Fabrication of Suspended C-NEMS Structures by EB Writer and Pyrolysis Method

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ABSTRACT

Carbon micro- and nanostructures has received widespread interest recently due to their potential applications in biomedical devices, chemical sensors, and microelectronics. In this work, we successfully fabricated carbon-micro and nano electromechanical systems (C-MEMS/NEMS) by UV/EB lithography and pyrolysis method. Our starting material is a negative photoresist, SU-8. We tried to solve charging problem by forming a thin metal layer before EB writing using various methods, such as EB evaporation, sputtering system and thermal evaporation. By partly depositing a thin layer of a metal to prevent the repelling of negative charged electrons, we have successfully formed various suspended carbon structures, such as bridges and networks.

Keywords: carbon-microelectromechanical systems, suspended structure, pyrolysis, photoresist

1 INTRODUCTION

Carbon comes in many forms, such as: diamond,graphite, buckeyballs, nanotubes, nanofibers, glassy carbon, and diamond-like carbon (DLC). These materials are used in a variety of applications, based on their different crystalline structures and morphologies which enable very different physical, chemical, mechanical, thermal and electrical uses. Recently Carbon micro and nano structures have attracted a lot of research interest because of its potential applications in biological, chemical and electronic devices [1,2,3]. For example, in biosensing application these micro or nanostructures can alter the catalytic activity, affect specificity of biological systems and highly specific molecular recognition processes [4,5]. Microfabrication of carbon structures using current processing technology includes focused ion beam and reactive ion etching [6,7]. Recently a novel technology to microfabricate carbon micro structures based on UV lithography and pyrolysis process was reported [8-10]. However the idea of fabricating various complicated suspended three dimensional carbon structures is still a big challenge. Here suspended C-MEMS structures were fabricated by EB lithography and pyrolysis by accurately controlling the processing parameters.

2 FABRICATION & PROCESSING

The fabrication of the suspended C-MEMS structures involved mainly three steps: (1) UV lithography, (2) EB lithography, and (3) pyrolysis process.

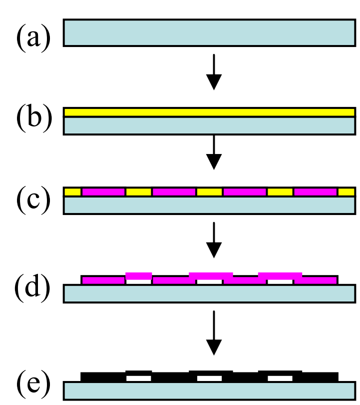

Figure 1:(a) Si substrate (100); (b) SU-8 film of 100μm thickness was spin-coated; (c) patterning the photoresist by UV exposure; (d) patterning suspended structures by EB writer, and then developing; (e) finally pyrolyzing the photoresist patterns to convert them to carbon structures.

The substrate we used were Si (100) surface, which was spin-coated with SU-8 negative chemically amplified resist. The SU-8 resist was then patterned to get SU-8 posts which have a diameter of 50μm and have a spacing of 50μm between them. The patterned photoresist posts (non-developed) were then transferred to E-beam lithography system to write the desired pattern on these posts. Eventually the unexposed photoresist was washed away in developing process to leave us the suspended SU-8 structures. The suspended carbon structures were obtained by pyrolysing the SU-8 structures in a diffusion furnace at about 900^0C for 1 hr in a forming gas environment. The process flow of the fabrication steps is shown in figure1.

3 RESULTS & DISCUSSION

Figure 2 shows the SU-8 suspended structures we obtained. Suspended thin SU-8 bridges of about 30 μm in width, 50 μm in length, and 10 μm in thickness were patterned between SU-8 post arrays. After pyrolysis, suspended carbon microstructures with about 15 μm in width, 50 μm in length, and 3-5 μm in thickness are shown in figure 3. It can be seen that after high temperature process the carbon posts and suspended bridges shrink isometrically and kept similar shapes as SU-8 structure. For some of the structures, because of the unbalanced drag force,

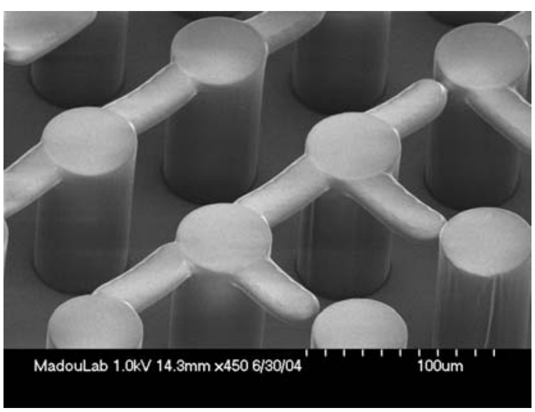

Figure 2: A typical SEM picture of SU-8 posts with suspended micro structures (before pyrolysis).

the posts were found to bend towards each other. A major problem here is charging up during EB writing on nonconductive SU-8 surface because of the accumulation of negative charged electrons. The repelling effect of the accumulated charge with the incoming electron results in further difficulty to focus and align the electron beam on surface.

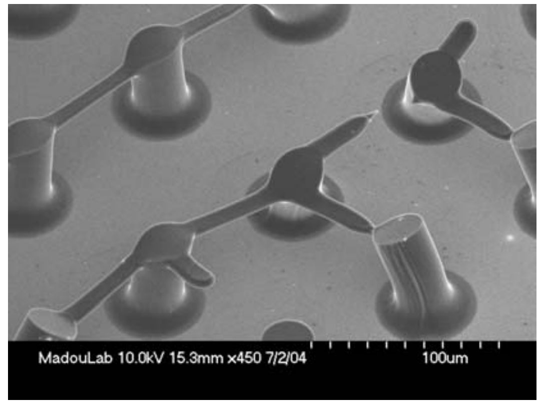

Figure3: A typical SEM picture of carbon posts with suspended micro structures (after pyrolysis).

In order to prevent the charging of the SU- 8, thin layers of gold (10 nm) were deposited by both sputtering method and e-beam evaporation method. After that EB writing was performed to pattern suspended structures without charge up effect. Unfortunately after removing Au layer by wet etching, it was observed that a thin SU-8 layer was formed which could not be removed by developer. Figures 4 and 5 show the thin SU-8 film thus formed. It was confirmed that underneath the thin sheet of SU-8 the posts were developed very well. Also, it was concluded that during both sputtering and EB evaporation processes, the SU-8 surface was attacked and exposed by the high energy ions and/or X-rays resulting in the surface cross linking and inability to pattern suspended structures.

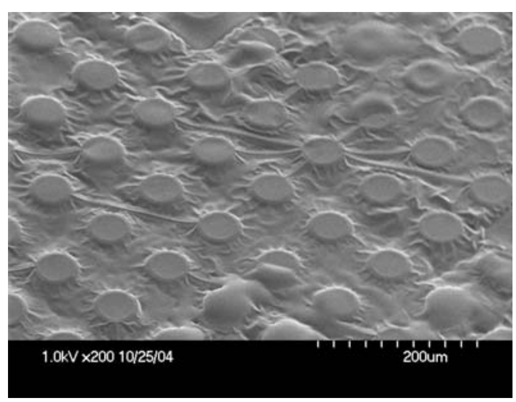

Figure 4: The typical SEM picture obtained from the SU-8 sample after e-beam writing, Au layer (formed by sputter deposition) removal, and developing.

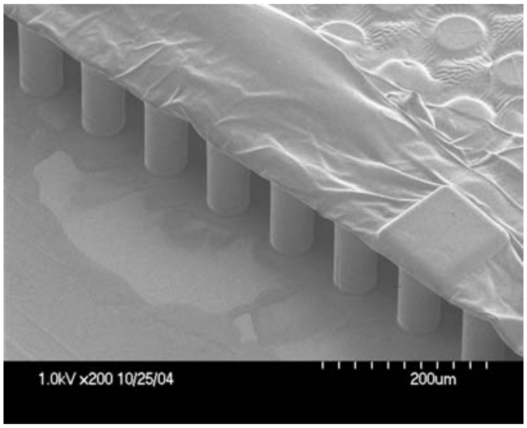

Figure 5: Typical SEM picture obtained from the SU-8 sample after e-beam writing, Au layer (formed by EB evaporation) removal, and developing.

In order to prevent both charge-up and complete cross linking of the surface, we partially mask the area of the SU-8 posts with a dummy wafer and then evaporate Au (10nm) on the unmasked part of the sample. Next, we do the routine aligning on metallized part and EB writing on unmetallized parts to obtain the desired suspended pattern. The EB written area was successfully developed. The SU-8 posts are then pyrolysed in an forming gas environment at 900^{0}C for one hour to convert it to carbon [9,10]. Figure 6 shows the perfectly horizontal suspended carbon microstructures with no bending of the carbon posts. It can be observed that the suspended carbon microstructures were about 10μm in diameter and about 50μm in length. In this case since there was equal drag force in both the directions there was no bending of the carbon posts. Figure 7 shows a ring type C-MEMS structure. Here there is inward bending of the carbon posts due to the radial nature of the drag force components. It can also be observed from figure 8 that the in case of the suspended structures that were patterened in a straight line. The bending of the posts occurred only at the edge posts because of unidirectional drag forces on these posts. Different suspended structures as desired can be generated by designing the pattern we want on the EBL.

4 CONCLUSIONS

In conclusion, suspended C-MEMS structures were formed by UV/EB lithography and pyrolysis method. We tried to solve charging problem by forming a thin metal layer before EB writing using various methods, such as EB evaporation, sputtering system. By partly depositing a thin layer of a metal to prevent the repelling of negative charged electrons, we have successfully fabricated various complicated suspended carbon structures.

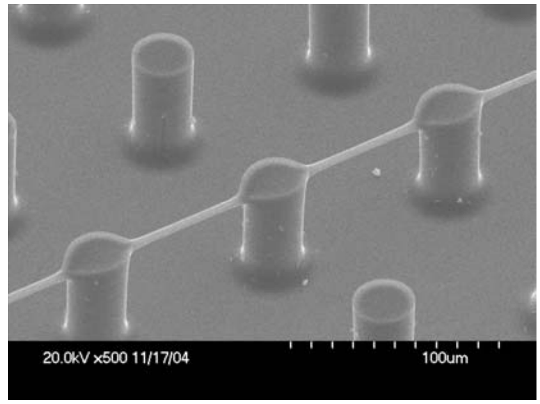

Figure6: Typical SEM picture horizontal carbon microstructures suspended between carbon posts obtained from the SU-8 sample after e-beam writing, Au layer (formed by EB evaporation) removal, and developing.

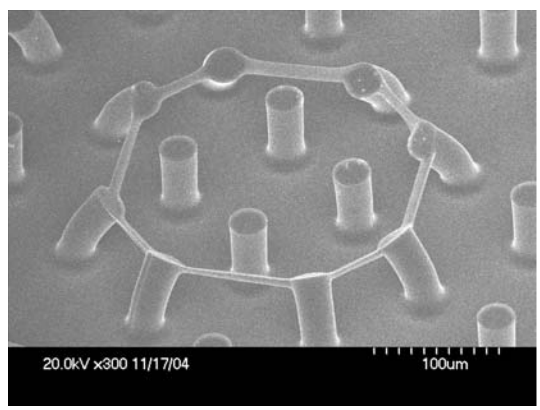

Figure 7: Typical SEM picture showing the Ring type C-MEMS structures fabricated by EBL and pyrolysis of SU-8 photoresist.

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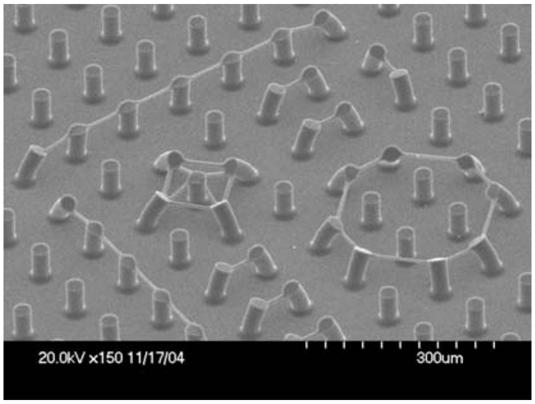

Figure 8: A SEM image of microstructures with various designs.

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