and the Y channel output is zeroed.

2.4 Functionality of Lock-in Amplifier

The Lock-In amplifier was central to the proper functioning of the system. This design used its oscillator and voltmeter sections. The oscillator generated a precise 26 KHz signal with amplitude of 0.5 V, peak to peak, that was amplified and used to excite the pad under test. The response from the pad was detected by an ultrasonic transducer probe and applied to a channel on the lock-in amplifier. The amplifier was set to display and transmit the readings to the host computer.

2.5 VP-9000 Motor Controller

The VP 9000 is a programmable stepper motor controller, which is capable of running up to four motors. The controller uses a microprocessor, support circuitry and possesses 64 Kilobytes of nonvolatile Random Access Memory, (RAM), for storing setup parameters and programs. Commands and data can either be entered using the RS-232 Serial Interface or by using the front panel menu. An alphanumeric display provides visual access to motor positions and setup parameters. The capability of having a host computer send commands to the controller through its RS-232 serial interface is available.

A unislide Velmex motor was used to move the sensor to different parts of the pad. A stepper motor was used for the angular displacement of the pad. A vacuum was used to hold the pad tight at the time of data acquisition to insure that there was no air-gap between the pad and the sensor. The VP 9000 is pictured in Figure 2.5

Figure 2.5: VP 9000 VELMEX Motor Controller

Motion can be specified in absolute as well as relative indices. An absolute index is measured relative to the absolute zero position. A relative index is measured in a specified direction for a specified distance from the present position. The instrument manual provided tables that allowed an estimate the number of steps required, by the motor, to cover a given distance. Of the four available lines on the VP 9000 only three were used. The instrument controlled the position of the sensor relative to the center of the pad, (X-axis), the height of the sensor above the pad surface, (Z-axis), and the angle of the pad with respect to the sensor position, (Radial axis).

2.6 PS-2520G Power Supply

The PS-2520G is a Programmable Power Supply from Tektronix. It offers three power outputs. Two of these are supply voltages from 0 to 36V and currents from 0 to 1.5A. The third one has a higher current capability of 0 to 3A and supplies voltages from 0 to 6V. The instrument has a Light Emitting Diode, (LED), display to indicate the voltage and current levels. The PS-2520G Programmable Power Supply is pictured in Figure 2.6.

Figure 2.6: PS-2520G Programmable Power Supply

The PS2520G possesses a GPIB IEEE-488 interface that enables a host computer to control it through the use of Standard Commands for Programmable

Instruments, (SCPI). The PS2520G was provided a 12V output voltage that was used to open a vacuum valve. Manipulation of the vacuum valve enabled a vacuum pump to create enough suction for the pad under test to be grabbed and held in place while measurements were being performed

Chapter 3

Temperature and Humidity Control

3.0 Temperature Control

Temperature plays a major role in the determination of the mechanical properties of CMP pads. A temperature controller was used in order to observe the effects of temperature on the CMP pads. Data was acquired while the pads were subjected to different levels of temperature.

The temperature controller accepts an input from a temperature sensor and has an output that is connected to a control element such as a heater or fan. There are various types of control. Some controllers are dedicated to a specific type of control while others offer a programmable type of control.

3.1 Types of Control

3.1.1 On/Off Control

An on-off controller is the simplest form of temperature control device. The output from the device is either on or off, with no middle state. An on-off controller will switch the output only when the temperature crosses a set point. For heating control, the output is on when the temperature is below the set point, and off above the set point. Since the temperature crosses the set point to change the output state, the process temperature will cycle within a small band of temperatures that contains the set point. In cases when the temperature cycles rapidly an on-off differential or “hysteresis” is added to the controller, which will prevent damage to contactors and valves. The differential ensures that the temperature exceeds the set point by a certain amount before reversing direction. The on-off differential prevents the output from “chattering” or making fast and continual switches, which occurs if the temperature cycles above and below the set point very rapidly. On-off control is usually used where precise control is not required, in systems that cannot handle having the energy turned on and off frequently, where the mass of the system is so great that temperatures change extremely slowly or for temperature alarms. A special type of on-off that is used for temperature alarms is a limit controller. The limit controller uses a latching relay, which must be manually reset. The latching relay is used to shut down a process when a certain temperature is reached.

3.1.2 Proportional Control

Proportional controls are designed to eliminate the cycling associated with on-off control. A proportional controller decreases the average power supplied to the heater as the temperature approaches the set point. A proportional controller gradually reduces the energy delivered to the heater to keep the temperature from overshooting the set point. Instead of overshooting, the temperature will reach and maintain a stable temperature at the set point. The proportioning action can be accomplished by turning the output on and off for short intervals. This “time proportioning” varies the ratio of “on” time to “off” time in order to control the temperature. The proportioning action occurs within a “proportional band” around the set-point temperature. Outside of the proportional band, the controller functions as an on-off unit with the output either fully on if the temperature is below the band or fully off if the temperature is above the band. However, within the band, the output is turned on and off as a ratio of the temperature value to the value of the set point. At the set point, which is the midpoint of the proportional band, the output on-off ratio is 1:1. If the temperature is further from the set point, the on- and off-times vary in proportion to the temperature difference.

3.1.3 PID Control

The third controller type provides proportional with integral and derivative functions, which is termed PID control. This controller combines proportional control with two additional adjustments, which helps the unit automatically compensate for temperature changes in the system. These adjustments, integral and derivative, are expressed in time-based units. The adjustments are also referred to by their reciprocals, which are termed RESET and RATE, respectively. The proportional, integral and derivative terms must be individually adjusted or “tuned” to a particular system through the use of trial and error. PID control provides the most accurate and stable control of the three controller types. It is most appropriately employed in systems that have a relatively small mass or those that react quickly to changes in the energy added to the process. PID control is recommended in systems where the load changes often and the controller is expected to compensate automatically due to frequent changes in the set point, the amount of energy available or the mass to be controlled.

3.2 Temperature Sensor

Many varieties of temperature sensors exist. The thermocouple was best suited to satisfy the requirements of the system used in this research. A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, which are joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that is directly correlated with the temperature. Thermocouples are available in different combinations of metals and calibrations. The four most common thermocouple calibrations are termed J, K, T and E. Each calibration has a different temperature range and accuracy. Although the thermocouple calibration dictates the temperature range, the maximum range is also limited by the diameter of the thermocouple wire. The K-type thermocouple was utilized during this research; see Figure 3.1.

Figure 3.1: K-Type Thermocouple

3.3 Solid State Relay (SSR)

A solid-state relay, (SSR), is a switch that contains no moving parts. Solid State Relays are used to switch various loads such as heating elements or resistive loads, motors, transformers or inductive loads and capacitive loads. A solid-state relay is often used when a line powered device needs to be turned on and off by a control circuit in order to provide isolation from the power line. Solid-state relays are SPST; normally open, switching devices with no moving parts, which are capable of millions of cycles of operation. By applying a control signal, an SSR switches “ON” the ac load current, which is an action similar to that of moving the contacts of a mechanical contactor. The SSR utilized in this research is pictured in Figure 3.2.

Figure 3.2: Solid State Relay (SSR)

3.4 Temperature Controller

The I-Series CNi16D temperature controller was utilized to control the temperature during the experiments. The I-Series CNi16D temperature controller provided an RS-232 interface, which enabled remote control by the use of commands, which were specified in its configuration manual and generated by a computer program. The instrument possessed both analog inputs and outputs. A thermocouple was connected to the analog input in order to sense the temperature. The RS-232 wiring assignments for attachment of the thermocouple to the controller are presented in Figure 3.3.

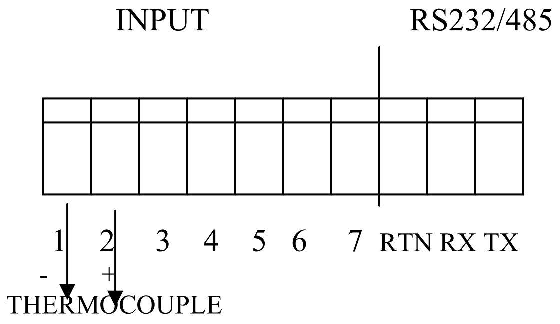

Figure 3.3: RS232 Wiring for Hookup of the Thermocouple to the Temperature Controller

The analog output operated a SSR that supplied power to the heater. The details of the hookup between the controller, SSR and heater are presented in Figure 3.4.

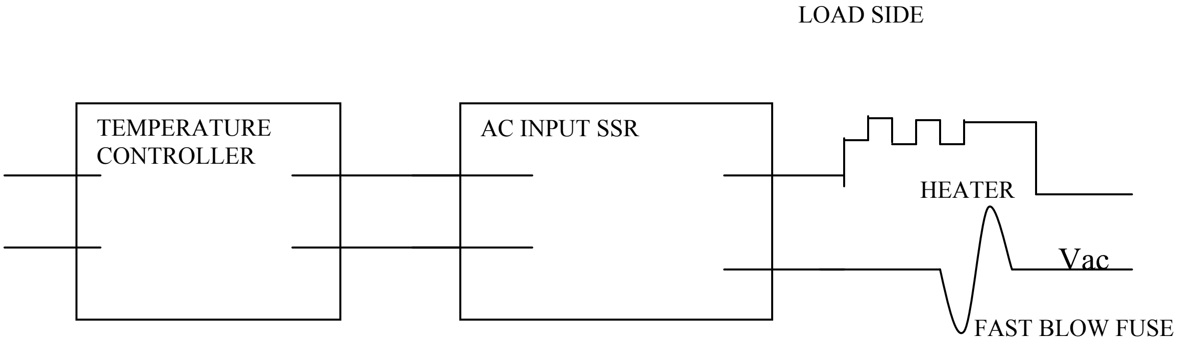

Figure 3.4: AC Controlled SSR for a Temperature Controller With a Mechanical Relay Output

The details related to the application of power and hookup of the SSR to the controller is presented in Figure 3.5.

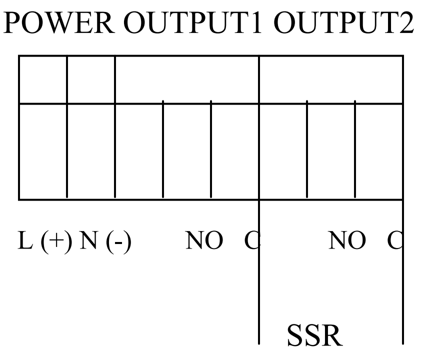

Figure 3.5: Power and SSR Wiring for the Temperature Controller

Depending upon the current temperature, once the set point was specified, the instrument enabled/disabled a relay. A temperature dead-band could be specified within which the controller maintained the state of the relay. The optional analog output could be programmed within a range of 0-10 V_{dc} or 0-20 mA. The output was selectable as either a control output or as a calibrated process value for retransmission, which is a unique feature among controllers. The type of control was also selectable. On/Off, Proportional-Integral, (PI), Proportional-Derivative, (PD), or Proportional-Integral-Derivative, (PID), can be selected. The I-Series CNi16D Temperature Controller is pictured in Figure 3.6.

Figure 3.6: I-Series CNi16D Temperature Controller

3.5 Humidity Control

Humidity was also found to be one of the factors that affected the mechanical properties of the pads. A chamber was designed for humidity control. The humidity control was activated whenever the humidity changed from ambient conditions. The humidity control consisted of both humidification and dehumidification apparatus, which activated when the moisture level deviated from the adjustable set point.

3.5.1 Humidification Apparatus

3.5.1.1 Set-Up

The humidification system consisted of a fan assembly with an absorbent wick inside the chamber and a water reservoir with a re-circulating pump outside the chamber. The computer controlled the pump automatically through the DAQ card. A small, adjustable re-circulating fan was added to the chamber to ensure the atmosphere was properly and completely mixed. The humidifier and fan assembly were connected. After attaching the fan electrical connections and water supply tubes the assembly was directed toward the front center of the chamber. Water inlet and drain tubes were connected to the appropriate fittings of the reservoir and re-circulating pump outside of the chamber.

The reservoir was only filled with distilled water to prevent the build up of contaminants and discoloration. The pump should be placed as close to the reservoir as possible for optimum operation. The re-circulating fan was normally placed in a rear corner, turned on high and aimed at about 45° so that it would direct air toward the center front of the chamber.

3.5.1.2 Operation

Once the setup was complete and the chamber well organized the power supply, humidification and dehumidification apparatus were connected to a relay board that was connected to the DAQ card. The DAQ card supplied the humidification or dehumidification apparatus proper activation signals. The pump, in the humidification apparatus, activates and fills the small reservoir in the fan assembly during humidification. The wicking material soaks up the water, the fan blows air through the water and the re-circulating fan activates. This action rapidly increases the humidity of the whole chamber.

During the humidification process, the pump was capable of supplying more water than the wick could retain. The excess water flowed from the fan reservoir through the drain tube and back to the pump reservoir. It was important to keep the drain tube as straight and clear as possible so that the return flow would not become blocked. Improper drainage would eventually cause the fan reservoir to overflow onto the chamber floor. The humidification apparatus is illustrated in Figure 3.7.

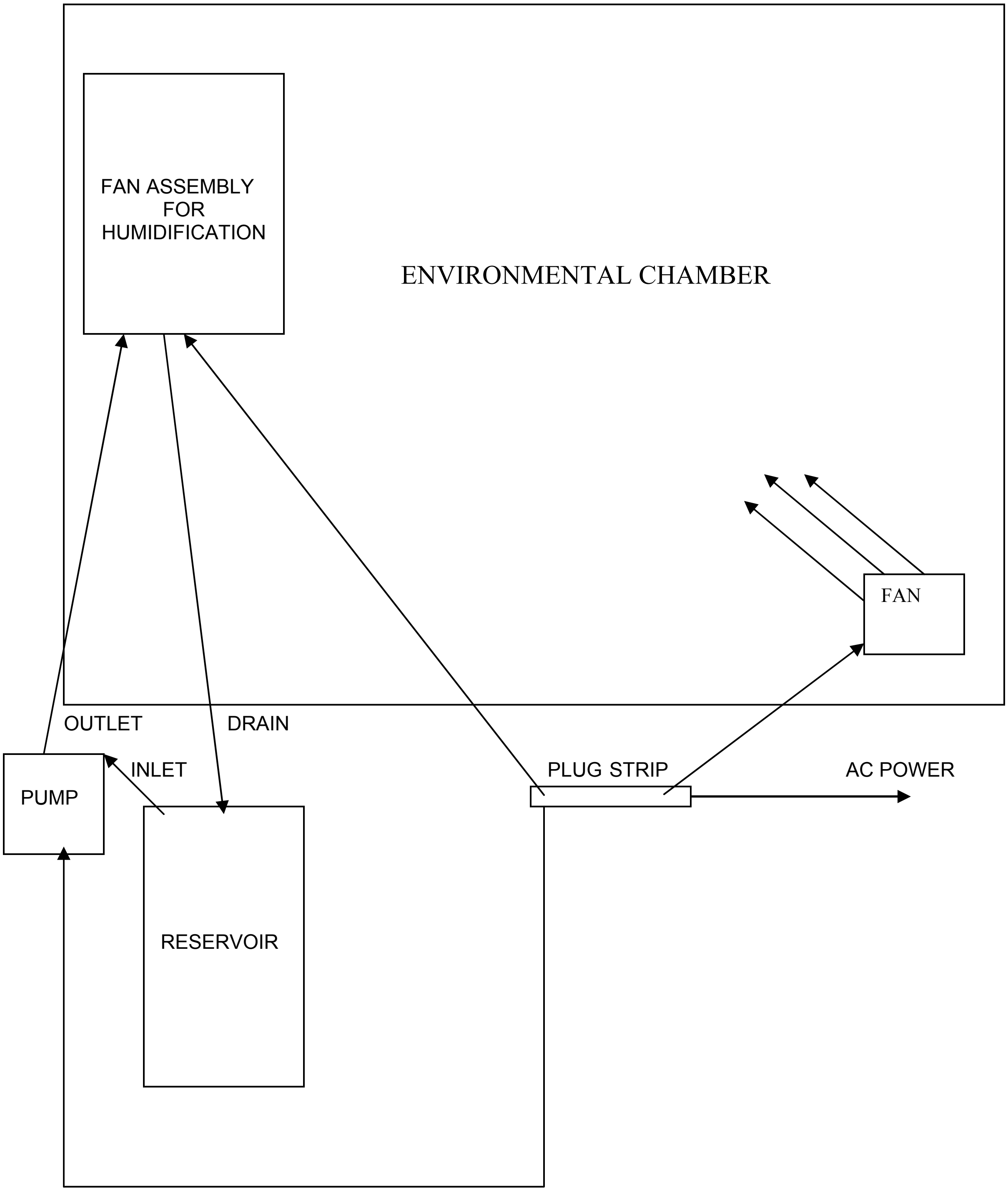

Figure 3.7: Humidification Apparatus

3.5.2 De-Humidification Apparatus

3.5.2.1 Set-Up

The Dehumidification apparatus consisted of a mounting bracket with two drying capsules mounted to the rear wall on the outside of the chamber. A vacuum pump was connected to the capsules on the rear wall via plastic tubing. Quick-connect tube fittings were designed to seal themselves when the tubing was detached. This design was required in order to insure that the chamber atmosphere would not be affected.

Inside the chamber a small re-circulating fan connected and placed in the left rear corner. The fan was directed at a 45° angle so that it would direct air to the front center of the chamber. The fan positioning produced a good mix of the atmosphere to ensure a uniform environment in the shortest possible time.

Once the tubing was attached the computer turned on the system. Humidity control requirements were a function of the desired level, the beginning level, chamber size, airflow rate and the chamber contents. Frequency of door activity and room humidity levels outside the chamber severely affected the systems ability to maintain the desired level of humidity inside the chamber. The dehumidification apparatus is illustrated in Figure 3.8.

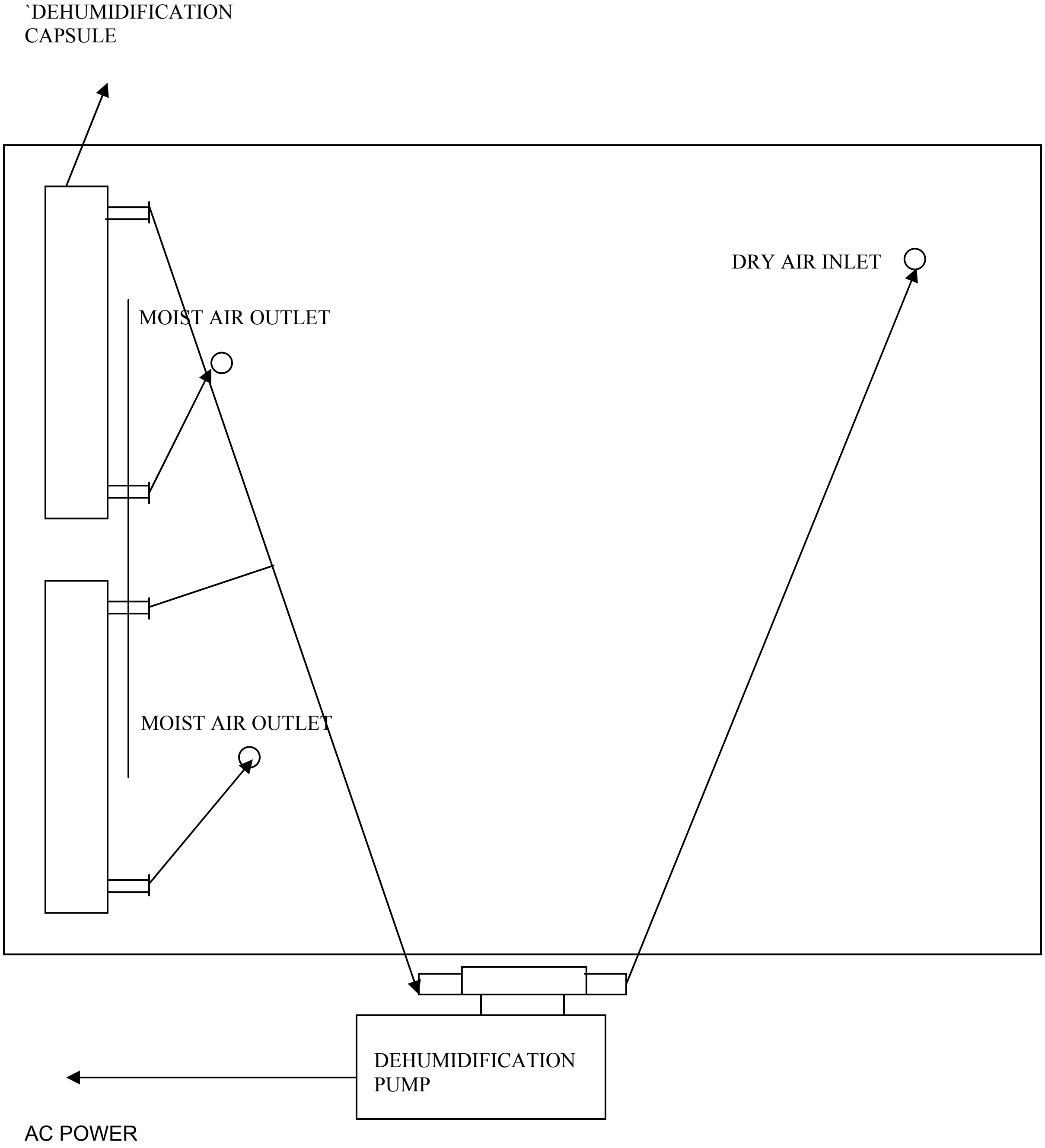

Figure 3.8: Dehumidification Apparatus

3.5.2.2 Humidity Sensor

The HIH-36 10 monolithic Integrated Circuit, (IC), humidity sensor is designed specifically for high volume Original Equipment Manufacturer, (OEM), users. Direct input to a controller or other device is facilitated by the sensor's linear voltage output. The HIH-3610 requires a current of only 200 μA, which makes it ideally suited for low drain battery powered systems. The sensor requires a supply voltage of 4.0 to 5.8 V and operates over a temperature range of -40° F to 185° F. The HIH-3610-001 Humidity Sensor is pictured in Figure 3.9.

Figure 3.9: HIH-3610-001 Humidity Sensor

The Relative Humidity, (RH), is derived from the mathematical relation

$$RH = (((\text{Voltage}/5.0)-0.016)/0.0062) \qquad 3.1$$

where the parameter “Voltage” is the voltage value obtained from the output of the sensor. The voltage output of the sensor was sensed by the analog input of the DAQ card.

3.6 Integration of the Humidity Apparatus

The 6035E Data Acquisition Card, from National Instruments, features sixteen channels for 16-bit analog inputs, two channels for 12-bit analog outputs, a 68-pin connector and eight lines for digital Input/Output.

The DAQ card was primarily used by the system to implement humidity control. A humidity sensor generated a signal, which was mathematically related to the actual humidity; see equation 3.1. The signal was sensed by the analog input of the DAQ. The signal was digitized and the digital value was sent to the program, which mathematically converted it to the actual humidity value. Based upon a calculation of whether the humidity level was to be increased or decreased, the program instructed the DAQ to output signals to the appropriate relays in order to enable the required system. The DAQ functioned in conjunction with the National Instruments SC-2050 I/0 Board and the SC-2062 Relay Board.

Chapter 4

System Integration

4.0 System Integration Tasks

System Integration for this research involved the tasks of integrating all the hardware and instruments together and bringing them under the control of a single software program. The tasks involved with this research for which the use of hardware became necessary were:

- Controlling the position of the sensor above the pad
- Controlling the pad position relative to the sensor
- Generating an excitation signal for the pad
- Measuring the response produced by the pad
- Controlling and tracking the humidity and temperature levels during the experiment.

4.1 Instruments Employed

This sub-section provides information about the hardware employed by the system. Table 4.1 provides basic information on all devices utilized during the testing. The instruments were connected to the computer via the like IEEE

GPIB488 and RS232C interfaces. A VC++ program was written to control the equipment from a console.

Table 4.1: Instruments Integrated Into the System

Instrument	Manufacturer	Function
VP 9000 Motor Controller	Velmex, Inc.	Control of motors used to move sensors
PS2520G Programmable Power Supply	Tektronix	Provided power to hold the pad while measurements were being carried out
Lock-In Amplifier 7260	EG&G (AMETEK)	Generated excitation signals. Measured responses
Data Acquisition Card 6035E	National Instruments	Control of switches used for tracking humidity
Temperature Controller and Sensor	Newport Instruments	Temperature control and measurement
SERVO – 260 Studio Amplifier	Samson	Amplify Oscillator Output
Humidity Sensor	Honeywell	Measure humidity

A model of the setup employed to carry out experiments on the pads is presented in Figure 4.1. In addition to the pad shape depicted in the Figure 4.1, pads can be semi-circular as well as circular without the gap in the center.

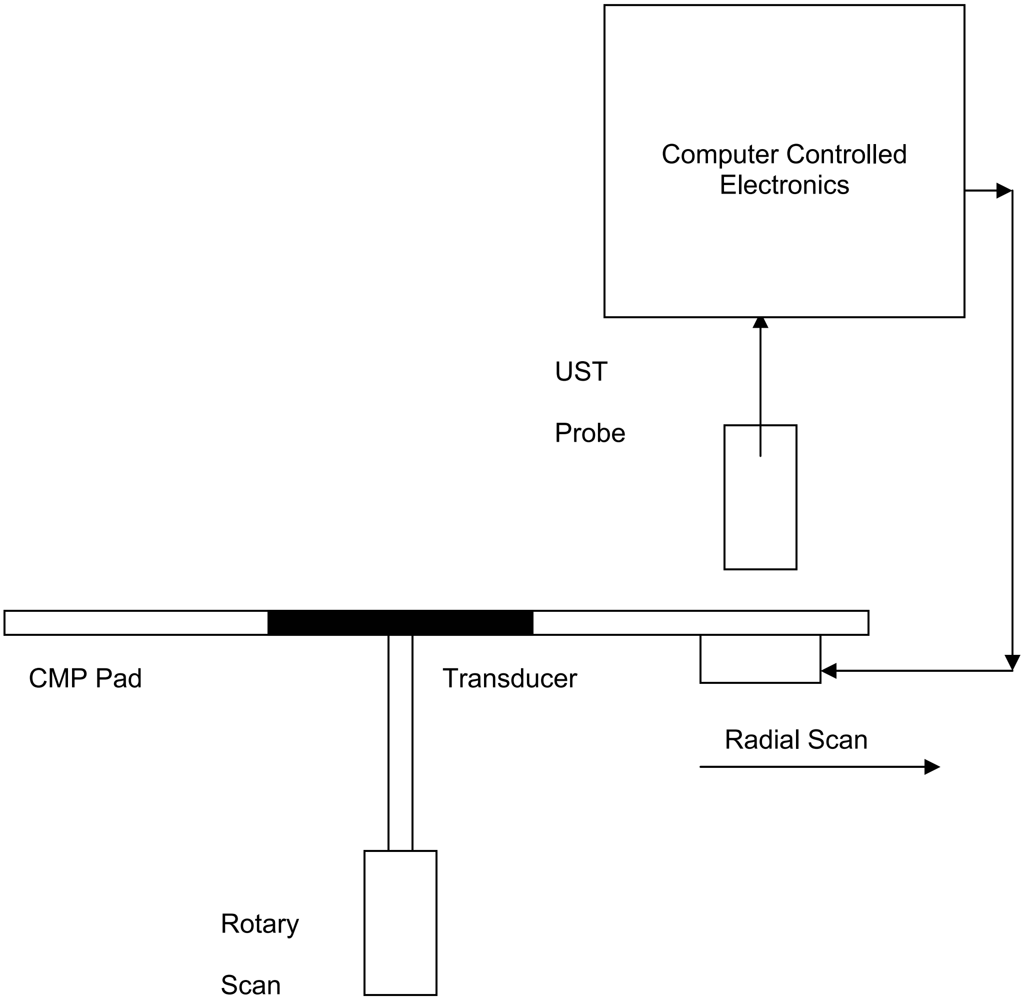

Figure 4.1: CMP Pad Test Set-Up

The assembly presented in Figure 4.1 was mounted on a finely polished aluminum table. The supports for the table could be adjusted so that the pad was always perfectly horizontal.

Temperature and the humidity control were required in the vicinity of the pads in order to study the effects of these physical factors on the pads. Therefore, the test setup depicted in Figure 4.1 was enclosed inside a wooden insulating chamber. The temperature and humidity control setup is illustrated in Figure 4.2.

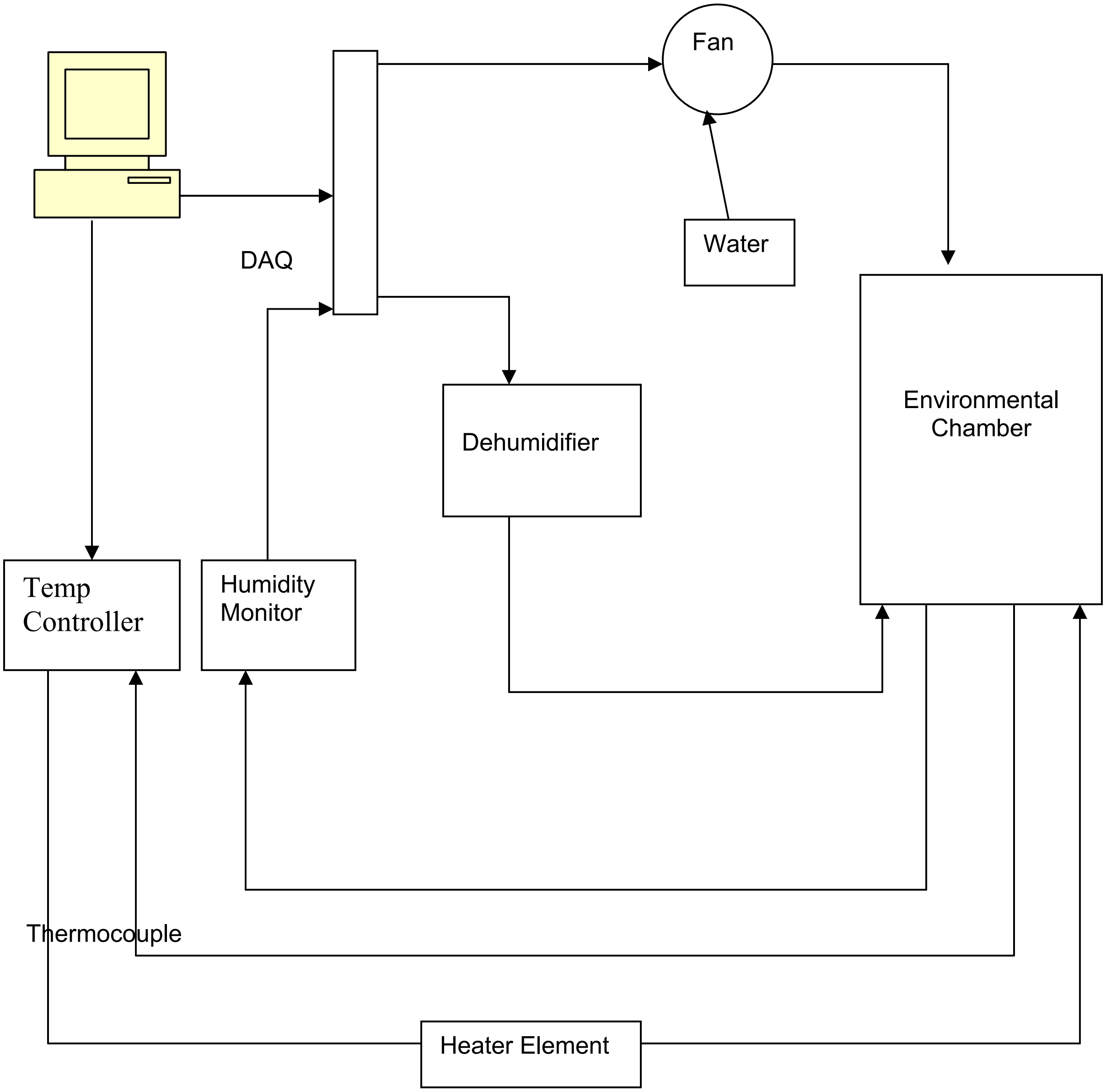

Figure 4.2: Temperature and Humidity Control

4.2 Hardware Integration

Device manufacturers outfit their instruments with communication capabilities in order to enable operators to control the instruments remotely. Ethernet, USB, Serial and Parallel interfaces are examples of communication connection capabilities that are routinely provided. Many instruments that use the GPIB IEEE-488 interface possess the capability of decoding the SCPI instruction set. Some instruments have very specific command formats, which are specified by their manufacturers. In order to control such devices from a host computer a communication link must first be established. Once the communication link is established the software is simply required to send instructions to the instrument in the form of bit strings. Manufacturers provide libraries that include commands specifically designed to make the instrument perform specific tasks. These library files were linked into the host computer's program, developed for this research, so that the commands offered could be used freely anywhere within the program.

4.3 Steps Required for Taking Measurements

The following steps were required in order to insure accurate measurements with respect to the functions of the individual instruments.

1. The position of the contact point of the sensor on the pad was located.

2. The sensor was moved to the point where the reading was to be taken. The Velmex 9000 moved the horizontal motor and vertical motor to establish the sensor over the contact point.
3. The vacuum pump was activated using the Tektronix Power Supply.
4. When the pad was firmly held, the sensor was pushed down to the desired depth in the pad and the pad was stimulated.
5. The amplitude of the response was measured using the Lock-In Amplifier.
6. Steps 1 through 5 were repeated for other points.

Measurements were taken only when the temperature and humidity were at the required level. The temperature and the humidity sensors notified the VC++ program of the current values of these parameters. Depending on the required value, the program activated the humidifier/dehumidifier using the DAQ and the heater using the Temperature Controller.

Chapter 5

Conclusions and Results

5.0 Conclusions

The main purpose of designing and building this software and hardware system was to characterize the CMP pad and study the response to varying physical conditions. The results can be used to find ways of making the pads more resistant to such changes, which will ensure a longer working life. Pads of various dimensions and geometry were tested using the system.

There are various types of scans that can be used to collect statistical data from the pads. This particular system was designed to enable operators to perform various scans such as random, linear, full and sector-wise scans. The research dealt with sector scans.

The circular pad under study had a diameter of thirty-two centimeters and a thickness of four millimeters. For the purpose of analysis the pad was divided into three 120° sectors. A zero position was marked on the pad as a reference point for the radial motor. Measurements were taken within a 60° sector within each of the 120° sectors. The three measurement sectors ranged from 0°-60°, 120°-180° and 240°-300°. These three sectors were identified as Sectors 0, 1 and 2 respectively.

There were four parameters associated with every measurement sequence. The values of these parameters determined the number of observations and the density of points in every sector. The four parameters were:

- Position: Each sector on the pad was identified by an integer. The position value specified the sector over which the measurements were made. A value of "1" specified sector 1, which ranged from 120°-240°.
- Radial Increment: This value specified the separation between consecutive points on a line within the sector. A value of "8" would leave eight millimeters between consecutive points.
- Angular Increment: Similar to the Radial Increment; Angular Increment was the angular separation between two neighboring lines within a sector.
- Depth: This parameter specified the depth to which the sensor was to be pushed into the pad a desired response point.

The data obtained from each of the runs were stored in text files.

5.1 Effects of Ambient Conditions

The pad response to changing conditions of temperature and humidity was the focus of this research. The parameters and their test ranges are presented in Table 5.1

Table 5.1: Test Parameters

Position	Radial Increment (millimeters)	Angular Increment (degrees)	Temperature (° Fahrenheit)	Humidity (%)
0	18	12	80, 90, 100	50, 60, 70
1	18	12	80, 90, 100	50, 60, 70
2	18	12	80, 90, 100	50, 60, 70

Experiments using the parameter values in Table 5.1 yielded nine sets of readings for each sector. The locations of test sectors for a pad are depicted in Figure 5.1.

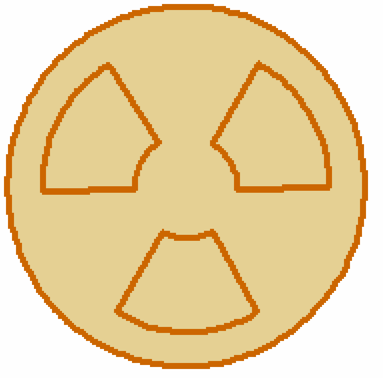

Figure 5.1: 60° Test Sectors for a Pad

In order to check for the effects of temperature and humidity on the pad's response a Multifactor Analysis F-test was used. The results from this test are presented in Table 5.2, Table 5.3, and Table 5.4.

Table 5.2: Test Values for Sector 0 (0°-60°)

Variable	F-Value	P-Value
Temperature	415.23	0.000
Humidity	94.13	0.000
Location	3.02	0.062
Temperature and Humidity	31.81	0.000

Table 5.3:Test Values for Sector1 (120°-180°)

Variable	F-Value	P-value
Temperature	410.48	0.000
Humidity	9.33	0.000
Location	2.73	0.021
Temperature and Humidity	4.51	0.002

Table 5.4:Test Values for Sector2 (240°-300°)

Variable	F-Value	P-value
Temperature	307.58	0.000
Humidity	19.99	0.000
Location	1.34	0.247
Temperature and Humidity	3.97	0.004

The p-values in Tables 5.2, 5.3 and 5.4 represent probability. The p-value tells whether the F-value is significant or not. A value of 0.05 was assumed, which is termed type1 error and denoted by alpha, (α). If the p-value is less than α value then the corresponding factor effected the pad characteristics. If the p-value is greater than 0.05 then the corresponding factor had no effect on the pad characteristics.

The results presented in Table 5.5 demonstrate that Temperature and Humidity affected the pad's response in every sector. The third column indicates that these two factors, acting together, also have an effect on the pad. Therefore, if these two factors change together the pad's response would be different than the response obtained when one factor remains constant and the value of the other factor allowed to change.

Table 5.5: Multifactor Analysis Results with PID Control

Factor	F-test Significance Sector 0	F-test Significance Sector 1	F-test Significance Sector 2
Temperature	Yes	Yes	Yes
Humidity	Yes	Yes	Yes
Temperature*Humidity	Yes	Yes	Yes

A system was developed to characterize CMP pads using an ultrasound technique. Stepwise hardware setup and integration were developed for the UST. The effects of physical factors such as temperature and humidity on the pad response were obtained and presented.

5.2 Future Work

This research demonstrated that the data acquired from this system could be used to analyze the behavior of the pads under changing ambient conditions. This analysis is very important since it helps in studying and improving pad properties, which will ultimately lead to better yields in IC manufacturing.

This system was designed to enable researchers to test pads using ultrasound testing. This system should be modified to run tests on pads using laser beams. In laser testing the response of the pad at a point is measured in terms of the extent to which a laser-beam aimed at a point is scattered. The modular nature of the software makes it very easy to integrate this type of testing into the system. All that would be required is the inclusion of the device drivers for the laser interferometer and the development of a new class that controls the laser. Coding for the laser experiments should follow the same philosophy as that for ultrasound testing.

References

[1] Franklin A. Diaz, “Test Automation and Design of Experiments for Microelectronics CMP Pads”, Masters Thesis, University of South Florida, December 2000

[2] http://www.taltech.com

[3] http://www.signalrecovery.com

[4] VP 9000 Motor Controller, Command Manual, VELMEX, INC.

[5] Tektronix PS-2520G Programmer Manual

[6] Model 7260 Lock-In amplifier instruction manual, EG&G instruments, Inc., 1997

[7] SC-205X Series User Manual

[8] SC-206X Series User Manual

[9] OMEGA, iSeries Controller Manual

[10] HIH-3610-001 Data Sheet, http://www.honeywell.com

[11] Prashant Datar, “System Integration and Testing using Object Oriented Programming Based Control”, Masters Thesis, University of South Florida, May 2003

[12] J.M. Steigerwald, S.P. Murarka and R.J. Gutmann, “Chemical Mechanical Planarization of Microelectronic Materials”, Wiley-Interscience, New York, 1997

[13] D. G. Totzke, et.al., NIST conference, 2001, pp. 259

[14] A.K. Sikder, et. al., Materials Research Society Symposium Proceedings, Vol 671, pp M1.8.1, 2001

Appendices

Appendix A

Temperature and Humidity Data

Sector one data is presented: Data for temperatures of 80, 90 and 100 degrees and humidity of 50, 60 and 70. The rows indicate the readings on one line.

Temperature-80; humidity-50

8.836000 8.786000 8.032000 8.235000 8.033000
8.279000 8.263000 8.633000 8.262000 8.226000
8.678000 8.620000 8.696000 8.615000 8.652000
8.698000 7.923000 8.685000 7.687000 8.356000
8.635000 8.256000 8.096000 8.680000 8.230000
8.632000 8.259000 8.082000 8.212000 8.236000

Temperature-90; Humidity-50

7.237000 6.832000 6.802000 6.823000 6.768000
6.839000 6.302000 7.537000 6.833000 6.806000
7.236000 6.902000 7.635000 6.989000 6.863000
6.899000 6.691000 6.905000 7.182000 6.836000
6.930000 6.860000 6.903000 6.730000 6.939000
6.856000 6.798000 6.876000 6.936000 6.933000

Temperature-100; Humidity-50

6.560000 6.136000 6.767000 6.736000 6.617000
6.727000 6.678000 6.768000 6.835000 6.682000
6.735000 6.761000 6.791000 6.802000 6.703000
6.860000 6.816000 6.855000 6.873000 6.878000
6.860000 6.965000 6.957000 6.838000 6.976000
7.003000 7.067000 6.993000 6.188000 6.973000

Temperature-80; Humidity-60

7.203000 8.268000 8.620000 8.663000 8.095000
8.336000 8.360000 8.669000 8.306000 8.275000
8.683000 8.263000 8.633000 8.650000 8.090000
8.256000 8.330000 8.306000 8.382000 8.239000
8.386000 8.363000 8.363000 8.260000 8.386000
8.368000 8.365000 8.366000 8.368000 8.320000

Appendix A (Continued)

Temperature-90; Humidity-60

7.893000 7.367000 7.661000 7.923000 7.793000
7.959000 7.788000 7.879000 7.986000 7.832000
7.915000 7.908000 7.823000 7.877000 7.832000
7.933000 7.973000 7.965000 7.959000 7.922000
7.980000 7.951000 7.068000 7.939000 7.933000
7.028000 7.633000 7.936000 7.905000 7.970000

Temperature-100; Humidity-60

7.161000 7.681000 7.032000 7.611000 7.033000
7.279000 7.263000 7.633000 7.272000 7.221000
7.678000 7.620000 7.691000 7.617000 7.652000
7.698000 7.223000 7.685000 7.687000 7.351000
7.635000 7.256000 7.091000 7.689000 7.230000
7.632000 7.259000 7.082000 7.222000 7.231000

Temperature-80; Humidity-70

7.287000 7.288000 7.693000 7.200000 7.630000
8.376000 7.330000 8.236000 7.355000 8.220000
7.232000 7.272000 8.222000 7.237000 8.672000
8.272000 7.352000 8.362000 8.389000 8.280000
8.339000 7.335000 7.360000 8.298000 8.350000
8.393000 7.357000 7.383000 8.370000 8.357000

Temperature-90 Humidity-70

7.630000 7.098000 7.083000 7.233000 7.600000
7.266000 7.627000 7.260000 7.369000 7.055000
7.263000 7.225000 7.665000 7.638000 7.027000
7.230000 7.362000 7.268000 7.277000 7.309000
7.295000 7.369000 7.360000 7.237000 7.353000
7.303000 7.507000 7.336000 7.296000 7.338000

Appendix A (Continued)

Temperature-100; Humidity-70

6.869000 6.807000 6.796000 6.902000 6.863000
6.906000 6.792000 6.876000 6.996000 6.822000
6.900000 6.922000 6.862000 6.882000 6.829000
6.957000 7.001000 6.973000 6.931000 6.964000
7.019000 7.063000 7.081000 6.983000 7.050000
7.099000 7.191000 7.001000 6.965000 7.632000