## AC 2011-2416: MICROWAVE PLASMA CLEANER DESIGN FOR SEMI-CONDUCTOR FABRICATION AND MATERIALS PROCESSING LABO-RATORY USE

#### Mustafa G. Guvench, University of Southern Maine

Mustafa G. Guvench received M.S. and Ph.D. degrees in Electrical Engineering and Applied Physics from Case Western Reserve University. He is currently a full professor of Electrical Engineering at the University of Southern Maine. Prior to joining U.S.M. he served on the faculties of the University of Pittsburgh and M.E.T.U., Ankara, Turkey. His research interests and publications span the field of microelectronics including I.C. design, MEMS and semiconductor technology and its application in sensor development, finite element and analytical modeling of semiconductor devices and sensors, and electronic instrumentation and measurement. He can be reached at guvench@usm.maine.edu.

#### Derek Richardson, Fairchild Semiconductor

Derek Richardson attended the University of Southern Maine where he received his Bachelor of Science Degree in Electrical Engineering. He is currently employed full-time at Fairchild Semiconductor as an Applications Engineer in the Mobile Solutions Product Line. Derek elected to research, design, and construct a Microwave Plasma Cleaner as a Senior Project in his undergraduate studies in Electrical Engineering under the advisement of Professor Mustafa Guvench.

# Microwave Plasma Cleaner Design for Semiconductor Fabrication and Materials Processing Laboratory Use

#### Abstract

This paper describes a microwave plasma cleaner designed and built for use in integrated circuit fabrication and materials processing laboratories. It is a much less expensive alternative to RF plasma cleaners because of the fact that very inexpensive and readily available household microwave oven is utilized to generate the microwave power to produce the plasma in the process chamber. The process chamber is an inverted Pyrex bowl placed on a metal base plate and is evacuated by a rotary vane vacuum pump capable of reaching milliTorr ultimate vacuum. The system built is portable on wheels, and employs two Rotameter flow meters with fine needle valves to control gas pressure and composition fed into the process chamber. Pressure is monitored with a digital thermocouple vacuum gauge. Uniform plasma is obtained at operating pressures of 100-1000 milliTorr range.

Currently the microwave plasma system built is being used to plasma treat the gold bonding pads of package and MEMS chips to facilitate organics free surfaces and improve the quality in wire bonding. However, such a system can easily be adapted to serve as plasma assisted dry etcher.

#### **1. Introduction**

The project reported here comprises the design and development of a microwave plasma cleaner for use primarily in the pre-wire-bonding plasma treatment of gold bonding pads of MEMS sensor chips and its package in order to facilitate organics-free surface and thus to improve bonding <sup>1</sup>.

Plasma etching is a common application used to remove organic surface contamination by exposing surfaces to an energetic radical species consisting of photons, electrons, ions, and reactive neutral species. Being a dry process which does not involve acids and VOC solvents, it is preferred in semiconductor wafer fabrication and chip bonding. The particles are energized and bombard the surface to cause sputtering, thermal evaporation, chemical reaction, and photodecomposition<sup>2</sup>. Typically in engineering applications plasma is created via a supply gas (oxygen, argon or a mixture) under vacuum which is exposed to RF (Radio Frequency) signals at 13.56MHz to provide the ionizing energy necessary for reactions. However, such equipment even at low power and small size tends to be expensive<sup>3</sup>. In our work we made use of microwave power available at 2.45GHz provided from a household microwave oven to produce the same energizing reactions. This method provides a much more viable and cost-effective solution for non-industrial plasma cleaning applications such as in university laboratories for education and research.

In our design the plasma and the sample to be cleaned are contained in a Pyrex chamber which resides inside the standard microwave oven. Vacuum and supply gas connections are terminated at the base plate of the vacuum chamber which exits the bottom of the microwave. The plasma can be controlled via duty-cycle variation of the microwave source operating at 1000W as well as the vacuum level, supply gas composition and flow-rates. Plasma composition and pressure are monitored by two gas flow meters with needle valves and a thermocouple vacuum gauge.

We would like to share our successful design and experience with the engineering and technology faculty and students from other institutions as an inexpensive in-house fabricated alternative to expensive RF powered plasma processing equipment for use in their semiconductor fabrication, chemical and materials engineering laboratories.

## 2. Microwave Plasma Cleaner

## 2.1 Objectives and Requirements

The objective of the project was to design and construct a fully functional microwave plasma cleaner unit. Main design criteria were:

- 1. Low cost
- 2. Chamber large enough to accommodate up to 4-inch wafers and all ceramic integrated circuit packages
- 3. Mobile solution to move from one lab to another and easy to operate
- 4. Using standard and readily available parts and components making it possible to maintain and reproduce if needed
- 5. Up to two gas inlets with adjustable mixing ratio and chamber pressure
- 6. Most importantly, safe operation, i.e., no potential leak of microwave radiation

## 2.2 Components

Figure 1 gives a schematic configuration of the system which is made up of (1) a microwave oven which will accommodate the plasma chamber and energize it, (2) a vacuum pump which will create vacuum of appropriate level (100 to 1000 milliTorr) in the process chamber, (3) a vacuum gauge to monitor chamber / vacuum line pressure, (4) two gas inlets with flow meters and needle valves to controllably mix two gases and to restrict the flows to allow adjustment of pressure, (5) a plasma chamber designed to accommodate sample sizes specified and designed to create uniform plasma for processing samples effectively.

For the microwave oven to create a uniform plasma in the chamber (unlike food being cooked which can be placed on a rotating plate for uniform heating) microwave feed should be directed at the center of the stationary plasma chamber. Most models available in the market feed microwave off-center and create non-uniform plasma in the chamber.



Figure 1 Configuration Schematic of Microwave Plasma Cleaner Unit

The vacuum pump chosen is a 1/2 H.P. rotary vane vacuum pump which can reach vacuum levels of 1 milliTorr. This low value of ultimate pressure assures that the chamber will be evacuated to between 100 and 1000 times smaller partial pressure compared to the process gases such that the purity of the gas composition will not be degraded by unwanted gases due to leaks or out-diffusion from the system's inner walls. A Kurt-Lesker digital vacuum gauge with a thermocouple vacuum sensor was chosen which has a wide reading range of 1 to 1999 milliTorrs. Two 150 mm long standard Rotameter flow meters with multi-turn needle valves provide manual control of vacuum level and gas composition ratio in the chamber.

Figure 2 gives a picture of the process chamber. It is an 8 inch diameter Pyrex bowl inverted and placed on a rubber gasket which is treated with a thin film of vacuum grease. Vacuum and gas feeding ports are all attached to a <sup>1</sup>/<sub>4</sub> inch thick aluminum base-plate from underneath. There are 4 gas feeders (four brass posts seen inside the chamber) to make sure that symmetric and uniform pressure is obtained for the uniformity of plasma. These gas feeders (diffusers) were intentionally chosen to be tall to elevate the supply gas so that it reached the top of the chamber and thus promoted uniformity of the plasma as it is sucked down to the vacuum port at the bottom center.



Figure 2. Microwave Plasma Process Chamber



Figure 3. Microwave Plasma Cleaner Assembled (on a metal utility cart for portability)

Figure 3 gives a photograph of the assembled microwave plasma cleaner system. It is built on a metal cart with wheels for portability and ease of use.

Gas tank line connections are done via <sup>1</sup>/<sub>4</sub> inch quick connects placed on the rear panel. Argon and oxygen are typical gases used in the cleaning process. For wire bond cleaning involving gold bonding pads, dried air is sufficient to achieve satisfactory results. This is achieved with particulate filters built in the lines together with gas dryer columns.

## 3. Operation of the Microwave Plasma Cleaner

After placing the sample in the chamber (preferably raised on a quartz pedestal) the vacuum pump is run with the flow meter needle valves tightly closed. This assures removal of room air and evaporation of VOC or water films left on the surfaces of the sample. The system should be degassed by running it without the sample in the chamber if the system was left idle for a long time. Power level and time settings of the microwave are set. The microwave oven is capable of delivering 1000 watts of power continuously, too much for plasma cleaning of a sample. Therefore, typically used process times and power levels needed are small (10 seconds and 10-20% power, respectively). This is as straightforward as running a microwave oven to reheat food in a kitchen.

Figure 4 gives photograph of the chamber during the cleaning cycle. Plasma generated inside is clearly seen due to the purple glow associated with it. In this case the flow rates were adjusted to give a pressure level of approximately 900 milliTorrs prior to turning on the microwave power.

In this set up the thermocouple vacuum gauge used was not completely shielded and isolated from the plasma, therefore, cannot read the pressure correctly when the plasma is on. In order to be able to monitor the pressure correctly while processing with plasma the thermocouple gauge needs to be shielded well electrically. This may be necessary for some plasma processes like plasma assisted chemical vapor deposition where gas pressure is the primary parameter controlling the reaction and deposition rate. For plasma cleaning applications chamber pressure is not as critical a parameter.



Figure 4. Photo of Microwave Plasma Cleaner's Chamber during its operation (Microwave powered plasma is visible with its characteristic purple glow)

## 4. Conclusions

A microwave powered plasma cleaner is designed using readily available standard components. With proper design of the plasma process chamber it is shown that uniform plasma can be produced and an inexpensive plasma cleaner can be made in-house for use in research or instructional laboratories for sample cleaning.

Currently the microwave plasma system built is being used to plasma treat the gold bonding pads of dual in line ceramic packages and MEMS chips to facilitate organics free surface and improve the quality in wire bonding. However, such a system can easily be adapted to serve as plasma assisted dry etcher, plasma assisted chemical vapor deposition system or a photoresist asher. However, a word of caution is in order for safety in the case of first two because of the hazardous and flammable gases involved.

## Acknowledgements

This project would not have been possible without the grants from Maine Space Grant Consortium (MSGC) and NASA.

# **References:**

- 1. Guvench, M.G., "Design and Fabrication of Impact (Acceleration) Sensors as Class Projects in a MEMS Course," Proc. A.S.E.E, AC 2009-2191, 2009.
- 2. Stephen A. Campbell "The Science and Engineering of Microelectronic Fabrication" Oxford University Press, 2001.
- 3. Harrick Plasma, <u>www.harrickplasma.com</u>