Detection of cluster ions in laboratory plasma analogous to plasma of ionospheric D-region

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An experiment was conducted to generate and detect hydrated, cluster and molecular ions in conditions close to that in the D- region of the ionosphere. A large plasma chamber having a volume of 6.5x103 cm-3 was used to produce nitric oxide plasma using an intense EUV source. After producing the NO+ plasma, water vapor was introduced in to the chamber through a water vapor control unit. Abundance of positive ions inside the chamber was measured with the help of a differentially pumped ion quadrupole mass spectrometer (IQMS) having a mass resolution (M/DM) of 1M and a mass range of 1-150 amu. Most commonly used sweep duration for scanning ion masses from 15 to 135 amu was 120 seconds. A Langmuir probe was also used to measure the electron densities and electron temperature inside the plasma chamber. On most of the occasions the pressures of NO and water vapor were kept equal. However, on some occasions, the pressure of water vapor was kept nearly half that of NO.

A number of ions, some of which are believed to be produced in such reaction but could not be observed earlier, and some which were not predicted earlier, were observed, in addition to the ions which have been observed earlier. The mass number of the most dominant ions, which have been detected for the first time, are in order of their abundance 102, 131, 115, 112, 117 and 88. Mass numbers of newly detected ions with intermediate abundance are: 43, 83, 93, 95, 99, 100, 103 and with low abundance are: 29, 54, 77, 81, 107, 109, 113, 114, 116, 119, 123, 127 and 128. Most of the ions detected in these experiments appear to belong to either of the following categories. (a) hydrated ions of NO+.(H2O)n series, NO2+.(H2O)n series, NO+.(H2O)n .X series, O2.(H2O)n series, (b)proton hydrates of H3O+.(H2O)n series, H3O+. (H2O)n. .X series, H3O+.NO.(H2O)n series, (c) cluster ions and (d) molecular ions. The ions with mass numbers 77 and 113 do not appear to belong to any of the above categories.

It was found that at a given pressure, different ions take different times to come to their peak abundance and this time appears to be pressure dependent. For NO and water vapor pressure of 5x10-2 Torr each, ions with mass numbers 66, 73 and 84 achieve their peak abundance in about a minute, mass numbers 48, 55, 83, 109 and 131 in 5 to10 minutes, mass numbers 91 and 102 in 10 to 20 minutes and mass numbers 43, 88 and 117 take more than 20 minutes.

It was found that there are thresholds of minimum and maximum operating chamber pressure, which is the total of NO and water vapor pressures. For the EUV source used in this experiment, the minimum pressure of NO at which the ion formation just starts is 10-4 Torr. At such low pressures the ions peaks were found to be very small and at times not periodic. As the NO pressure (and also the water vapor pressure) was increased, the ion peak heights increased and the peaks became more periodic. The maximum production of hydrated and cluster ions occurred at NO pressures of 1x10-1 Torr and water vapor pressure of 5x10-2 Torr. Very strong formation of ions was also seen at NO and water vapor pressures of 7x10-2 Torr, each. As the pressure inside the chamber was increased beyond 1.5x10-1 Torr (NO + water vapor), the ion formation stopped suddenly. When the chamber pressure is brought down to 1.5x10-1 Torr, the ion formation started again.