Fabrication of Ultrahigh Aspect Ratio Trenches by Two-Step KOH Anisotropic Wet Etching

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In this work, we present a novel approach to achieve very high aspect ratio trenches by a two-step potassium hydroxide (KOH) anisotropic wet etching. This approach consists of two successive KOH etching. After the first KOH, the sidewalls are protected against subsequent KOH etching and window openings at the trench bottom were realized by plasma etching prior to the second KOH etching.

Before applying this method in sub-micron structures, test samples with a pitch of 3 µm were used. First, the Si (110) wafers were cleaved along the <111> direction which resulted in a straight wafer edge along a {111} crystalline plane. An oxide layer was thermally grown on top of those wafers by thermal oxidation in air[1]. This straight edge of the wafer was then used to align the MLA150 Maskless Aligner so that the line pattern was parallel to this cleaved edge. After pattering the oxide layer by plasma etching, samples were etched in aqueous KOH solution. Since KOH etches the silicon {111} surface significantly slower than {110} and {100} surfaces, trenches with certain height were obtained. Etch profile and etch front were investigated with respect to concentrated- and temperature-dependent KOH etching.

In the second part of the fabrication, an oxide layer was thermally grown on the trench structure including the sidewalls and trench bottom by oxidation as seen in Fig.1. Etching the oxide at the trench bottom is critical prior to the second KOH step. We protected the top of the trenches with metal during plasma etching of the trench structure. 50 nm of chromium was shadow-evaporated from both sides with a shadow angle of approximately 60 degree. Since the substrate is tilted with regard to the evaporation target, such that only the tops were coated as showing in Fig.1-d. It was rather challenging to plasma etch the oxide layer grown on the trench bottom. Different plasma conditions were evaluated to obtain a desirable etch profile as shown in Fig.2. It was found that the etch rate of the oxide on the trench bottom is significantly slower than that of the blanket etching. RIE plasma etching at 20 mT, 20 sccm of CF_4, and 100 W of RF power resulted in a vertical etch profile at the interface between the oxide and bulk silicon without any lateral etching. Afterwards, the second KOH anisotropic wet etching was performed to enhance the aspect ratio with smooth sidewalls as seen in Fig.3.

Via this two-step KOH anisotropic wet etching approach, we propose that we can be easily control the duty cycle of the gratings which tends to deteriorate due to lateral etching of the {111} crystalline planes. Secondly, this approach can help minimize the linewidth difference seen in the freestanding gratings where the linewidth of the grating bars at the top are narrower due to prolonged lateral etching than those at the bottom[2]. Currently, fabrication of sub-micron trenches, and investigation of the effect of the surfactant-added solution on the etch uniformity, sidewall smoothness and etch front are underway.

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[1] Dey R. K., Shen J., and Cui B., J. Vac. Sci. Technol. B, 35(6), 2166 (2017).

[2] Ahn, M., Heilmann, R. K. and Schattenburg, M. L., J. Vac. Sci. Technol. B 25(6), 1071 (2007).

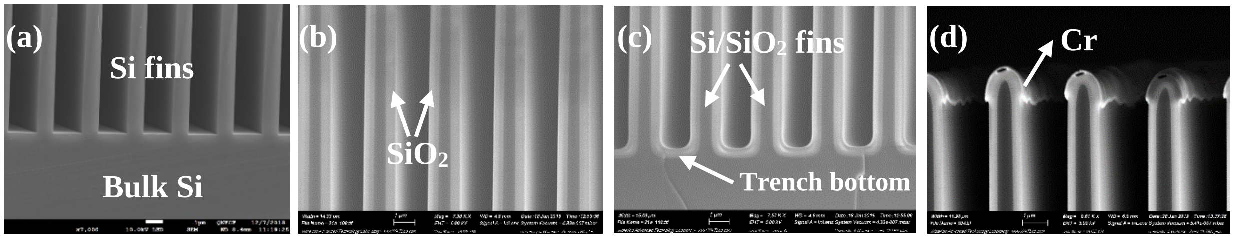

Figure 1: Cross-sectional SEM images after the first KOH etching: a typical trench structure with a depth of approximately 30 µm (a), after thermal oxidation on the sidewalls (b), on the trench bottom (c), and after 50 nm of chromium shadow-evaporation with a shadow angle of approximately 60 degree (d).

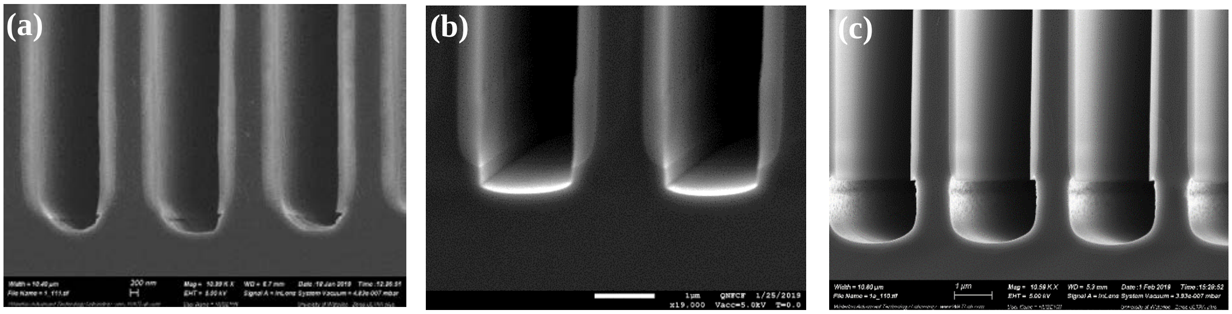

Figure 2: Oxide/silicon interface profile at the trench bottom after being etched in different plasma conditions: CF_4/Ar (a), CF_4 alone (b), and CF_4/O_2 (c).

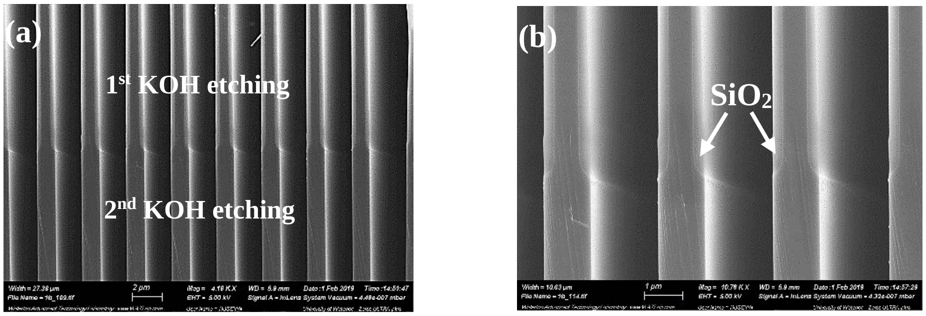

Figure 3: Cross-sectional SEM images after the second KOH from the sample which was etched in CF_4 plasma alone: a typical trench structure with a total depth of approximately 60 µm (a), and a zoomed-in view of part (a) to carefully observe the oxide/silicon interface after the second KOH etching.