# Deep Grooves in Borofloat Glass by Wet Bulk Micromachining

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**Abstract.** In this work, deep grooves of more than 300 μm depth are fabricated in a high-quality Borofloat glass wafer using wet bulk micromachining in buffered HF (BHF) solution. The Cr/Au/photoresist layers are used as the etching mask. These masking layers showed very good chemical resistance to etching in BHF solution. The etchant provides smooth etched surface morphology with an excellent etch rate of 11.1 μm/min. The proposed process is very useful for the formation of deep grooves with smooth vertical sidewalls and uniform bottom surfaces.

**Keywords:** Buffered HF · Wet chemical etching · Borofloat glass · Masking layers · Etch-rate

## 1 Introduction

In the microfabrication process, the glass is the second most widely used material after silicon owing to various interesting properties such as high chemical resistance, high heat resistance, high electrical isolation, low optical absorption, etc. Micromachining is an approach that is widely used for the development of microstructures in glass wafers. Borofloat glass is broadly utilized for the formation of various microstructures for microelectromechanical systems (MEMS) applications such as Bio-MEMS and optical-MEMS because of its superior physical, chemical, and mechanical properties [1, 2]. The optical properties of Borofloat glass-like high transparency and less absorption makes it suitable for the fabrication of lenses and other optical applications where low optical loss is essential. Also, the excellent mechanical properties of Borofloat glass-like high thermal expansion coefficient and good electrical insulation properties make it an ideal candidate for the fabrication of different MEMS sensors and actuators [3].

There are various approaches like mechanical, plasma, and chemical utilized for the development of deep structures like cavities and through-hole in glass wafers. Mechanical approaches comprise traditional and ultrasonic drilling, electrochemical discharge, and powder blasting. These processes provide very rough surfaces [4]. Plasma is also used for glass etching, but it provides a very slow etch rate of the order of 10 nm/min [5]. Besides, chemical processes such as dry and wet chemical etching are widely used. Among them, dry etching has the advantages of providing smooth surfaces and high uniformity, but it is expensive and exhibits a very low etch rate. Wet bulk micromachining


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is a cheap and easy approach to form microstructures in glass and silicon wafers [6–14]. It is utilized in several applications for glass micromachining such as wafer thinning, through-hole development, microchannels fabrication for different MEMS applications [1, 15]. Generally, hydrofluoric acid (HF) is most commonly used for glass etching [5]. However, the aggressive behavior of concentrated HF can severely damage the associated masking layer. In addition, it provides rough surface morphology and creates surface nonuniformities. To perform selective etching of glass, various kinds of masking layers such as Cr/Au, multiple metal stack Cr/Au/Cr/Au, amorphous silicon, polysilicon, and silicon carbide are employed [6, 15–18].

In this work, we have developed a process for the formation of deep grooves in a Borofloat glass wafer using wet bulk micromachining in Buffered HF (BHF) solution.

## 2 Experimental Details

In this study, a 500 $\mu$m thick, 4-inch diameter Borofloat glass (HK9L) wafer is used. Firstly, Cr/Au masking layers with 30 nm and 200 nm thickness, respectively, are deposited on both sides of the wafer using the DC magnetron sputtering process. Here, the deposition of metals is performed at room temperature. The thickness of deposited films is observed by an in-situ thickness monitor.

After the deposition of Cr/Au masking layers, pattering of the masking layer is performed using photolithography. In this process, the hexamethyldisilazane (HMDS) is spin-coated on Cr/Au at 3000 rpm for 30 s followed by spin coating of the positive photoresist AZ1512HS at 3000 rpm for 30 s. Here, the HMDS works as a primer to enhance the adhesion of the photoresist layer. The photoresist-coated wafer is pre-backed in an oven at 90 °C for 30 min. Thereafter, the wafer is exposed under UV illumination in a mask aligner after aligning it with an appropriately designed mask pattern. Then the wafer is developed and post-backed for 1 h at 120 °C. After this step, Cr and Au layers are etched using wet chemicals. In this process, first, the top Au layer is etched in potassium iodide (KI) solution. Subsequently, the Cr layer is etched in the Cr etchant prepared by mixing 1.645 g ceric ammonium nitrate ($Ce(NH_4)_2(NO_3)_6$) with 0.43 ml nitric acid ($HNO_3$) in 100 ml DI water. After the selective etching of Cr and Au layers, the wafer is thoroughly cleaned in DI water. A Teflon container, as shown in Fig. 1, is used for glass etching. To fabricate deep grooves in the Borofloat glass wafer, the wet bulk micromachining is performed in buffered HF solution (BHF), which is prepared by mixing HF and ammonium fluoride ($NH_4F$) in a ratio of 1:7. After preparation of BHF, it is shifted in Teflon container for subsequent etching process. In this work, BHF is chosen for glass etching because it makes very low damage to the photoresist layer, therefore the masking layer durability in the etching process is sufficiently improved. In this process, the backside of the wafer is protected by Cr/Au and photoresist layers. Process steps used in this work are schematically illustrated in Fig. 1.

## 3 Results and Discussion

Etch rate is outlined as the vertical distance etched per unit time and is calculated by measuring etch depth for a particular etch time. In the semiconductor industries, a high

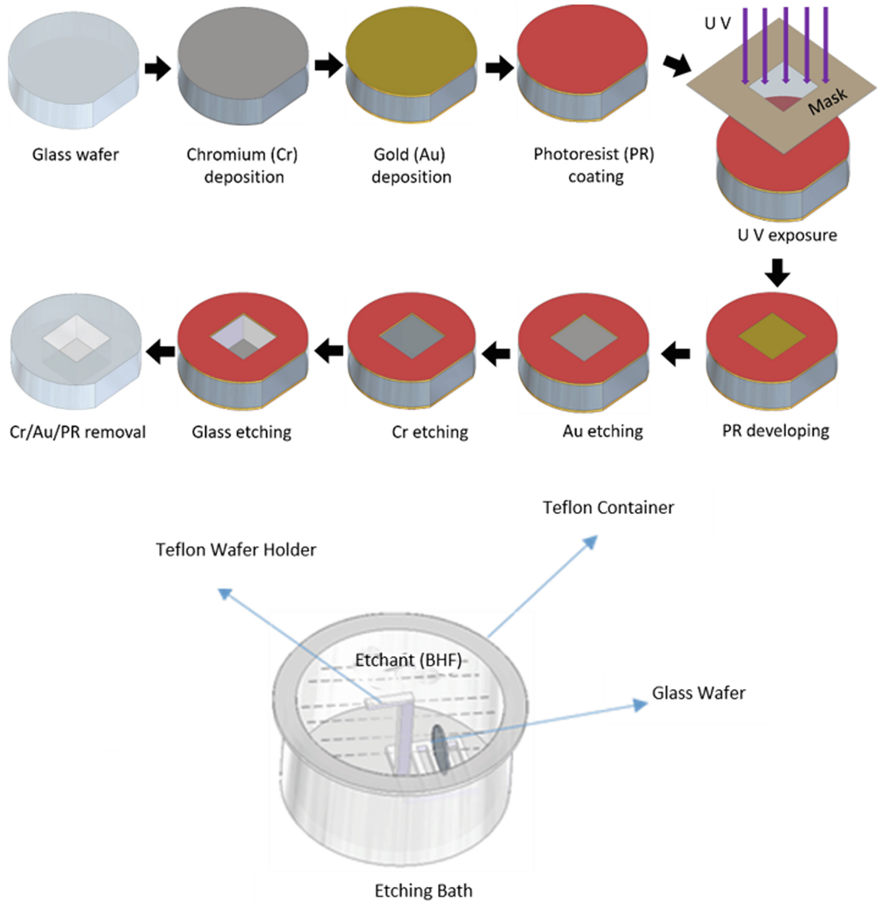


**Fig. 1.** Schematic representation of process steps used to form deep grooves in Borofloat glass wafer using wet bulk micromachining in BHF.

etch rate is required to enhance productivity and to reduce the overall cost of the product simultaneously. Figure 2 shows the 3-D optical image of an etched sample measured using a 3D laser scanning microscope (OLYMPUS OLS4000). It is evident from Fig. 2 that the sidewalls of the groove are very smooth. Also, there are no notching defects observed on the edges of the pattern. Moreover, it can be noticed from Fig. 2 that the mask layer (Cr/Au/photoresist) is steadily intact with the wafer surface.

Furthermore, the depth and edge profile of the etched groove is also measured using the 3D laser scanning microscope, and it is depicted in Fig. 2. Here red line signifies the depth profile of the developed groove, yellow line provides the depth and scan length measurement, whereas the blue line is the marker line which covers the scan area. It can be easily seen that the square groove possesses sharp edges with minimal lateral etching. The etch depth of the sample after 30 min of etching is measured to be 332.792 μm, which gives the etch rate 11.1 μm/min. This etch rate is two times higher than the previously reported results for soda-lime glass [19]. Moreover, the etched depth profile in Fig. 2 indicates that the bottom surface of the groove is uniform. Furthermore, the average etched surface roughness ($R_a$) measured using a 3D laser microscope is 0.26 μm, which is useful for the formation of various microstructures with the smooth surface finish for applications in MEMS.

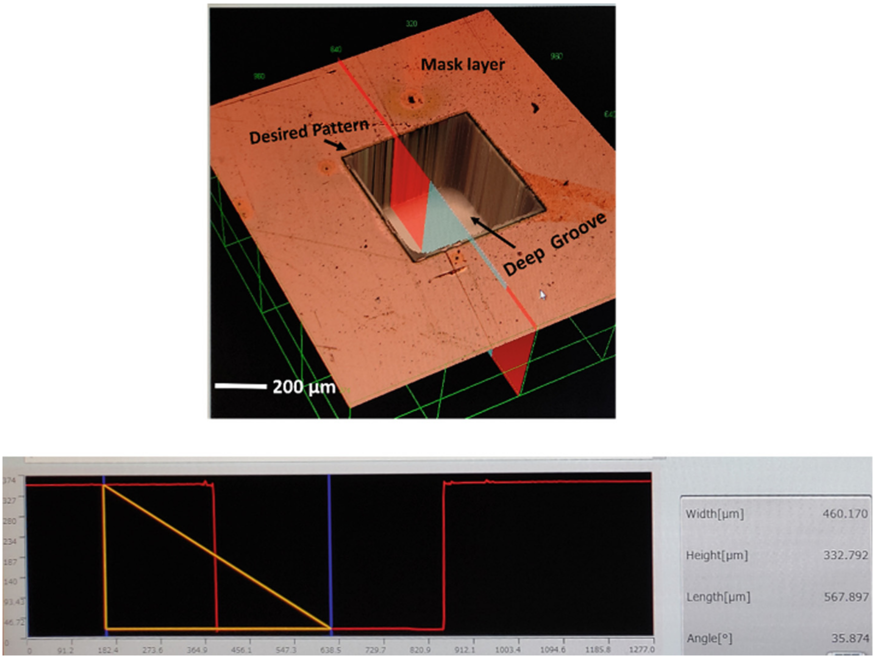


**Fig. 2.** Optical photograph and etch depth profile of a deep groove formed in Borofloat glass wafer using wet bulk micromachining in BHF solution (Etch time: 30 min, etch depth: 332.792 μm).

After performing glass etching, the total width of the window of the square groove is calculated and undercutting is calculated, which was measured to be around 3μm. Further analysis is performed after removing the photoresist layer and metal mask layer to observe the under etching and the results are shown in Fig. 3. The total under etching after removing of all masking layers is measured to be ~30 μm. The present study reveals that, the BHF provides excellent etching with minimal lateral etching for Borofloat Glass.

## 4 Conclusions

In this work, a simple method has been developed to fabricate deep grooves with a higher aspect ratio and smooth surface finish in the Borofloat glass wafer. The thin films of Cr/Au are deposited by DC sputtering and used as the main masking layer. A positive photoresist, which is used for the patterning of Cr/Au using photolithography, is worked as an additional mask layer over Cr/Au thin film. These layers served as a very good

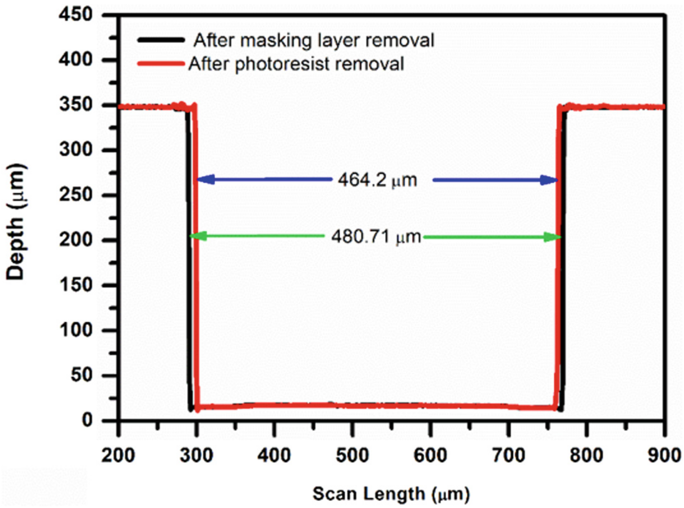


**Fig. 3.** Etched profile after removing photoresist and metal masking layers.

masking layer for the selective etching of glass for the development of deep grooves in Borofloat glass using BHF as an etchant. Thus, the developed approach paves a simple and efficient way to produce deep grooves with a higher aspect ratio in a low-cost and rapid manner.

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