Application of an electrostatic autoresonance ion trap mass spectrometer

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A new mass spectrometer (ART-MS) has been developed which is based on autoresonant ion excitation from an electrostatic ion trap [1]. While most mass spectrometer types (e.g. quadrupoles) analyze ions of only one charge to mass ratio at any instant, a new type of mass spectrometer accumulates and analyzes all ions continuously. Key benefits of this mass spectrometer include: an unlimited mass range, higher sensitivity and faster scan rates than used in quadrupole or magnetic sensor mass spectrometers, low power consumption, and a compact size.

The mass spectrometer is well suited for applications which require a simple and sensitive instrument capable of simultaneous monitoring several very low, and often fast changing partial pressures of different gases. Such applications include temperature Programmed Desorption spectroscopy (TPD), the analysis of residual gases in a vacuum chamber, the identification of chemical contaminants in air, the detection of hazardous materials and explosives.

A schematic diagram of the ART-MS is shown in Figure 1. Negative anharmonicity is a common feature of short electrostatic beam traps with length to diameter (Z/r) ratios of less than 2. Ion traps with negative anharmonicity exhibit lower oscillation frequencies with increasing ion energy. Many electrostatic ion trap-based MSs do not perform well if there is a strong ion-energy dependence of the ion oscillation frequency. Nevertheless, negative anharmonicity is beneficial, even necessary, to achieve autoresonant ion extraction in our high speed mass spectrometers. Autoresonance is approached with a frequency-varying but small rf potential applied to key trap electrodes. The rf is scanned from high to low frequency and, when it almost matches the instantaneous oscillation frequencies of an ion, ions can become phase locked with the rf driving signal. This phenomenon of phase locking of particle oscillation frequencies to a driving frequency, within an anharmonic potential well, is known as autoresonance and can occur provided the rf amplitude exceeds a critical threshold value. As the applied rf frequency is continually ramped down, an autoresonant ion will oscillate with ever-increasing energies and amplitudes in order to keep in synchronization with the applied frequency. Eventually, as the driving frequency reduces to a critical pumping frequency the ion either hits a side electrode, or leaves the trap through a semitransparent mesh electrode for ion detection. The continual and simultaneous autoresonant pumping of ions of many masses makes it possible to collect a full 0-300 amu mass spectrum in less than 100ms. A fast acquisition of a full mass spectrum can eliminate interpretation ambiguities in TPD spectra which often occur when complex cracking patterns are present and only a limited number of masses are measured with a conventional MS.

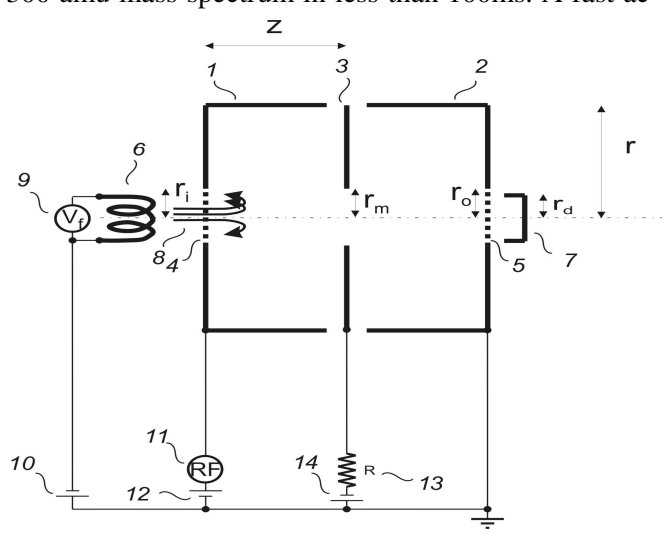

Figure 1. ART-MS schematic. Electrons 8 are emitted by the filament 6 and enter an electrostatic ion trap 1, 2, 3 and ionize gas within the trap. Trapped ions are autoresonantly excited by a small rf voltage 11 and mass selectively ejected from the trap through a mesh 5 into an ion detector 7.

References

[1] A. V. Ermakov and B. J. Hinch, Rev. Sci. Instrum. **81**, 013107 (2010)

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