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Extremely High Selective Etching of Porous Si for Single Etch-Stop Bond-and-Etch-Back SOI

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Extremely high selective etching of porous Si has been investigated for the ultra thin film (UTF) single etch-stop bond-and-etch-back (BE) silicon-on-insulator (SOI). Etching selectivity of ~10^5 is achieved by a mixture of HF, H_2O_2 and H_2O due to inner reaction by capillary induced penetration of the etchant into the pores. This results in excellent thickness uniformity of 96.8nm±4.5nm (±4.7%) across the 5 inch wafer.

I. Introduction

Fully depleted MOS FET's on SOI require the active layer thicknesses of <100nm with the very small thickness variation because the threshold voltage is highly sensitive to the SOI thicknesses.[1-3] Etching selectivity's in excess of 10^4 are absolutely necessary for the large area UTF BE-SOI[3]. A low doped epitaxial layer over a boron heavily doped (p^{++}) Si prime wafer was applied for the first BE-SOI with a single etch-stop.[4] The prime wafer was etched off by a mixture of HF, HNO_3 and CH_3COOH (1:3:8) with an etching selectivity of a few 100's down to the epitaxial Si layer. The limited selectivity allowed by this technique resulted in only relatively thick Si layer and moderate uniformity.[5] Though higher selectivity has been achieved by a double etch-stop technique, special care and control of the etchant are necessary to maintain a selectivity of over 10^4.[3] Further, the process temperatures (epitaxy, bonding, etc.) are severely limited by doping profile broadening of the etch-stop layer toward the active layer because the selectivity is highly sensitive to the doping concentration. We have investigated the etching characteristics of porous Si, demonstrate extremely high etching selectivity of ~10^5, and propose the UTF single etch-stop BE-SOI named ELTRAN® (Epitaxial Layer TRANsfer).

II. Etching Selectivity in Porous Si

The etching characteristics of porous and nonporous Si have been investigated by three alkali-free etchants; 49%HF:70%HNO_3:98%CH_3COOH (3:25:25), 49%HF:30%H_2O_2 (1:5), and 49%HF only, as shown in Fig. 1. The three etching selectivity's are summarized in Table I.

A general mechanism for etching Si by HF based acid solutions is understood such that oxidizing acid agents form oxide reactive products with Si which are subsequently removed by HF, so that oxidizing rates depending on the agents dominantly rule the etching characteristics particularly for nonporous Si. The etch rates are obtained to be 2, ~10^{-5} and ~2×10^{-6}μm/min for nonporous Si by HF/HNO_3/CH_3COOH, HF/H_2O_2 and HF respectively. The highest rate is apparently due to the most reactive oxidizing agent of HNO_3, while the less reactive agent of H_2O_2 or no agent, i.e., HF only, gives the drastic reduction in the etch rate down to 10^{-5}~10^{-6}μm/min.

In addition to this mechanism, the enormous surface to volume ratio (~$200m^2/cm^3$)[6] in porous Si is expected to enhance the etching rate tremendously, if the etchant completely penetrates the porous Si. Capillary phenomenon through the pores is a concern for the etchant to penetrate the porous Si. Contact angles were measured for the three etchants on Si to be 40°, 76.8° and 69° for HF/HNO_3/CH_3COOH, HF/H_2O_2 and HF respectively. All the angles are lower than 90°, so that capillary induced penetration into pores actually takes place for these etchants.[7] All the etching rates for porous Si are always higher than that for nonporous Si. However, HF/H_2O_2 etchant system shows exceptionally dramatic increase of selectivity as large as ~10^5, while much lower selectivity's of 2.24 and 20~30 are obtained in the

other two etchants. It should be noted that the thickness reduction in porous Si was observed as soon as the specimen was immersed in $HF/HNO_3/CH_3COOH$, whereas a long induction period was necessary to start the thickness reduction in HF/H_2O_2. These facts suggest that $HF/HNO_3/CH_3COOH$ etches rapidly both porous and nonporous Si mainly due to surface reaction with high oxidizing agent rather than inner reaction inside porous Si, and that HF/H_2O_2 slowly etches nonporous Si due to less reactivity of H_2O_2, but greatly reduces the porous Si thickness after an induction period mostly due to inner reaction inside porous Si. This speculation has been confirmed by a cross-sectional high-resolution SEM as shown in Fig. 2. The pore diameter inside the porous layer was clearly enlarged by HF/H_2O_2 during the induction period. In comparison, HF etchant gave extremely low rates even for porous Si ($\sim 10^{-5}$μm/min) resulting in low selectivity, apparently due to no oxidizing agent in the etchant. Other factors of surface tension and viscosity should be taken into consideration for more detailed discussion on capillarity.

III. Bond-and-Etch-Back SOI

A single etch-stop BE-SOI is fabricated, as follows.[8]

1) Anodization of a 5 inch Si prime wafer surface in a mixture of HF, H_2O and C_2H_5OH to form a porous Si layer (~12μm thick).
2) Preoxidation of the porous Si layer[9] at 400°C-1h.
3) Epitaxial Si growth on porous Si by CVD with the thickness ranging from 100nm to a few μm.
4) Bonding the prime and a Si handle wafer, both of which are thermally oxidized, as shown by X-TEM in Fig. 3.
5) Grinding the prime wafer down to porous Si.
6) Selective etching the remaining porous Si, leaving behind the epitaxial Si layer on the handle wafer.

The epitaxial growth part has been already reported in detail by us.[10]

The SOI layer thickness variation was evaluated as 507nm±15nm (±3.0%) and 96.8nm±4.5nm (±4.7%) across the entire 5 inch wafer as shown in Fig. 4. The excellent uniformity's achieved by the single etch-stop method are due to the extreme selectivity of 10^5 and they are identical to the epitaxial layer uniformity. In practical point of view, this high selectivity exclusively enables us to fabricate BE-SOI in batch process. The etching selectivity is not degraded by the high temperature bonding because this is not sensitive to doping profile but to structural difference. In addition, this method is insensitive to the presence of particles on the wafer and in the etchant during etching process since our etching mechanism is based on inner reaction of porous Si in which pores are interconnected as described above.

The defect density, mainly stacking faults, is $\sim 10^3 cm^{-2}$ and the surface micro roughness is evaluated as 0.08nm (rms) in 1μm□ measured by AFM without surface polishing.

IV. Conclusions

It is demonstrated that etching selectivity between porous and nonporous Si reaches $\sim 10^5$. The selective etching allows excellent thickness uniformity's of 507nm±15nm (±3.0%) and 96.8nm±4.5nm (±4.7%) across the entire 5 inch wafer. This method is currently being applied to form monocrystalline Si layers on transparent substrates owing to substantial versatility of bonding technology.

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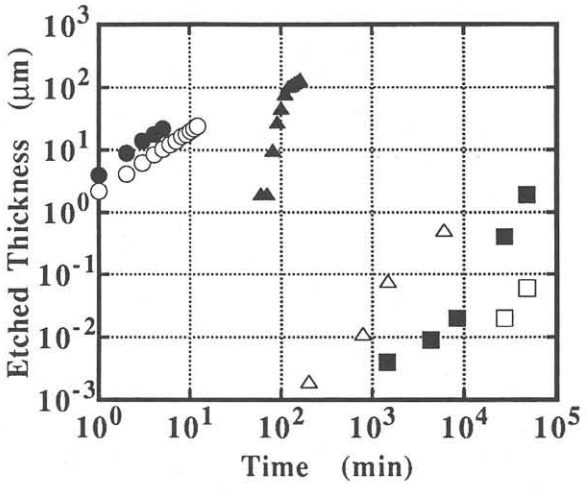

Fig. 1. The etching characteristics of porous Si (closed markers) and nonporous Si (open markers) by immersing in $HF/HNO_3/CH_3COOH$ (circles), HF/H_2O_2 (triangles) and HF (rectangles) as a function of etching period from one minute up to one month. Note large increase in selectivity by HF/H_2O_2.

Table I. The etch rates for porous Si and the etching selectivity's between porous Si and nonporous Si by three etchants.

Etchant	$HF/HNO_3/CH_3COOH$	HF/H_2O_2	HF
Etch Rate (μm/min)	4.5	2.4	4.5×10^{-5}
Etching Selectivity	2.24	$\sim10^5$	20~30

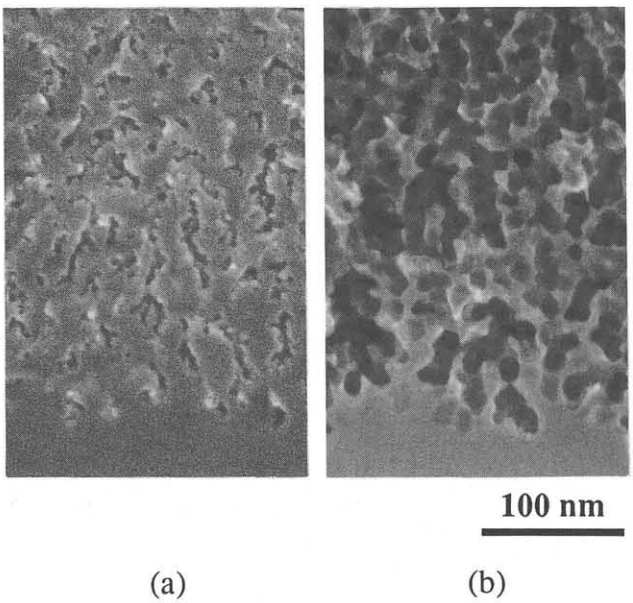

Fig. 2. Cross-sectional high-resolution SEM micrograph of porous Si : (a) as anodized porous Si, and (b) after immersing in HF/H_2O_2 for 50 min.

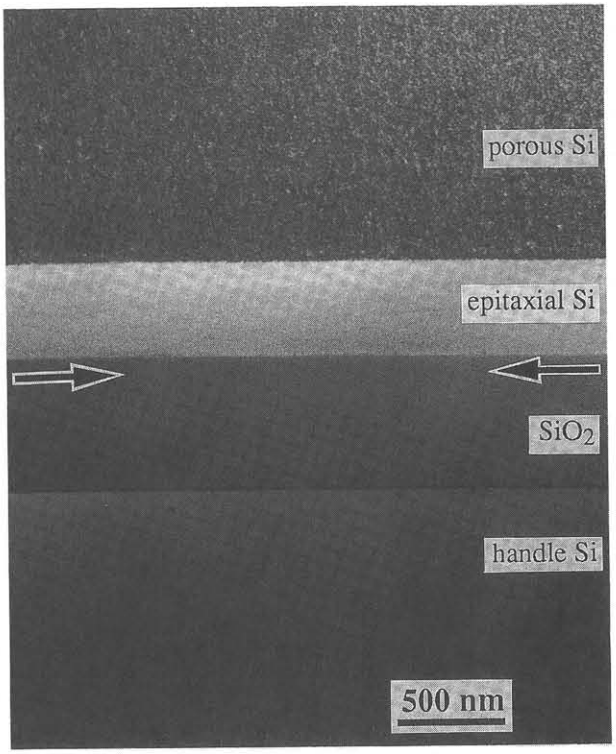

Fig. 3. XTEM micrograph to show the bonding configuration. The arrows in the oxide indicate the bonding interface between the two Si wafers. The upper device wafer has a surface oxidized epitaxial Si layer over porous Si and the lower handle wafer has an oxide layer on top of it. Note no defects observed in this micrograph.

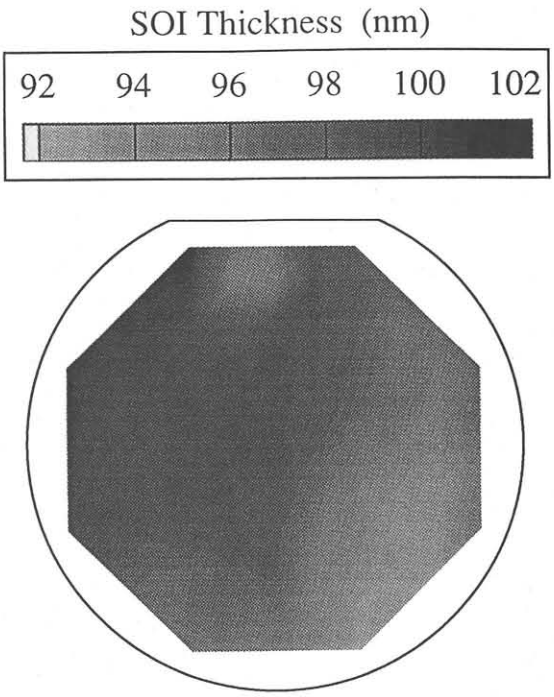

Fig .4. SOI thickness variation across a 5 inch wafer with around 5 mm edge exclusion. The uniformity is evaluated as 96.8nm±4.5nm (±4.7%) at 97 points.