JOURNAL OF MATERIALS SCIENCE 13 (1978) 2105–2108

Application of ion-etching of grooves into quartz for surface acoustic wave devices

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The application of r.f.-sputter etching techniques to the fabrication of grooves in the surface of quartz is reported. This process has been used for the construction of devices which employ the interaction of surface acoustic waves with arrays of well-defined parallel grooves. Devices have been produced with grooves up to 2.5 μm deep, which have substantially rectangular profiles and controllable mark-to-space ratios. The groove geometries have been characterized using Talysurf, optical microscopy, SEM and TEM techniques.

1. Introduction

Ion-etching has become the preferred method for the fabrication of grooves in devices which employ the interaction of surface acoustic waves (SAW) with a number of well-defined grooves. A recent publication [1] has described in detail the method and characteristics of the ion-etching process when grooves are etched into the surfaces of quartz and lithium niobate using a collimated beam of neutralized argon ions [ion-beam etching (IBE)] through an AZ1350J photoresist mask. Satisfactory results were obtained only when groove depths did not exceed 1.5 μm. In these laboratories, a different but related and more simple and readily available technique, r.f.-sputter etching (SE), has been used successfully to etch grooves up to 2.5 μm deep for use in SAW devices. In this process the masked substrate, placed on the water-cooled cathode, is bombarded by positively-charged argon ions. The etching area is much greater for SE than for IBE and hence offers obvious advantages in production. However, for IBE the angle of incidence may be varied to give optimum etching conditions, whilst for SE the ion flux is usually restricted to normal incidence. In consequence, particular care must be taken in the selection of a masking material and of etching conditions.

Typical ion-etching equipment, operating conditions, mask materials and the resulting geometries have been discussed in a number of papers, e.g. [2–5] and articles have appeared on theoretical aspects of ion etching and on the chemical/physical mechanisms thought to be involved [3, 4, 6]. The majority of the data available, however, relate to semiconductor materials used in the fabrication of integrated circuits. The problem of pattern erosion under ion bombardment and its influence on substrate etch rate, line widths and edge profiles has been studied by several workers [6, 7]. In particular, severe trenching has often been observed at the side of a pattern stripe and this has been attributed mainly to enhanced erosion caused by the increased ion flux at the bottom of the stripe resulting from reflection at the sloped sides of the stripe [8].

The purpose of the present investigation was

(a) to explore the possibility of using SE in the production of grooves in single-crystal quartz suitable for the fabrication of SAW devices. Experience has shown that such suitability can be determined in terms of deviation from the mark–space ratio (1 : 1) and the profiles/slopes of the grooves (i.e. a rectangular geometry),

(b) to determine a suitable masking material and establish appropriate etching conditions.

2. Method

Several series of samples were prepared in the

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TABLE I Typical results

Mask	Conditions	Quartz etch rate at D_1 (Å min^{-1})	Quartz etch rate at D_2 (Å min^{-1})	Horizontal etch rate of mask (Å min^{-1})
Al	r.f. current 0.2 A r.f. voltage 0.85 kV Power density 0.38 W cm^{-2} Film thickness 5000 Å*	10	25	120
Ti	r.f. current 0.5 A r.f. voltage 1.9 kV Power density 0.76 W cm^{-2} Film thickness 7000 Å†	115	110	190

*The maximum obtainable in a controlled manner.
†The maximum to allow good definition through the resist mask

following manner. AT- and ST-cut quartz substrates were coated with either evaporated Al or sputtered Ti films which were subsequently chemically etched into arrays of parallel stripes (16 μm wide) using standard photolithographic techniques. Argon SE was then carried out under one of two sets of experimental conditions, namely with a power density of 0.38 W cm^{-2} and r.f. sputtering voltage of 0.85 kV, and with a power density of 0.76 W cm^{-2} and r.f. sputtering voltage of 1.9 kV (see Table I). The former set was that which years of experience with this particular equipment have shown to give a reproducible etch rate with uniformity over a large area. The second set resulted from using the maximum power density obtainable. In all cases normal incidence of the argon ion beam was used.

Measurements of the dimensions and profiles of the grooves were obtained using Talysurf measurements, optical microscopy, SEM and TEM (two-stage replication) techniques. In this way deformation of the stripe geometry, horizontal etching of the mask, the groove profiles and relevant etch rates could readily be ascertained.

3. Results

The evolution of the groove profile with etching time through an Al mask is shown schematically in Fig. 1. The large and unacceptable divergence from rectangular geometry of the groove comprised three main features;

(a) a large concavity across the centre of the groove,

(b) trenching at the side of the stripe, and

(c) a high horizontal etch rate (shrinkage) of mask in relation to the vertical etch rate of the quartz.

We believe that whilst the first of these observations can be explained in terms of a preferential redeposition of material removed from the edge of the mask (obeying an inverse-square distribution) causing a variable effective etch rate of the quartz across the groove, the second is due [2] partly to this redeposition and partly to forward reflection of the incident ions at the mask edge. General redeposition (and back-diffusion) of sputtered material and crystallographic aspects of the mask material are believed to be additional factors responsible for the high mask shrinkage/substrate etch rate ratio (see Table I).

Since changes undergone by the mask are to a large extent determined by the way in which the etch rate depends on the angle of incidence (θ) of the ions on the material, preferential redeposition can be greatly reduced by ensuring that near-normal incidence ($\theta = 0$) occurs over the entire mask. If faceting occurs at the mask edge resulting in local non-normal incidence, the mask etching rate can reach a maximum ($\theta = \theta_m$) and then preferential deposition will become a maximum. Hence when etching grooves $> 1\,\mu$m deep where good mask definition and control are essential, it is desirable to choose a mask material for which the variation of etching rate with θ is small and always at a low value; such a material is Ti [3, 9].

Subsequent trials using Ti as the mask material were more successful and the evolution of the corresponding groove profile with etching time is shown schematically in Fig. 2. It is evident that although limited trenching at the side of the groove was again present (see Figs. 3a to d) the pronounced concavity of the groove was absent resulting in an acceptable profile. Moreover,

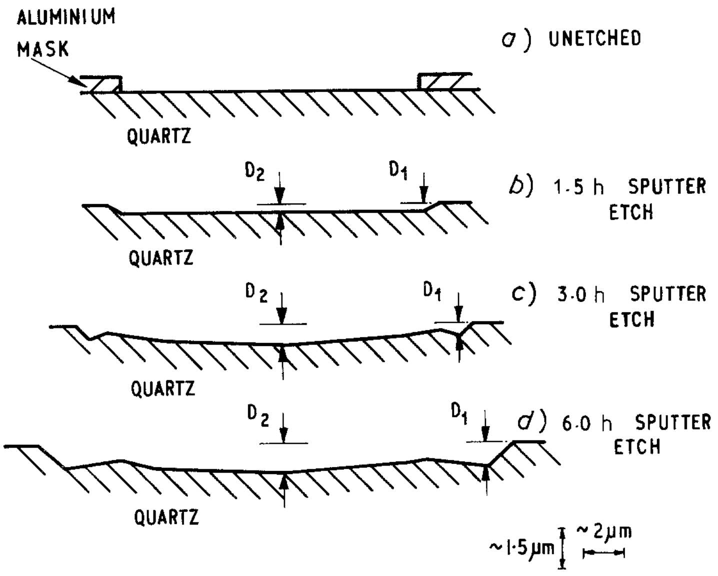

Figure 1 The evolution of the groove profile using an aluminium mask. (The metal masks are not shown for the sputter-etched samples).

the ratio of mask shrinkage:substrate etch rate was significantly reduced from that in the case of the Al mask (see Table I). The controlled removal of the quartz had resulted in an excellent surface finish (see Figs. 3a and c). The absence of the central depression in the groove implies that preferential redeposition of the mask material was significantly lower than that in the case of the aluminium. The more uniform etching rate of Ti with θ means that any facet formed on the edge of the mask will have only a limited effect on the etching rate of the mask and therefore the amount of material preferentially redeposited from the mask edge. Moreover, the etch rate of Ti is lower (by a factor of ~ 3) than that of Al under similar conditions, which would also reduce the effect of preferential redeposition. This last factor also contributes towards the observed differences in the mask shrinkage:quartz etch rate ratios for the two metals. The geometry of the grooves obtained in this way using the simple SE technique appears to be comparable with that obtained [1] using the more complex IBE technique. This suggests that the effects/mechanisms of material removal in the two processes are little different.

4. Conclusions

The sputter-etching technique has been used successfully to cut into quartz substrates shallow patterns (up to 2.5 μm deep) of required geometry

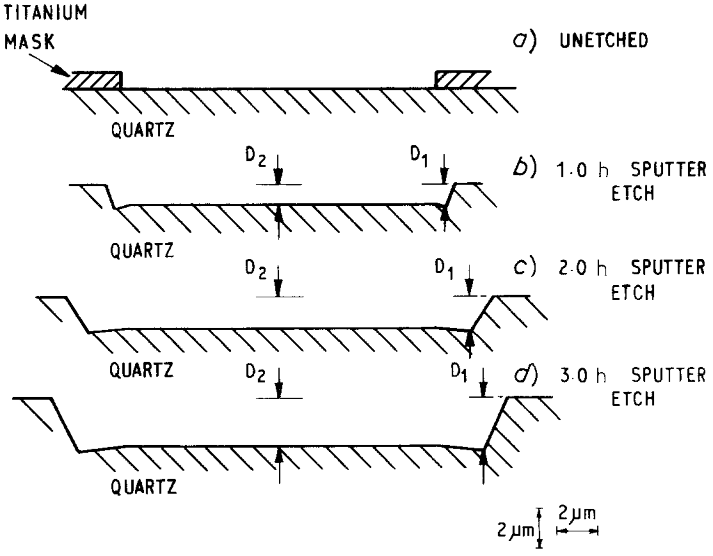

Figure 2 The evolution of the groove profile using a titanium mask. (The metal masks are not shown for the sputter-etched samples).

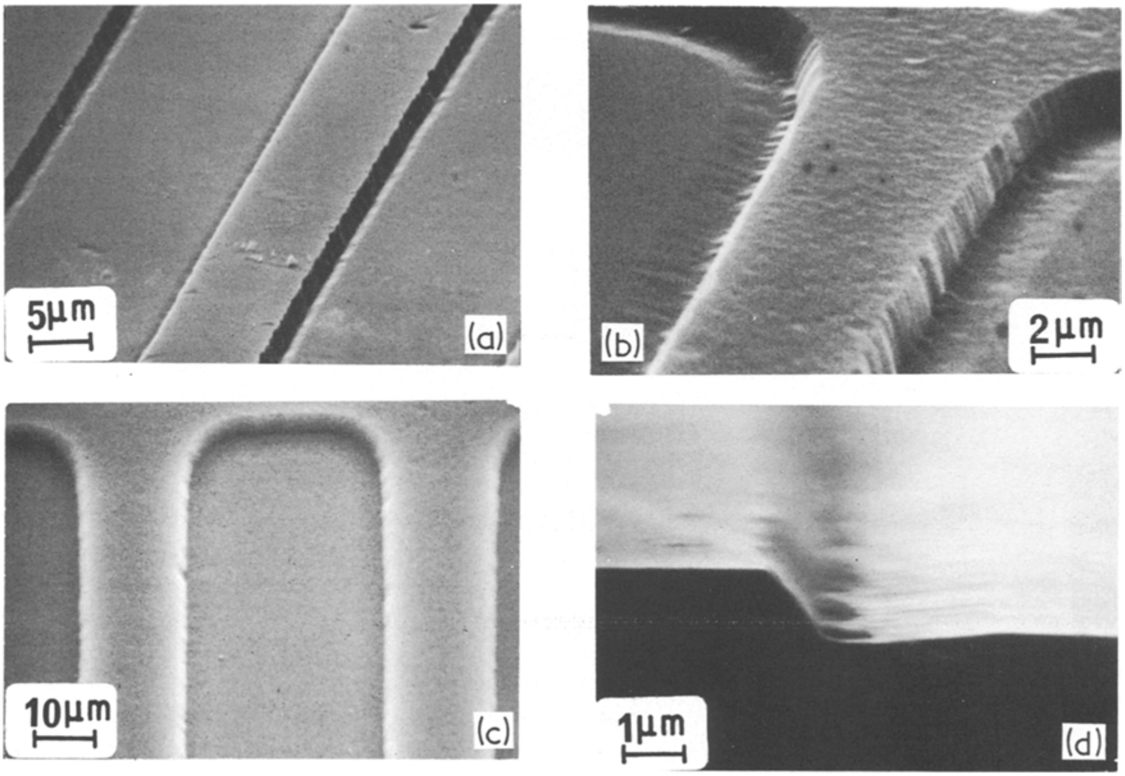

Figure 3 Typical grooves in quartz obtained using a Ti mask.

suitable for fabrication as SAW devices. The results have illustrated the importance of considering the effect of combinations of different materials, and its influence on topographical development. Ti appears to be an appropriate mask material for quartz, and under the etching conditions described above the grooves exhibited acceptable geometry with only one defect, that of slight trenching at the edges of the grooves. This artifact, however, is unlikely to have any deleterious effects on the propagation of surface acoustic waves. SAW devices have been constructed using this technique and have exhibited performance characteristics currently considered acceptable.

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Received 25 October 1977 and accepted 27 February 1978.