A Novel Fabrication Technique of Cylindrical Ion Traps using Low Temperature Co-fired Ceramic Tapes

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ABSTRACT

This work concentrates on a novel technique for the fabrication of miniaturized cylindrical ion trap structures (CIT) to be used as replacements of commercial hyperbolic structure ion trap mass spectrometers. Low temperature co-fired ceramic (LTCC) tapes (Dupont 951), commonly known as "green tape", were used to fabricate a CIT structure of 2.75 mm in diameter. The fabrication process included a stainless steel die, which was used to obtain the impressions, for automatic alignment of stainless steel end plates. The ring electrode structure made out of green tape and the stainless steel endplates, were plated with electro-less Ni and electro-less Au to obtain a conducting surface. The green tape CIT structures were tested for background contamination and out-gassing under vacuum in a Saturn 2000 MS Mass Spectrometer. Experiments showed that no considerable out-gassing or contamination is present at pressures of 10^{-4} to 10^{-6} Torr. Other techniques to fabricate CIT structure involving green tapes are being explored as an alternative.

Keywords: green tape, cylindrical ion trap, miniaturization, vacuum contamination.

INTRODUCTION

LTCC manufactured by Dupont, are soft and pliable ceramic tapes, often called green tapes in their unfired state. The soft and flexible nature of this material allows for the batch fabrication of a large variety of complex 3-D structures using lamination, punching, and drilling. 3-D structures fabricated out of laminated green tapes turn into ceramics when fired. The shrinkage during the firing process is repeatable and uniform in all directions making green tapes apposite for fabrication of high precision meso and micro-scale structures. Once turned into ceramics, green tape structures can be plated with electro-less Ni or Au to achieve uniform metallization required for electrical conduction.

FABRICATION PROCESS

The fabrication process consists of the following steps as shown in Figure 1.

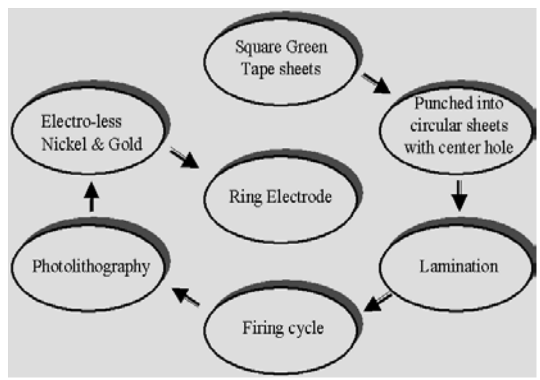

Figure 1: Schematic of the fabrication process.

First, circular green tapes, with a center hole, were punched with a hammer punch. 70 of such circular tapes were put in a stainless steel die (see Figure 2) and pressed in a hydraulic press at 8100 psi at 80°C for 15 minutes.

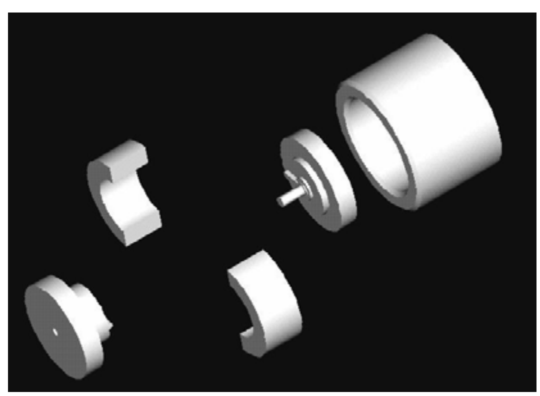

Figure 2: An exploded view of the Stainless Steel Die.

The thickness of the structure pressed in the green tape is defined by the design of the die and not the pressure. Beyond that thickness, any increase in pressure would be passed on to the stainless steel cage in which the die is placed. This gives a semi-hard 3-D structure with all the patterns from the die transferred on it. The green tape is still in its green state, ready to be fired.
The sample is then fired in air according to the firing cycle provided by Dupont, see Figure 3.

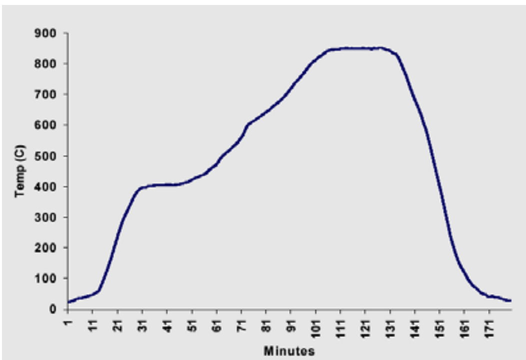

Figure 3: Recommended firing cycle [3].

The temperature is ramped up at 10°C/minute to 350°C and then kept constant for 30 minutes. At this temperature, green tape looses all its organic components. The temperature is again increased at the same ramp rate to 850°C where it is kept for 30 minutes. The sample is allowed to cool slowly to room temperature.
The green tape sample turns into hard ceramic during the firing cycle. Using an SR100 set up, photolithography is done on the sample to metallize specific areas on it using negative photo-resist PKP.

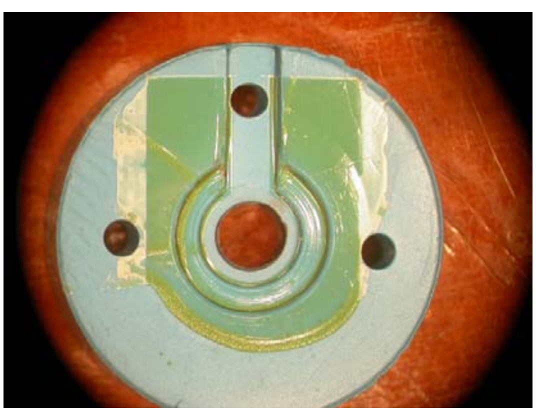

Figure 4: Green tape CIT structure with photolithography done.

The exposed sample is developed and then directly plated with electro-less Ni or Au to achieve metallization. The immersion solution plates the entire sample, which is then dipped in the photo-resist stripper to get rid of the unwanted metal as in the standard lift-off process. The photo-resist and metal present on the sample are removed. Ni was used as the first layer due to its better adhesion. The Au plating on top of the Ni ensured a highly conductive layer.

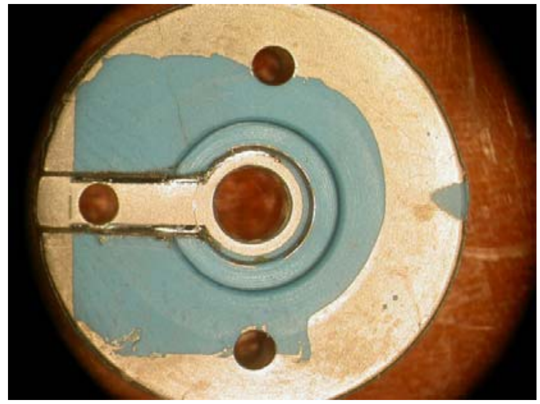

Figure 5: Green tape CIT structure plated with electro-less Ni.

The electro-less Ni and Au are plated for 2-3 minutes and 10 minutes, respectively to get sufficiently thick layers of metal required to operate at high voltage and frequency. Experiments were performed with test parameters up to 2.3 kV_{pp}, 0.01 A at 3MHz to confirm the quality of the plating and to investigate the breakdown voltage.

VACUUM FEASIBILITY TEST

An experiment was performed to confirm the feasibility of green tapes in vacuum applications. Out-gassing of the ceramics might interfere with or contaminate compound analysis instruments such as a mass spectrometer. The setup consisted of a Saturn 2000 Ion Trap Mass Spectrometer, which typically operates in the range of 10^{-6} to 10^{-4} Torr. A green tape sample was taken directly from the oven and placed inside a vacuum chamber extension, which replaced the inlet system of the mass spectrometer, to ensure a clean sample. The turbo pump current and startup time were consistent with the normal operation, indicating no significant out-gassing of the green tape structure.
Mass spectrometric analysis showed that the contaminants in the vacuum chamber extension, filled with the green tape structure, did not differ significantly from the background signal contaminants of the empty vacuum chamber

extension. It may be concluded from above that there is no noticeable out-gassing from the fired green tape structure.

CONCLUSIONS

A fabrication process for a ring electrode of a CIT structure was designed and tested that uses a die to create the detailed impressions of an electrode channel, automatic alignment cut and includes a predefined distance from the endplate to the cylinder. Green tape laminated at 8100 Psi at 80°C seemed to be non-porous and no significant out-gassing was observed in vacuum at 10^{-6} to 10^{-4} Torr thus making them useful in vacuum applications.

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