Instructional Materials for a Technician-Level Course in Plasma-Aided Manufacturing

David M. Hata
Portland Community College

Abstract

Plasma-aided manufacturing is a critical technology in the manufacture of integrated circuits, MEMS, and other nano-scale components as well as the surface modification and coating of a variety of materials. As a result, there is a growing need for technicians to be equipped to install, maintain, and troubleshoot plasma-based tools. Community colleges have been ill-equipped to meet this need, lacking educational materials, teaching laboratories, and knowledgeable faculty.

Portland Community College, through a grant from the Advanced Technological Education Program at the National Science Foundation, has addressed this need by developing technician-level educational materials, prototyping a teaching laboratory for plasma-aided manufacturing, and training community college faculty.[1] This paper provides a summary of PCC's three-year development and implementation effort.

Introduction

The lack of instructional materials is a major deterrent in developing and implementing a technician-level course in RF plasma processing at the community college level. A search of the literature produced only graduate-level textbooks.[2,3]

Equipment needed to implement a teaching laboratory to support a technician-level course was also lacking. Equipment to support simple plasma demonstrations was available from scientific equipment companies, e.g. Fisher Scientific, but no plasma training systems were on the market. Low-end process tools that could be adapted to serve as a training system in a teaching environment were available, but the minimal cost of these production systems was in the range of $60,000 to $80,000.

Given these deficiencies and the fact that few community college instructors had the technical experience in plasma-aided manufacturing to produce needed instructional materials in RF plasma technology, virtually no courses in RF plasma technology were being offered in technician-level degree programs. To address these deficiencies, the National Science Foundation awarded Portland Community College a three-year grant through their Advanced Technological Education Program. This paper describes the products and results of this three-year project.

Educational Materials Development

Plasma-aided manufacturing is a muti-disciplinary discipline. Prerequisite knowledge includes topics from general chemistry and general physics, mathematics, electronics, vacuum technology, and materials processing.

Educational materials development efforts focused on three areas: basic plasma physics, the RF power delivery system, and simple plasma-based manufacturing processes. The result was a set of six instructional modules:

- Selected Topics from Electric Circuits
- Introduction to Plasma Physics
- Transmission Lines
- RF Power Delivery
- Metallization by Sputtering
- Safety

Each module contains textual material, questions and problems, and a suite of laboratory exercises to form a complete learning package consistent with most lecture/lab structured, technician-level courses. For example, the table of contents for the RF Power Delivery module is given below.

RF Power Delivery
Table of Contents

4.1 Introduction
4.2 RF Power Sources
4.3 RF Power Measurements
4.4 Chamber Impedance
4.5 Impedance Matching
4.6 Summary
4.7 Questions and Problems
4.8 Laboratory Exercises
    Lab Exercise 4.1. RF Power Measurement
    Lab Exercise 4.2. Impedance Matching
4.9 Appendices
    4-A RFS-301 RF Training System
    4-B Seren R300 13.56 MHz Power supply
    4-C RF Training Match Specifications
    4-D Bird 4421 RF Power Meter/4021 Power Sensor
4.10 References

Developing the text material for each module was not difficult since basic core knowledge for the study of gas plasmas already exists in the literature. For example, fundamental principles of plasma physics can be found in textbooks authored by Roth, Chapman, and Sugawara.[3,4,5] Material on the fundamentals of transmission lines and impedance matching can be found in basic electronic communications textbooks by authors such as Gary Miller.[6] And, manufacturing processes such as sputtering are described in textbooks by Quirk and Serda and Stanley Wolf.[7,8] The six modules brought information from these varied sources together and presents the information a concise and coherent presentation.

Laboratory Improvement

Laboratory development proved to be much more challenging. Developing and implementing a teaching laboratory for a technician-level course in RF plasma-aided manufacturing began with implementation of very basic gas plasma demonstrations from chemistry and physics. Equipment to support these demonstrations is readily available from a number of scientific equipment supply companies that market to high school and college science departments. For example, the structure of a DC plasma could be shown using a half-coated fluorescent tube, high-voltage DC power supply, and Tesla coil. Another demonstrated the optical emissions of a gas discharge using a power supply to energize a gas tube and student spectrometer to view to spectrum of the emitted light.

Although existing demonstrations could be used in their original form, it was decided that modifications to these basic demonstrations to increase their value in the classroom/laboratory. For example, by replacing the fixed-output DC power supply with a variable-output DC supply allowed the DC excitation voltage to be changed in small increments. In the optical emission demonstration, it was found that some students, and the instructor, could not see the colored lines using a student spectrometer. By replacing the student spectrometer with a fiberoptic spectrometer manufactured by Ocean Optics, a graph of “Intensity versus Wavelength” could be displayed on a computer monitor, yielding not only qualitative information, but also quantitative information as well.

Two pieces of equipment were critical to laboratory development. The first, the MFJ-259B SWR Analyzer, shown in Figure 1, provides a low-cost alternative to expensive network analyzers in making impedance measurements at RF frequencies. The MFJ-259B measures impedance and other transmission line properties in the frequency range of 1.8 MHz to 170 MHz. With the MFJ-259B, low-cost experiments in transmission line fundamentals and impedance matching could be implemented.

Figure 1. The MFJ-259B SWR Analyzer.

The second piece of equipment was developed in partnership with MKS Instruments, Inc. The PPTS-1A Plasma Training Systems proved to be an ideal system to perform capstone laboratory exercises in a technician-level RF plasma technology course at half the cost of commercial plasma processing systems. The PPTS-1A, shown in Figure 2, consists of a six-inch, six-way cross that serves as the process chamber, high vacuum pumping system, MFC gas delivery system, and RF generator/matching unit.[9] The chamber is evacuated using a scroll pump/turbomolecular pumping system capable of achieving pressures in the 10^{-6} torr regime. Gases, nitrogen and argon, are delivered into the chamber via mass flow controllers from a gas cylinders. The powered electrode is a magnetron-sputtering electrode powered by a 300-watt, 13.56 MHz RF generator and manual match. Material is sputtered from a copper target.

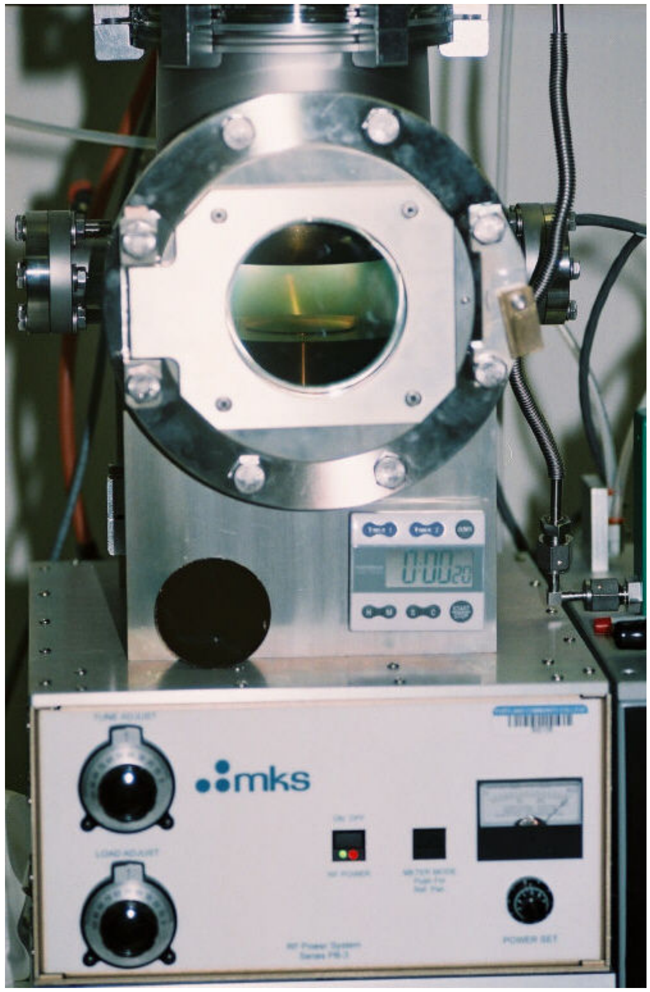

Figure 2. The PPTS-1A table-top plasma training system.

With the PPTS-1A, copper can be deposited on the surface of glass disks or silicon wafers. Chamber pressure, power, and processing time are the variables in the manufacturing process. Process recipes have been run with chamber pressures in the range of 30 millitorr to 100 millitorr, RF power levels in the range of 50 watts to 300 watts, and process times up to 10 minutes.

The PPTS-1A is basically a manual system that requires the student to be an active part of the experiment. Manual operation reinforces not only the operations that need to be performed, but also the sequence or recipe that must be followed. The cost of the PPTS-1A is approximately one-half the cost of low-end process tools.

Faculty Enhancement

Three, two-day faculty workshops have been hosted by Portland Community College. Workshops were held in May of 2003 and March and August of 2004. A total of twentysix faculty members from twenty-one colleges in fourteen states have attended workshops. Two additional workshops will be offered in 2005.

The two-day workshop is equally divided between classroom presentations and laboratory activities. In this manner, each participant gets an overview of the breadth of topics and the instructional modules and a hands-on experience with each demonstration and laboratory experiment. Laboratory time also allows each participant to evaluate the equipment used in each laboratory activity so that they can make more informed purchasing decisions for their program and institution.

Follow-up surveys from fifteen of the twenty-one educational institutions represented at RF Plasma Technology workshops in 2003 and 2004 provided the following information

- Fifty-five students at three institutions used the materials during Fall term/semester of 2004.
- Three workshop participants are not teaching during the current academic year.
- Eight of the institutions will be using some or all of the materials during Winter term or Spring term.
- Two institutions do not include plasma technology in their curriculum, nor have future plans to incorporate material on plasma technology.
- Funding for laboratory equipment is a problem in implementing the laboratory portion of the educational materials.

The results are encouraging since no two-year programs offered a lecture-laboratory course in plasma technology in 2001 when the NSF/ATE Project began. Three years later, eight two-year programs are using the materials developed by this Project in their curricula.

The educational materials have been classroom tested for the past three academic years in MT 240 RF Plasma Systems, a required course in PCC's associate of applied science degree program in Microelectronics Technology. A plasma technology teaching laboratory supports the laboratory component of MT 240, a total of 30 laboratory clock-hours. The laboratory is configured for a minimum of six teaching stations.

The laboratory has proven its value in providing a transition from fundamental experiments and demonstrations to an actual process tool, e.g. oxide etcher. Along with PCC's MT 223 Vacuum Systems course, these courses cover the two most important enabling technologies in the manufacture of integrated circuits.

Over the past three years, graduates of PCC's Microelectronics Technology program have continued to be hired by Intel Corporation, Oregon's largest high-tech employer.

Graduates have been able to step into manufacturing areas using plasma-based tools and have been able to test out of in-house computer-based-training modules in the area of plasma technology.

Next Steps

The original proposal was only partially funded by the National Science Foundation. Development of textual material and experiments in microwave-based plasma processing was cut from the original project design. Instructional material development in this area would be a logically next-step for a following project.

For colleges planning to use the materials developed through PCC's current NSF project, assistance in the form of consultancies would aid in implementation. Assistance in seeking federal and local grants to fund equipment acquisition should be provided and then followed by assistance in setting up a teaching laboratories.

Educational materials will be transferred to the National Center for Manufacturing Education (NCME) at Sinclair Community College in Dayton, OH, for dissemination to interested faculty. This will ensure that the materials will continue to be available after the conclusion of PCC's grant.

Summary

Portland Community College has successfully met the three major goals for NSF Project # 0101533. Those goals include the development of technician-level instructional materials, implementation of a teaching laboratory for plasma-aided manufacturing, and faculty training through two-day workshops hosted by PCC.

Through PCC's grant, the number of colleges offering technician-level courses in plasma-aided manufacturing has increased to eight educational institutions. However, funding for equipment continues to be the major roadblock in implementing teaching laboratories to support experiential studies in plasma technology.

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Biographical Information

DAVID M. HATA
Mr. Hata retired in 2003 after 32 years of teaching at Portland Community College in Portland, OR. During his tenure at PCC, he taught in the EET and Microelectronics Technology programs and served as Principal Investigator for seven National Science Foundation grants. He is a past recipient of ASEE's Chester F. Carlson Award and Robert G. Quinn Awards and past Chair of the Two-Year College Division.