Ciliary motion in PECVD silicon carbide and silicon oxynitride microstructures

G. Rehder and M.N.P. Carreño[a]
Departamento de Sistemas Eletrônicos, Escola Politécnia, Universidade de São Paulo
61548, CEP 05424-970, São Paulo, SP, Brasil.

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The development of arrays of amorphous hydrogenated silicon carbide (a-SiC:H) and silicon oxynitride (SiO_xN_y) based microstructures that produce ciliary motion is presented. The arrays are fabricated by bulk micromachining of c-Si substrates and they are completely based on materials obtained by a low temperature PECVD (plasma enhanced chemical vapor deposition) technique. Chromium metal is sandwiched between these two materials and it is used as a contact metal and heating element. The ciliary motion is obtained by applying an external synchronized electrical voltage to the cantilevers, which move due to thermal expansion caused by the Joule Effect.

Keywords: MEMS; silicon carbide; Joule effect.

En este trabajo es presentado el desarrollo de matrices bidimensionales de microestructuras basadas en carburo de silicio amorfo hidrogenado (a-SiC:H) y oxinitruro de silicio capaces de realizar movimiento ciliar controlado. Las microestructuras son fabricadas por micromaquinado de volumen de substratos de silicio cristalino c-Si y están totalmente definidas en materiales obtenidos a bajas temperaturas por la técnica de PECVD (deposición química de la fase vapor asistida por plasma). Cromo metálico es embebido entre estos dos materials para ser utilizado como contacto y como elemento resistivo para calentar por efecto Joule. Aplicando una tensión externa de forma sincronizada a los cantilevers, se genera una corriente eléctrica, también sincronizada, que calentará las estructuras por efecto Joule y por causa de la expansion térmica producirá el movimiento ciliar.

Descriptores: MEMS; carburo de silício; efecto Joule.

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1. Introduction

The motivation for developing this study lies in the technological and economical importance of MEMS and its wide variety of applications, such as pressure and temperature sensors, accelerometers, micro-channels, micro-lenses and others. Furthermore, the development of MEMS devices that produce controlled and precise motion are of great interest [1, 2].

Due to the great impact of this technology, it is necessary to improve the fabrication processes and develop new materials to continue its advancement. Also, the integration of MEMS and IC fabrication are of great importance [3]. For these reasons, our research group has been working to develop materials deposited at low temperatures (less than 400°C) by PECVD (plasma enhanced chemical vapor deposition) with appropriate characteristics for MEMS, such as low intrinsic stress and chemical selectivity. In fact, our group has obtained materials such as amorphous hydrogenated silicon carbide (a-SiC:H) [4,5] and silicon oxynitride (SiO_xN_y) [6, 7], both suitable for MEMS fabrication [8, 9] and used in the present work. Furthermore, both materials have good selectivity in chemical etching, since a-SiC:H is resistant to HF and selectively etched in a CHF_3 and O_2 plasma, while and SiO_xN_y is easily etched in HF and it has a small etch rate in a CHF_3 and O_2 plasma. Also, the materials are resistant to KOH.

Previously, we demonstrated the process of fabricating self-sustained silicon carbide micro-bridges that produced controlled motion due to thermal expansion of the SiC film [10]. Continuing the earlier work, this paper describes the fabrication process of a more complex structure composed of arrays of cantilevers (4x8) of a-SiC:H and SiO_xN_y deposited by PECVD at low temperatures that produce controlled and synchronized ciliary motion, due to the Joule effect. The cantilevers are fabricated by bulk micromachining of the silicon substrate. Standard photolithography and selective etching are used to define the geometry of the structures which are 500 μm in length and 100 μm in width. Sputtered chromium is used as a heating element and contact metal.

2. Experimental procedures

The fabrication process involves two PECVD depositions (a-SiC:H and SiO_xN_y); one sputtering deposition (chromium); three photolithography steps – three masks (definition of chromium film, two definitions of SiO_xN_y); one plasma etch (definition of a-SiC:H); one KOH etch (bulk micromachining of silicon substrate). The sequence of steps for fabricating an array of cantilevers is shown in Fig. 1.

All the materials utilized are deposited by r. f. PECVD in a capacitively couple reactor. The deposition parameters were chosen according to previous research [4–7] that established them appropriately to obtain near stoichiometric films with low intrinsic stress.

The structures are characterized visually via a tilted optical stereoscope. Microleads are use to polarize the structures with an external dc bias. A Labview routine was created to control the frequency and duty cycle of the bias applied to each individual row of the array. The structures' responses are observed as the voltage pulses on and off. The expected

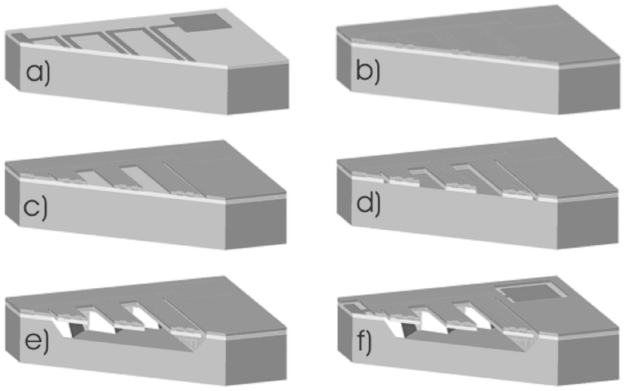

FIGURE 1. Sequence of steps of the fabrication process: a) deposition of 1-micron of a-SiC:H over $\langle 100 \rangle$ silicon substrate, then deposition and patterning of metal contacts ($\sim$0.3 μm); b) deposition of 1.5 μm of SiO_xN_y; c) patterning of $SiO_xN_y$by lithography and HF etching; d) patterning of SiC by plasma (50% CHF_3 and 50% O_2) etching; e) silicon etching in KOH solution (28.7% at 80°C); f) patterning of SiO_xN_y using photolithography and HF etching to open chromium contacts.

result is that current will flow through the contacts, thermally expanding the materials and causing the structures to move.

3. Results

Arrays of cantilevers can be fabricated using the fabrication process described. Symmetric and asymmetric arrays of cantilevers are shown in Fig. 2. Note that the cantilevers are bent slightly upwards due to the small intrinsic stress of the bilayer of a-SiC:H/SiO_xN_y films. Each row of cantilevers can be polarized independently, allowing for a sequential motion similar to ciliary motion. When voltage is applied to the structures, the current flows through the contacts, thus dissipating heat due to the Joule Effect. Therefore, the materials expand and the cantilevers move downward, inside the cavity. When currents in the range of 20 mA are applied, the cantilevers tend to flatten becoming, leveling with the substrate surface. Up and down motion with frequencies of up to 25 Hz were observed with no visual delay.

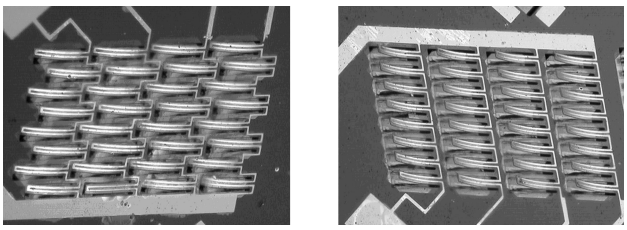

FIGURE 2. Arrays of symmetric and asymmetric cantilevers.

4. Conclusion

In this work we demonstrated the feasibility of fabricating arrays of self-sustained cantilevers based on amorphous hydrogenated silicon carbide (a-SiC:H) and silicon oxynitride (SiO_xN_y) deposited by PECVD at low temperatures that permit a controlled and synchronized motion, similar to ciliary motion. This process proved to be very effective, despite the aggressiveness of the final processing step, which uses conventional photolithography to expose the chromium contacts.

This work showed promising possibilities for implementing this process in specific applications such as optical switches and micropositioners.

[a] Corresponding author: Phone: (+5511) 3091-5256 Fax: (+5511) 3091-5585 e-mail:carreno@lme.usp.br.

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