References

1 CAMENISCH, J.L., PIVETEAU, J.M., and STADLER, M.A.: 'Blind signatures based on the discrete logarithm problem'. Advances in Cryptology-EUROCRYPT'94, LNCS 950, (Springer-Verlag, 1995), pp. 428–432

2 CHAUM, D.: 'Blind signatures systems'. Advances in Cryptology-CRYPTO'83, (Plenum, 1983), p. 153

3 FERGUSON, N.: 'Single term off-line coins'. Advances in Cryptology-EUROCRYPT'93, LNCS 765, (Springer-Verlag, 1994), pp. 318–328

4 POINTCHEVAL, D., and STERN, J.: 'Provably secure blind signature schemes'. Advances in Cryptology-ASIACRYPT'96, LNCS 1163, (Springer-Verlag, 1996), pp. 252–265

5 POINTCHEVAL, D., and STERN, J.: 'New blind signatures equivalent to factorization'. Proc. 4th ACM Conf. on Computer and Communication Security, 1997, pp. 92–99

6 CHAUM, D., FIAT, A., and NAOR, M.: 'Untraceable electronic cash'. Advances in Cryptology-CRYPTO '88, LNCS 403, (Springer-Verlag, 1990), pp. 319–327

7 RABIN, M.O.: 'Digitalized signatures and public-key functions as intractable as factorization'. Technical Report, MIT/LCS/TR212, MIT Lab., Computer Science, Cambridge, MA, USA, January 1979

8 SIMMONS, G.J.: 'Contemporary Cryptology: The Science of Information Integrity' (IEEE Press, N.Y., 1992)

9 SHAMIR, A., and SCHNORR, C.P.: 'Cryptanalysis of certain variants of Rabin's signature scheme', *Inf. Process. Lett.*, 1984, **19**, pp. 113–115

10 DIMITROV, V., and COOKLEV, T.: 'Two algorithms for modular exponentiation using nonstandard arithmetics', *IEICE Trans. Fundam. Electron. Commun. Comput. Sci.*, 1995, **E78-A**, (1), pp. 82–87

Initial results for a quadrupole mass spectrometer with a silicon micromachined mass filter

S. Taylor, J.J. Tunstall, R.R.A. Syms, T. Tate and M.M. Ahmad

Initial results are presented from tests of a low voltage, low power, miniature quadrupole mass spectrometer with a novel silicon micromachined mass filter. The construction of the device is discussed, along with its mounting on a conventional ion source and testing in a vacuum system. Results are presented for the operation of the lens including a mass spectrum for an argon/air mixture and the effect of cage voltage, emission current and pressure on the performance.

Quadrupole mass spectrometers (QMS) have been widely researched and developed as sensors and diagnostic tools for over 40 years [1]. They 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 ultra clean processes for ULSI are a priority. QMS based on cylindrical rods for the mass filter are now highly developed and successful [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 for our work. The conventional arrangement uses circular cross-section metallic rods as the mass filter (typical dimensions: rod-length: 50–225mm; diameter: 5–15mm) excited electrically at voltages up to 1kV depending on the application. We have produced a micromachined quadrupole lens made from silicon with 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 0.5mm diameter electrode rods is given in [5].

A quadrupole mass filter thus realised was mounted onto a conventional VG ANAVAC ion source which was in turn attached to a vacuum flange. External connections from the mass lens and the ion source were made to pins on the outside of the flange. The ion source was connected to an emission regulator. The filament which produces the electrons for ionisation of the gas was held at –78.5V, (filament return was set at –76.0V), the focusing element was set at –7.7V and the source cage held at 11.0V. With argon gas in the vacuum, system ions were produced in the source, which in turn passed through the mass filter. A split phase RF alternating voltage (amplitude V = 20V), and a direct voltage ramp (U(t): $0 < U < 10$V), was applied to the quadrupole rods. The U/V voltage ratio was kept fixed and the voltages scanned from high to low values with the ratio adjusted so that the effective scan-line would pass close to the tip of the Mathieu stability diagram for singly charged argon ions [1].

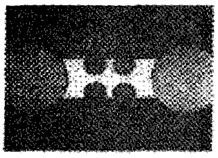

Fig. 1 *End-on optical microcope view of micromachined quadrupole mass filter*

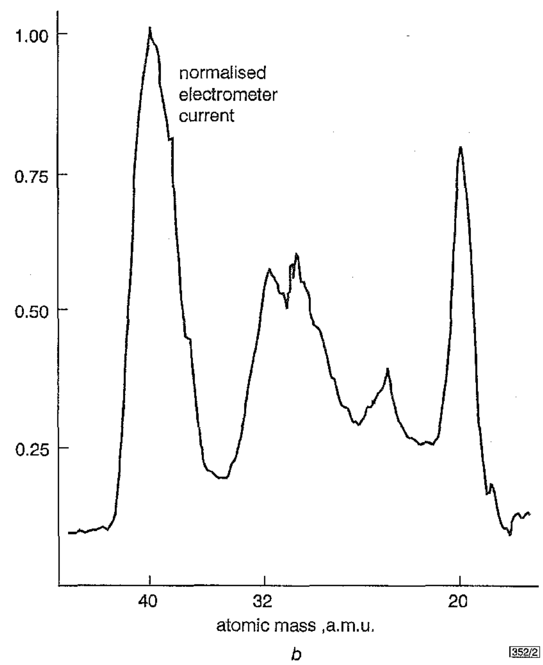

Fig. 2 *Typical spectrum obtained from output of electrometer for an argon/air gas mixture*

Gas pressure was 5.0×10^{-5}Torr and frequency of RF voltage was 6MHz. Argon peak at mass 40 is clearly seen, along with a broad peak for air. Also apparent is the doubly charged argon peak at mass 20

Fig. 1 shows an end-on optical microscope view of the micromachined quadropole mass filter. A typical mass spectrum is plotted in Fig. 2 showing the output from the electrometer (ion current) for an argon/air gas mixture. From peaks at mass 40 ($M = 40$) and mass 20 the mass scale can be calibrated and the resolution of the QMS ($M/\Delta M$) at half height can be calculated.

There are several parameters that can be varied which affect the performance of a mass spectrometer. Our first investigation was to see how resolution varied with cage voltage. The spectrum was scanned for a range of cage voltages ensuring that both the singly-charged argon peak and the doubly-charged argon peak were recorded. Along with the positions of the peaks the ion current was measured so that the sensitivity for the peaks at $M = 40$ and $M = 20$ could be determined. A general trend of decreasing resolution for increased cage voltage (ion energy) was seen. It can be shown the mass peak width ΔM (in a.m.u.) of an ideal quadrupole lens is given by [1]:

$$\Delta M \simeq 4 \times 10^9 V_z / f^2 L^2 \qquad (1)$$

where V_z is the ion axial energy in eV and L the electrode length (metres). For the QMS tested here at $V_z = 6$eV (corresponding to a cage voltage of 6V), $f = 6$MHz and $L = 20$mm, eqn. 1 predicts a maximum resolution of 24 which is close to the value obtained in practice (Fig. 3). The fall off in resolution for low cage voltages is not predicted by eqn. 1 and is 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. As the cage voltage increases, the ions produced become more energetic, allowing higher transmission with a corresponding decrease in resolution evidenced by a broadening of the mass spectra.

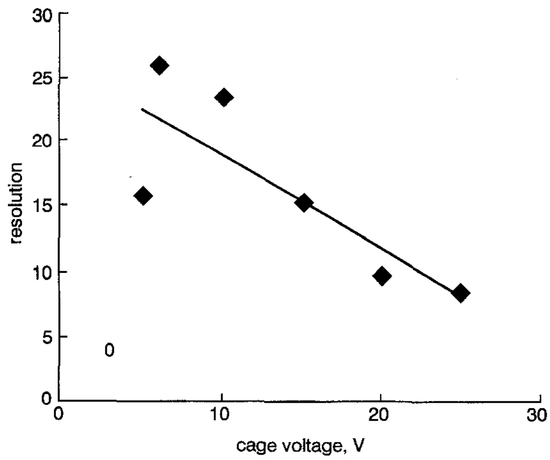

Fig. 3 *Experimental variation of half-peak height resolution against cage voltage, for emission current of 100 μA*

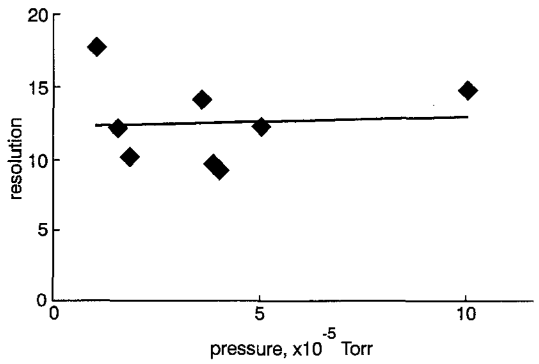

Fig. 4 *Resolution against pressure, for cage voltage of 10 V and emission current 80 μA*

Best straight-line fit is shown

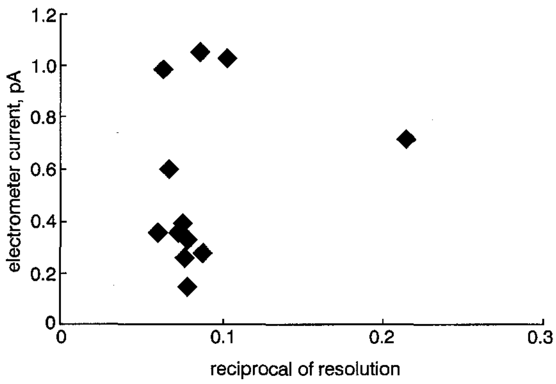

Fig. 5 *Sensitivity against reciprocal of resolution with emission current 80 μA and cage voltage 10 V*

Another consideration was to see how resolution varied with pressure. The cage voltage was set at 10V and the emission current was set at 80μA. The QMS operated consistently over the pressure range considered, 10^{-6}–10^{-4} torr, with no significant loss of resolution for higher pressures (Fig. 4).

Our next investigation was to vary the emission current and see the effect on the resolution of the mass 40-argon peak. The cage voltage was set at 10V. The resolution reaches a maximum at an emission current of 60μA, with a decrease in resolution as the emission current increases. An instructive plot to consider in this case is sensitivity against the reciprocal of the resolution, (which is proportional to ΔM). Fig. 5 shows a 'C' type curve indicating a maximum in the resolution. This type of plot is typical of the variation in sensitivity with ΔM for a conventional QMS mass filter and may be predicted theoretically [7].

In conclusion, we have demonstrated for the first time a QMS with a silicon-based, fully micromachined mass filter operating at low power and low voltage. The micro-QMS filter behaves as a conventional mass lens with a typical trade-off between sensitivity and resolution. The variation of resolution with cage voltage behaves as expected, with a decrease in resolution as the ion energy is increased. These initial results show definite quadrupole and mass filtering operation even though the conditions for optimum performance have yet to be established.

Acknowledgments: The authors would like to thank J.H. Leck and J. Batey for many useful discussions and EPSRC for their support.

9 January 1998

Electronics Letters Online No: 19980410

S. Taylor and J.J. Tunstall (*Department of Electrical Engineering and Electronics, Liverpool University, Brownlow Hill, Liverpool L69 3GJ, United Kingdom*)

R.R.A. Syms, T. Tate and M.M. Ahmad (*Optical and Semiconductor Device Section, Department of Electronic and Electrical Engineering, Imperial College of Science, Technology and Medicine, London SW7 2AZ, United Kingdom*)

References

1 DAWSON, P.H.: 'Quadrupole mass spectometry and its applications' (AIP, New York, 1995)

2 BATEY, J.H.: 'Quadrupole gas analysers, residual gas analysis', *Vacuum*, 1987, **37**, (8–9), pp. 659–668

3 FERRAN, R.J., and BOUMSELLEK, S.: 'High pressure effects in miniature arrays of quadrupole analysers for residual gas analysis from 10^{-9} to 10^{-2} torr', *J. Vac. Sci. Technol.*, 1996, **A 14**, (3), pp. 1258–1264

4 TAYLOR, S., SYMS, R.R.A., DOREY, H.A., and TATE, T.J.: 'Improvements in and relating to quadrupole mass spectrometers'. British Patent 9,506,972,1995

5 SYMS, R.R.A., TATE, T.J., AHMAD, M.M., and TAYLOR, S.: 'Fabrication of a microengineered quadrupole electrostatic lens', *Electron. Lett.*, 1996, **32**, (22), pp. 2094–2095

6 AUSTIN, W.E., HOLME, A.E., and LECK, J.H.: 'The masss filter: Design and performance' *in* 'Quadrupole mass specrometry and its applications' (Elsevier, Amsterdam, 1976), pp. 121–152

7 MA, F.M., and TAYLOR, S.: 'Simulation of the ion trajectories through the mass filter of a quadrupole mass spectrometer', *IEE Proc. A*, 1996, **143**, (1), pp. 71–76

Quadrature demodulation technique used in laser Doppler velocimetry

J. Czarske and O. Dölle

The authors present a technique for applying quadrature demodulation to determine the frequency of Doppler signals. This technique enables low-frequency signals with less than one signal period to be measured. The dependence of measurement error on signal-to-noise-ratio and measurement time is also investigated.

Introduction: Laser Doppler velocimetry (LDV) is an established technique for measuring velocity, especially that of fluid flows. The LDV system is based on determining the Doppler frequency of the generated electrical beat signal, which is proportional to the velocity of the scattering particles, suspended in a fluid flow. Zero point counters are often used in LDV signal processing, allowing on-line frequency measurements, but requiring several signal periods since only two zero point measurement values per period are available. Hence, small signal frequencies cannot be measured with a high time resolution, so that the potential of LDV in certain fields such as the measurement of crystal growth or complex acoustic waves has not been fully realised. Fast Fourier transformation (FFT) processors are potentially advantageous in processing LDV signals with a poor signal-to-noise-ratio (SNR) but have intolerably high measurement errors at low numbers of periods. In this Letter we demonstrate that the recently developed quadrature demodulation technique (QDT) can overcome these drawbacks. The QDT allows on-line, directional Doppler frequency measure-