

## A LIGA Fabricated Quadrupole Array for Mass Spectroscopy

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### Abstract:

A linear array of nine quadrupoles was fabricated using the LIGA process. Pole heights ranging from 1 to 3 mm were fabricated using synchrotrons X-ray exposures to form free standing **polymethylmethacrylate (PMMA)** molds into which copper, gold or nickel were electroplated. Metrology studies were performed to determine the dimensional precision of the quadrupoles **identifying** a normalized deviation from the mean diagonal measure of  **$\pm 1.8$  percent**. **Fabrication and** packaging issues to align and attach electrically isolated aperture structures were also addressed.

### 1. Introduction

Mass spectroscopy continues to be a standard method for the identification and characterization of chemical species. Given the utility and capabilities of this analytic technique, the benefit of including a mass spectrometer as part of an instrument suite for space exploration is obvious. The National Aeronautics and Space Administration (NASA) has adopted a strategic theme of "faster, better, cheaper" in space instrument planning. A logical extrapolation of this effort is to reduce the size of instruments resulting in savings in mass and power with the attendant reduction in launch costs. Historically NASA has launched exploration space craft analogous in size and weight to small cars (e.g. **Cassini** spacecraft weight is approximately 1000 kg) but is moving rapidly toward reduced size craft of the new millennium class which are the size of shoe boxes **weighing** in the 10's of kilograms. Although the total size of the craft will be reduced, the expectation is that this will occur without a reduction in analytic performance and if possible an improvement in capability. To meet this requirement in the area of mass spectroscopy, a project was initiated to address a **LIGA** fabricated quadrupole array. Reduced size quadrupole mass filters have been fabricated using conventional machining and assembly techniques with pole lengths of approximately 25 mm and rod diameters of 2.0 mm<sup>1,2</sup>. The pole array described in this paper represented a reduction in dimension of approximately one order of magnitude with pole lengths of 2.2 mm.

### 2. Design

The design objective of this device was to provide a reduced size quadrupole mass filter with a mass range of 1 to 300 AMU with a full width at half maximum (FWHM) resolution of 0.5 AMU. This compares with the 15 to 212 AMU range and 1 AMU

resolution of the mass spectrometers on the Viking I and II spacecraft which were landed on Mars in 1976. In addition to the analytic performance requirements, a proposed application required that the instrument operate after sustaining a 50,000 g deceleration in a Martian surface penetrator probe.

The quadrupole mass filter was proposed by Paul et al<sup>1</sup> in 1958. In the original design the pole faces were of a hyperbolic cross section. Fabrication of the poles using the LIGA process allows for a reduced size device with the hyperbolic pole faces of the original design as opposed to the round faces allowed by using round polished rods. Orient, Chutjian and Garkanian<sup>1</sup> showed that in order to achieve a resolution of 0.5 AMU at a mass number of 300, the pole dimensions would need to be precise to 0.1 percent.

The design to fabricate the LIGA quadrupole assembly is shown in schematic cross section as figure 1 and as expanded components as figure 2. In this approach the assembly consists of the metallic (preferably non-magnetic) pole section with an entrance and exit aperture located concentric to the throat of the quadrupole but electrically separated from the poles by dielectric spacers.

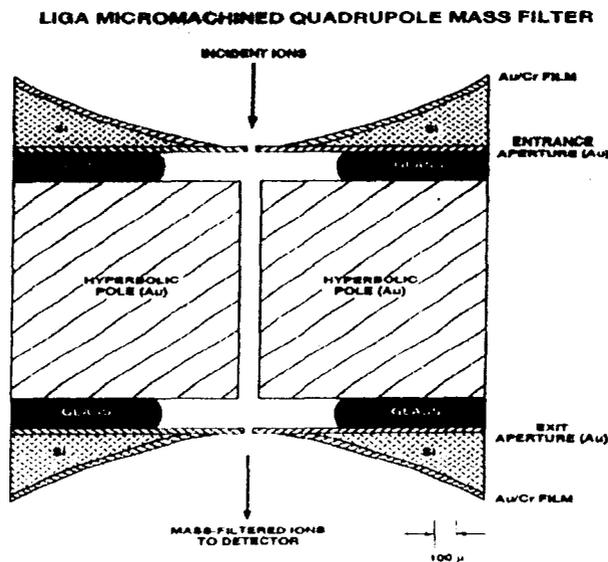


Figure 1. Quadrupole schematic cross-section

The poles were fabricated by exposing polymethylmethacrylate (PMMA) sheets to synchrotron radiation through X-ray masks consisting of nominally 35 micron thick gold electroplated patterns on 200 micron thick silicon wafers to achieve a backside dose in the PMMA of approximately 4 kJ/cc. The exposed areas were then developed away using the solvent system developed by Ghia and Glaushauer<sup>4</sup>. This resulted in a freestanding PMMA mold which was then attached to a plating base which had been separately prepared. The plating base consisted of an alumina substrate onto which had been deposited 2 to 3 microns of gold by sputtering. This film was then lithographically patterned to form a conductive base which corresponded to the pattern of the mold but also provided connectivity of all poles for ease of electroplating. To establish better keying and reduced lateral plating under the mold, an additional lithography step was performed which blanked off all exposed metal areas except those corresponding to the PMMA mold. Five to ten microns of additional gold was then plated into this pattern to create a raised relief

corresponding to the mold pattern. The PMMA mold was then fitted over this relief and held against the base under compression while electroplating occurred. Electroplating was attempted in three different systems; copper sulfate, gold cyanide and nickel sulfamate. Both the copper and gold baths provided very unsatisfactory results as the deposits were grown to the 2 to 3 mm thicknesses of the PMMA molds. Success was achieved using a nickel sulfamate bath resulting in a lapped thickness of 2.2 mm, Continued work is in progress to establish satisfactory plating results in a non-magnetic metal.

The entrance and exit apertures were fabricated by lithographically defining the holes on a 200 micron silicon substrate using a thick film novalac resist (SJR-5740 or AZP-4620) and electroforming a film of gold into the pattern to a depth of approximately 25 microns. A second pattern of photoresist was deposited onto the backside of the wafer corresponding to the electroformed holes and used as a lift-off pattern to create an etch mask following deposition of a 5000 Å of gold film. The wafer was then etched from the backside to open the silicon to the electroformed holes. An additional layer of 5000 Å of gold was deposited on the back side following etching to create an electrical connectivity between the conductive gold layers of either side.

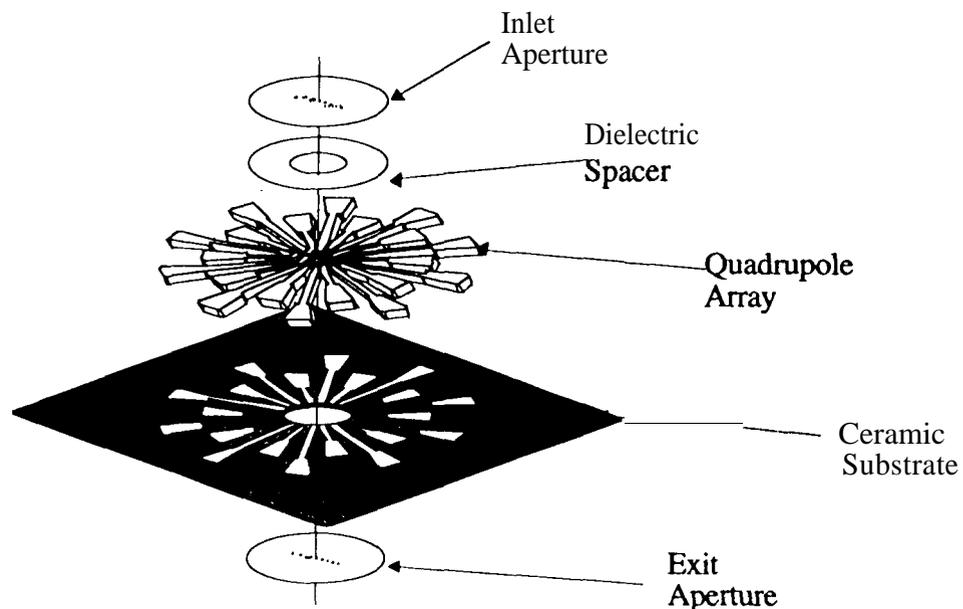


Figure 2 LIGA fabricated linear quadrupole array assembly

**Assembly** was accomplished using a 100 power microscope with digital position readout to 0.5 micron. The apertures were positioned over the quadruples by digital dimensional reference rather than with fiducial marks. Several methods were investigated to hold the aligned assembly in place. These included using Torr Seal™ as an adhesive, high temperature solder preforms, anodic bonding of glass to gold films, diffusion (thermal compression) bonding and a mechanical jig for unbended constraint. The obvious concerns in any bonding method were having a system which did not outgas as would be the case with conventional organic adhesives, will not migrate to other surfaces such as occurs with low temperature solders and will not alter the mechanical alignment of the poles as a result of the bonding process.

The diagonal distance across each quadruple array was measured using a microscope with digital position readout accuracy to 0.5 micron. The results of this exercise are illustrated in figure 3. As can be seen from figure 1 the diagonal measure across the 9 poles ranged from 188 to 195 microns with an average value of 191 microns. This represented a normalized deviation from the mean of 1.8 percent. This was approximately an order of magnitude greater than the design objective of agreement to within 0.1 %. As can be seen in figure 3, the dimensional change is a function of position in the linear array. This results from the differential stresses that are created in going from a circular geometry of the outer bond pads to the linear geometry of pole array. If only the 3 center poles; numbers 4,5, and 6 are considered, the deviation from mean is below the required 0.1 %. It is anticipated that in the next design iteration that the stresses will be matched sufficiently to meet the design criteria,

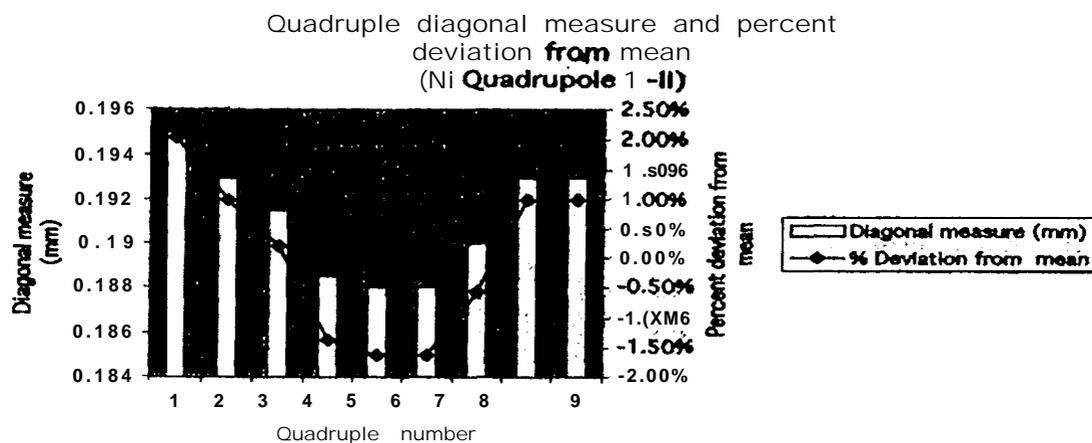


Figure 3 Diagonal measure of individual quadruples

### 3. Conclusions

An ability to fabricate a multipole linear quadruple array greater than 2 mm in height using the LIGA process has been demonstrated. Based on the results to date, additional improvements in electroplated metal and stress uniformity are required for an optimized device. Stress matching for all poles is anticipated to produce dimensional tolerances to within the design objective of 0.1 % precision.

### Acknowledgments

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<sup>1</sup> O.J. Orient, A. Chutjian, V. Garkanian, Rev. Sci. Instrum. 68(3), March 1997, pp1393-97

<sup>2</sup> R.J. Ferran, S. Boumsellek, J. Vac. Sci. Technol. A14, 1258 ( 1996)

<sup>3</sup> W. Paul, H.P. Reinhard, U. von Zahn, Zeitschrift fur Physik, Bd. S. 143-182 (1958)

<sup>4</sup> V. Ghia and W. Glaushauer, "Verfahren fur die Spannungsfreie Entwicklung von bestrahlten Polymethylmethacrylat-Schichten." Offenlegungsschrift DE3039110, Siemens AG, Munich.