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MEMS Fabrication of Micro Cylindrical Ion Trap (µCIT) Mass Spectrometer for CubeSats Application

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Abstract

Microelectromechanical Systems (MEMS) technology is used to fabricate arrays of micro Cylindrical Ion Traps (µCIT) which are integrated into a miniaturized mass spectrometer (MS). The micro µCITs are built from silicon wafers and requires high machining precision, smooth surface, and high dimensional uniformity across the array for optimum mass spectrometer performance. In order to build these 3D miniature structures several MEMS processing techniques were explored and a process was developed and tested. By using the developed MEMS process, the required µCIT 4 x 4 arrays were fabricated. This included a chip design variation in which mechanical locking pits and posts were machined in the Ring Electrode (RE) chip and End Plate (EP) chips respectively, for self-assembly. The size of the assembled µCIT is only 12 mm x 12 mm x 1.5 mm. It is a key component for the miniature mass spectrometer. The micro cylindrical ion trap mass spectrometer has the advantages of low-power operation, simpler electronics and less-stringent vacuum system requirements. The MEMS batch production capabilities will also greatly lower the cost. It is a promising candidate for CubeSat and nanoSats applications for exploration of chemical distributions in space.

1. Introduction

Mass spectrometry plays an important instrumental role in planetary science**.** There were many different mass spectrometers used in NASA's space flight missions, include Mars exploration and other planetary scientific missions. For CubeSats and NanoSats applications, reduction in mass, power consumption and cost are required. A miniaturized mass spectrometer which could be used on a CubeSat or NanoSats is in ever-increasing demand to do *in situ* analysis for a wide range of applications including astro-biology research.

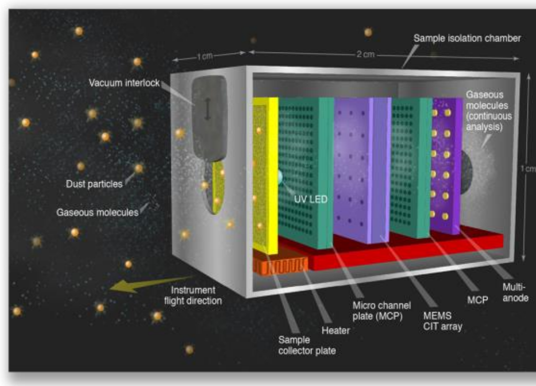

Figure 1: A concept of a µCIT mass spectrometer CubeSat which would provide in situ chemical analysis.

With the advantage of MEMS technology, it is possible to build extremely small structures. Several research groups have demonstrated the use of MEMS fabrication techniques to miniaturize MS components. For example, various mass analyzers, ionization sources, micromachined electrospray ionization devices, and microscale vacuum pumps have been successfully fabricated. A cylindrical ion trap mass spectrometer is a similar concept which uses MEMS fabrication to miniaturize a mass spectrometer.

One significant advantage that MEMS fabrication strategies have over conventional machining methods is that they enable low-cost batch production of high precision geometries and easy integration of these geometries to obtain millimeter-scale assemblies. MS miniaturization is typically accompanied by a reduction in sensitivity. In the case of miniature ion trap MSs, this loss of sensitivity results primarily from the lower transmission of ions and electrons into and out of the traps, as well as from the lower ion storage capacity of the smaller ion traps. Sensitivity can, in principle, be regained by using an array of miniature ion traps that operate in unison. Arrays of microfabricated miniature ion traps can also operate at much lower trapping voltages, thereby significantly reducing the overall power consumption of the MS system. The array approach has the additional advantage that MS arrays could be used to perform parallel analysis.

By leveraging prior MS miniaturization efforts at SRI, we have developed MEMS processing techniques and fabricated the required cylindrical ion trap for miniature mass spectrometer, which can be used for chemical analysis and astrobiology research.

2. MEMS Fabrication of µCIT

A simplification drawing of the cylindrical ion trap and a 4 x 4 array of µCIT are shown in Figure 2. It includes a Ring Electrode (RE) chip and two End Plate (EP) chips which are assembled into the uCIT. The RE chip is made of ~500 µm thick Si, and includes an array of thru-hole apertures ~600 µm in diameter. The EP chip is ~400 µm thick and includes an array of thru-hole apertures ~250 µm in diameter. There is a ~60 µm gap (set by the height of a post structure on the EP chip) between of the RE chip and each EP chips when they are assembled. Each of the EP and RE chips are coated with a metallization pattern, including coating of the thru-holes sidewalls. The fabrication of these miniature CITs, requires high machining precision, smooth surfaces, and dimensional uniformity across the array for optimum mass analysis performance.

Four inch silicon wafers were used for the fabrication these RE chip and EP chips. The thru-holes were etched using a Deep Reactive Ion Etch (DRIE) process and gold metallization of the electrodes accomplished via e-beam evaporation in a planetary deposition mode. We also designed two variations of pit and post structures which were etched into the RE chip and EP chips respectively to explore two methods for self-assembly.

After several fabrication iterations, in which several different DRIE, metallization patterning, and assembly and bonding techniques were explored we have arrived at a simplified fabrication strategy which allow us to achieve 1) good uniformity and smoothness of the cylindrical structures etched in Si; 2) minimal contamination across the chip; 3) good

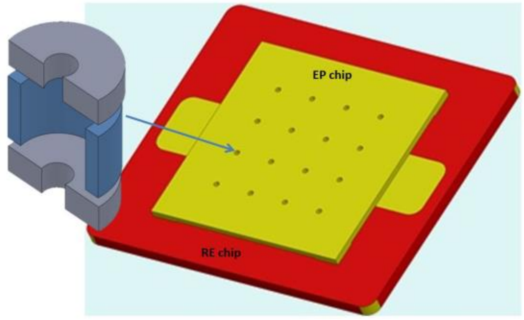

Figure 2: Drawing of µCIT and 4x4 array of µCIT.

metallization coverage; 4) high alignment accuracy (~3 µm, ~1% of thru-hole diameter) between the three trap electrodes after assembly; and 5) a reduction in the ion trap array chip capacitance to 25 pF. Figure 3 shows SEM images of fabricated RE and EP chips and an l image of an assembled µCIT.

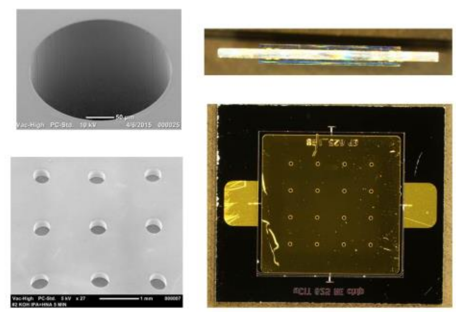

Figure 3: MEMS processed chips and assembled µCIT chip.

4. Summary and Conclusions

MEMS technology has proven to be extremely valuable for building miniature scale 3-D structures with an accuracy and ease not possible with conventional machining methods. We have fabricated and integrated a µCIT chip which is a key component for a miniaturized mass spectrometer. This technology development will likely lead to the development of next-generation low-power portable chemical analyzers, which can be mass produced in a cost-effective manner due to the batch production capabilities inherent in MEMS processing. The low power consumption and low cost of these miniature mass spectrometers make them a good candidate for CubeSats and NanoSats applications.