Making Alumina Microcomponents from Al Powder

J.-S. Kim[1,a], K. Jiang[1,b], L. Falticeanu[2,c], G. J. Davies[d], and I. Chang[2,e]

School of Engineering
[1]Mechanical and Manufacturing Engineering,
[2]Metallurgy and Materials School of Engineering,
University of Birmingham, Birmingham, UK, B15 2TT
[a]jsk238@bham.ac.uk, [b]k.c.jiang@bham.ac.uk , [c]lucianfalticeanu@yahoo.co.uk,
[d]G.J.Davies@bham.ac.uk, [e]i.t.chang@bham.ac.uk

Abstract

Alumina microcomponents have distinguishing advantages over Si counterpart. However, the shrinkage of alumina, as high as 20%, makes it difficult to produce precision components meeting a high tolerance. A new fabrication process presented to greatly reduce the shrinkage by producing alumina microcomponents from ultrafine Al powder. The process consists of forming Al powder components through sintering and turning the Al powder component into alumina. In this way, the shrinkage occurring in sintering the Al powder component will be compensated by the expansion appearing when the Al powder component turns into alumina. The process has proven successful.

Keywords: alumina microcomponent, micro-moulds, ultrafine Al powder, sintering

1. Introduction

Alumina has very good thermal, mechanical and chemical inertness properties, which make it suitable for applications in high temperature, high pressure and chemical corrosion conditions. The ceramic MEMS offer alumina a lot of new applications [1]. Present micro ceramic fabrication techniques come from traditional integrated circuit (IC) technologies, where wet etching [2] and dry etching [3] are the main approaches. But stable mask material that can withstand the aggressive etching conditions is a prerequisite for such etching processes. Chemical vapour deposition (CVD) is another way to grow ceramic film on a wafer. However, it is difficult to obtain high aspect ratio and thick structures using CVD due to its planar nature of the process. Screen printing can be used to pattern thicker micro patterns, but its lateral resolutions are generally limited to 100 µm. There are also some techniques which are scaled down from the current ceramic forming techniques, such as co-extrusion [4], slip casting [5], rapid prototyping [6,7] and selective laser sintering (SLS) [8,9]. Although the abovementioned techniques are in development and in use, they are limited by the small dimensions they can be applied to. For example, a pressure assisted slip casting was used for micro fabrication of column and nozzles of 10 µm size and high aspect ratio, but only suitable for thin wall thickness structures and disk-like substrates [10].

Sintering process is widely used in both ceramics and metallic powder injection moulding process and can also be used in microcomponent fabrication. Some researchers used photoresist structures [11], such as using deep SU-8 moulds, to make moulds for forming patterns from powder suspension or powder polymer precursor. It is usually combined with the mould releasing method to extract the structures by either pyrolysis decomposition or chemical dissolution of the photoresists [1,11].

2. Experimental and Results

The techniques presented in this research combine both high resolution features patterning technique using photolithography and the simplicity of a suspension-based powder deposition technique. By combining Ultra-Thick SU-8 Process (UTSP) and micro-moulding process, a new novel process for microfabrication is developed. The process of producing net shape microcomponents using Al alloy powder starts from making SU-8 master moulds based on the UTSP process. In producing 1 mm thick microstructure, SU-8 50 (Microchem, USA) is cast on to a wafer and baked at 65°C for 2h, and then at 95°C for 15h. Afterwards, the baked SU-8 is exposed under UV light . The wafer is baked again at 65°C for 15 minutes and then at 90°C for 25 minutes before fully developed in EC solvent supplied by Chestech, UK. A negative soft mould is produced from the SU-8 master mould. A widely adopted soft moulding technique is using elastomer PDMS to pattern the micrometer and sub-micrometer sized structures. The PDMS slurry is prepared by mixing the PDMS precursor with curing agent in a weight ratio of 10:1. The mixture is then poured on the SU-8 master mould template and cured at 65°C for 4h. After it is cooled to room temperature, the cured PDMS was peeled off from the SU-8 master mould template. The metallic powders used in the experiments are micron sized Al powder (mean size 2.5µm) and nano sized Cu powder (less than 70nm). The metallic powder mixture is made of 80wt% micron-sized Al powder, 5 wt% nano-sized Cu powder and 15wt% adhesive binder. The powders and binder is mixed with acetone to form slurry.

Then the cavity of patterned PDMS mould is filled up with the slurry using immersing method. Once the slurry is dry, the shaped green component can be achieved by peeling off the soft PDMS mould. Next, the moulded component is placed inside a furnace filled with Ar gas and heated to 600°C for 6h and cooled down to room temperature. The fabricated Al-based microcomponent is then oxidized at 1450°C for 70h in air. The oxidation of aluminium is described by the reaction Eq. 1.

$$4Al + 3O_2 \rightarrow 2Al_2O_3. \quad (1)$$

Fig. 1 shows a micro alumina gear was fabricated following the process described above.

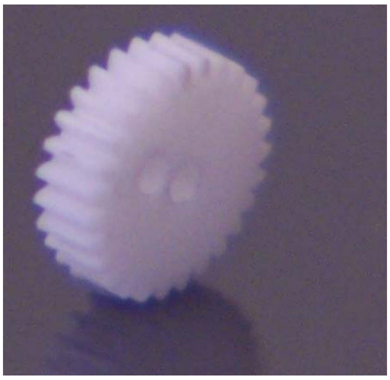

Fig. 1. A alumina microgear.

3. Summary

Alumina microgears produced following the above process were investigated. Fig. 2 illustrates the SEM images on the fractured surface of a alumina microgear. The microstructure of the alumina looks uniform and dense from these images. The dimensions of the alumina components were measured and the shrinkage ratio was found to be about 2%, which is in big contract to 20-30% shrinkage ratio when a component is sintered from alumina powder directly.

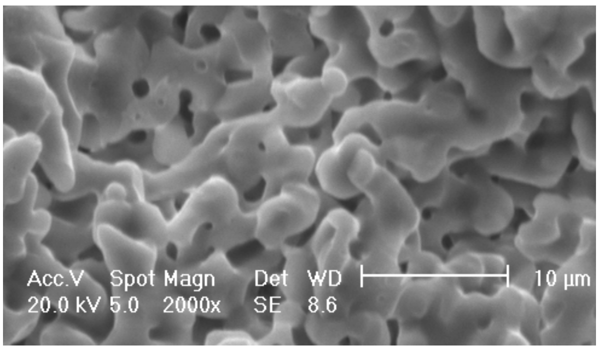

Fig. 2. SEM images on the fractured surface of microgears.

The proposed process shows a way of fabricating three-dimensional alumina microcomponents with little shrinkage while keeping good sintered density.

4. References

[1] L.-A. Liew, W. Zhang, L. An, S. Shah, R. Lou, Y. Liu, T. Cross, M. L. Dunn, V. Bright, J. W. Daily, R. Raj, K. Anseth, "Ceramic MEMS – new materials, innovative processing and future applications", Am. Ceram. Soc. Bull., vol. 80, pp. 25-30, 2001.

[2] W. Eidelloth, W. J. Gallagher, R. P. Robertazzi, R. H. Koch, B. Oh, R. L. Sandstrom, "Wet etch process for patterning insulators suitable for epitaxial high-T superconducting thin film multilevel electronic circuits", Appl. Phys. Lett., 59, 1257-1259, 1991.

[3] F. Rousseau, A. Jain, T. T. Kodas, M. Hampden-Smith, J. D. Farr, R. Muenchhausen, "Low-temperature dry etching of metal oxides and ZnS via formation of volatile metal ß-diketonate complexes", J. Mater. Chem., 2, 893-894, 1992.

[4] Van-Hoy, C., Barda, A., Griffith, M. and Halloran, J. W., 'Micro fabrication of ceramics by co-extrusion', J. Am. Ceram. Soc., 1998, 81, 152-158.

[5] Wang, S., Li, J.-F., Watanabe, R. and Esashi, M., 'Fabrication of lead zirconate titanate microords for 1-3 piezocomposites using hot isiostatic pressing with silicon molds', J. Am. Ceram. Soc., 1999, 82, 213-215.

[6] Halloran, J. W., 'Freeform fabrication of ceramics', Brit. Ceram. T., 1999, 98, 299-303.

[7] Knitter, R., Bauer, W. and Gohring, D., 'Manufacturing of ceramic microcomponents by a rapid prototyping process chain', Adv. Eng. Mater., 2001, 3, 49-54.

[8] Bourell, D. L., Marcus, H. L., Barlow, J. W. and Beaman, J. J., 'Selective laser sintering of metals and ceramics', Int. J. Powder Metall., 1992, 28, 369-381.

[9] Subramanian, P. K. and Marcus, H. L., 'Selective laser sintering of alumina using aluminium binder', Mater. Manuf. Process., 1995, 10, 689-706.

[10]Bauer, W., Ritzhaupt-Kleissl, H.-J. and Hausselt, J., 'Micropatterning of ceramics by slip pressing', Ceramics International, 1999, 25, 201-205.

[11] U. P. Schonhölzer, R. Hummel, L. J. Gauckler, "Microfabrication of Ceramics by Filling of Photoresist Molds", Adv. Mater., 12, 1261-1263, 2000.