

# TECHNICAL NOTE

## The Optimization of Electron Energy for RGAs

Residual Gas Analyzers (RGAs) have been used in vacuum research applications for 25 years. Their role has changed in the last 10 years, as the RGA evolved from a research instrument to a production tool. As a production tool, the RGA can increase productivity, improve product yield, increase throughput and reduce costs, all of which ultimately increase profits.

The RGA is commonly used for identifying the residual gases in a vacuum chamber. In the RGA, residual gases are ionized, separated by mass-to-charge, and plotted based on their ion intensities as a mass spectrum. When gas mixtures are analyzed, it is sometimes difficult to identify which gas species are within the process. For example, the peak at mass 28 could be either nitrogen or carbon monoxide. With the help of a mass spectra library, the RGA can determine which gases contribute to specific mass peaks.

The exact fragmentation pattern observed will depend on the energy of the bombarding electrons. Figure 1 shows the number of argon ions, of different charge states, produced per incident electron per Torr of gas pressure as a function of electron energy. This graph shows the number of argon ions,  $N$ , formed per electron per Torr at 0°C versus electron energy.

The appearance potential is the minimum electron energy required to produce a specific ion from a specified substance. The appearance potential for  $\text{Ar}^+$  is 15.7 eV. The number of argon ions produced rises steeply with energy until a maximum is reached at about 55 eV. As the electron energy rises above this level, the rate of  $\text{Ar}^+$  production slowly decreases.

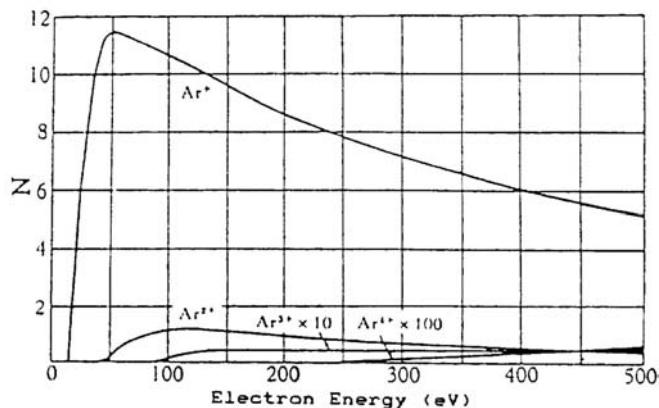


Figure 1. Number of argon ions, of different charge states, produced per incident electron per Torr of gas pressure as a function of electron energy.

Typically, in mass spectrometry, electron impact ionization is carried out at the electron energy of 70 eV. This value is chosen for two reasons. First, it is above the minimum energy required to produce at least some positive ions from any sufficiently volatile chemical species. Second, it is near the energy at which the rate of ion production is at its maximum for most of the common gases. Thus, operating at 70 eV provides a universal detector with good sensitivity for gases typically encountered.

Sometimes there is a problem with mass spectral overlap (ions with differing chemical composition from chemically distinct source molecules, but with the same mass). For example, there is a problem with detecting small amounts of water vapor in argon, as is often desired when monitoring a Physical Vapor Deposition (PVD) process. Normally, water vapor is monitored at 18 AMU ( $\text{H}_2\text{O}^+$ ). Since the quadrupole mass filter shows a mass-to-charge ratio, not mass value,

there is overlap from the doubly charged argon-36 isotope, which also shows up at a mass-to-charge ratio of 18. Approximately 3,400 parts per million of all argon atoms are the mass 36 isotope. Also, at 70 eV, the doubly charged argon ion,  $\text{Ar}^{+2}$ , has about 15% of the intensity of the singly charged  $\text{Ar}^+$  ion. Thus, there will be approximately 510 ppm (3,400 ppm times 15%) of  $^{36}\text{Ar}^{+2}$  at 18 AMU, making it impossible to detect several ppm of water vapor at the same mass. Another ion from water vapor, for example, the  $\text{OH}^+$  at 17 AMU, could be used instead. Unfortunately,  $\text{OH}^+$  at 17 AMU from water vapor has an intensity of only 25% of that of the parent ion,  $\text{H}_2\text{O}^+$ . Thus, to detect several ppm of water vapor require the detection of less than one ppm of ion current at 17 AMU. This is difficult because there will be some tailing of the 510 pm  $^{36}\text{Ar}^{+2}$  peak at 18 AMU over onto 17 AMU.

The best solution to this argon/water vapor problem is to make use of the appearance potential. A list of appearance potentials for various ions from common gases is given in Figure #2.

From Figure #2, it can be seen that the appearance potential for  $\text{Ar}^{+2}$  is 43.5 eV, while that for  $\text{H}_2\text{O}^+$  is only 12.6 eV. Therefore, by choosing an electron energy below 43.5 eV but above 12.6 eV, it is possible to produce the water vapor ion without producing doubly charged argon ions, thus permitting the detection of water vapor at 18 AMU.

Ion	Gas	Mass-to-Charge	Appearance Potential (eV)
$\text{Ar}^+$	argon	40	15.7
$\text{Ar}^{+2}$	argon	20	43.5
$\text{Ar}^{+3}$	argon	13.3	>70
$\text{N}_2^+$	nitrogen	28	15.6
$\text{N}^+$	nitrogen	14	24.3
$\text{O}_2^+$	oxygen	32	12
$\text{O}^+$	oxygen	16	17.3
$\text{CO}_2^+$	carbon dioxide	44	13.8
$\text{CO}^+$	carbon dioxide	28	19.4
$\text{O}^+$	carbon dioxide	16	19.1
$\text{C}^+$	carbon dioxide	12	22.7
$\text{CO}^+$	carbon monoxide	28	14.1
$\text{O}^+$	carbon monoxide	16	23.4
$\text{C}^+$	carbon monoxide	12	20.9
$\text{H}_2\text{O}^+$	water vapor	18	12.6
$\text{OH}^+$	water vapor	17	18.1
$\text{H}_2^+$	hydrogen	2	15.5
$\text{HF}^+$	hydrogen fluoride	20	16.1

Figure 2. List of Appearance Potentials

## INSTRUMENTATION

The Transpector XPR3 sensor and electronics are capable of operation at electron energies below 70 eV, with reduced electron emission (200  $\mu\text{A}$ , maximum). For purposes of monitoring PVD processes, it is recommended that the Transpector XPR3 be operated at 40 eV with an electron emission current of 200  $\mu\text{A}$  in order to reduce power to the filament. The Transpector XPR3 can be easily switched between 70 eV, 400  $\mu\text{A}$  for background monitoring, and 40 eV, 200  $\mu\text{A}$  for process monitoring using INFICON software, either TWare 32 or FabGuard.

## APPLICATIONS

It is possible to change the electron energy in the INFICON Transpector CIS2 or Transpector CPM to any electron energy between 10 and 100 eV. Especially below 20 eV, it is necessary to limit the electron emission current so as not to overpower the filament, which would result in shortened filament life. Setting the electron energy is accomplished using INFICON software by selecting the TUNE PARAMETERS menu while operating in the TUNE mode.

Low electron energy also has uses in metal-organic CVD (MOCVD). Figure 3 shows the mass spectrum for dimethylethylamine alane (DMEAA) taken on aluminum MOCVD cluster tool using a 200 AMU Transpector CIS system with the electron energy set to 70 eV. The ion at 102 AMU represents the parent ion minus a hydrogen atom. The peak at 103 AMU, because of its intensity relative to that at 102 AMU, represents not the precursor parent ion of DMEAA, but rather the carbon-13 isotope peak for the parent ion minus hydrogen. The pattern of peaks below 76 AMU is almost identical to that for pure dimethylethylamine (DMEA). Figure 4 is a spectrum of DMEAA taken under the same conditions as the spectrum in Figure 3, except that the electron energy was only 12 eV with 200  $\mu\text{A}$  of emission current. Allowing for the ten-fold decrease in emission current, note the relative decrease in the intensities of lower mass fragment ions. The differences between the two spectra are more readily apparent when the ratios of mass selected ion currents to the total ion current are plotted as a function of electron energy, as shown in Figure 5. Note that the intensity ratios at masses 102 and 73 are maximized at 12 eV. This translates to significantly improved detection efficiency for DMEAA at the lower electron energy. The fact that the intensity ratio for the peak at 73 AMU—which could be a fragment ion from DMEAA or the parent ion of already dissociated dimethylethylamine—also maximizes at low electron energy, suggests that the former explanation is more likely.

## DMEAA in $H_2$ at 35°C

Electron Ionization Energy: 70 eV, Multiplier Voltage: 1000 V, Reactor Pressure 0.500 Torr,  $H_2$  Flow: 200 sccm, DMEAA Flow: 10 sccm

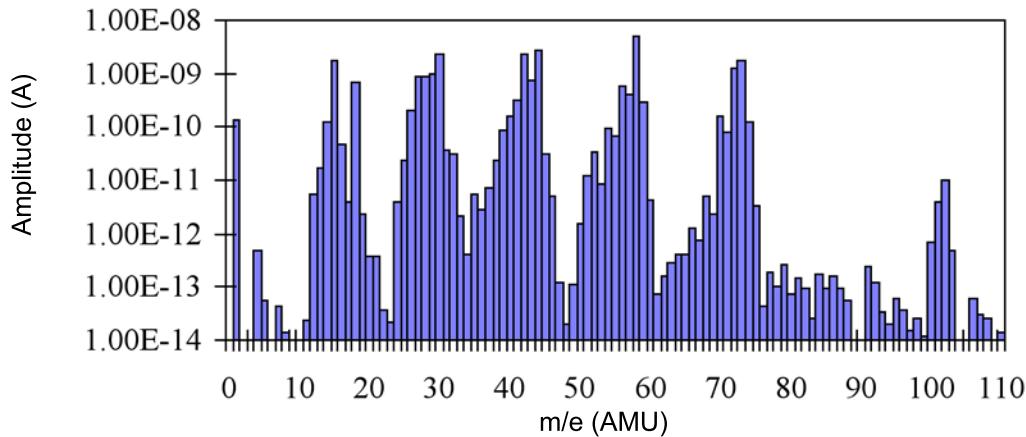


Figure 3. Mass Spectrum of DMEAA aluminum MOCVD precursor at 70 eV electron energy

## DMEAA in $H_2$ at 35°C

Electron Ionization Energy: 12 eV, Multiplier Voltage: 1500 V, Reactor Pressure 0.500 Torr,  $H_2$  Flow: 200 sccm, DMEAA Flow: 10 sccm

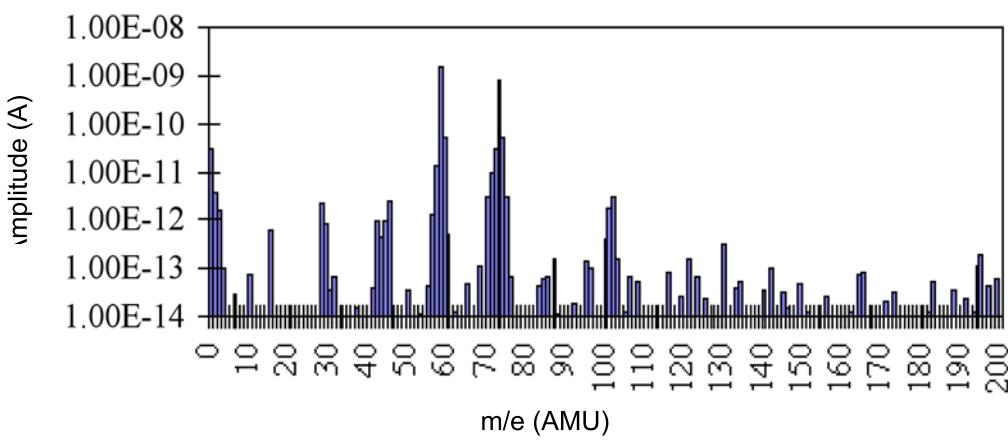


Figure 4. Mass spectrum of DMEAA A1 MOCVD precursor at 12 eV electron energy

## Effect of Electron Energy on Electron Impact Spectrum of DMEAA

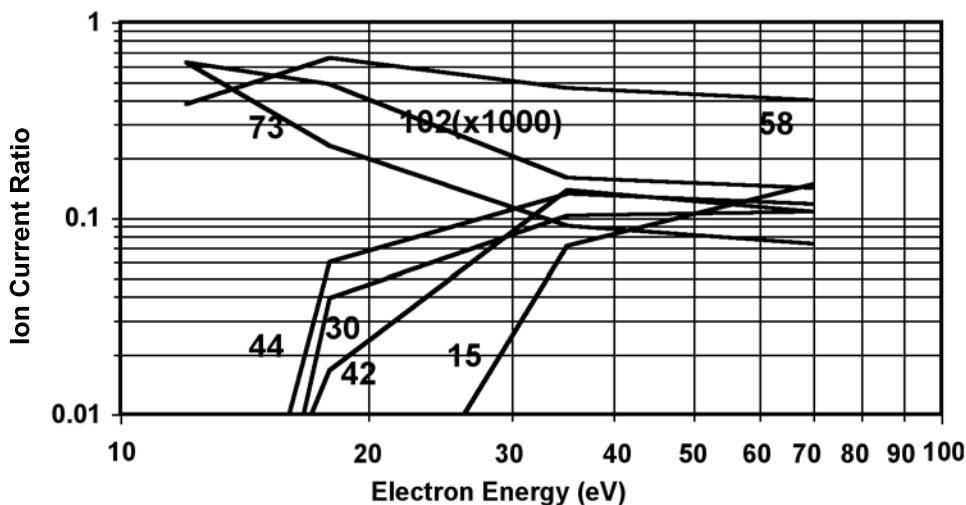


Figure 5. Ratio of mass selected to total ion current at selected masses from DMEAA at various electron energies

### CONCLUSION

Electron impact ionization at 70 eV, while appropriate to residual gas analysis because of universal volatile substance detection at generally high sensitivity, is not always the best approach to process monitoring because of problems with spectral overlap and complicated spectra from complex molecules. Operation of the Transpector XPR3, Transpector CIS2, or Transpector CPM at an electron energy of 40 eV makes it a

simple task to detect low ppm concentrations of water vapor in a PVD argon atmosphere. Likewise, the detection of small concentrations of HF in the presence of large quantities of Ar in CVD tools is also possible at electron energies below 43.5 eV. Complicated MOCVD precursors, such as DMEAA, will produce simpler spectra and improved precursor detection limits at very low electron energies.

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