Enhanced Detection of Trace Gases with V-lens™ Ion Optics Technology

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THE CHALLENGE

When the elimination of trace levels of contamination in vacuum systems is of critical importance, any improvement to the limits of detection (minimum detectable concentration) of the measuring instrument has obvious value. One approach for effecting such an improvement is to reduce the baseline noise of the instrument.

The most common instrument used for detecting trace contamination in vacuum systems is the Quadrupole Mass Spectrometer (QMS, Figure 1). In a conventional QMS, a line of sight exists from the ion source through the mass filter. Much of the baseline noise in the QMS is due to species that have enough energy to maintain a near-linear trajectory through the quadrupole without being filtered. While many QMS systems employ an off-axis detector to minimize baseline noise due to these high energy ions, even when this source is eliminated, significant residual noise remains. This residual noise is due to the presence of metastable neutrals in the ion beam.

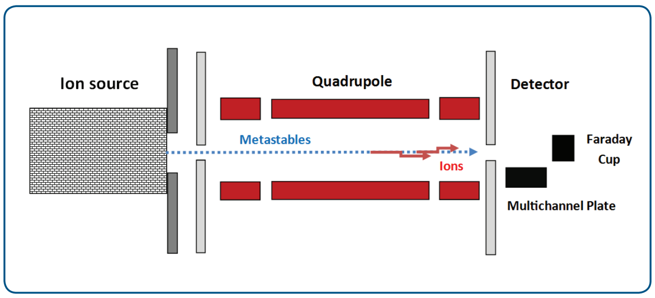

Figure 1 - Schematic of a single quadrupole residual gas analyzer with standard ion optics (without a deflector lens). Metastable neutrals can access the downstream optics and decay into ions, which are detected and cause 'baseline lift'.

METASTABLE NEUTRALS AND ION CURRENT

Metastable neutrals are generated in the ion source of the QMS by the collision of energetic electrons with incoming, neutral gas molecules. Purposeful electron-neutral collisions are employed to generate the positive ions that can be analyzed by the quadrupole section and quantified at the detector (Figure 2a), however, not all electron-neutral collisions produce positive ions. Some portion of the electron-molecule collisions transfer an amount of energy to the gas molecules that is insufficient for ionization; in these cases, the transferred energy promotes the molecule to an electronically excited state (Figure 2b).

Molecules or atoms in electronically excited states are termed metastable since the excited state has only a short lifetime before the molecule returns to its electronic ground state, either through conversion to positive ions by electron loss (initiated by further collisional processes) or through other energy-loss mechanisms such as energetic photon emission. Since metastable neutrals are already in a high energy state, very low energy interactions can add sufficient energy to produce positive ions.

In a standard QMS, metastable neutrals pass freely into the quadrupole mass analyzer where, since they are not charged, they are unaffected by the RF field. If at some point after entering the mass filter they decay into positive ions, they will be subject to fewer RF cycles and therefore will not be filtered as efficiently as an ion with a similar mass-to-charge ratio that entered the mass analyzer normally. Unfiltered ions created in this manner can be in the low ppm range and they contribute to baseline shift and noise. The inability of the mass analyzer to reject these ions is most pronounced in the low mass range of the instrument where the electrostatic fields are weaker; this results in a more elevated baseline at low mass.

The propensity to produce metastable neutrals varies with the nature of the gases present in the ion source. Argon is of particular concern since it tends to produce relatively large numbers of metastable neutrals. In processes where Argon constitutes the bulk of the gas under analysis (i.e. degas chambers), elevation in the low mass baseline is very clear.

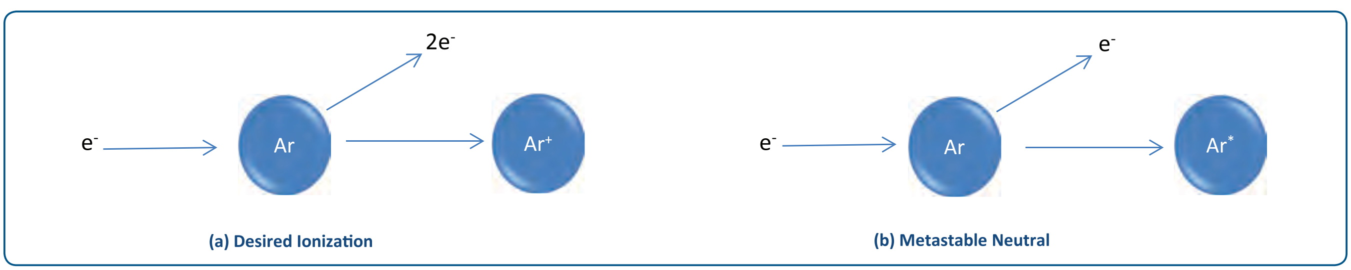

Figure 2 - Electron impact collisions producing: (a) positive ions and (b) metastable neutrals

THE SOLUTION

V-lens™ Technology

V-lens™ technology is a patented, ion optic system capable of double-focusing ions and blocking of neutrals. This ion optic system steers and focuses the ion beam prior to its entrance into the quadrupole mass filter; thus optimizing the transmission of ions, whilst the deflector lens eliminates the line of sight between the ion source and the quadrupole. Figure 4 shows the trajectories for different species as they pass through the V-lens device. The negative potentials on the lens elements focus and steer the ions of interest (shown in red) through an off-set circular aperture in lens 2 and on into the quadrupole. The negative potential of lens 1 repels electrons and negative ions (shown in green), preventing them from entering the mass analyzer. Metastable and other neutrals unaffected by the potentials on the plate (shown in blue) follow a line of sight trajectory, impinging on the surface of lens 2 away from the off-set aperture. Thus lens 2 functions as a blocker (or baffle), preventing the entry of unwanted neutral species, including metastable neutrals, into the mass analyzer.

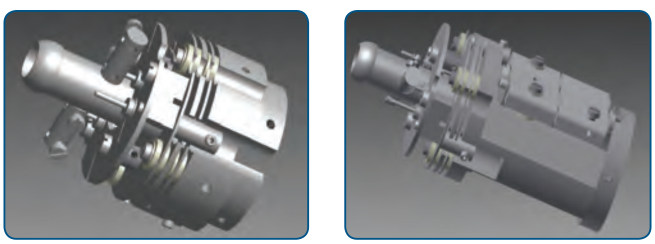

Figure 3 - A standard QMS ion source (left) compared with the V-lens ion source (right).

Improved Detection Limits and Reduced Noise

The focusing of the ion beam that occurs within the V-lens unit improves the overall transmission of ions to the quadrupole. This enhances the sensitivity, by up to a factor of 2 and significantly improves the limits of detection of the QMS. Removing the line of sight that allows metastable neutrals to enter the mass filter eliminates the associated baseline currents and noise, producing a further improvement in detection limits across the entire mass range of the analyzer.

The deflector lens reduces the elevated baseline at low mass by improving the rejection of both long-lived and short-lived metastable neutrals. Metastables with relatively long lifetimes, like all neutrals, are directly blocked from entering the mass filter as shown in Figure 4. Very short-lived metastables that decay to ions within the V-lens unit do not have the targeted energy since they are not produced in the ion source and therefore their trajectories differ from those selected by the fields in the V-lens and they are blocked as well.

Figure 5 shows a typical, theoretical baseline for Argon, that portrays the large elevation of baseline at the lower m/z values. As previously noted, this increase in the baseline is due to interference caused by metastable decay in the downstream optics of a QMS. Figure 5 is a theoretical representation of how the gas and m/z dependent baseline characteristic is eliminated with the use of the deflector in the V-lens ion optics.

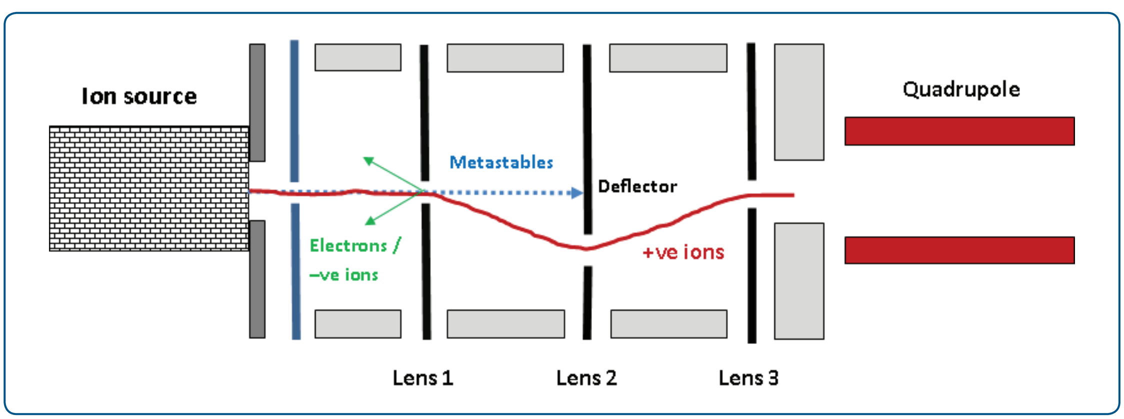

Figure 4 - Plots showing the trajectories of negative ions (green), positive ions (red), neutral (blue) and negative ions in the V-lens ion optics.

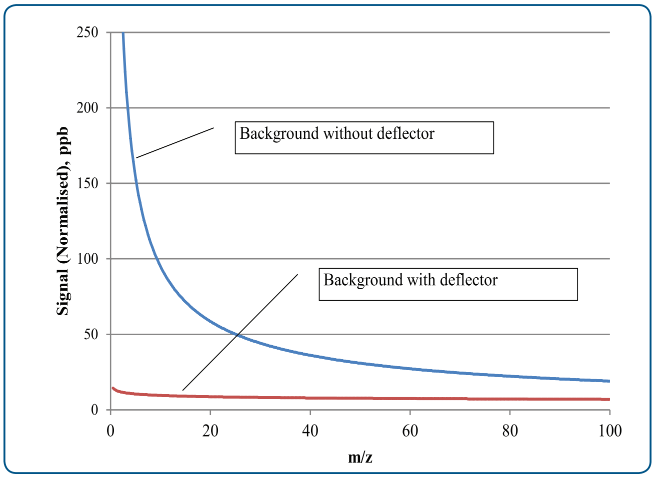

Figure 5 - The effect on baseline for analysis of Argon with V-lens technology.

Figure 6 shows real data from the sampling of Argon from atmospheric pressure with and without the V-lens ion optics in a Cirrus™ system (MKS Instruments). In the upper pane the baseline noise is typically at 25ppb at high masses (relative to the zero, in black), however it rises significantly at lower masses due to the presence of metastable neutrals. In the lower pane one can see how the baseline is consistently low across the entire mass range. This not only makes the detection of underlying trace components at lower levels possible, but also provides a consistent lower limit of detection (LLOD) of 15ppb or better (minimum detectable concentration 3 sigma baseline noise).

ENHANCED DEGAS MONITORING - WITH V-lens™ TECHNOLOGY

The 300mm Resist-Torr® RGA system was developed by MKS Instruments to monitor photoresist contamination in the degas chambers of 300mm PVD (Physical Vapor Deposition) wafer processing tools. The degas chambers on these tools operate by heating the wafer in an argon atmosphere to drive off contamination. Since Argon is particularly apt to form metastable neutrals, the RGA systems on these chambers exhibit elevated baseline currents and noise.

V-lens technology was fitted to an MKS 300mm Resist-Torr RGA and the modified system was deployed to monitor the degas chamber of a 300mm PVD tool. Our tests showed that the addition of the V-lens ion source significantly improved the detection of contaminants and enabled tighter control over the potential for contaminated wafers entering the PVD tool. Figure 7 clearly shows the absolute reduction and greater consistency in the background noise levels. This noise reduction led to an improvement in the limit of detection from 100 ppb to 10 ppb and helped to prevent zero offsets, simplifying data visualization and comparisons.

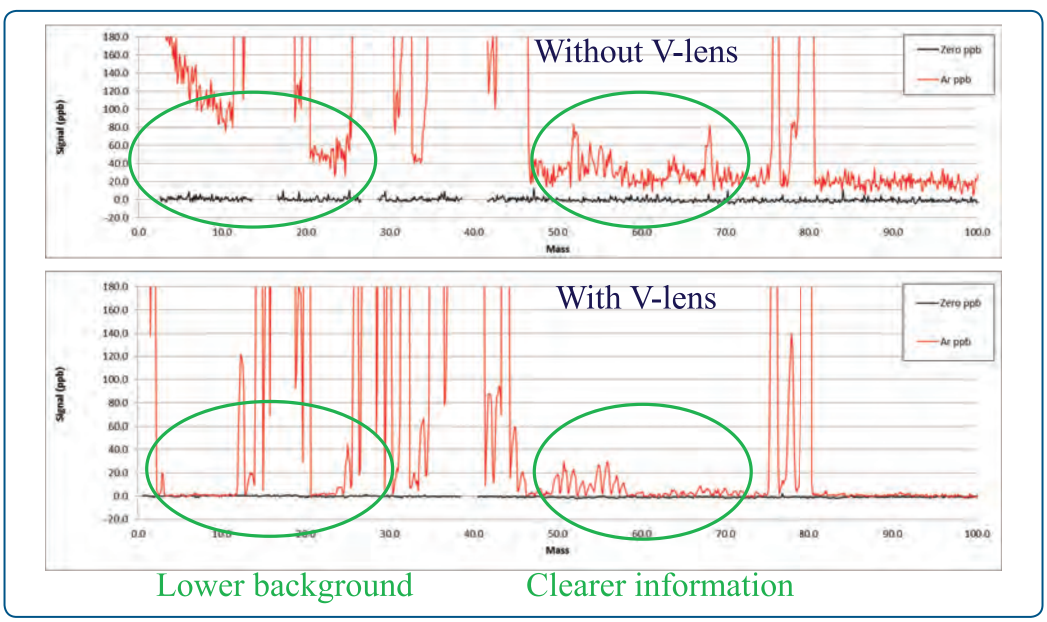

Figure 6 - Data acquired with a Cirrus system from purified Argon at atmospheric pressure, with and without V-lens technology.

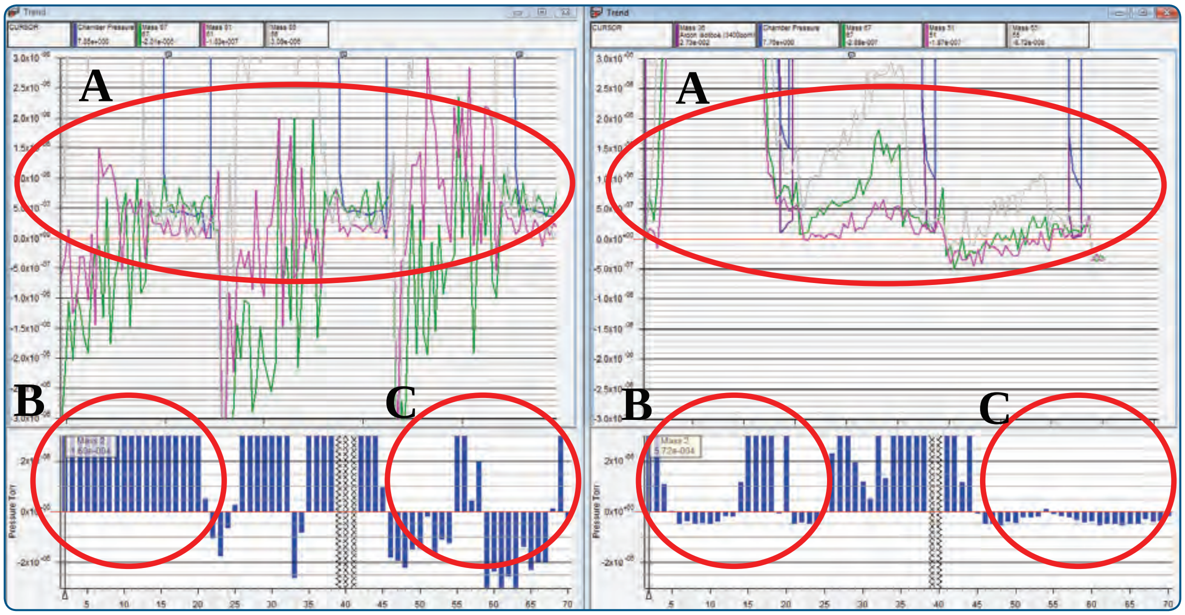

Figure 7 - Data acquired from a degas chamber using a 300mm Resist-Torr system, with and without V-lens technology. The trends clearly show the reduction in noise for small signals with V-lens technology (A), while the bar charts show that baseline shifts at low and high masses are also much reduced (B and C). The improvement in limits of detection is 10-fold, going from 100 ppb to 10 ppb.

CONCLUSION

- V-lens technology significantly reduces background noise and enhances sensitivity in QMS-based residual gas analyzers.
- The addition of V-lens technology increases sensitivity and consistently and reliably produces lower limits of detection for QMS sensors in the low ppb range without compromising any other aspect of the instrument's performance.
- The V-lens technology achieves these results even with gases that inherently produce large amounts of metastable species that would otherwise increase the baseline noise in a conventional QMS system not using V-lens technology.
- This novel approach to controlling the ion species entering a QMS should yield improvements in any application where achieving the lowest possible levels of contamination detection is important.

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