SIMPLE FABRICATION OF HYDROPHOBIC SURFACE FOR HIGH-TEMPERATURE MICROSYSTEMS

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ABSTRACT
Artificial hydrophobic surface applicable for high-temperature microsystems is proposed using macroporous silicon. Appropriate anodizing condition results in extremely small solid to void area fraction. Contact angle as high as 155° is obtained with thin deposition of noble metal. This technique is simple to fabricate and effective for the microchannel-based fluidic system. The microstructures and measured contact angles are discussed along with additional treatments.

Keywords: Wettability control, porous silicon, two-phase flow, contact angle

1. INTRODUCTION
Wettability is one of the most important issues for microsystems with liquid handling. Recently many kinds of fluidic devices have been developed by using locally hydrophobic and hydrophilic parts in liquid-gas two-phase systems, including valves and pumps [1]. For example, hydrophilic surface gives capillary force and pull the liquid strongly in a microchannel, while hydrophobic surface blocks the liquid phase. These functions are indispensable not only for the biochemical applications but power MEMS or micro engine systems including microthruster for pico-satellites [2, 3].

Though we can easily obtain good hydrophilic surfaces using glass or oxidized silicon, heat-resistant hydrophobic surface is difficult to fabricate. Polymer-based coating represented by Teflon cannot be used at higher temperature than 300 °C. Recently surface modifying technique [4-6] were tested to reduce the area fraction using DRIE technique. However, the fabrication process needs high-cost and moreover this technique cannot be applied to the deep channels. This paper proposes a novel fabrication method of hydrophobic surface by using anodization of silicon substrate[7-9]. In order to improve its durability against many kinds of fluids for a long-term operation, platinum and gold depositions are also tested and the relationship between their microstructures and obtained contact angles is discussed.
2. PRINCIPLE

The contact angle that shows surface wettability is determined by the Young’s equation that is dependent on the inherent surface tensions of solid, liquid and solid/liquid interface. And also, it is well known that the contact angle changes due to the surface roughness and contaminations. Also the artificial surface roughness by MEMS technology successfully controlled the wettability in references 5 and 6. Their results were compared with the Cassie’s equation for rough surface as,

$$\cos \theta' = f (\cos \theta + 1) - 1$$

where $\theta'$ is apparent contact angle on the rough surface and $\theta$ is the contact angle on flat surface. This equation suggests that the apparent contact angle is dependent on the solid-to-void area fraction and the smaller fraction yields larger hydrophobicity. We employ the anodization of silicon as a simple method to form a surface of extremely small $f$. The morphology of porous silicon is known to change depending on many parameters; type of conductivity, electric resistivity, current density, composition of electrolyte, etc. For the most part of this paper, the macroporous of n-type (100) silicon is treated because better hydrophobic results were obtained from it in advance.

3. EXPERIMENTS

Two kinds of n-type (100) silicon wafer are used to obtain macroporous surface. One is two-sides-polished silicon wafer of 500µm thickness and 30Ωcm resistivity. The other is one-side-polished of 610µm and 125Ωcm. The anodization is performed for 10 minutes in the solution of HF/water/ethanol (16.5:16.5:67.0) while the current density is controlled by the illumination intensity. Both flat and grooved surfaces of 30Ωcm wafers are anodized and different microstructures depending on current are obtained (Fig. 1). It has to be noted that the inner surface of the anisotropically-etched groove shows same morphology as the flat surface, which means that our method is applicable to the silicon microchannels. Because the macroporous surface using 260mA/cm² moves up or down as much as 4 µm during and after anodization, only the porous silicon using 15mA/cm² is treated hereafter. For practical application, three kinds of surface are tested; clean and non-oxidized silicon just after HF cleaning, EB-deposited platinum of 120nm thickness and gold of 10nm thickness because this porous surface changes its property by itself mainly due to oxidation. Microstructures of these surfaces are shown in Fig 7. Contact angle is measured by sessile drop method and listed in Table 1.

4. DISCUSSION AND CONCLUSIONS

Comparison of SEM photographs and measured contact angles confirms the validity of Cassie’s equation. Both the thick film deposition and excess oxidation/etching blow
away the sharp tips of original macroporous surface resulting in small contact angle (Table 1). The key to obtain the stable superhydrophobic surface as seen in Fig. 3 is thin-film deposition keeping these nanoscale sharpness. The isotropic oxidation of insufficient macroporous surface followed by HF etching sometimes works effectively to enhance the hydrophobicity, which will be reported in another paper. For example, we successfully obtained the fraction of 0.15 from the macroporous surface of originally
As indicated in Ref. 8, local anodization is also possible using masking or doping technique even in the microchannels. It can be concluded that our application of macroporous silicon to hydrophobic surface has a great impact on the development of future microfluidic devices.

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