

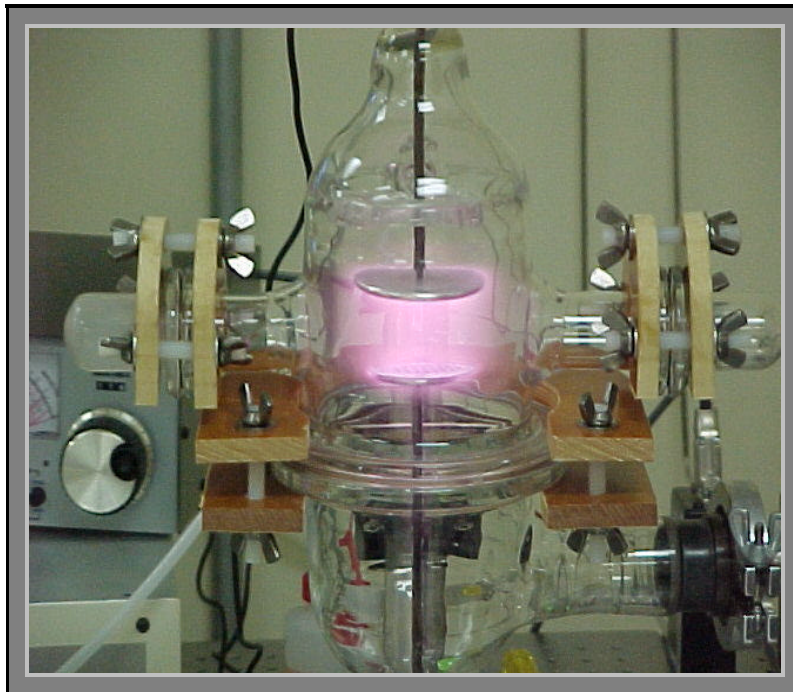
test specification for

An Automated RF Tuner For RIE Applications

submitted to:

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EXECUTIVE SUMMARY

The Reactive Ion Etching (RIE) system in the Emerging Materials Research Laboratories (EMRL) uses RF power to strike the plasma used in the dry etching process. In order to achieve high quality etching, the RIE system requires that the plasma absorb a constant amount of power. Uniform power transfer from the RF source to the plasma is maintained by matching or tuning the RF source to the respective RF load, which is composed of two electrodes and the plasma. The plasma acts as the dielectric between the two electrodes—therefore, making the RF load capacitive. The capacitive impedance of the load is continuously changing due to changes in temperature, pressure, and the dielectric constant of the plasma. Currently, the matching or tuning of the source and load is performed manually in the RIE system. Unfortunately, this makes the RIE process both tedious and difficult to reproduce. Furthermore, the results are significantly dependent on the person operating the system and their tuning skills.

The Automated RF Tuner is designed to establish and maintain a maximum Voltage Standing Wave Ratio (VSWR) of 1.1, which is an acceptable percentage of reflected power for the RIE application. The Tuner accommodates a PC interface which enables monitoring capabilities and limited software control of the tuning network. The PC monitor software has the ability to graphically display the forward and reflected power detected by the tuner circuitry. The Automated RF Tuner is packaged in a standard 19-in. aluminum rack mount enclosure, which provides proper shielding from the electromagnetic emissions of the internal components of the device.

The Automated RF Tuner utilizes the matching techniques and the power detection circuitry of a manually operated MFJ-962D “T” Network Roller Inductor Tuner in conjunction with a micro-controller and a set of servomotors. The micro-controller operates with an impedance tuning algorithm to control the servomotors which, in turn, rotate the mechanical variable impedance devices of the tuning network (refer to Figure 1.) The buffered output of the detection circuitry of the MFJ-962D provides inputs to the micro-controller that determines the relative positions of the mechanically varying impedance components in the matching network. The PC interface permits software control of the tuner and also graphically displays the matching network performance (i.e., forward and reflected power).

The Automated RF Tuner is inexpensive compared to its counterparts on the market because the system is customized to serve only RIE applications. Limiting the target applications to only RIE systems simplifies the physical interfaces and the algorithm used to vary the variable impedance components, which then, match the load to the source. The Automated RF Tuner’s PC interface is favorable because it employs technology and equipment already used in the existing RIE system.

This device will significantly simplify the RIE process by automating the matching process and allowing the operator to leave the RIE system unattended because the matching will be conducted and monitored automatically. Also, the tuning will be performed utilizing the same matching algorithm regardless of the operator. Therefore, the results will be more repeatable which implies more refined recipes for etching can be developed. Also, by simplifying the process of etching, more people can be easily trained to assist in the etching process; therefore, the fabrication time of the semiconductor devices can be minimized.

1. INTRODUCTION

The RIE (Reactive Ion Etching) process uses RF power to strike the plasma used in the dry etching process. In order to produce high quality etching on semiconductor wafers, the power absorbed by the plasma must be relatively constant. Therefore, the changing RF load impedance must be continuously matched to the RF source causing the etching process to be tedious and significantly dependent on the operator of the system and their matching strategies. If this process was automated, the dependency on the operator of the system would be eliminated and the results of the RIE recipes would be more repeatable.

The design constraints for the proposed system are:

1. **Matching Ability:** The automated tuner will establish and maintain a maximum VSWR of 1.1 source to load match.
2. **On-board Controller:** The automated control system will consist of a dedicated on-board micro-controller, which maintains primary control over the tuning network.
3. **PC Interface:** The automated control system for the tuner will have a user interface (i.e., PC) for monitoring the tuning network.
4. **Dual Mode Operation:** The system will be capable of both manual and automated operation.
5. **Power:** The system will operate with a 60 Hz, 120V AC power source (i.e., standard wall outlet).
6. **Electromagnetic Compatibility:** The system will conform to FCC emission limits for scientific RF equipment.
7. **Physical Packaging:** The design will be packaged in a 19-in. aluminum rack mount enclosure measuring 17-in. in depth and 3 standard EIA rack units (5 ¼-in.) in height.
8. **Cost:** The component costs of the design will not exceed \$1000 dollars.

Following these design constraints should allow for a simplified RIE process to be establishing utilizing a customize RF matching setup.

In order to reach these design constraints, tests must be performed on individual components to ensure proper operation of the finished product, such as the interaction of the components must be tested, and these tests must be specified in order to ensure all design constraints are met. Electromagnetic Capability (EMC) testing is a commonly specified test; however, since the Automated RF Tuner is classified as a scientific instrument, the emission energy of the specified frequency of operation, 13.56 MHz, is unlimited [3]. Therefore, the EMC testing need not be specified in this document.

2. TEST SPECIFICATION

In order to produce a successful modification from an existing manual RF tuner, all interfaces between components should be tested for functionality before the system is integrated. Therefore, several test stages were used, such as a motor control test, control signal test, and algorithm test.

In Table 1, the proposed evaluation scheme is summarized. The tests represent levels that must be attained in order to complete the finished product: interface testing level, functionality testing level, and final testing level. The control system of the Automated RF Tuner is composed of three components the PC, the servomotors, and the micro-controller. Each interface between these components must be tested before the system can be integrated. The interface testing level consists of the Motor Control Test Suite and the Control Signal Test. After this first level is attained, the functionality of the device must be tested, which consists of the Algorithm Test. The final testing level consists of the RIE Run and the Physical Packaging testing. If the final testing level is achieved, the Automated RF Tuner will have met all design constraints.

Requirement	Motor Control Test Suite	Control Signal Test	Algorithm Test	Physical Packaging	RIE Run
Matching Ability			•		•
On-board Controller	•	•	•	•	•
PC Interface		•	•	•	•
Dual Mode Operation			•		•
Power	•		•	•	•
EMC ¹	N/A	N/A	N/A	N/A	N/A
Packaging				•	
Cost				•	

¹ EMC testing does not have to be tested due to this qualification as a scientific instrument [3].

Table 1. A summary of the proposed tests to evaluate the integration and functionality of the Automated RF Tuner. The tests represent levels that must be attained in order to complete the finished product: interface testing level, functionality testing level, and final testing level.

2.1. Motor Control Test Suite

The Motor Control Test Suite includes both manual motor control and micro-controller motor control. The purpose of the test is for characterizing the operation of the servomotors, which respond based on the pulse width of the input signal to the motor [9]. During manual motor control, pulsed signals are sent via a pulse generator to the servomotors to test the response of the servomotors. Each servomotor has a neutral pulse width setting [9], which results in no movement, a counter-clockwise rotation setting, and a clockwise rotation setting. The manual part of this test is conducted to characterize the individual motor with their exact neutral setting and to determine if

modifications should be made to their operation. During the micro-controller motor control test, the motors are tested for their response to the micro-controller's generated pulse signals [1]. The motors are tested to verify they respond as expected. Since these tests are characterization test, the results are logged for reference.

2.2. Control Signal Test

The Control Signal Test verifies that the signals received and sent by the micro-controller are compatible with the servomotors, the PC, and the micro-controller itself. This test is necessary because the main components in this system (i.e., micro-controller, PC, and servomotors) are designed with standards unique to themselves; therefore, they must be designed to work together. The Control Signal Test consists of testing of the serial connection between the micro-controller and the PC [4], the input to the micro-controller from the RF matching network, and the output signal to the servomotors. The serial connection between the micro-controller and the PC is tested by programming the micro-controller to send data to the PC via an RS-232 serial link. This data is then monitored for accuracy at the PC side and visa-versa. The RF power detection input to the micro-controller is tested for compatibility to the micro-controller's 5-volt signal limit [1]. This is measured by monitoring the existing manual MFJ-962D tuner's minimum and maximum RF forward and reflected power signal strengths while in operation. This signal is equivalent to the signal received by the micro-controller in the automated RF tuner configuration since the same MFJ-962D circuitry is used for power monitoring [6]. In testing the micro-controller's output to the servomotors, the output pin of the micro-controller is monitored by an oscilloscope. The pulse-width of the micro-controller output signal is monitored to ensure proper motor control commands have been issued. Any discrepancies in the signal will be accounted for in the implementation of the signal in the algorithm.

2.3. Algorithm Test

The Algorithm Test is needed to verify the expected results of the matching algorithm. In this test, the micro-controller processes a specific set of reflected power values in which the tuning steps are known, therefore, simulating the input from the matching network to the on-board controller. This is a pass or fail test in which the results of the test are logged. This test is used to optimize the algorithm and also test the capability of the on-board controller and the servomotors.

2.4. Physical Packaging

All components are selected with the constraint that they will fit in a 19-in. rack unit. Therefore, the ultimate test is that the components are small enough to be contained in this packaging and cheap enough for the total cost of the device to be under budget. The device will be totally enclosed within the unit. Also, the micro-controller is enclosed in box within the 19-in. rack unit because this component is designed to operate with constant voltages; therefore, it must be isolated from the radio frequency signals.

2.5. RIE Run

The RIE Run is the final test of the operation of the Automated RF Tuner. In this test, the automated tuner is used to tune the RF source to the RIE chamber. In this test, a plasma is struck and the tuner attempts to match the plasma to the source. The success of this test is defined by the automated tuner minimizing the reflected power and maintaining the acquired minimum level. The maximum allowed Voltage Standing Wave Ratio (VSWR)[7] is 1.1. The analog power meter associated with the MFJ-962D [6] measures the condition of the match. Another visual verification will be the intensity of the plasma. If the intensity of the plasma remains stable, then constant power is delivered to the load [2]. The manual and automated modes of operation are tested for proper cooperation in implementation of the algorithm. The operator overseeing the RIE Run tests the monitoring software for proper functionality.

3. RESOURCES

In conducting most of these tests, the equipment used can be found in most laboratories. The RIE Run is the final test and must be run in the Thin Films Laboratory in Simrall Hall 418 where the Automated RF Tuner will be implemented after its completion.

3.1. Motor Control Test Suite

For the manual motor control test, the Design Lab on the 3rd Floor of Simrall Hall is used; however, any lab can be used in which the proper equipment is available. The necessary equipment are a pulse generator, a multimeter, and the servomotors. For the micro-controller motor control test, the equipment needed is a computer, micro-controller, serial cable, 5-volt power supply, and servomotors. This test can be conducted any lab. This test also verifies the AC power source produces the needed power to the micro-controller and the servomotors.

3.2. Control Signal Test

In testing the serial connection between the micro-controller and the PC, a serial cable, a PC, and a micro-controller are needed. This test can be conducted anywhere this equipment is available. The input to the micro-controller from the RF matching network is tested in the Thin Film Laboratory in Simrall Hall 418. The equipment used is a multimeter, the MFJ-962D, the ENI RF Source [5], and the RIE Chamber [8]. The test of the output of the micro-controller to the servomotors is conducted using the micro-controller and an oscilloscope. This test is conducted in the Design Laboratory on the 3rd Floor of Simrall Hall.

3.3. Algorithm Test

The Algorithm Test is run with a PC, serial Cable, and the Automated RF tuner. The location of this test is not critical since the equipment used in this test is portable.

3.4. Physical Packaging

The Physical Packaging test verifies that all components can be packaged within the 19-in. rack unit without causing adverse effects on any given component. This test is performed by laying all parts into their respective places inside the rack unit and monitoring the system for malfunctions when all components are operational. This can be done in any laboratory.

3.5. RIE Run

The RIE Run is conducted in the Thin Film Laboratory in Simrall Hall 418. The equipment necessary in this test is the ENI RF source, the Automated RF tuner, PC, and the RIE chamber.

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