SUPERHYDROPHOBIC TRANS-SCALE STRUCTURE USING A COMBINATION OF A SILICON MICROBOWL AND CNT FOREST FOR BIOMIMETIC ARCHITECTURE

Ju-Hyun Kim, Yong-Bum Park, and Yang-Kyu Choi
Nano-Oriented Bio-Electronics Lab, Division of Electrical Engineering, School of Electrical Engineering & Computer Science, KAIST, Daejeon, 305-701, Korea

ABSTRACT

A new method to fabricate the trans-scale structure of the micro-scale bowl and the nano-scale carbon nanotube (CNT) forest is presented. The new method mimics the natural structure of a superhydrophobic surface like a lotus leaf. The robust silicon microstructure (Si microbowl) and the subsequent CVD growth of CNT have successfully combined the nanoscale CNT forest on the Si microbowl for enhanced hydrophobicity. The proposed two-step process enables the fabrication method of the trans-scale structure to be simple and stable. A high contact angle (CA) of 168° was achieved by process optimization and surface treatment with perfluoro-decyl-trichloro-silane (FDTS).

KEYWORDS: Superhydrophobic, Trans-scale, Microbowl, CNT, Biomimetics

INTRODUCTION

There has been intensive research to realize a hydrophobic surface using the mono-scale microstructure [1] or the hierarchical trans-scale structure, which consists of two mono-scale roughnesses of nano- and micro-structures, based on microbeads [2], and polymer pillars [3]. These polymeric microstructures, however, have problems in terms of chemical, physical, and thermal stability. Moreover, they impose a constraint on the subsequent nanostructure formation, restricting it to room temperature with polymer-friendly chemicals.

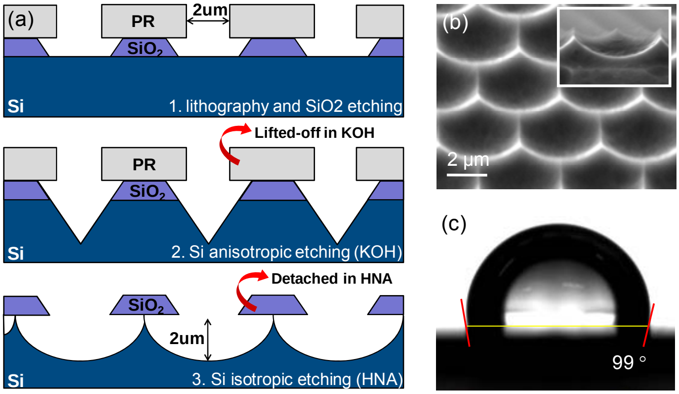

Figure 1. (a) Process flow of Si microbowl fabrication. (b) SEM image of fabricated Si microbowl. (c) Measured contact angle on Si microbowl.

To overcome these problems, we fabricated a robust silicon microstructure (Si microbowl) using a wet etching method. The direct CVD growth of CNT was followed to combine the nano-scale CNT forest on the Si microbowl and enhance the hydrophobicity. The proposed method has improved the formation of trans-scale structure for superhydrophobic surfaces in terms of simplicity, stability, and compatibility with CMOS process. Various contact angles (CA) with different thicknesses of the TiN buffer layer and CNT growth times were studied and chemical-assisted improvement of the contact angle using FDTS was discussed as well.

EXPERIMENTAL

The fabrication process of the Si microbowl, a micro-scale component, is schematically shown in Figure 1(a). First, thermal oxide was grown on the silicon wafer to serve as an etching stopper for subsequent silicon etching. Perfectly ordered arrays were delineated on the thermal oxide by photolithography. Second, the sample is immersed into BOE solution to etch the oxide until the silicon substrate is exposed. Third, sequential anisotropic and isotropic etchings of silicon are employed to attain a microbowl structure with nano-scale apexes. Anisotropic etching of the silicon by KOH solution produces pyramidal shaped trenches. Then, this patterned silicon is etched by HNA (hydrofluoride-nitric-acetic acid) solution, which tapers the pyramidal shape into the microbowl shape. The fabricated Si microbowl and measured contact angle are shown in Figures 1(b) and 1(c), respectively.

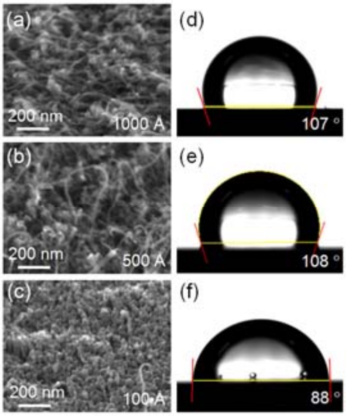

Figure 2. SEM images of different buffer layer (TiN) thicknesses [(a), (b), and (c)] and corresponding measured CA [(d), (e), and (f)] on the mono-scale CNT forest.

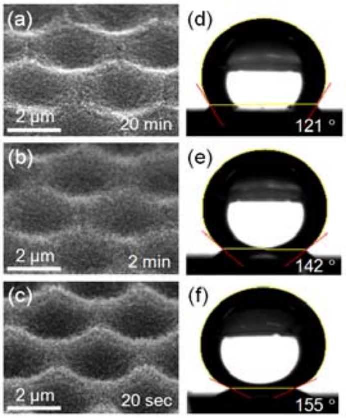

Figure 3. SEM images of different CVD growth times [(a), (b), and (c)] and corresponding measured CA [(d), (e), and (f)] on the trans-scale CNT forest.

The CNT forest, a nano-scale component, was formed by CVD with a TiN buffer layer and Co catalyst. For process optimization, various thicknesses of TiN were deposited on the flat silicon substrate since the final morphology greatly depends on this buffer layer thickness. The surface morphologies and corresponding contact angles are shown in Figure 2. Among the three kinds of TiN thickness, a CNT forest of 500 Å TiN showed the highest contact angle of 108° due to the low CNT density and high capability of air trapping according to the Cassie-Baxter model.

RESULTS AND DISCUSSION

According to aforementioned optimization, the combination of two mono-scale structures was done by means of direct CNT growth on the Si microbowl. Figure 3 shows the surface morphology and corresponding contact angle of the trans-scale CNT forest with various conditions of growth time with a fixed TiN thickness of 500 Å. The trans-scale structure showed improved hydrophobicity, but excessive growth of CNT for 20 min, which adversely led to the planarization of the Si microbowl morphology. The flattened surface lost its hydrophobicity and the contact angle was decreased to 121°, which is not attractive compared to the mono-scale structures. Since shorter growth time was preferred to accommodate more air tapping sites, the growth time of 20 sec was chosen, thereby a contact angle of 155° was achieved. With the aid of chemical treatment using FDTS, a hydrophobic group, a contact angle of 168° was attained at the trans-scale CNT forest. The hydrophobic characteristic was analyzed for various control groups and compared in Figure 4(b).

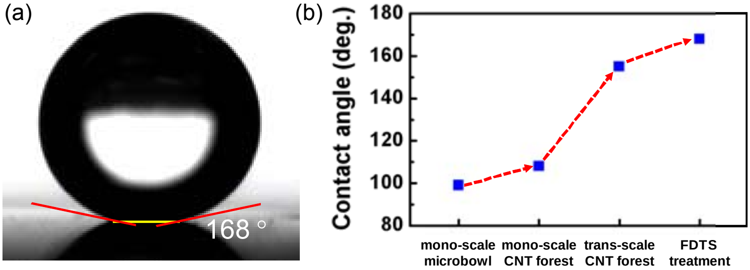

Figure 4. (a) The CA measurement after chemical surface treatment with vapor phase FDTS on the trans-scale CNT forest [Fig. 3(c)]. (b) CA comparison for various experimental groups.

CONCLUSIONS

The fused fabrication method of the Si microbowl and CNT forest presents a simple and fancy way to mimic the beneficial properties of nature. Moreover, the proposed trans-scale structure can be used for various applications, such as bio and chemical sensors, due to its enlarged surface area.

ACKNOWLEDGEMENTS

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