Proposal # 1: Development of a MEMs Based Micro Gas Analysis System

Hopwood and McGruer, Northeastern University

Goals and Objectives

The goal of this project is to develop a novel micro gas analysis system (MGA) consisting of a microplasma source for gas excitation, a microspectrometer to measure the atomic and molecular emission intensity, and an optical system coupling the light source and detector. The MGA will provide a compact, low-cost method for detecting gas impurities such as H_2O, O_2, H_2, CO_2, CH_4, etc. to be monitored during gas delivery to many processes in semiconductor manufacturing. Develop effluent gas sensors for detection of reactor products (foreline, scrubber, exhaust). Optimize microgas analyzer, 200→1 ppb. Evaluate sensitivity to H_2O, fluorocarbons.

Project Description

There is a need for reliable and accurate continuous monitoring of impurities in ultra pure gases used in semiconductor processing. The International Semiconductor Technology Roadmap calls for impurities such as H_2O, O_2, H_2, CO_2, CH_4, etc. to be monitored during gas delivery to many processes. Reliable and accurate continuous emission monitors (CEMs) are presently being developed to provide real-time information on the release of toxins from hazardous waste incinerators and the metal processing industry [1]. Perhaps the most mature technology for the continuous monitoring of airborne contaminants is inductively coupled plasma atomic emission spectroscopy (ICP-AES). This technique samples air from the environment, dissociates and electronically excites the air sample, and detects the photon emission from impurities using an optical spectrometer. ICP-AES has been used in analytical chemistry for quite some time using an argon ICP torch, but recent advances allow for accurate determination of impurities in air with detection limits (DLs) of a few $\mu g\text{-}m^3$, i.e., parts per billion [2,3]. These sensitive DLs are accomplished using background subtraction of a clean-air reference spectrum. Although current CEMs are capable of remarkable DL performance, the cost, size, and power requirements of the entire system preclude use in many applications. Here we describe progress toward creating a low-cost, low-power portable CEM using MEMS fabrication technology.

Laboratory-scale ICP-AES systems typically use an atmospheric-pressure plasma formed within a quartz tube that is several *cm* long and 2-5 *cm* in diameter. A water-cooled, helical coil wound around the tube couples radio-frequency energy (10-60 MHz, 1-2 kW) to the gas sample and forms a discharge. The relatively high pressure of the plasma allows three-body electron-ion recombination to occur within the interior of the discharge. This causes the plasma to constrict away from the walls of the plasma chamber. This constriction is critical because the atmospheric plasma is quite hot (T_{gas}~5000 K) and would damage the chamber walls if it were to contact them.

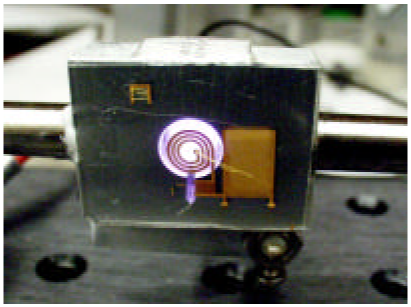
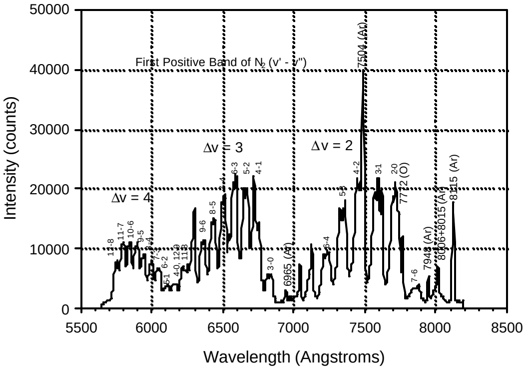


Figure 1. A micromachined inductively coupled plasma generator sustains an argon discharge. The coil shown at the center is 5 mm in diameter.

To miniaturize the ICP-AES concept and fabricate an instrument using MEMS techniques, modifications must be made to the plasma source. First, the plasma source will be operated at a reduced pressure. Lower pressure produces a nonequilibrium plasma in which the electron gas is much hotter than the atoms and molecules (T_e~30,000 K vs. T_{gas}~500 K). Optically-detectable excited states are still created by the energetic electron gas, but the relatively cool neutral and ion gases eliminate thermal management problems associated with the high-pressure, equilibrium plasma torches now in use. Second, the 3-D helical geometry of the ICP coil is difficult to microfabricate. We have replaced the large helical coil with a microfabricated flat, spiral-shaped coil that couples radio frequency energy into the plasma.

Large-scale optical spectrometers typically use diffraction gratings and long optical path lengths to resolve closely spaced emission wavelengths. The typical resolution of the instruments used in CEM is about 0.1 nm. Because these long path lengths are not compatible with MEMS technology, we have developed a small, micromachined Fabry-Perot interferometer. This type of spectrometer is quite suitable for microfabrication since it is essentially planar. Currently, the microspectrometer has a resolution of approximately 20 nm. Through improvements in the fabrication process and the development of feedback control, the resolution will be improved to ~1 nm. This resolution will result in a detection limit for the micro gas analyzer on the order of parts per million. The plasma generator is microfabricated by electroplating a gold spiral-shaped antenna and two interdigitated capacitors on a glass wafer[33]. The individual die are diced from the wafer and bonded to a 6-mm thick aluminum substrate that contains a 6-mm diameter cylindrical vacuum chamber as shown in Figure 1. The optical emission spectrum from an air plasma generated by this micromachined plasma source is shown in Fig. 2. The spectrum was acquired using an EG&G optical multichannel analyzer with a resolution of approximately 1 nm. The spectrum is dominated by the first positive band of molecular nitrogen. The trace amounts of argon that naturally occur in air (~0.9%), however, can clearly be seen in the spectrum as well. It is the goal of this project to detect trace amounts of gaseous impurities in high purity gases using an integrated microspectrometer. The Fabry-Perot microspectrometer selectively transmits a narrow band of wavelengths that are determined by the separation between to microfabricated mirrors. The mirror separation is mechanically scanned using electrostatic actuation between electrodes on the substrate and the cantilevered beams that support the upper mirror.

Figure 2. Optical emission spectrum obtained from an air microplasma showing trace amounts of argon.



The microplasma source has been demonstrated using a 5 mm diameter antenna. To further decrease the size of the final instrument however, scaling the antenna to a diameter of 2 mm is currently underway. In addition, the operating conditions for the plasma source such as power, gas pressure, and chamber size will be optimized to increase the excitation intensity of various contaminants of interest to the semiconductor industry. Simultaneously, the microspectrometer's spectral resolution will be improved by pursuing improved mirror reflectivity, fabrication and assembly techniques, and electronic sensing and control.

1. Gerhard A. Meyer and Michael Seltzer, “Continuous ICP measurement of hazardous metals in stack gas emissions,” American Laboratory, vol. 29, pp. 34L, 1997.
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4. J. Hopwood, O. Minayeva, and Y. Yin, "Fabrication and Characterization of a Micromachined 5 mm Inductively Coupled Plasma Generator," accepted for publication, J. Vac. Sci. Technol. B, vol. 18, Sept/Oct 2000.