A NOVEL FABRICATION METHOD OF HOLLOW NANONEEDLES APPLICABLE FOR SINGLE CELL OPERATION

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ABSTRACT

In this work, a novel method, utilizing FIB (focused ion beam) nanomachining, PECVD refilling and wet-etching release processes, to fabricate the in-plane hollow nanoneedle, has been developed. A separate process was employed to verify and optimize the PECVD refilling process. A 170nm-wide hollow nanoneedle with a 14nm-wide nanochannel has been successfully fabricated. The nanoneedle has a good potential for single cell operation including delivery and extraction of biological components such as DNA, RNA, proteins and drugs.

KEYWORDS: Nanoneedle, Fabrication, Cell Operation

INTRODUCTION

Delivery and extraction of biological components such as DNA, RNA, proteins and drugs have great significance in single cell operation. Recently, micro/nanoneedles have been treated as an important part of the delivery or extraction system in micro/nanoscale. The hollow microneedles fabricated in different methods have been widely reported [1-2], but the scale is too large for cell operation without damaging the cell. The nanoneedle based on AFM was developed for single cell operation [3-4], but the process of injection or extraction with the non-hollow nanoneedle was complex, inconvenient, and with limited capacity. Therefore, we propose an approach to use hollow needles in nanoscale for single cell operation with simple process and little damage, as shown in Fig. 1. The in-plane freestanding hollow nanoneedle, as the critical part of the system, can mechanically penetrate the cell membrane with a minimized hole, and deliver/extract biological components into/from the cell through a connected microfluidics system.

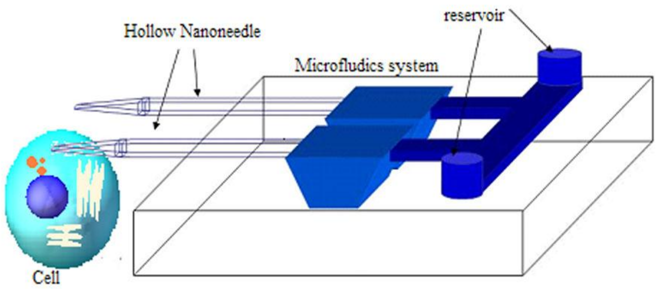


Figure 1: The schematic view of hollow nanoneedles applicable for cell operation.

In this preliminary work, a novel method, utilizing FIB (focused ion beam) nanomachining, PECVD refilling and wet-etching release processes, to fabricate the in-plane hollow nanoneedle, has been developed.

EXPERIMENTAL

SiC is chosen as the nanoneedle material owing to its high resistivity, excellent mechanical property, chemical inertness and biocompatibility. The simplified process is schematically illustrated in Fig. 2. A 4-inch silicon wafer is used as the substrate. In order to study the application of the method in different scales, nano-trenches in different widths and depths and length of 2.5µm are etched by FIB, as shown in Fig. 2(a). A 300nm-thick low-stress SiC layer is deposited to refill the trenches with PECVD process, and a 400°C annealing is employed to reduce the stress further in order to avoid deformation of the needle after release. It is well-known that PECVD is a process with imperfect step coverage and gap refilling capability, which is, interestingly, enabling feature for formation of the enclosed nanochannel in our process. As shown in Fig. 2(b), PECVD SiC film grows faster on the top convex corners, where the trench will be sealed first and the enclosed nanochannel will be built in the trench.

(a) (b)

(c) (d)

Figure 2: The process of experiment.
a) Etching nanochannels with the width each is by FIB, b) PECVD 300nm-thick SiC, c) Etching a hole on one end of the channel by FIB and HNA etching for 5 minutes, d) Releasing the nanoneedle

After a release holes on one end of each channel are opened by FIB, the sample is immersed in the HNA (1HF: 3HNO3: 8CH3COOH) solution for 5 minutes to isotropically etch the silicon under the nanochannel, as shown in Fig. 2(c). Fig. 2(d) shows the results after micromachining by FIB to release the hollow nanoneedle.

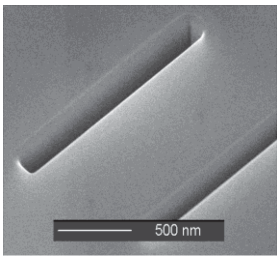
RESULTS AND DISCUSSION

The critical step to fabricate a hollow nanoneedle is to form an enclosed nanochannel with a well-controlled size and profile. A separate process was employed to verify and optimize the PECVD refilling process, and results are shown in Fig. 3. It can be seen in Fig. 3(b) that the trench was completely sealed and a enclosed microchannel is formed. It is demonstrated clearly that PECVD is a process with imperfect step coverage and gap refilling capability. Fig. 3(a) shows that when the trench is too wide it cannot be sealed on the top, while Fig. 3(b) shows that the narrow trench can be sealed with the same sickness of SiC.

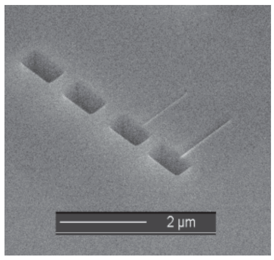
(a) (b)

Figure 3: SEM of PECVD step coverage for trenchs.
(a) A partially refilled trench and (b) a completely sealed trench.

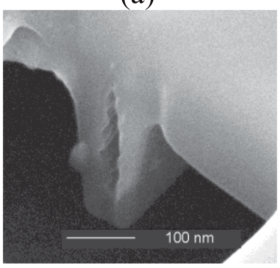
The SEM pictures of results at each step are shown in Fig. 4. The trench with original width of 300nm was not completely sealed on the top, whereas the nanochannel was unobservable for the 50nm-wide trench. The hollow nanoneedles were successfully constructed from the 100nm-wide and 200nm-wide trenches.



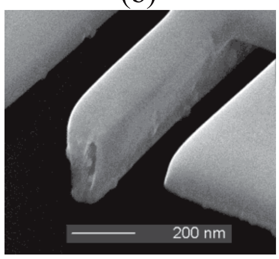
(a)



(b)



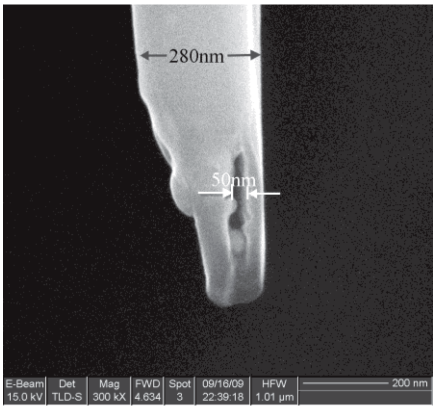
(c)



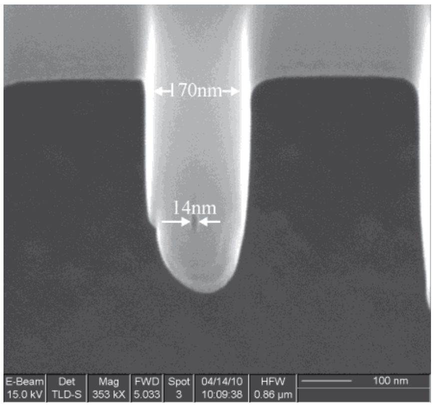
(d)

Figure 4: The results of each step in the experiment by SEM.
a) Etching nanochannels by FIB, b) PECVD 300nm-thick SiC and etching a hole on one end of the channel by FIB, c) HNA etching for 5 minutes, d) Releasing the needle

The feature size of the hollow nanoneedle is determined by its original trench size, PECVD parameters and the final FIB process. The profile of the nanoneedles could be trimmed to sharp tip or rectangular tip as shown in Fig. 5. A 170nm-wide hollow nanoneedle with a 14nm-wide nanochannel, which is much smaller than the reported hollow nanoneedles, is demonstrated in Fig. 5 (b). The nanoscaled size is very important for the single cell operation owing to its minimized damage. The mechanical property of the nanoneedles and fluidic characterization of nanochannel are still under investigation.



(a)



(b)

Figure 5: SEM pictures of fabricated hollow nanoneedles with different feature size and profile.

CONCLUSION

Taking advantages of the nanofabrication capability of FIB and imperfect step coverage feature of PECVD process, a novel method to fabricate the freestanding in-plane hollow nanoneedle has been developed. A 170nm-wide hollow nanoneedle with a 14nm-wide nanochannel, which is, to our best knowledge, the smallest hollow needle has ever been reported, has been fabricated. The nanoneedle will be integrated with micro fluidics and applied for single cell operation in the future work.

ACKNOWLEDGEMENTS

This work was supported by National Science Foundation of China (No. 60976085)

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