Low Power Remote Plasma Cleaning of Vacuum Chambers

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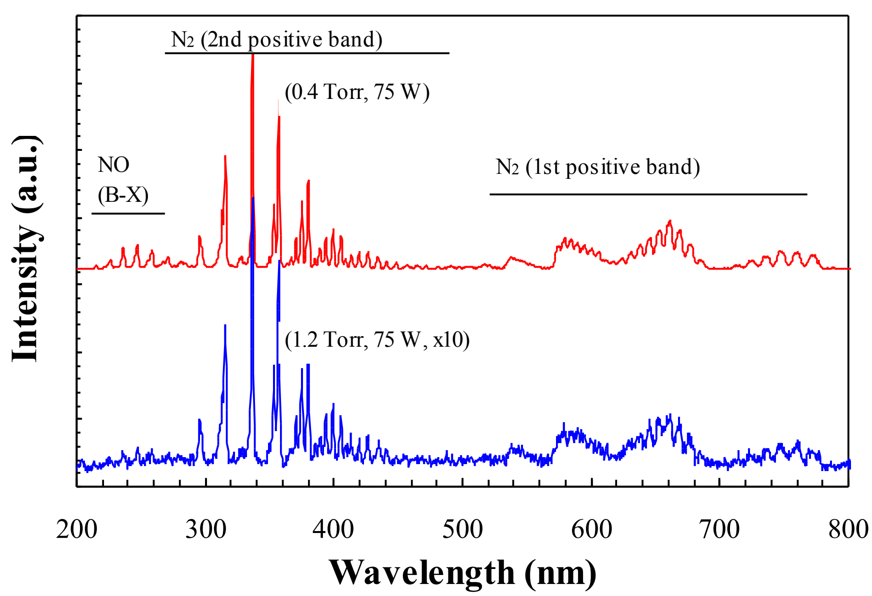
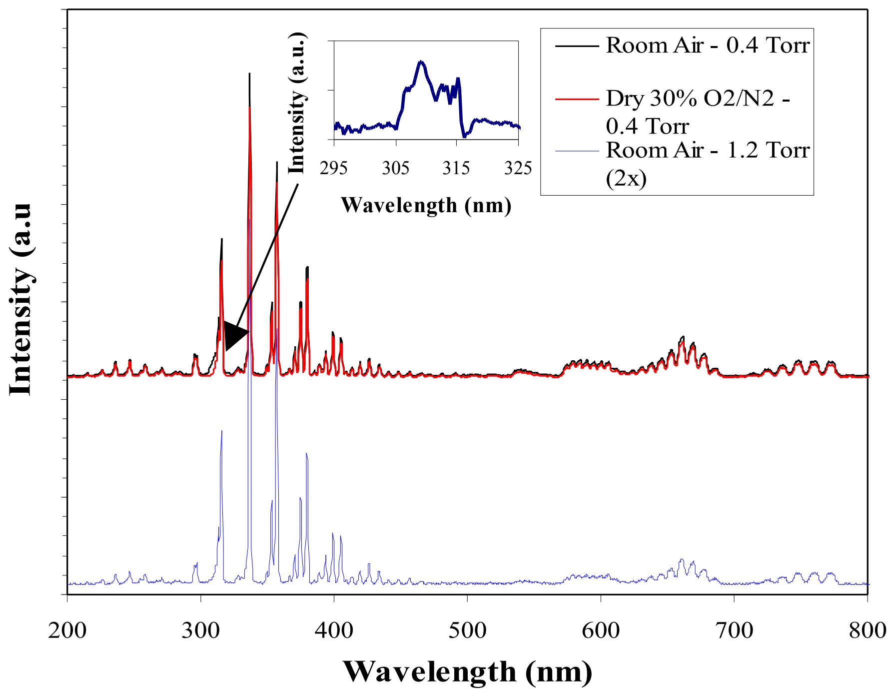
This paper is based on a presentation given at the Technical Conference at the Society of Vacuum Coaters. It describes preliminary data characterizing low power remote plasma cleaning of carbon and hydrocarbon contamination. A complete paper will be available in the Proceedings of said conference. Low power means below 100 W. Remote, or downstream, cleaning means that it is not the plasma itself that does the cleaning but the products of the plasma (O atoms, O_3, and OH radicals) that ash and remove carbon contamination. Two types of low-power remote plasma cleaners were studied, the "emitter type" (XEI Scientific, Evactron Model C) and the "ICP type" (DSS1-100, Dry Plasma Systems). Several experiments were performed: Emission spectra were taken of the plasma produced by both systems. Quartz Crystal Monitors (QCMs) were used on both systems to determine basic information on the cleaning effectiveness under various operating conditions. Finally, Prof. James Boulter at University of Wisconsin, Eau Claire performed experiments using the emitter type with Fourier Transform – Reflection Absorbance Infrared Spectroscopy (FT-RAIRS) and Thermally Programmed Desorption – Mass Spectroscopy (TPD-MS).

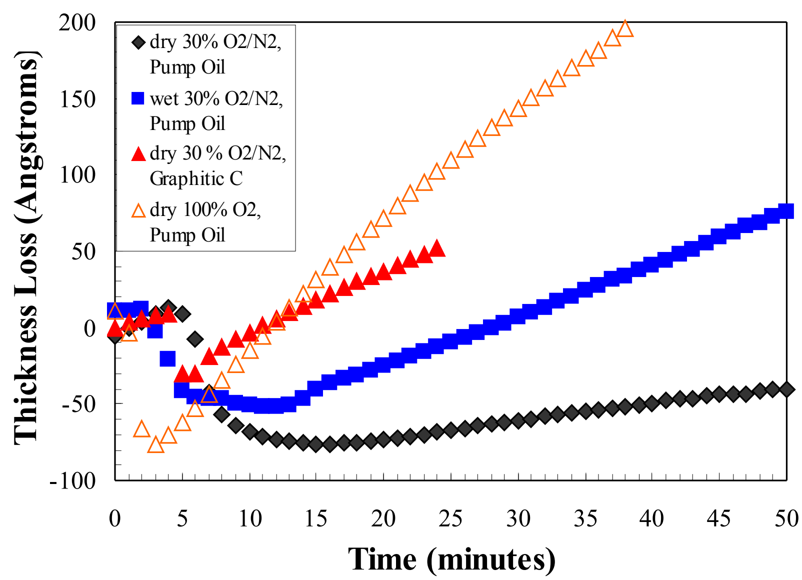
The emission spectra were taken near the plasma sheaf of each cleaner. By coupling a fiber optic through a vacuum feedthrough between the plasma region and the vacuum chamber and routing the fiber optic to a spectrophotometer, emission spectra of the plasma can be obtained. Shown below are the emission spectrum for the ICP type at low pressure (0.4 Torr) and high pressure (1.2 Torr) using room air as the plasma gas. At high pressure for the ICP type the absorption features are attenuated by a factor of 10. At the higher pressure, less energy is used to excite N_2 and NO, more energy is used to create non-radiating radicals such as O atoms through secondary reactions.



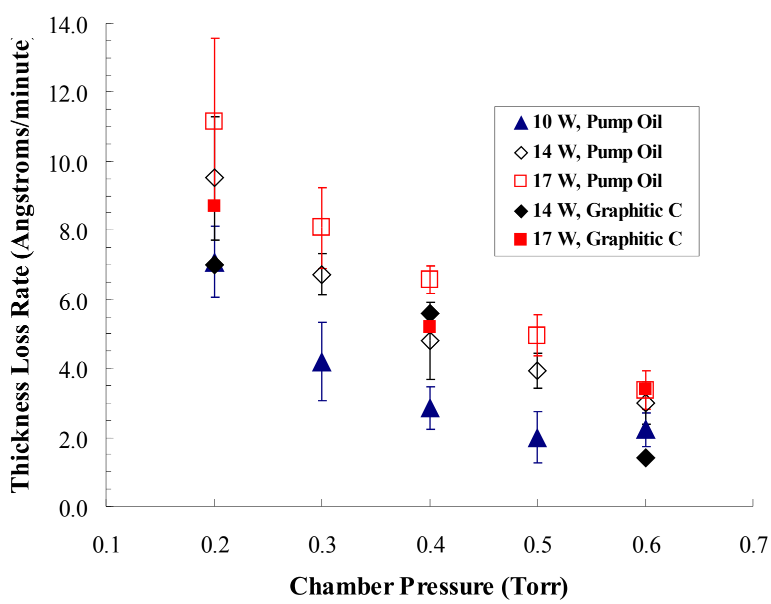
Below are the emission spectra for the emitter type of plasma cleaner at 0.4 Torr and 1.2 Torr. The signal of the 1.2 Torr spectra is multiplied 2x. Although less emission is seen for the emitter type at higher pressure, the amount of signal diminishes only by a factor of 2; and this can be explained by the contraction of the plasma sheath at higher pressure in the region of the fiber optic. Also shown is a spectra taken with a dry 30% O2 in N2 mixture. We can take a difference spectrum and see OH emissions around 310 nm.



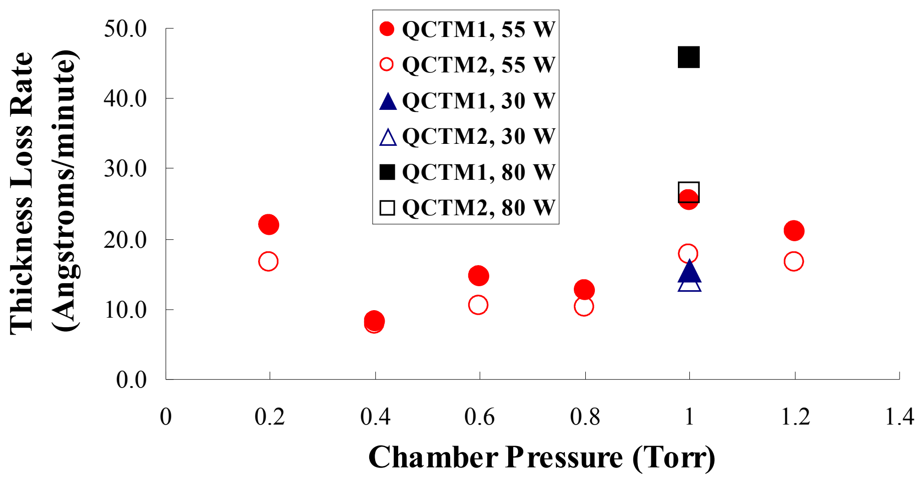
For the second set of experiments, hydrocarbon and carbon contamination can be deposited on the QCMs. For all studies, the QCMs were placed in the middle of a vacuum chamber about 15 cm from the port with the remote plasma cleaning device. A graph of thickness loss versus time for several QCM studies is shown below. Different oxygen containing gas mixtures and types of contamination are used. For all traces freshly deposited layer of pump oil or graphitic carbon was used. There is an induction period immediately after the RF plasma is turned on. During this period, oxygen radicals and other species such as NO (if N_2 is present) are incorporated into contamination. When a sufficient number of oxygen radicals have been added to the contamination, it can form volatile compounds and be removed. Oxygen gas is the most effective at removing the pump oil contamination, followed by a mixture of water in 30% O_2, with the balance N_2. Dry 30% O_2, balance N_2, removed the pump oil at a slow rate compared to the pump oil removal rate of the other two mixtures. However, the same dry mixture removed graphitic carbon at a rate comparable to the wet O_2/N_2 mixture pump oil removal rate.



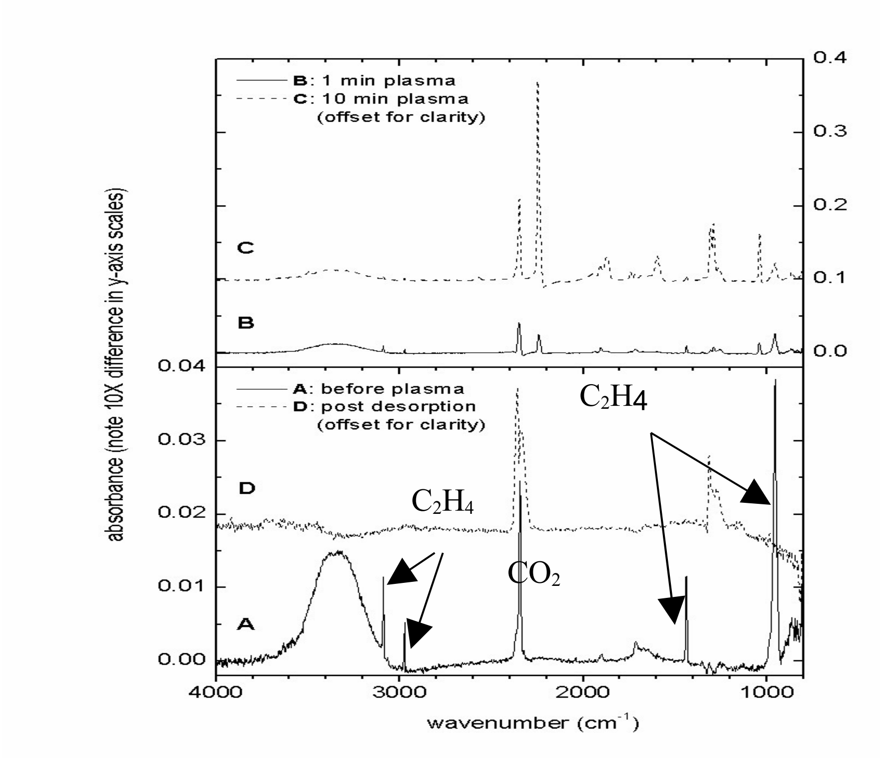
Results for the QCM studies in the form of thickness loss rates are shown below. For the emitter type of plasma cleaner, room air as the oxygen source and hydrocarbon mechanical pump oil as the contamination, there is a strong dependence of the thickness loss rate on chamber pressure. As the pressure increases, the loss rate on the QCM decreases. This decrease in the loss rate is due to an increase in the number of three body collisions in the vacuum chamber. Also, as the pressure increases, the size of the plasma sheaf extending into the chamber decreases. As expected, there is an increase in the cleaning effectiveness as RF power increases. Results for graphitic carbon fall within the range of loss rates seen with hydrocarbon pump oil, indicating that the same cleaning efficiency with room air will occur with hydrocarbons and graphitic carbon.



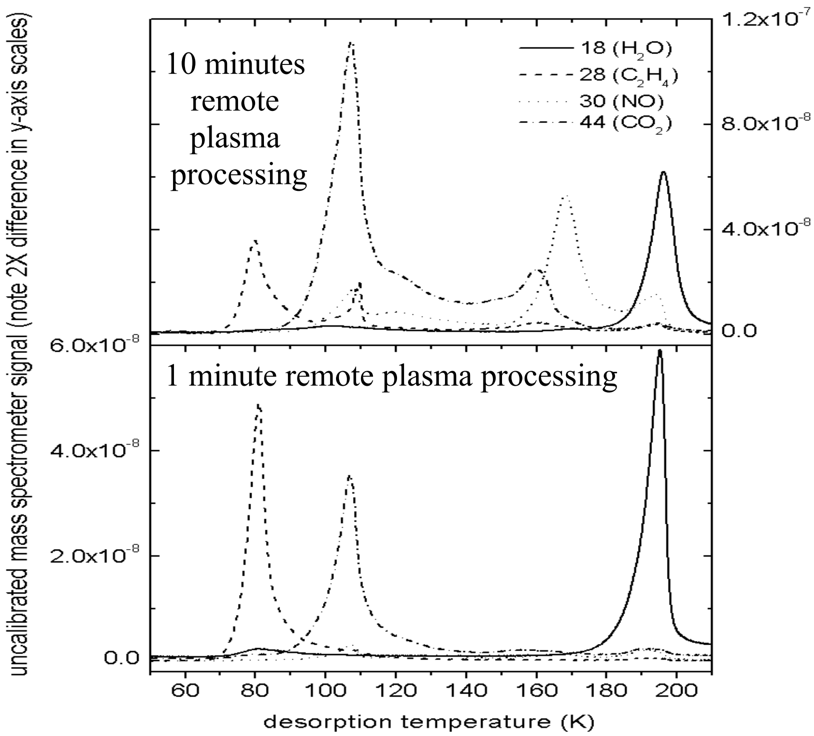
Shown below are thickness loss rates recorded using the ICP type of plasma cleaner, room air and hydrocarbon pump oil as the contaminant. Most of the measurements were done with the RF power set to 55 W. There is an overall greater cleaning effectiveness seen with the ICP type as compared to the emitter type. The pressure dependence of the thickness loss rates seen with the ICP type is different than the dependence seen with the emitter type. Between 0.2 and 0.4 Torr there is a decrease in the loss rate, but above 0.4 to 1.0 Torr the loss rate increases. This increase in loss rate as the pressure increases is believed to be due to the secondary reaction products, formed due to a flow constriction between the plasma region and the rest of the chamber. For 1.0 Torr, as the RF power increases, there is an increase in the thickness loss rate.



The FT-RAIRS and TPD-MS experiments were done with the "emitter" type of plasma cleaner. The sample mirror was cooled to 48 K and a layer of ethylene is grown on the mirror. Typically the mirror is exposed to $2x10^{-8}$ Torr of ethylene for 10 minutes. A 1 mm orifice separates the turbo pumped main chamber at 60 Microtorr from a differentially pumped chamber with the plasma cleaner. The plasma cleaner is run at 0.1 Torr and 20 W. The gas used for the experiment is compressed air that has been treated to remove CO_2 and water. Ethylene absorption lines are at 3089, 2974, 1437 and 955 cm^{-1}. Carbon dioxide absorption lines are around 2345 cm^{-1}. Unidentified absorption lines attributed to intermediate products are seen in the region between 2000 and 1400 cm^{-1}. Note that the lower half of the figure appears ten times the size of the top half, due to y-axis scaling.



Shown below is the TPD-MS of ethylene thin films at 48 K after 1 minute (below) and 10 minutes (above) of plasma processing using the emitter type remote plasma cleaner. Note that the lower half of the figure appears twice the size of the top half, due to y-axis scaling. There is a large increase in the amount of CO_2 on the cold surface. This cannot come from the gas flow since the gas used had had its CO_2 removed. Our interpretation of this data is that the CO_2 is formed by O-atom oxidation of the ethylene and it remains on the cold mirror. The layer of CO_2 on the mirror prevents further loss of ethylene. There is also NO on the mirror, NO is a by product of the air plasma.



In summary, experimental Studies were done on two types of Low-Power Remote Plasma Cleaners. QCM Studies show cleaning effectiveness under different operating conditions (pressure, power, contaminant, gas used). ICP-type Plasma Cleaner are more effective at removing hydrocarbons than the Emitter type. Emission Studies suggest that more non-radiating species are present when ICP-type Plasma Cleaner is run at higher pressure. QCM Studies show two different pressure regimes for cleaning. FT-RAIRS and TPD-MS qualitatively confirm QCM results.