An investigation on development of MEMS in LTCC by embossing technique

D. Andrijasevic\textsuperscript{a}, W. Smetana\textsuperscript{a}, S. Zoppel\textsuperscript{b}, W. Brenner\textsuperscript{a}

\textsuperscript{a} Institute of Sensor and Actuator Systems, Vienna University of Technology, 1040 Vienna, Austria
\textsuperscript{b} Forschungszentrum Mikrotechnik, Fachhochschule Vorarlberg, 6850 Dornbirn, Austria

Abstract

The latest results achieved during the investigation of possibilities for producing MEMS in unfired green Low Temperature Co-fired Ceramic (LTCC) by embossing technique are presented in this paper. Ceramic tapes in unfired state are subjected to compression by means of using tools specially designed and developed for this purpose. Structures obtained in this way demonstrate high repeatability and surface quality comparable with those gained by other techniques. In comparison with traditionally used laser cutting or injection moulding for ceramic processing, this technique offers better resolution and further miniaturisation, improved rigidity of small structures and possibility to profile the vertical walls in U- and V-shapes. The main focus of this paper will be on the optimisation of embossing parameters (embossing force, embossing time and temperature) in order to get repeatable and reliable results. Structures produced in this way could be successfully used in optical as well as in medical applications.

Keywords: LTCC, embossing, MEMS mass production, 3D packaging.

1. Introduction

Low temperature co-fired ceramic (LTCC) is well-established process that has been in use for many years in the microelectronics packaging industry. LTCC technology is widely used for wireless and high-frequency applications in order to make multilayer hybrid integrated circuits.

Using ceramic for building micro devices seems to have several very important advantages in comparison with other materials: reliability, thermal stability, possibility to develop “System in Package” (integrated and embedded passives component: capacitors, inductors and resistors), outstanding tribological properties, high packaging density, cost efficiency for high volumes \cite{1,2,3}. Ceramic also demonstrates high level of biocompatibility, chemical inertness, resistance to high temperatures, bending, wear, corrosion, etc. \cite{4,5,6}. In some application, it is necessary to expose the structure to high pressure, and for this purpose, ceramic seems to be the perfect choice too. The LTCC could be fired at around 900°C due to a special composition of the material what permits the co-firing with high conductive materials (silver, copper and gold). It is also important to stress out that the price of LTCC is much lower in comparison with silicon and the development time is considerably shorter \cite{7}. The precision of the process is determined by the homogeneity of the feedstock and by the amount of the sintering shrinkage. Due to all these restrictions, it is possible to conclude that traditionally used techniques generate unacceptably high costs and cycle time due to stringent requirements for repeatability and therefore they are not serious candidates for mass production.

In contrary, with technique proposed here will be possible to replicate complex 2D and 2½D patterns onto ceramic surface very accurately and swiftly, what will economically justify additional cost required for tool production. By lamination embossed tapes, will be possible to build up complex 3D structures like multilayer channel systems.

2. Embossing tools

In the preliminary investigation, two differently patterned tools have been used. The structure like grid has total dimensions 1mm × 1mm, and dimensions of internal window 140 μm × 140 μm (Fig. 1.).

Fig.1. Embossing tool shaped like a grid.
The tool structured like concentric circles has outer diameter of 1.6 mm, while the inner diameter of the smallest circle is 170 μm (Fig. 2.). The height of pattern for both tools was 45 μm.

![Fig. 2. Embossing tool shaped like grid.](image1)

The tool was fabricated by selective laser structuring of a thick photoresist layer, which was spin-coated on a glass wafer. The used laser was an Yb:Glass regenerative amplifier (HighQLaser) with a pulse duration of 330 fs and a repetition rate of up to 10 kHz. The laser was operated at its second harmonic wavelength of 520 nm. The well defined threshold for the ablation with ultrashort laser pulses provides a process parameter window where the resist is selectively removed from the underlying substrate without affecting the substrate. In this fashion it is possible to generate 2½-dimensional structures where the height is solely determined by the thickness of the resist layer. After a cleaning procedure, a 50 nm thick Ni-coating was sputtered on the laser structured resist. Subsequent micro-electroplating generates a 100 μm thick metallic tool which was bonded on an embossing tool holder.

![Fig. 3. Tool fabrication process.](image2)

3. LTCC Substrates

LTCC as a structuring material suitable for fabrication very diverse MEMS devices draws recently great attention of researchers who deal with this topic because of many outstanding properties that LTCC can offer. Some of them are: thermal stability, possibility to be easily integrated in electrical circuits, biocompatibility, resistance to corrosion, bending, wear, etc.

In presented work, glass ceramic (alumina + anorthite) GC tapes supplied by CeramTec AG with nominal thickness of a selected single tape 320 μm were used. Required hardness of the LTCC has been achieved after low temperature firing at 950 °C. In the case of embossing the structures with height bigger than 120 μm, it is necessary to laminate few layers of ceramic tapes in order to get the needed thickness of the basic layer (the lamination process was performed in two approaches: samples were rotated for 180° to obtain equal lamination conditions, at the pressure force of around 30 kN (120 bars), temperature 70 °C within 90 s). Due to the fact that the height of the tool used in this work is only 45 μm, it was satisfactory to use single tape substrates (see Fig. 4).

![Fig. 4. 3D profile of grid shaped tool.](image3)

![Fig. 5. The embossing force versus time.](image4)

4. Embossing process

Embossing process has been performed at a universal testing machine Schenk Trebel RM 250, used to subject material sample or structure to compression ("crush it") in order to experimentally determining suitability of LTCC for this kind of machining. Ceramic samples, tools, as well as the parts of machine in contact with samples and tools, were pre-heated at 70 °C and the temperature was kept constant during the whole embossing process. This enables easier "flow" and deformation of the ceramic. The optimal pre-heated temperature was determined by experiments which shown that on the higher temperature ceramic cleaves to the tool, and on the lower it is rigid and appearing of cracks is relatively often. Samples were exposed to embossing forces in the range of 0.5 kN to 5 kN with step of 0.1 kN. The requested force was achieved after maximum 80 s, depending on the pressing rate. After achievement of requested pressing force, the substrate was exposed to the pressing force for additionally 15 s. Then, the substrate was completely unloaded (Fig. 5.).
Based on experience, it was known that embossing parameters and especially embossing force must be optimized for every structure geometry and dimensions separately. Deviations in repeatability of replicated structures might be based on the fact that on the equipment used in experiments, all embossing parameters (pressure force, time and temperature) can be controlled only very roughly (± 10 %) However, it is possible to conclude that the best results were obtained for pressing force of app. 1 kN, at temperature of 70°C.

Some irregularities and defects in the ceramic replica that are noticed, are partly the consequence of tools imperfections and this is the subject of on-going research. On the other hand, the embossing parameters on the existing equipment cannot be fully controlled and this also might cause above mentioned problems.

5. Obtained results

Preliminary investigation and optical inspection by means of the surface quality is performed at scanning electron microscope (SEM) and non-contact optical profilometer. The obtained results fully proved the potential of the proposed replication technique by LTCC embossing.

The manufactured structures before firing process are depicted in the Fig. 7 and Fig. 8.

It can be easily seen that obtained structures demonstrate high repeatability and the embossed shapes are accurate replications of the tool patterns. Based on measurements performed at VEECO Dektak 8, it was possible to conclude that the best results are achieved for embossing force of 1kN. Further investigation regarding embossing force optimisation is in progress.

6. Roughness issues

A special attention has been paid to investigation of the ceramic roughness before machining, after machining and after the firing. For this purpose, non-contact optical profilometer FRT MicroSpy Fringe Projection has been used.

In all cases, the average central line (CLA) was in the range from 1.5 to 2.2 μm, independently of the phase when the measurement was done, or the tool used for embossing. Although after the firing ceramic looks smoother, the irregularities are deeper and therefore, the average roughness remains the same.

As an illustration, SEM photos of unfired and fired unmachined ceramic are given below (Fig. 9.).

For some application, especially in Bio MEMS, achieved surface roughness seems to be good enough and it enables controlled cell proliferation. In MOEMS application, this roughness is not acceptable (for instance, in the case of optical fibres coupling) and therefore, it is necessary to continue the research in the direction of identification factors with influence and their adjustment in order to reduce final surface roughness.

Preliminary analysis of improvement of ceramic surface roughness by using chemical reactions (sol gel on PMMA basis; polymerization performed at 75 – 145°C with heating rate of 10° C/10 min; the thickness of formed layer: 700 nm) is under investigation.
7. Conclusion and future work

Novel replication technique for structuring unfired LTCC in order to produce complex 3D microstructure for bio- and optic-applications by embossing is presented in this paper. In addition, the list of advantages of LTCC as a MEMS material is given in comparison with other materials. The usability of the presented technique in view of existing technologies is also discussed. The results obtained in preliminary phase of research confirmed totally the potential of described technique.

Future work and research will be focused on the advanced optimization of working parameters, foremost embossing force, temperature and time. The suitability of different ceramic tapes supplied (the content of glass, thickness, recommended firing conditions) by different producers will be also investigated and based on attained results, general recommendation regarding selection of the particular tape will be given. Moreover, it will be very important to improve the embossing tools in order to avoid any kind of defects and irregularities. Finally, the issue of surface roughness and its influence on the concrete application will be considered with special regard.

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