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Recrystallization of Polycrystalline Silicon Islands on Fused Silica

Yutaka Kobayashi, Akira Fukami and Takaya Suzuki

Hitachi Research Laboratory, Hitachi, Limited,
Hitachi, Ibaraki, 319-12, Japan.

Cracks in zone melting recrystallized silicon on fused silica could be eliminated by recrystallizing polycrystalline silicon which was previously etched to form islands of silicon. The islands must be less than 250 x 500 μm^2 in size when silicon thickness was 0.5 μm and 50 x 100 μm^2 in size when silicon thickness was 1.0 μm. The recrystallized silicon islands were a single crystal with some subgrain boundaries, consisting of arrays of discrete dislocations. The orientation of crystals was (111) in almost all cases. The electron field effect mobilities of devices on recrystallized silicon were 300 - 700 cm^2/Vs, the same as that of devices on bulk silicon with an orientation of (111) when the device threshold voltages were the same.

1. Introduction

A structure that is composed of crystalline silicon on a fused silica structure (SOI) offers many advantages for such display devices as active liquid crystal displays and for high speed, large scale integrated circuits. This structure can be prepared by recrystallizing polycrystalline silicon on fused silica using an Ar laser beam[1,2], CO_2 laser beam[3], carbon strip heater[4] or an RF-heated carbon susceptor[5]. However, regardless of the method used, cracks appear in the recrystallized silicon, because of the difference in thermal expansion coefficients of the silicon and fused silica. When MOSFETs are fabricated in a silicon layer that contains cracks, the characteristics of the devices are abnormal. Therefore, it is necessary to eliminate cracks in such structures.

Two groups[1,3] attempted to eliminate cracks in silicon layers by laser-recrystallizing polycrystalline silicon, which had been etched to form islands of silicon surrounded by narrow stress-relief grooves. However, conditions that might influence elimination of cracks, for example, island area, have not yet been clarified. Moreover, only continuous silicon was recrystallized in the zone melting recrystallization methods that made use of a carbon strip heater, arc-lamp[6,7] or an RF-heated carbon susceptor[5].

In this presentation, the conditions necessary for the elimination of cracks in zone melting recrystallized silicon are clarified. Then, crystalline quality of the recrystallized silicon islands and characteristics of elemental devices fabricated on the island are described.

2. Experiments and results

Figure 1 illustrates a previously reported recrystallization method in which an RF-heated carbon susceptor was used[5]. We used this method to deposit a 0.5 or 1.0 μm thick polycrystalline silicon on an optically polished fused silica substrate. The polycrystalline silicon film was then etched with a dry etching technique to form islands with areas of from 5 x 5 μm^2 to 4 x 4 mm^2. The silicon surface was covered with a 1.2 μm thick layer of silicon dioxide using a vapor phase deposition process. The wafer was next moved across the surface of the carbon susceptor, which was characterized by the presence of a narrow, high temperature zone. The temperature and width of the high temperature zone were about 1450 °C and 1 mm, respectively. The wafer was moved at a speed of 0.1 - 2 mm/s.

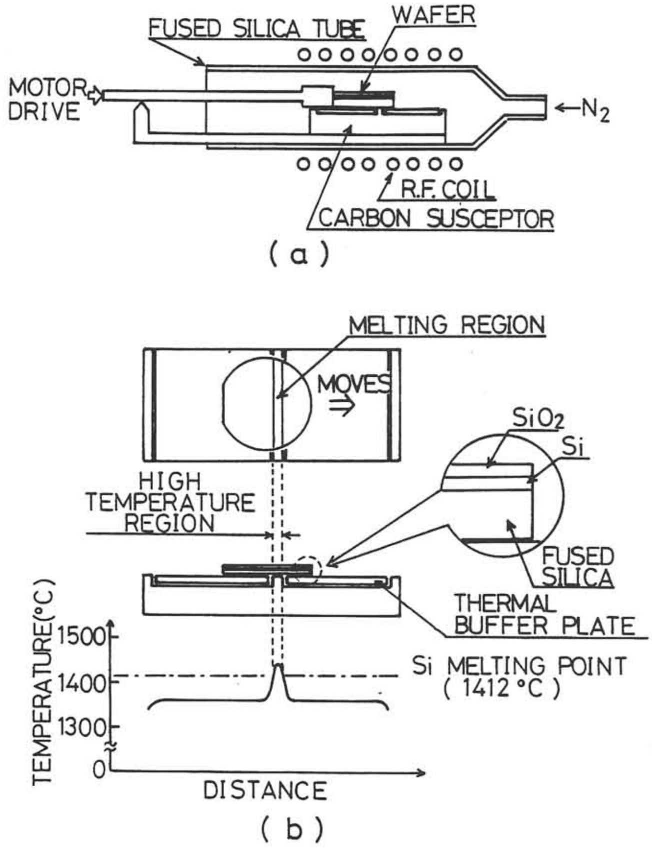

Figure 1. (a) Schematic diagram and (b) illustration of the zone melting recrystallization method.

The crack density of the recrystallized silicon was measured after the encapsulating SiO_2 layer was etched off. As shown in figure 2, cracks disappeared when recrystallized islands of polycrystalline silicon were less than 250 x 500 μm^2 in size when silicon thickness was 0.5 µm and when islands were less than 50 x 100 um^2 in size when the silicon thickness was 1 µm.

Figure 3 shows a SEM photograph of the Sirtl etched silicon surface. The lines of dark dots were etch pits, which correspond to dislocations. These indicated that recrystallized silicon islands had some subgrain boundaries consisting of arrays of discrete dislocations, but no grain boundaries. This absence of grain boundaries indicated that the recrystallized silicon in an island was a single crystal. The orientation of the recrystallized silicon islands was observed with a TEM technique. In almost all cases, the orientation of the silicon islands was (111). Figure 4 shows a typical diffraction pattern observed for one island.

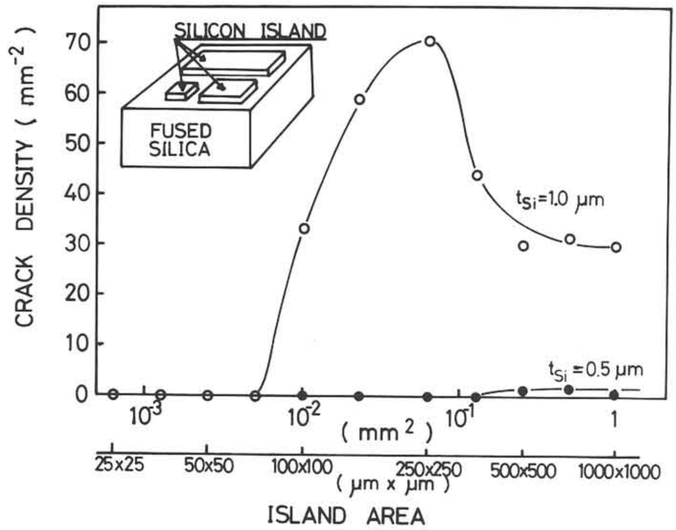

Figure 2. Disappearance of crack with recrystallization of polycrystalline silicon islands.

It has already been reported that the orientation of recrystallized silicon was (100) where polycrystalline silicon was continuously recrystallized on fused silica[5]. The difference in the orientation of the silicon island and the continuous silicon may be caused by a difference in heat flow during the recrystallization of the melt.

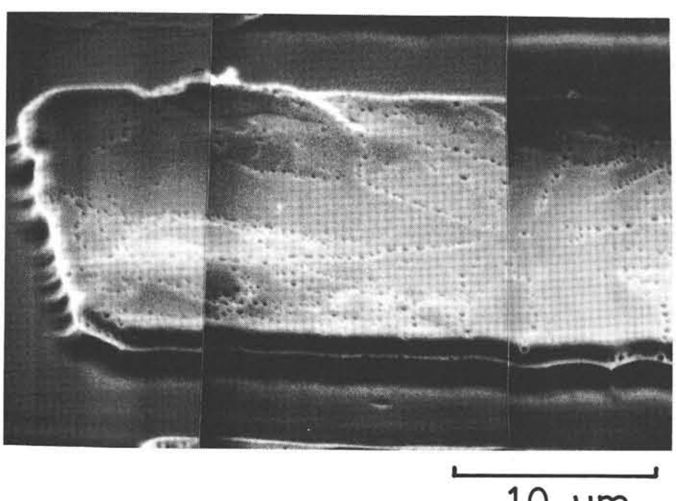

Figure 3. SEM photograph of a Sirtl etched recrystallized silicon surface.

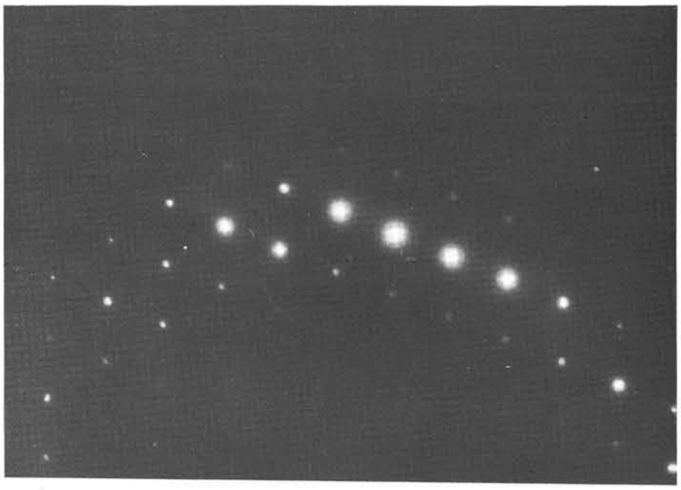

Figure 4. A typical diffraction pattern of the crystallized silicon.

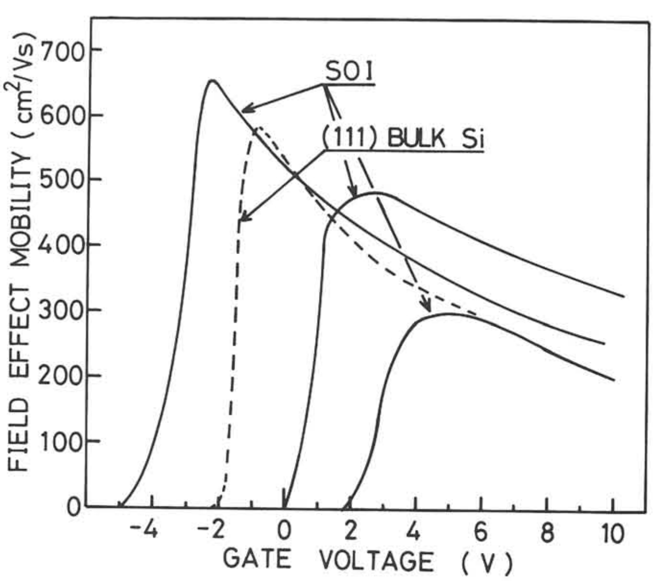

Figure 5. Field effect mobility of MOSFETs on the recrystallized silicon islands.

In order to study the electrical properties of the recrystallized silicon islands, ring type, Al-gate and n-channel MOSFETs were fabricated on them. The thickness of the gate oxide film was 1200 Å. Gate length(L) and width(W) were 20 and 680 µm, respectively. Figure 5 shows the field effect mobilities of devices with a drain voltage of 0.1 V. Reference MOSFETs were also fabricated in bulk silicon with an orientation of (111), using the same fabrication process. Their field effect mobility is also shown in the figure. Electron mobilities were seen to depend on the device threshold voltage. The field effect mobility of a device on a recrystallized silicon island was the same as that of a device on bulk silicon with an orientation of (111) for the same device threshold voltages. In the silicon island, tensile stress could not increase the electron mobility, such as in recrystallization of a continuous polycrystalline silicon film[5], because the orientation of the recrystallized silicon island was (111).

Leakage current was also measured at a drain voltage of 5 V, and found to be 1.5×10^{-11} A/µm.

Inverters of E/E type were fabricated on the recrystallized silicon island. Dimensions(W/L) of the driver MOSFET were 20 µm/200 µm and those of the load MOSFET were 100 µm/200 µm. The (W/L)ratio(β_R) of the load device and the driver device was 5. Figure 6 shows characteristics of the inverter. The gradient of the transient region from an ON level to OFF level was about -1.8. The calculated value of the gradient was about $-\sqrt{\beta_R}$, or -2.2 in this inverter. So, the measured gradient value of the inverter was nearly the same as the calculated value.

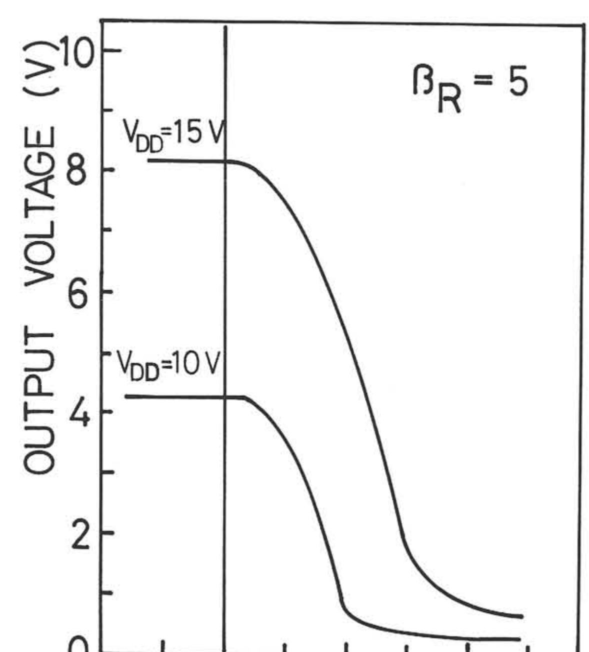

Figure 6. Characteristics of the inverter on the recrystallized silicon islands.

3. Summary

Cracks in recrystallized silicon on fused silica could be eliminated by recrystallizing after the polycrystalline silicon was etched to form islands. The recrystallized silicon was a single crystal with an orientation of (111). The field effect mobility of recrystallized silicon was the same as that of bulk silicon. E/E inverters having good chracteristics could be fabricated on the islands. These results showed that high quality silicon films could be obtained by recrystallizing polycrystalline silicon islands on a fused silica substrate.

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