



# Performance improvements for a miniature quadrupole with a micromachined mass filter

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## Abstract

Conventional quadrupole mass filters are usually constructed from metallic rods of length 50–225 mm and diameters 5–15 mm. In this study the conventional arrangement has been replaced with a micromachined mass filter made from silicon with Au metallised specially drawn glass fibres of length 30 mm and diameter 0.5 mm. This assembly was mounted on a vacuum flange with a VG ANAVAC ion source and a Faraday plate collector. Conventional electronics were adapted to run at 6 MHz and mass spectra in the range 0–50 amu were obtained. The results indicate a linear mass scale with 5–10% valley separation between O<sub>2</sub>/N<sub>2</sub> peaks and a best resolution at 10% peak height of 2.7 amu at mass 40. It is believed that the recent improvements in performance are due to optimisation of the electronics coupled with refinements in the micromachining technique employed. © 1999 Elsevier Science Ltd. All rights reserved.

## 1. Introduction

Quadrupole mass spectrometers (QMS) have found a wide range of applications in the medical field, chemical process industries and more recently in process monitoring in semiconductor fabrication plants where ultraclean processes for ULSI are a priority. QMS based on cylindrical rods for the mass filter are now highly developed and successful [1,2]. Only in recent years have economic methods of precision lens assembly been devised [3], however, the mass filters are still bulky and require large drive voltages at RF frequencies. If the cost, the size and voltages can be reduced then the range of applications for these types of QMS would increase: this is the motivation behind this work. The conventional arrangement uses circular metallic rods as the mass filter (typical dimensions: rod length: 50–225 mm; diameter: 5–15 mm) excited electrically at voltages up to 1 kV depending upon the

application. Here, a micromachined quadrupole mass filter is made from silicon with Au metallised borosilicate glass drawn to diameter as the electrodes [4]. The correct electrode spacing and alignment are achieved through the use of V-shaped grooves etched into the silicon. A description of the fabrication of such a device using 0.5 mm diameter electrode rods is given in [5]. Initial results showing the effect of ion energy and emission current on MicroQuad operation were reported in [6]. In this paper, we present results showing improved performance of the MicroQuad.

## 2. Experimental

A 30 mm micromachined quadrupole mass filter was mounted onto a commercial VG ANAVAC ion source which was in turn attached to a vacuum flange. The micromachining technique for the production of this filter was improved from that reported previously [5,6] by further recessing the earthed silicon ground plane with respect to the rods. This was found by numerical

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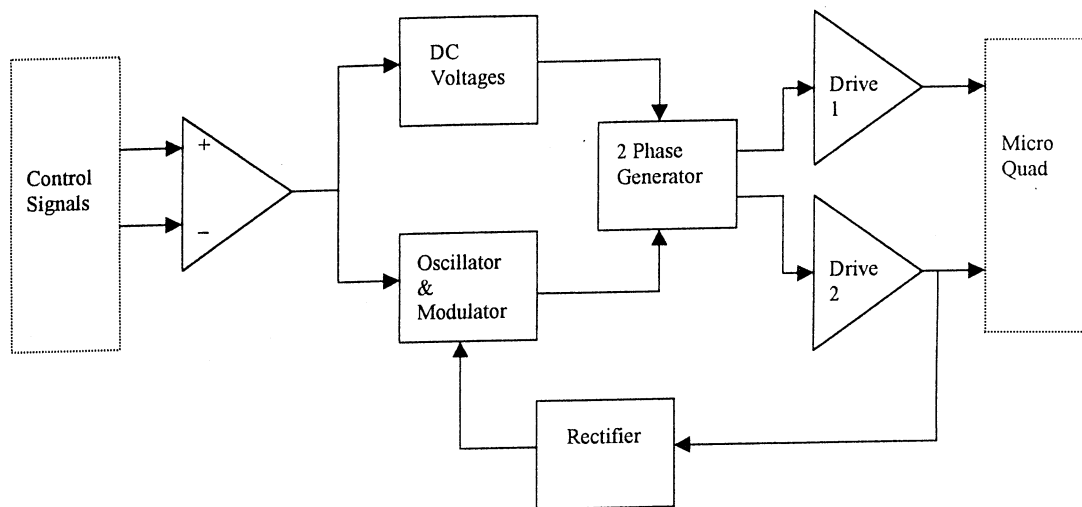


Fig. 1. Block diagram of the improved electronics drive unit for the MicroQuad.

simulation to give a closer approximation to the required hyperbolic field profile for the ideal QMS operation [7].

The electronic drive circuit to the MicroQuad rods is shown in block diagram form in Fig. 1. The incoming control signals indicate to the RF unit what mode to operate in (normal, total ion or beam off) and provide a “program” voltage to control the mass position to be analysed. After buffering and scaling, the program voltage is passed to a circuit, which generates precise DC voltages and also to the Oscillator and Modulator. The Oscillator utilises a crystal to generate a stable sine wave at 6 MHz. The Modulator varies the amplitude of this “RF” in a precise relationship to the program. Feedback to the modulator is used via a precision active rectifier to ensure tight control over the absolute voltages being applied to the MicroQuad. The two-phase generator sums the DC and RF voltages and provides a two-phase output. By introducing the micromachined quadrupole mass filter the ratio of (RF frequency/electrode radius)<sup>2</sup> is reduced by a factor of at least 10. Hence the maximum RF voltage required in any given application is reduced by the same factor (i.e. of the order of say, 500 V to less than 50 V for an instrument with a mass range up to 100 amu). This allows smaller, simpler and less expensive RF supplies to be used. The high speed and current capability of the output stages eliminates the need for a tuned circuit which normally requires inductors and tuning capacitors to resonate the load. This opens up the possibility of a very compact RF unit being implemented directly in silicon.

### 3. Results and discussion

Thus improved the MicroQuad was tested on two separate occasions separated in time by about 3 months.

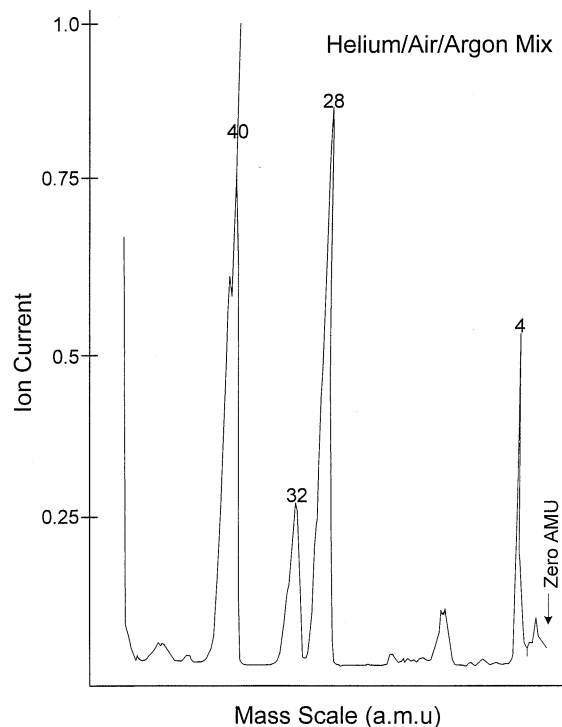


Fig. 2. Typical spectra obtained from the output of the electrometer for an argon/air/helium gas mixture. Total gas pressure  $6 \times 10^{-6}$  mbar, ion energy 14 eV emission current 1.7 mA, pole bias  $-3$  V and the RF frequency 6 MHz. Ion current normalised to  $10^{-12}$  A.

For the first occasion the results are shown in Figs. 2 and 3. Fig. 2 shows MicroQuad spectra for an argon/air/helium gas mixture. From the peaks at mass 4 and 40 the mass scale was calibrated and found to be linear, with 5–10% valley separation between  $O_2/N_2$  peaks. The resolution of the QMS (peak width at 10% peak height) was calculated at 2.7 amu at mass 40. Fig. 3 shows similar

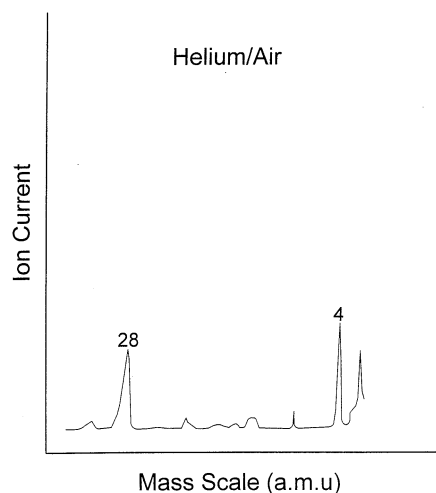


Fig. 3. Spectra obtained for an air/helium gas mixture, same test conditions as for Fig. 2.

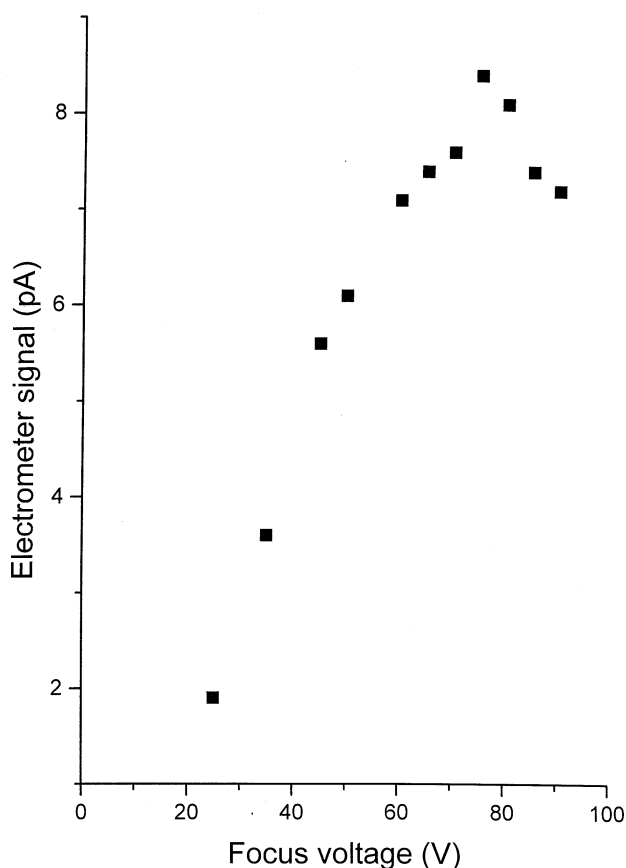


Fig. 4. Ion signal against focus voltage for an argon peak, emission current 1 mA, ion energy 10 eV, and pressure in  $10^{-7}$ – $10^{-8}$  mbar range.

spectra for a helium/air mixture. In both cases the ion energy was set at 14 eV, pole bias to 3 V and ion emission current to 1.7 mA. The total pressure was  $6 \times 10^{-6}$  mbar measured on a Penning gauge.

As observed previously [6] there was a fall off in resolution for low cage voltages and this was felt to be

probably due to low-energy ions having poor entrance efficiency into the mass filter since the optics for the ion transmission from the source were not optimised. To investigate this the ion source was modified to allow a focus voltage to be applied to the exit plate before ion entry into the mass filter. The second phase of testing began. The first point to make is that the MicroQuad operated consistently and in agreement with previously obtained results (Figs. 2 and 3) after the three-month downtime, indicating good instrument stability and reproducibility. Reliable QMS operation was obtained up to pressures in the  $10^{-4}$ – $10^{-3}$  mbar range and the highest operating pressure was felt to be a limitation of the ion source, rather than the mass filter.

The results of the focus investigation are shown in Fig. 4 for the argon peak, and thereafter a focus voltage of 65 V was chosen as the operating point. Interestingly, the shape of the argon peak did not significantly improve with focus, indicative that the ion coupling to the mass filter may not be the only reason for the loss in resolution obtained at low ion energies.

The next investigation was to vary resolution of the mass 40-argon peak by adjusting the DC to RF voltage ratio (U/V) on the electronic drive unit. The ion energy was set at 10 eV and the emission current and pressure at

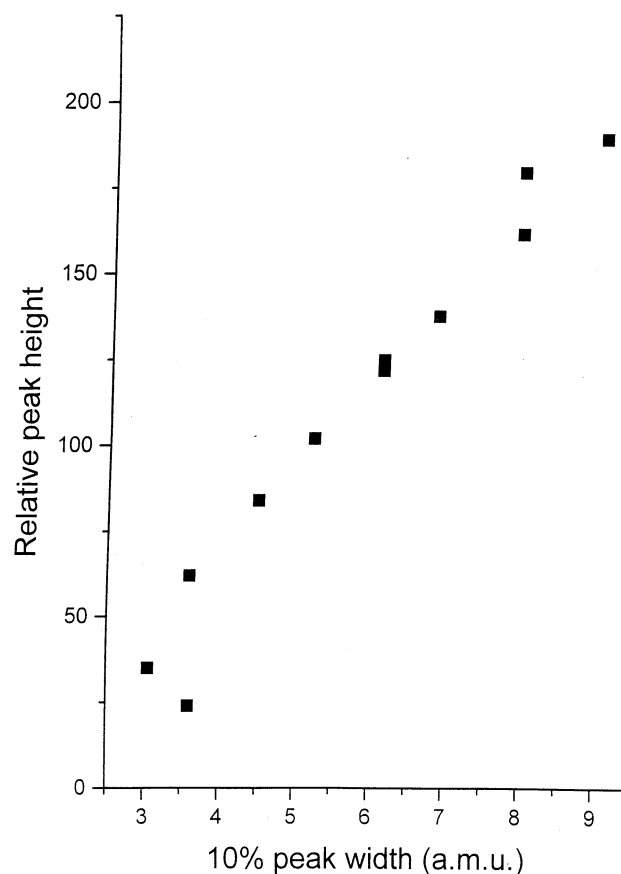


Fig. 5. Relative peak height against peak width (resolution) for ion energy 10 eV.

1 mA and approximately  $5 \times 10^{-6}$  mbar, respectively. The resolution reaches a maximum of around 3, with a decrease in resolution for further increase of U/V resulting in less ion signal current. Fig. 5 shows a plot of relative argon peak height versus resolution with the familiar “C”-shaped curve. This type of plot is typical of the variation in ion signal current with resolution for a conventional QMS mass filter and may be predicted theoretically [8].

In conclusion, we have demonstrated stable and reproducible quadrupole operation for a silicon-based QMS with a fully micromachined mass filter operating at low power and low voltages. Performance improvement over initial prototypes is felt to be due to improved design of the micromachined filter and the use of a direct RF driving electronics as opposed to a tuned circuit. The MicroQuad mass filter behaves as a conventional mass lens with a typical trade-off between ion signal and resolution. Improved ion focussing is shown to increase sensitivity but not to improve peak shape and this issue remains the subject of further investigations.

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