Fabrication of PDC SiCN ceramic micro gear (MEMS)

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1) Introduction

1.1. What is Micro engineering?

Micro engineering can be described as the techniques, technologies and practices involved in the realization of structures and devices with dimensions on the order of micrometers.

MEMS often refer to mechanical devices with dimensions on the order of micrometers fabricated using techniques originating in the integrated circuit(IC) industry, with emphasis on silicon-based structures and integrated microelectronic circuitry. However, the term is now used to refer to a much wider range of microengineering devices and technologies. In fact, MEMS are microengineered devices that convert between electrical and any other form of energy and rely principally on their three-dimensional mechanical structure for their operation.

At the beginning of 1990s, microengineering was presented as revolutionary technology that would have as great an impact as the microchip. It promised miniaturized intelligent devices that would offer unprecedented accuracy and resolution and negligible power consumption. The technology would permeate all areas of life. In brief, MEMS have these advantages;

Suitable for high-volume and low-cost production

Reduced size, mass, and power consumption

High functionality; improved reliability

Novel solutions and new applications [1]

The harsh and high temperature environments have a significant challenge to current MEMS technology. MEMS for extreme temperature environments have attracted much attention due to their many potential applications, such as optical MEMS for high power laser applications and microcombustors for MEMS power sources.

To fabricate the MEMS for high-temperature applications we have to select suitable refractory materials and develop appropriate microfabrication techniques.

The Materials that would be able to fabricate by traditional microfabrication processes cannot operate at high temperatures for extended periods of time. Also, the technique usually used for high temperature MEMS, is time consuming and expensive. Therefore, the development of new materials and appropriate microfabrication techniques for high-temperature MEMS and improving properties of these fabrications are interesting for engineers. [2]

1.2. Polymer derived ceramics

The ceramic materials made by polymer derived ceramic (PDC) process have unusual properties. It has excellent resistance to mechanical deformation and to oxidation at temperatures as high as 1500^0C.The absence of creep at such high temperature is particularly surprising in view of the amorphous nature of PDCs. Nevertheless, the amorphous structure has other advantages: it does not contain defects such as grain interfaces and slip bands which are present in crystalline materials, these defects are often the source of failure in silicon. In summary, SiCN is much more robust than silicon and therefore, more suitable for MEMS applications in extreme temperature and harsh environments. The polymer route to processing also means that PDC-MEMS are likely to be low cost devices. [3]

Fig. 1 compares the aspect ratios achieved and maximum operating temperature of traditionally microfabricated MEMS with that of the polymer derived SiCN MEMS. [2]

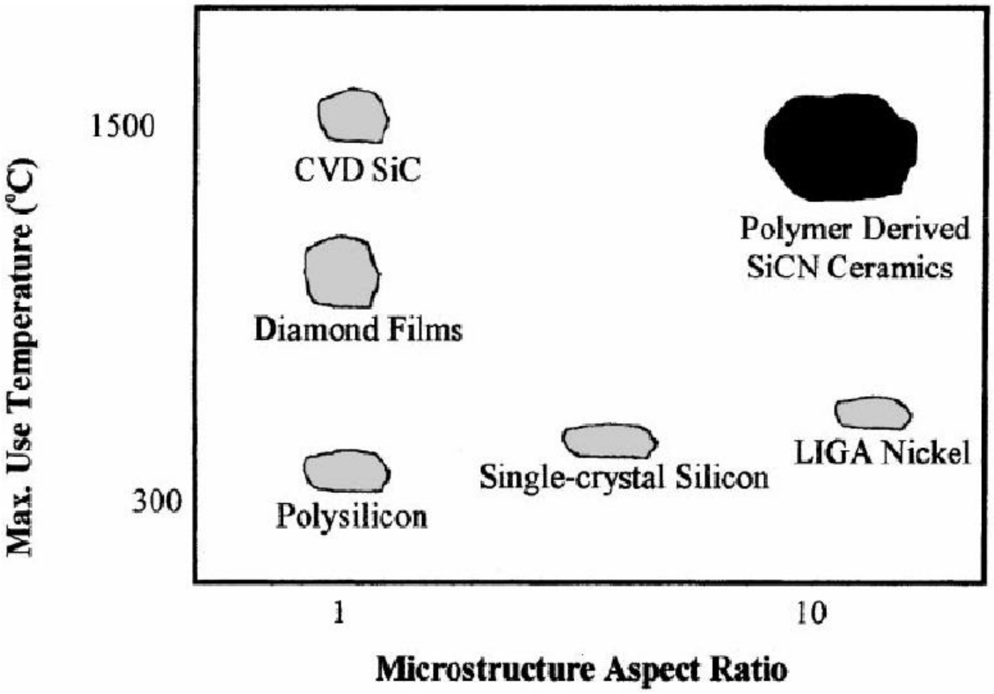

Fig. 1. Diagram of microstructure aspect ratio against maximum use temperature for different MEMS materials and processes.

2) Injectable polymer derived ceramics

The technique that used to fabricate this kind of MEMS is a novel technique. This new technology is based on the recently developed polymer-derived ceramics, which are bulk ceramics fabricated by the thermal decomposition of compact crosslinked polymer powders. The polymer-derived ceramics are amorphous alloys of silicon, carbon, and nitrogen (SiCN) which remain thermally stable up to 1500°C. The composition of the new ceramics can be varied through the use of different polymer precursors, and can be tailored to produce SiCN with excellent thermal and mechanical properties. Table 1 compares the physical properties of SiCN with those of Si and SiC. Young's modulus, Poisson's ratio, and density are in the same range as those of SiC and Si. The creep resistance of SiCN is comparable to that of SiC, while its oxidation resistance exceeds that of the same materials. In addition the thermal shock resistance of SiCN appears very promising for high-temperature applications.

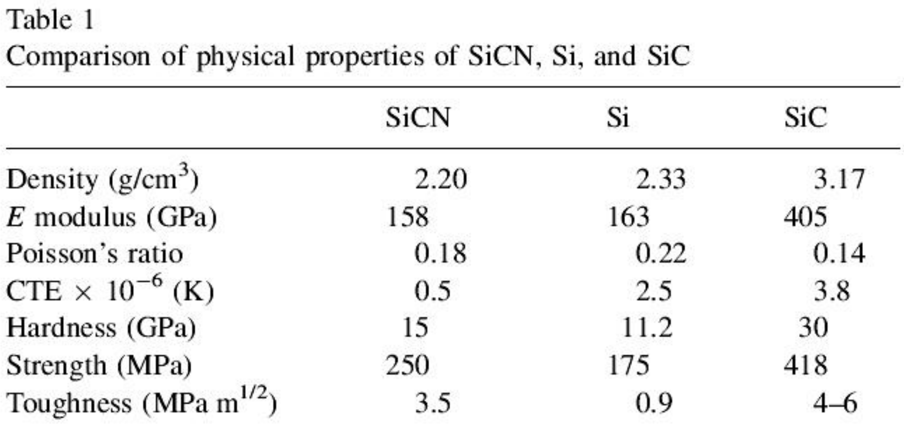

Table 1
Comparison of physical properties of SiCN, Si, and SiC

	SiCN	Si	SiC
Density (g/cm^3)	2.20	2.33	3.17
E modulus (GPa)	158	163	405
Poisson's ratio	0.18	0.22	0.14
CTE $\times$ 10^{-6} (K)	0.5	2.5	3.8
Hardness (GPa)	15	11.2	30
Strength (MPa)	250	175	418
Toughness (MPa m$^{1/2}$)	3.5	0.9	4–6

SiCN may be obtained from liquid- or powder-based polymer precursors. However, the SiCN obtained from the powder-route shows relatively low strength and hardness due to the high porosity of powder-derived ceramics in general (typically ~10 vil. % porosity). Therefore, liquid polymer precursors are more suitable to develop a micro-casting technique for the fabrication of SiCN MEMS structures. [2]

3) Microfabrication

Fig. 2 shows the process flow in the fabrication of SiCN MEMS using polymer precursor. First, a mold is fabricated using standard photolithographic techniques that schematically shown in Fig. 3. Second step is casting liquid polymer precursor into the mold and the mold and polymer precursor are then heated at ~ 250^{0}C to solidify the polymer (This step is called "thermal setting"). (Adding 5wt% photonitiator into the mold, along with a liquid precursor of SiCN and exposing to UV light is reported). After thermal setting, the polymer becomes a transparent solid, and may be separated from the mold if suitable techniques are used. To crosslink the polymer part, heating apply to ~ 400^0C under isostatic pressure. After crosslinking, the polymer becomes infusible, remaining transparent. In the final stage (pyrolysis), the crosslinked polymer part is heat-treated at ~1000^0C to convert it to a monolithic ceramic part. Fig.4. shows the schematic of fabrication process for SiCN MEMS. [2, 4]

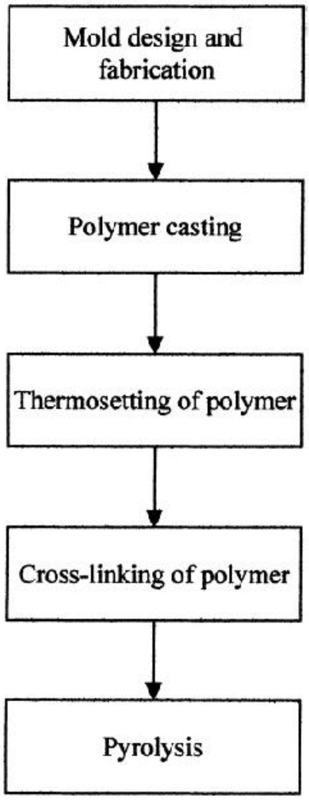

Fig.2 . General processing steps in the fabrication of injectable polymer derived ceramics.[2]

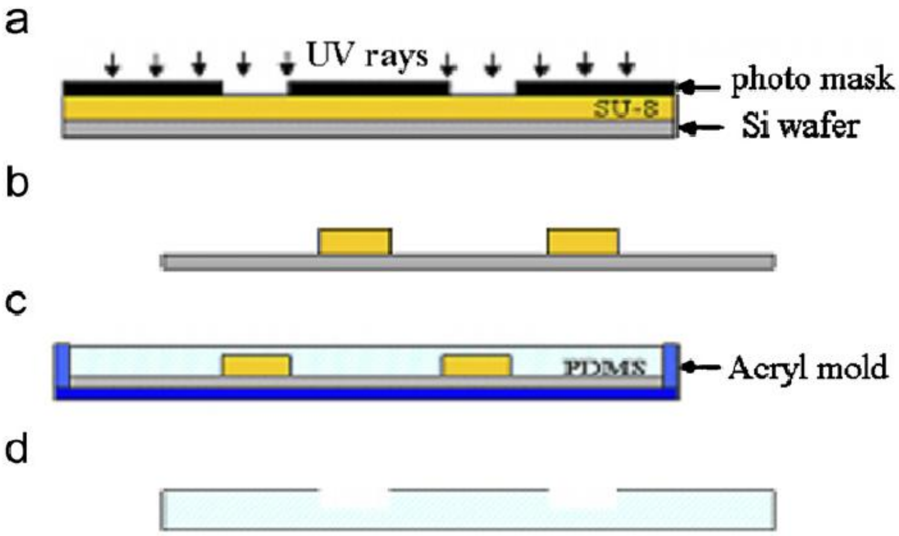

Fig. 3. Fabrication process sequence of micro mold.

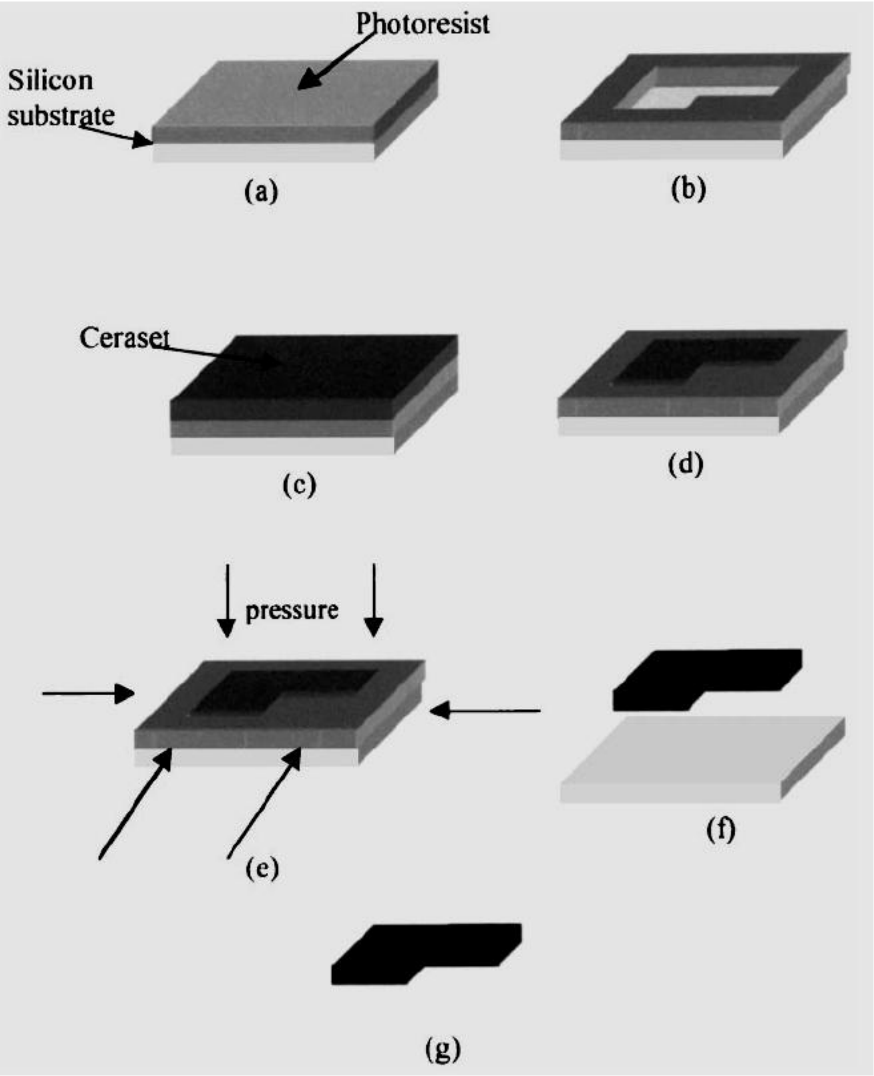

Fig.4. Schematic of fabrication process for SiCN MEMS

4) Materials and reactions

SU-8 is a well known negative, epoxy type photoresist based on EPON SU-8 resin that is used as a photoresist to make micro mold.

A Silicon substrate is used that the photoresist spun on it.

Polysilazane is used as the starting polymer that it has Ceraset commercial name from Lanxide company. Polysilazane is also producing by Kion corporation.

The photoresist is patterned using standard UV-lithography and developed.

As it is shown in Fig.4 after lithography and developing the photoresist the liquid precursor (Ceraset) is then cast into the cavities and the wafer is thermal set in an oven. Then the solid Ceraset that covered a thin layer on top of wafer is polished off and the wafer is crosslinked under isostatic pressure. During pyrolysis the SU-8 decomposes and the SiCN part no longer adheres to the substrate. [2, 4]

Fig.5 presents the reaction mechanism of conversion of liquid polysilazane into SiCN ceramic. [4]

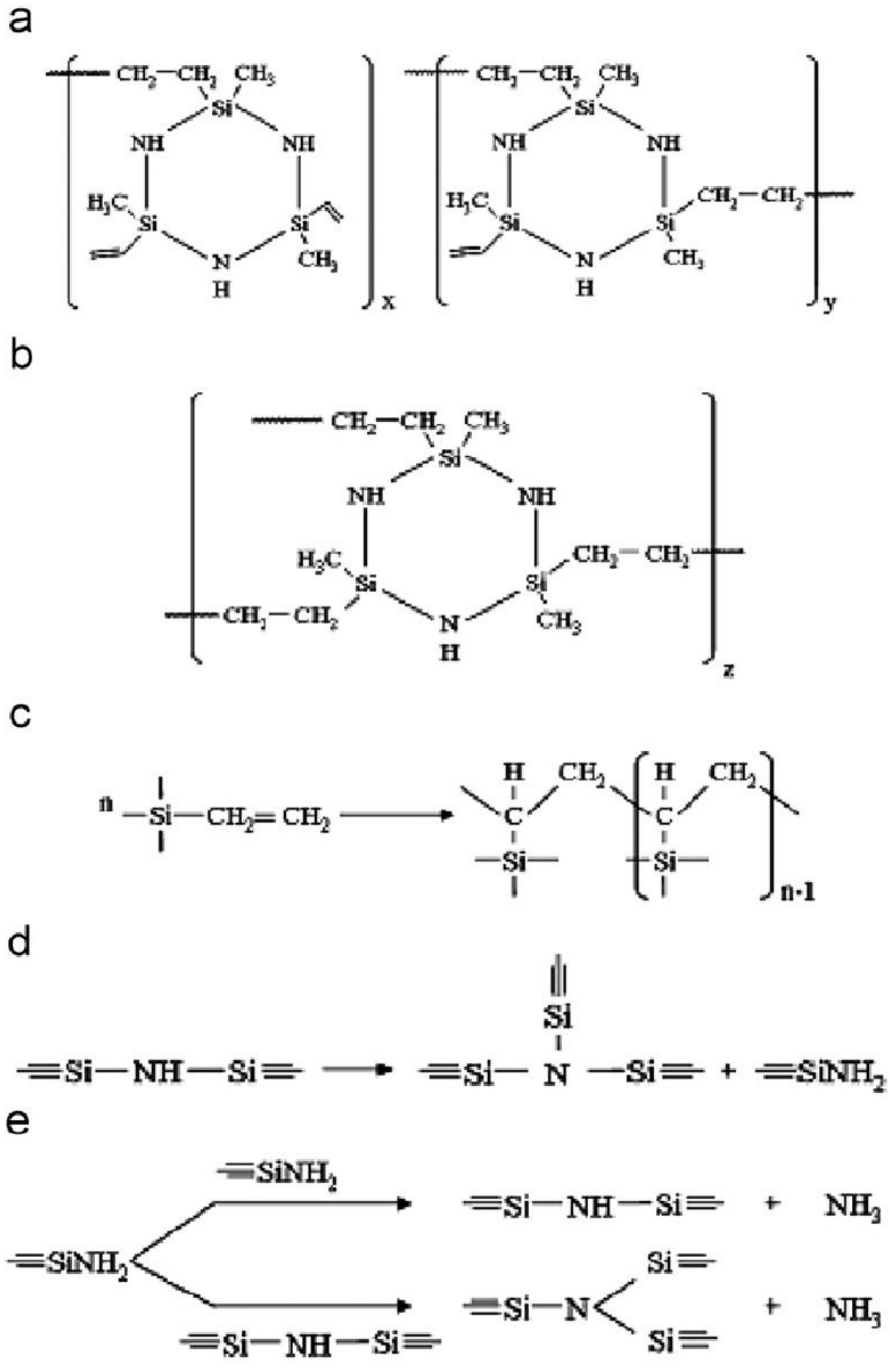

Fig.5.Reaction mechanism of SiCN.(a)beginning molecular structure (b) crosslinking between Si-H and N-H groups (c) crosslinking between vinyl group and Si (d, e) H_2 and NH_3 gases are released and the Si-C-N ceramic is formed. [4]

5) Size and shape limitations

Due to studies on the size range of samples that can be successfully cast, it has been found that the samples will crack at the crosslinking and pyrolysis stages if the length exceeds a certain critical value, which is a function of the sample thickness, being larger for thicker samples. The Ceraset experiences volume shrinkages of 5 and 25% during crosslinking and pyrolysis, respectively. However, at the same time the ceraset adhesion to the silicon substrate results in a tensile stress, σ, in Ceraset structure. This tensile stress in turn induces a shear stress, τ, at the silicon/Ceraset interface. Assuming a disk shape sample, the tensile and shear stresses are related by

$$\sigma = (r/2h)\tau$$

Where σ increases with the progress of heat treatment. Let τ_c and σ_c be the critical values for which the sample will peel off from the substrate and fracture, respectively. Then if the ratio r/h is too large (which corresponds to thin sample), then σ_c will be reached first and sample will crack. If the sample is thick, then τ_c will be reached first and sample will peel off from the substrate without cracking. The problem can be prevented by using crosslinked Ceraset as the substrate, because it will shrink together with microstructures. [2]

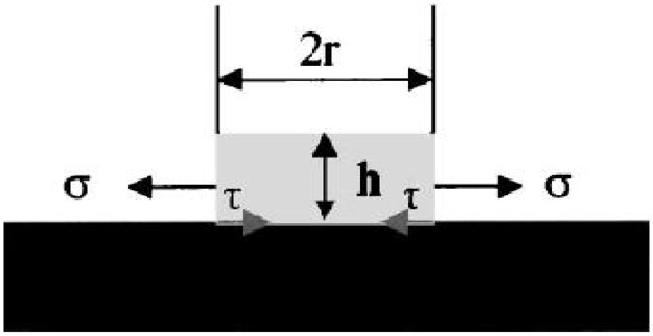

Fig.6.Induced stresses during heat treatment of Ceraset on silicon.

It could be concluded that the diameter of the gear is depended to its thickness and studies show that the diameter of the samples can be up to 10 mm.

References:

[1]L.L.Faulkner, Microengineering MEMS & Interfacing

[2] Li-Anne Liew, Wenge Zhang, fabrication of SiCN ceramics MEMS using injectable polymer-precursor technique

[3] J.S.Kong,D.M. Frangopol,A methodology for analyzing the variability in performance of MEMS actuator made from a novel ceramic

[4] Gwiy-sang Chung, Characteristics of SiCN microstructures for harsh environment and high-power MEMS applications