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Opinion paper

Processing study of SU-8 pillar profiles with high aspect ratio by electron-beam lithography

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ABSTRACT

We report the fabrication of micro-pitched SU-8 pillar arrays with height up to 5 μm and aspect ratio of 7.14:1 by electron beam lithography (EBL) at 100 keV, combined with a hot developing process. Careful study of processing latitude for geometry parameters of SU-8 pillars was conducted to achieve three different profiles, vertical pillar for biosensing application, trapezoidal shape for antireflection of light in solar cells as well as in displays, and final pillars with thick residuals in the gaps. It was found in our work that SU-8 is particularly a good candidate for tall micro/nano structures with various shapes when the unavoidable proximity effect in the EBL was exploited, which was enhanced by the ultra-high sensitivity of epoxy groups in SU-8. Optical properties of the fabricated structures have been characterized. To the best of our knowledge, pillar like structures of SU-8 in the height range of 5 μm have not been addressed sufficiently despite their broad potential applications in bioscience, environment protection, display and renewable energy sources etc.

1. Introduction

Large area submicron structures with high aspect ratio (HAR) can find extensive applications in cross disciplinary areas, such as scaffolds for trapping biomaterials [1], cells and liquids [2], antireflection layers in solar cells [3] and metallic pillar arrays for local surface plasmonic resonators (LSPRs) as sensors when they are covered by a layer of noble metals as suggested by our earlier work [4]. For constructions of these devices, resists with 5–10 μm thickness are usually needed. However, the majority of applications with electron beam lithography (EBL) deals with resists below 1 μm in thickness for nanostructures. It is believed that EBL at high tension such as 100 kV should also be capable of replicating submicron structures in thick resists such as chemical amplified resist (CAR), SU-8. Negative tone resist SU-8 was initially designed for deep ultraviolet lithography (DUV) [5–7]. It was then successfully applied in micro-electro-mechanical systems (MEMS) [8]. Owing to its ultra-high sensitivity (roughly 150 times of PMMA) leading to sever proximity effect, SU-8 had not been applied in EBL until the end of 1990s [9–10]. Even though, the reported study of EBL on SU-8 are limited to the resist thickness below 500 nm, resulting in an aspect ratio up to 3.8:1 [2]. Few works on HAR SU-8 structures by EBL have been reported.

In this paper, we proposed a process by e-beam direct write at 100 kV to fabricate desired HAR SU-8 pillars with different profiles. The processing parameters such as implanted charge dosage, pattern design, baking and developing temperature for desired profiles were carefully studied. Optical measurements of the reflectance by HAR SU-8 pillars were carried out in near infrared region.

Fig. 1 schematically illustrates the process flow for the replication of micro pitched SU-8 pillar arrays by EBL. A layer of SU-8 resist supplied by MicroChem Ltd., with two different thickness of 5 μm and 10 μm respectively, was spin coated on a fresh Si wafer after a layer of HMDS as adhesion layer, followed by a precisely controlled two-step pre-bake at 65 °C for 3 min and 95 °C for 10 min on a hot plate, respectively. It was found in our experiments that such a two-step bake is necessary for reducing the strain between SU-8 and Si substrate, which may cause collapse of the tall SU-8 pillars. E-beam exposure was carried out by a state-of-the-art beam writer, JEOL 6300FS at the electron beam energy up to 100 KeV with a typical beam current of 500 pA and an 8 nm beam-spot size. Post-exposure bake (PEB) was carried out by a similar two-step bake at 65 °C for 1 min and 95 °C for 3 min on a hot plate. A developing process was immediately carried out by the SU-8 developer (supplied by TELTEC Ltd.) at 45 ± 2 °C for 10 min, and finally the sample was thoroughly rinsed in IPA (also heated at 45 ± 2 °C).

The lithography property of such a thick SU-8 layer was first measured by contrast curves under the developing temperatures of 20 °C, 30 °C and 40 °C respectively, as shown in Fig. 2. The filled symbols depict the remaining thickness of SU-8 after developing, whilst the open symbols represent the thickness of the scum between the lithography features. Extremely high sensitivity as 1 $\mu C/cm^2$ was measured. With such a high sensitivity, proximity effect by both forward scattering and backscattering of electrons is the main issue in EBL, as reflected by the scum thickness in Fig. 1. Therefore, dealing with the proximity effect is the central concern in the processing study of this work.

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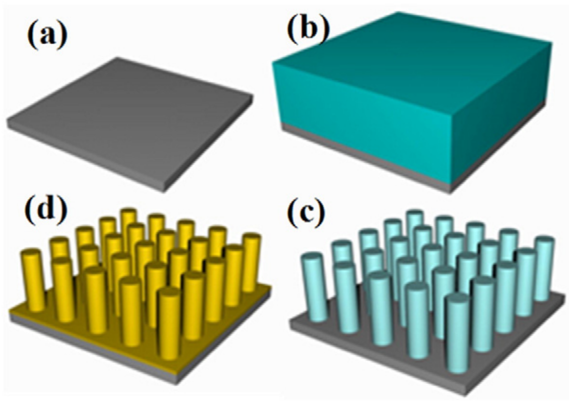

Fig. 1. Schematic view of the fabrication process of tall vertical gold pillars with SU-8 cores on Si substrate combined with electron beam lithography and flood thermal deposition process.

2. Formation of SU-8 tall pillars as scaffolds for bio-materials

HAR micro/nano structures such as tall pillars are needed as scaffolds in the area of bio-sensing for trapping cells and liquids, using capillary force existing at the micro/nano scale. To improve the trapping efficiency, high surface-to-volume ratio is demanded, which requires the pillar as tall as possible.

The main attempt in this part of EBL study is to reduce the influence of proximity effect on the verticality of pillars. Following the temperature effect on the contrast curves in Fig. 2, a hot developing process was applied in the fabrication of vertical pillar arrays. Fig. 3a and b shows the initially fabricated pillars developed at room temperature. Their profile features were characterized by high resolution scanning electron micrometer (SEM) FEI-Sirion 200 and Zeiss SIGMA HD respectively. The average height of the pillars is 4 μm and the lattice pitch is 3 μm. The designed dimension of each pillar is 1 μm in length for square pillars (Fig.3a) and in diameter for round pillars (Fig.3b), respectively. From Fig. 3a, it can be clearly seen that, affected by the proximity effect, the pillar top is square as designed, but the bottom becomes round shape. Also, the foot size in both Fig. 3a and b is expanded as a result of e-beam spreading by electron forward scatterings with SU-8 resist. By applying the hot developing process [11–12], the broadening of pillars in lower part was significantly reduced. Fig. 3 (c) and (d) shows that the pillars developed at 45 °C with the height of over 5 μm and the pitch of 2 μm. The pillar dimension is 0.7 μm (Fig.3c) and 1 μm (Fig. 3d), respectively, giving rise to aspect ratios of 7.14:1 and

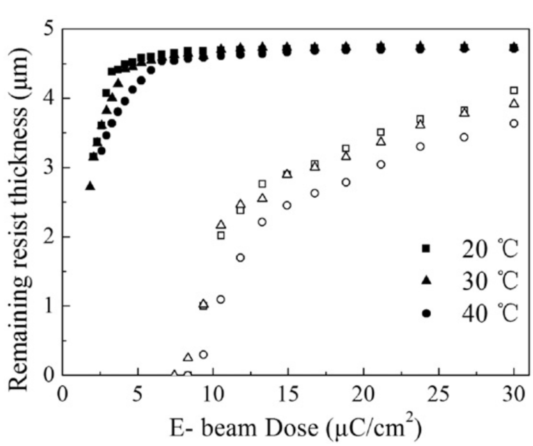

Fig. 2. The contrast curves (the filled symbols) and the residual resist thicknesses (the open symbols) of SU-8 measured by Tencor P15. The developments were undertaken at three different temperatures: 20 °C (the squares), 30 °C (the triangles) and 40 °C (the circles).

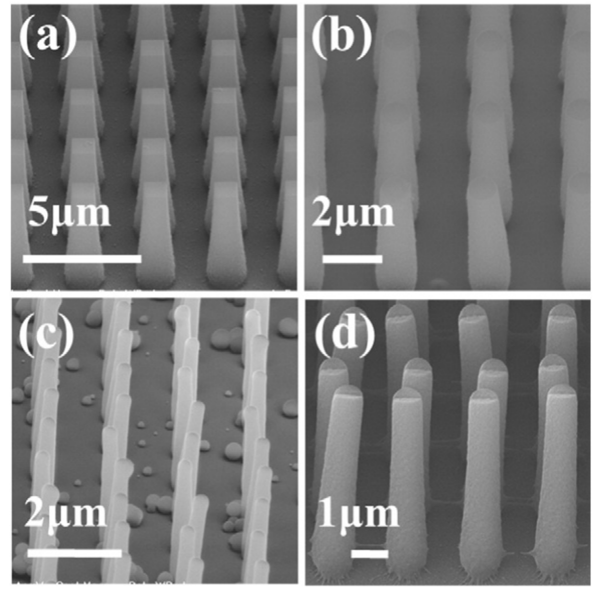

Fig. 3. SEM images of SU-8 pillars taken by FEI-Sirion 200 (a–c) and Zeiss SIGMA HD (d). Detailed descriptions are given in the text.

5:1, respectively. Both the verticality and the height of the pillars presented in Fig. 3 indicate that EBL at 100 kV is feasible for microstructures in thick resist up to at least 5 μm in thickness. These pillar arrays can be applied for biomaterial trapping as scaffolds.

It was initially found that the process presented above was not very stable when room temperature was used for the development because of the narrow processing window owing to the high sensitivity of the resist. By using hot developing process proves, the yield is effectively improved and the dose latitude is broadened. The full-width at half maximum of a vertical pillar changes from 900 nm to 1250 nm in the dose range used. With a fixed dose, the standard deviation of the pillar dimension is around 12 nm, indicating a ~1% of fluctuation.

3. Antireflection layer for solar cells

For InGaN/GaN solar cells, the effective and broadband antireflection design of the interface between air and the top surface can greatly improve its conversion efficiency [13], especially for sub-wavelength structures. As well known, a micro/nanostructured SU-8 layer coated on the surface of the solar cells should be able to enhance the light transmission. Its actual efficiency depends on the refractive index and the surface topography such as trapezoidal profile, of the coated SU-8. By electron beam lithography on thick SU-8, periodical pillar arrays with trapezoidal profile have been successfully built, as shown in Fig. 4. For comparison, two different thicknesses of 5 μm (Fig. 4a) and 10 μm (Fig. 4b) were tested. To keep the scaling factor, two nominal edge lengths of the pillar tops were designed to be 0.5 μm (for 5 μm

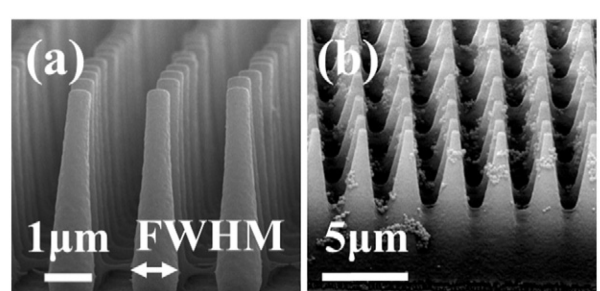

Fig. 4. SEM images of trapezoidal profile SU-8 pillars with a height of 5 μm (a) and 10 μm (b) respectively. FWHM was defined as the maximum lateral dimensions.