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The 19th International Conference on
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TRANSDUCERS '17

Kaohsiung

JUNE 18 - 22, 2017 ■ KAOHSIUNG, TAIWAN

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TRANSDUCERS '17 KAOHSIUNG — CONFERENCE AT A GLANCE

SUNDAY, JUNE 18

11:00 - 20:00	Conference Registration and Check-In
12:30	Industry Sessions Registration
13:00 - 15:10	Industry Session - Start-Up (Room 301a)
15:10 - 15:30	Break
15:30 - 17:30	Industry Session - IoT (Room 301a)
17:40 - 20:00	Welcome Reception

MONDAY, JUNE 19

07:30 - 17:30	Registration			
08:30 - 09:10	Welcome Address and Technical Program Introduction			
09:10 - 09:50	PLENARY PRESENTATION I Alexander Kalnitsky, *Taiwan Semiconductor Manufacturing Company, Ltd. (TSMC), TAIWAN*			
09:50 - 10:30	PLENARY PRESENTATION II Albert van den Berg, *University of Twente, NETHERLANDS*			
10:30 - 11:00	Break and Exhibit Inspection			
11:00 - 11:40	PLENARY PRESENTATION III Kenneth S. Johnson, *Monterey Bay Aquarium Research Institute, USA*			
11:40 - 11:50	Transducers 2019 Conference Presentation			
11:50 - 12:00	Announcements			
12:00 - 14:00	Lunch and Exhibit Inspection			
12:30 - 14:00	Industry Session - IDM (Room 301a)			
14:00 - 16:00	Poster/Oral Session M3P (Refreshments Available)			
	ROOM 301a	ROOM 301b	ROOM 304a	ROOM 304b
16:00 - 17:30	Session M4A Bio Probes	Session M4B *In Vivo*	Session M4C Microphones & Other Physical Sensors	Session M4D RF MEMS I
18:20 - 21:00	Sunset Beach Reception			

TUESDAY, JUNE 20

	ROOM 301a	ROOM 301b	ROOM 304a	ROOM 304b
08:30 - 10:00	Session T1A Droplets INVITED SPEAKER	Session T1B Bio Imaging INVITED SPEAKER	Session T1C Piezoelectric Transducers INVITED SPEAKER	Session T1D RF MEMS II INVITED SPEAKER
10:00 - 10:30	Break and Exhibit Inspection			
	ROOM 301a	ROOM 301b	ROOM 304a	ROOM 304b
10:30 - 11:45	Session T2A Cell Analysis	Session T2B Chemical Sensors	Session T2C Graphene	Session T2D Optical Transducers I
11:45 - 14:00	Lunch and Exhibit Inspection			
12:30 - 14:10	Industry Session - Fab (Room 301a)			
14:00 - 16:00	Poster/Oral Session T3P (Refreshments Available)			
	ROOM 301a	ROOM 301b	ROOM 304a	ROOM 304b
16:00 - 17:45	Session T4A Cell Culture	Session T4B Gas Sensors I	Session T4C Stretchables & Wearables	Session T4D Energy Harvesters

SIMPLE AND COST-EFFECTIVE METHOD FOR FABRICATION OF OPTICALLY TRANSPARENT SUPERHYDROPHOBIC THIN FILM USING REUSABLE PUA MOLD AND ROLL-TO-ROLL MACHINE

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ABSTRACT

In this paper, a cost-effective method for mass production of optically transparent super-hydrophobic PDMS thin film is proposed and characterized. The dual-scaled micro/nano PDMS patterns are re-replicated using a photoresist mold (reverse image), PDMS mold (dual-scaled positive structures) and UV curable polyurethane acrylate (PUA, negative structures) mold. The PUA mold can be employed as a reusable mold for continuous production of the super-hydrophobic PDMS thin film in a home-made roll-to-roll (R-to-R) system. The proposed method is extremely simple and cost-effective in comparing with previous methods. Thanks to the proposed PUV mold and the roll to roll system, continuous production of transparent super-hydrophobic PDMS film is possible, which will be a basis for mass production. The experimental results reveal that the proposed method has great potential to extend the utility of the optically transparent super-hydrophobic thin film.

KEYWORDS

PUA micro/nano mold, Super-hydrophobic PDMS film, Roll-to-roll system.

INTRODUCTION

Micro-/nano structures are becoming very critical for novel biomimetic smart surfaces and dry adhesive applications. Inspired by such amazing natural wonders, there have been tremendous efforts to create artificial super-hydrophobic surfaces with water contact angles greater than 150° for applications such as self-cleaning, antisticking, and drag reduction applications [1]. It was found that a hierarchical dual micro-/nano-scale structure design is an effective way to create super-hydrophobic surfaces [2-4]. Various materials such as silicon [5] and carbon nanotubes [6] have been studied and developed to create hierarchical micro-/nano-structured surfaces like lotus leaves which had super-hydrophobic and self-cleaning effects. However, those ideas still suffer from transparency. For the surface to be optically transparent the material of the film must be essentially transparent and the surface roughness must be less than the wavelength of the visible light.

To overcome this, research has been conducted on films such as polymethylmethacrylate (PMMA), polystyrene (PS), and polydimethylsiloxane (PDMS) in various fields requiring high optical transparency. The PDMS structure reported in the previous report [7] has greatly improved hydrophobicity but can't be reused because thick photoresist is used as the mold structure.

In this paper, we report the details of fabrication method based on reusable PUA (UV curable polyurethane-acrylate) mold and roll-to-roll system. They are developed for overcoming drawbacks of currently available fabrication methods and efficiently manufacturing super-hydrophobic thin film with a large scale. PDMS films can be produced continuously through the reusable PUA mold and the roll-to-roll system, which can greatly shorten mass production and production time The new fabrication process and successful experimental results reveal that the proposed idea has significant potential for diverse use of the super-hydrophobic transparent PDMS thin film.

EXPERIMENT METHODS

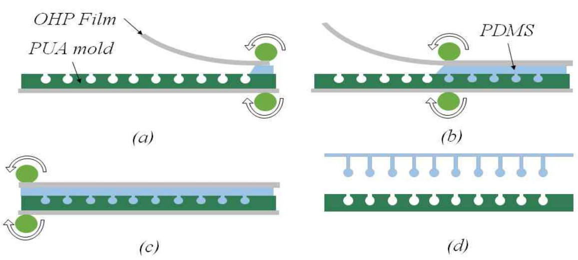

Figure 1: Fabrication flow chart of Roll to Roll method for a hydro-phobic PDMS film.

A large-area PDMS super water-repellent film was produced using the PUA mold and roll-to-roll machine (Figure 1) having a new method. Since the roll-to-roll technique can be continuously produced, mass production of super water-repellent film using PDMS polymer is possible. In the mass production process of the super water-repellent film, the PUA mold is placed between the respective OHP films in-(a) the PDMS is poured on the upper surface of the PUA mold, and then it is designed to be transferred between rolls having a constant interval. The PUA mold and the PDMS between the rolls are transported according to the rotation direction of the roll and coated with a constant thickness in-(b). At this time, the PDMS solution is filled into the PUA mold by the pressure of the roll in-(c), and PDMS is subjected to the hardening process on the hot plate to complete the film production in-(d). The greatest advantage of the roll-to-roll system is that it does not require a process to remove bubbles by using a vacuum pump, which can shorten the production time and has the advantage of continuous process due to the characteristics of the roll process

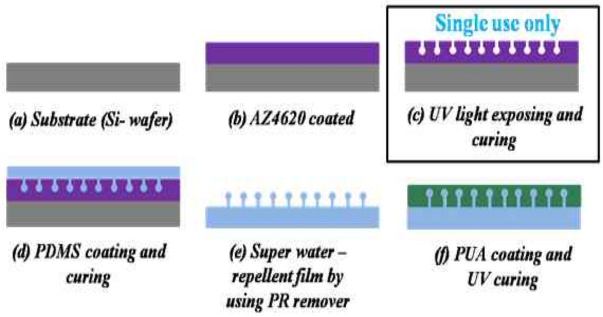

Figure 2: Schematic of fabrication process

Figure 2 show a process of reusable PUA mold. First, a thick AZ4620 (photosensitive agent) was multi-coated onto a 4-inch silicon wafer in-(a). After that, the micro/nano structure is prepared by adjusting the baking time and the UV irradiation amount and then cured in-(b-c). In the next step, the PDMS is coated on the inside of the concave angle, and then the PDMS is cured so that the engraved pattern is completely transferred in-(d). Finally, the photoresist layer is chemically dissolved using AZ Remover solution, and the wafer and PDMS are separated to complete the fabrication in-(e). However, the mold method using a photosensitizer has disadvantages that it can be used only once because the mold separates the PDMS super water-repellent film by removing the photosensitizer, and has a fatal disadvantage from the point of view of mass production because of a long production time. In order to overcome this problem, a mold using UV curable polymer was further developed in-(f).

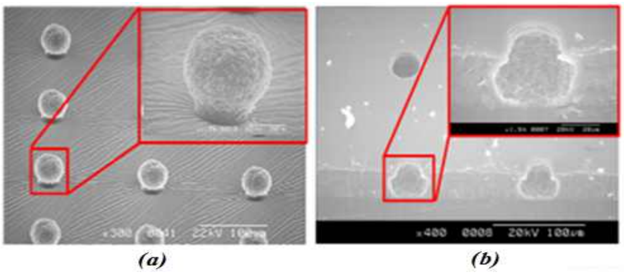

Figure 3: SEM images of (a) PDMS mold (positive), (b) replicated PUA mold (negative)

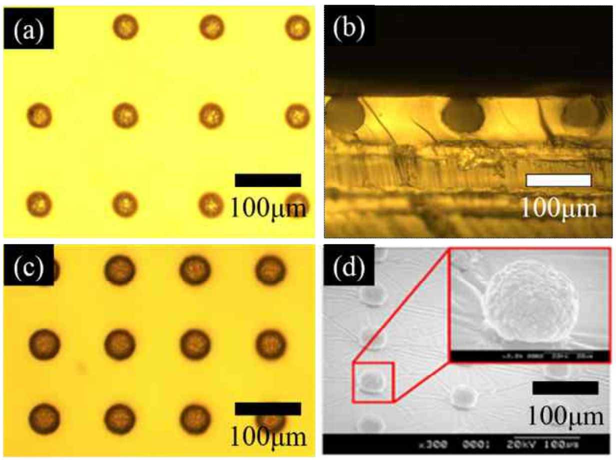

Figure 4: Optical images of (a) replicated UV-curable polymer mold (PUA) image, (b) the PUA mold cross section, (c) re-replicated ultra-hydrophobic film striped from the UV-curable polymer mold and (d) the PDMS SEM image

The reusable mold can be fabricated by pouring the UV polymer into the PDMS mold and then irradiating UV. The UV curable mold image is shown in Figure 3. The results of curing with PUA were confirmed to be flattened in all parts except micro-/nano structure as shown in 3-(b), and it was confirmed that PDMS pattern was transferred to PUA as shown in 4-(b) (Negative). PUA has high hardness of material and it is confirmed that PDMS casting or deformation due to external force is very small and stable production is possible [8]. As a result of using UV curable polymer mold, stable production and reuse of the device are possible, and since the mold can be manufactured in the form of an array, it is advantageous in that it can be manufactured in a larger area than the conventional method using the PR mold

RESULTS AND DISCUSSIONS

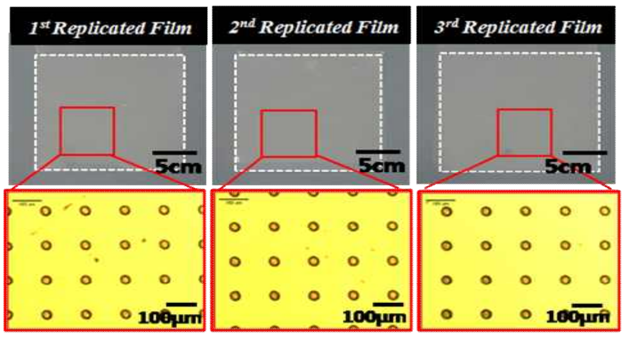

Figure 5: Optical microscope images of PDMS films repeatedly fabricated using the reusable PUA mold

The super water-repellent PDMS film was produced three times using the roll-to-roll method, and the shapes and characteristics of them were analyzed. The reusable PUA mold was able to overcome the drawback of being able to use only one time of the existing photoresist mold. In addition, the PDMS transfer using the roll-to-roll process can produce PDMS samples continuously, it was shortened by about 46 hours. The fabricated samples are shown in Figure 5, and the shapes of micro-nano structures and structure spacing were transferred even in the continuous process, confirming the possibility of producing a PDMS super water-repellent film

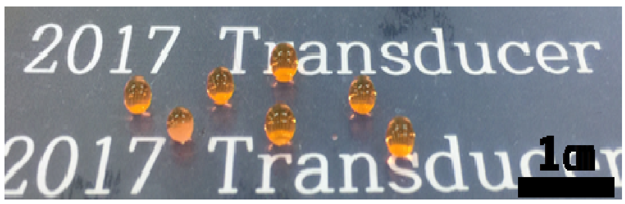

Figure 6: Optical images of showing the transparent and self-cleaning behavior of super-hydrophobic PDMS film

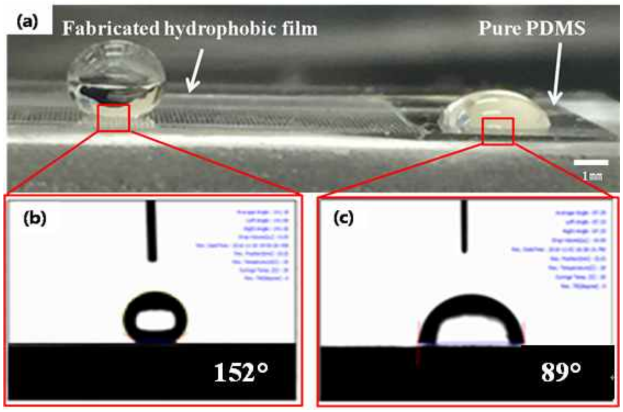

Figure 7: Optical images of water droplet on patterned PDMS film and non-patterned PDMS

Super-hydrophobicity is experimentally confirmed by the measurement of water contact angles on two different PDMS samples as shown in Figure 8. The contact angles is greater than 150° and the roll-off angle is less than 10°. Optical transparency is also experimentally verified using a printed paper in Figure 9. These results indicate that the PUA mold and the roll-to-roll process have successfully produced an optically clear large-area super water-repellent film and have excellent water repellency.

Figure 8: Optical images of showing the transparent and self-cleaning behavior of super-hydrophobic PDMS film

The super water-repellent film has a self-cleaning effect that can remove surface contamination only by the flow of water without any physical or chemical action. On the surface of the fabricated PDMS film, micro-nano protrusions such as a lotus leaf were produced. Due to such a protrusion structure, contaminants such as dust on the surface also remain on the surface of the protrusion without touching the surface under the protrusion. The possibility of a self-cleaning effect such as keeping the surface clean at all times because the surface tension of the water caused the water to fall on the surface after collecting the dust by itself. As shown in Figure 8, when droplets are dropped onto the PDMS surface using a syringe, the water collects the dust and drops in the direction of gravity. The self-cleaning effect of the surface of the PDMS film having the micro-nano protrusion pattern can be applied to the glass window and the outer wall of the building or the part where continuous pollutant management is required, and the cost reduction effect can be expected accordingly.

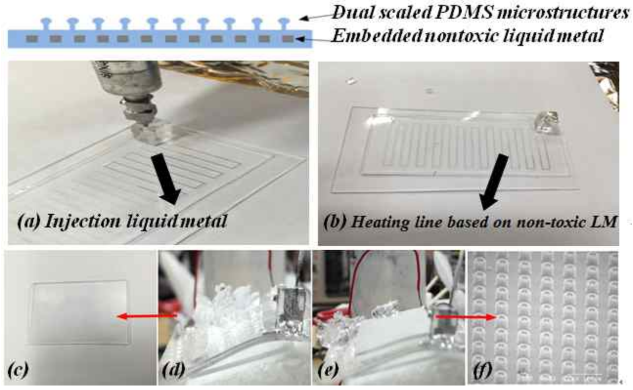

Figure 9: (a) Schematic of heater-integrated PDMS thin films, Optical images of (b) transparent super hydrophobic PDMS thin films integrated with a heating element, blocks of ice on (c-d) a normal PDMS thin film (e-f) super hydrophobic PDMS thin film

Micro-heater structures into the PDMS thin film through microfluidic channels for further applications of the transparent super-hydrophobic thin film (Figure 9). The non-toxic liquid metal-based micro-heater also provides the capability of self-healing behaviors. PDMS was cured on a circuit mold fabricated by photolithography process and then attached by plasma treatment with a flat PDMS in order to efficiently circuit liquid metal (Galinstan) with high viscosity [9]. Unlike metal wires, liquid metal can easily be formed even after it is cut and adhered to maintain the electric conductivity. After the temperature is increased, it is slipped and removed even at a slight slope. Therefore, micro-hydrophobic microstructure films with temperature controllable hot-wire circuits can be self-cleaned and prevent freezing and snowing in winter without much concern for the size and shape of the area if they are produced in tile format.

CONCLUSIONS

We report a cost-effective fabrication method for continuous production of optically transparent super-hydrophobic PDMS thin film. Feasibility of the thin film is successfully demonstrated using various methods.

PDMS film production using a conventional PR mold has a limitation in mass production because it has a disadvantage that it has a long process time and mold reuse is impossible. In order to overcome this problem, a pattern was transferred to the PUA using a PDMS positive film as a base material, and a reusable mold was fabricated. PUA, which is a UV-curable polymer used, has a high hardness of the material, less deforming due to casting and external force, and has high thermal stability during curing, so that it can be reused stably. Through the reusable PUA mold and Roll to Roll process, it is proved that continuous process of optically transparent PDMS film with super water repellency is possible. We also demonstrated the superiority of PDMS super water-repellent film prepared by applying water-repellency measurement, optical permeability, self-cleaning test, snowfall test with temperature increase through heating elements and solar panel using manufactured film. The new fabrication process and successful experimental results reveal that the proposed idea has significant potential for diverse use of the super-hydrophobic PDMS thin film in various industries under realistic conditions.

ACKNOWLEDGEMENTS

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