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Single Crystallization of Aluminum on SiO_2 by Thermal Annealing and Observation with Scanning μ-RHEED Microscope

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We have found single crystallization of Al on SiO_2 via-hole patterned Si wafer by thermal annealing. SiO_2 via-holes were completely planarized with Al by selective and nonselective chemical vapor deposition using dimethylaluminum hydride and hydrogen. Single crystallization of Al on SiO_2 was observed with a scanning μ-RHEED microscope. It was found that polycrystal Al film on SiO_2 was changed into single crystal (111) Al over several hundred μm length on several 10μm wide checker pattern arrays after the annealing at 645°C.

1. Introduction

Aluminum interconnection in submicron VLSI circuits requires the complete planarizing method of depositing aluminum[1,2] and the improvement of crystal quality. The interconnection failure induced by an electromigration (EM) and a stress migration (SM) generally occurs at grain boundaries. Single crystal Al interconnection can dramatically improve the EM and SM endurance.[3] Single crystal Al was deposited on Si surface. However, the single crystal Al film on SiO_2 has not been achieved. Practically, it is important to obtain single crystal Al on SiO_2, because most of Al interconnection is formed over the insulating layer such as SiO_2 and PSG.

The authors have reported the selective deposition of single crystal Al on Si and the complete planarization of via-holes with Al by the selective and nonselective chemical vapor deposition (CVD).[1,2] We report, in this paper, that completely planarized Al film on SiO_2 via-holes can be single crystallized by thermal annealing. Single crystallization was observed with a scanning μ-RHEED microscope.[4]

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2. Experimental

2-1. Sample Preparation

Figure 1 shows a schematic cross-sectional view of the sample. Aluminum was deposited by low-pressure CVD using dimethylaluminum hydride [DMAH: $(CH_3)_2AlH$] and hydrogen. At first, Al was deposited into SiO_2 via-holes selectively by thermal decomposition. Then, adding the plasma excitation for 1 minute, the deposition mode changed into nonselective one. Aluminum films began to deposit nonselectively on SiO_2 as well as the selectively deposited Al. The SiO_2 via-

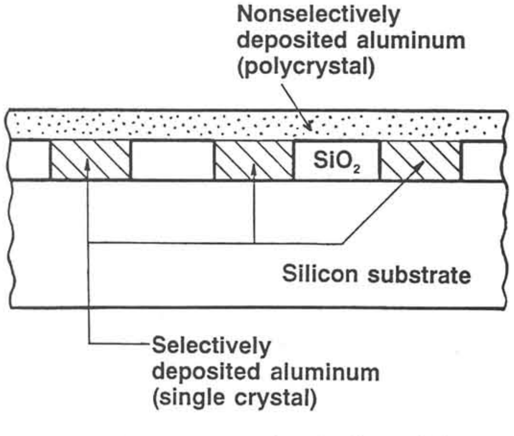


Fig. 1. Schematic cross- sectional view of the sample. Via-holes were completely planarized by selective and nonselective CVD aluminum.

holes were completely planarized by selective and nonselective deposition. The selectively deposited Al was confirmed to be (111) and (100)Al single crystal on (100) and (111)Si substrate, respectively.[1,2]

2-2. Annealing in Scanning μ-RHEED Microscope

Figure 2 shows a schematic block diagram of the scanning μ-RHEED microscope.

The electron beam from the RHEED gun was irradiated onto the sample surface with a glancing angle of 2°-3°. The electron beam diameter was 0.1μm . The reflected diffraction beam from the sample was observed as a RHEED pattern on the fluorescent screen. Any three spots of the RHEED pattern were simultaneously selected for imaging. The scanning μ-RHEED images were obtained from the intensity change of the diffraction spots when the incident beam was scanned. The image data were simultaneously introduced to the image processor. The scanning μ-RHEED images of different diffraction spots were able to be superimposed in the image processor. The distribution of normally rotated micrograin inside same plane's grain parallel to the surface was successfully observed from the scanning μ-RHEED images with a resolution of less than one micron.[4]

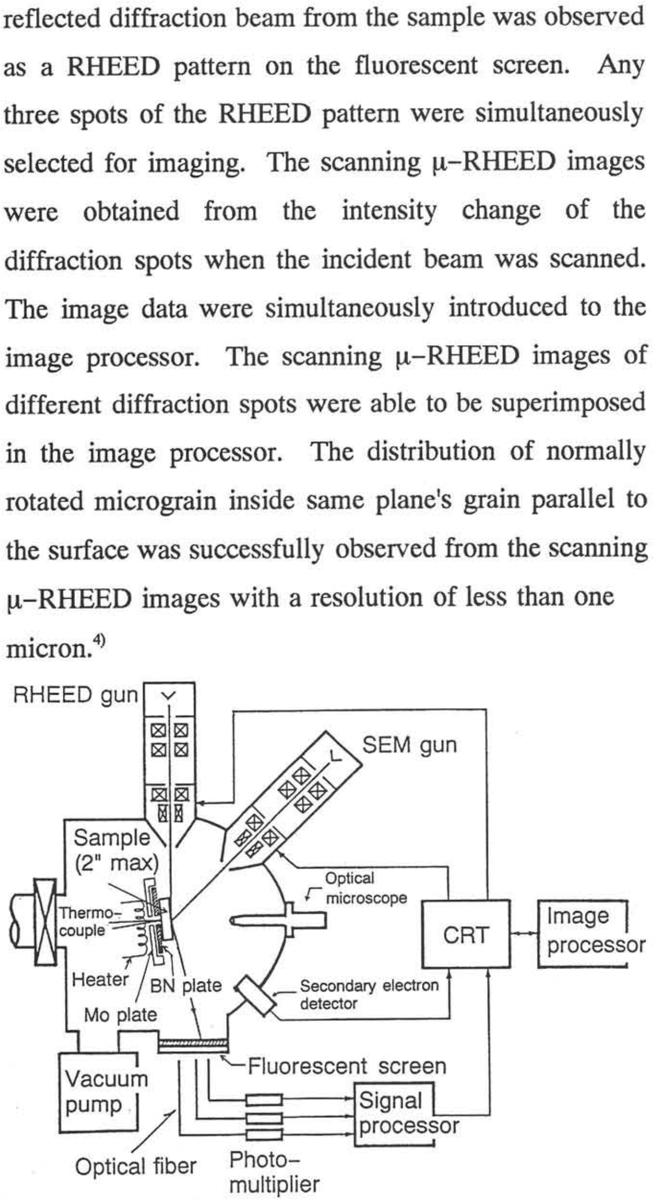


Fig. 2. Scanning μ-RHEED microscope. A sample can be heated up to 1000°C.

The completely planarized Al film on SiO_2 via-holes was annealed in the chamber and crystallinity of Al film was *in-situ* observed. The sample was heated by the resistive heating from the back surface. The annealing temperature was measured with the thermocouple. The pressure in the chamber during the annealing was below $5x10^{-6}$Pa.

The crystallinity of the sample before and after the annealing was also evaluated with the X-ray diffract meter and the conventional RHEED machine (JEOL, JEM-2000FX).

3. Results and Discussions

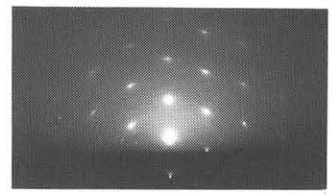
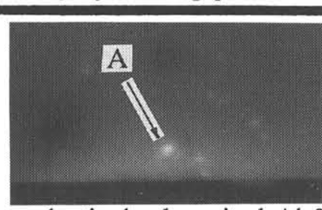
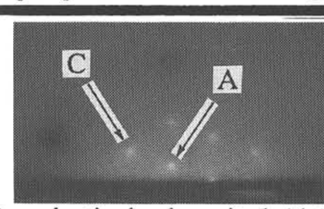
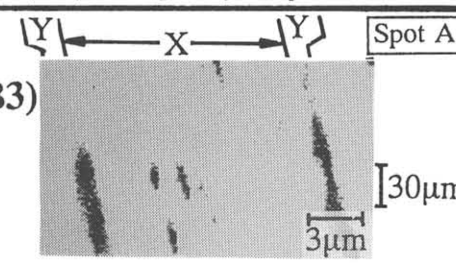
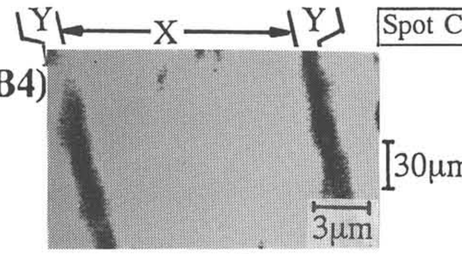
Aluminum film was deposited on (111)Si substrate with 1μm thick SiO_2 via-holes. The annealing temperature was 645°C and the duration was 15 min.

Table 1 summarizes the conventional RHEED patterns, the μ-RHEED patterns and the scanning μ-RHEED images before and after the annealing.

Before the annealing, a strong (100)Al peak was observed in the X-ray diffraction spectrum. The conventional RHEED pattern was ring pattern as shown in Fig. (A1) of Table 1, so that the nonselectively deposited Al was polycrystal. However, the conventional RHEED patterns can give the only average information of the area larger than 100μmx1mm because of its large electron beam diameter. The grain size was observed using the scanning μ-RHEED image. In the μ-RHEED pattern of Fig. (A2), weak spots were observed because of a small electron beam diameter. Figure (A3) shows the scanning μ-RHEED image using the diffraction spot A in Fig. (A2). The nonselectively deposited Al on SiO_2 was found to be polycrystal consisted of several micron grains.

Figure (B1) shows the conventional RHEED pattern after the annealing. A spot pattern with weak rings was observed, so that the grain size of the Al film was grown larger than that before annealing. The μ-RHEED pattern after the annealing exhibited a clear spot pattern as shown in Fig. (B2). This μ-RHEED spot pattern was confirmed to be the RHEED pattern when the electron beam was irradiated on (111) plane with incident azimuth along [$\bar{1}$01]. The X-ray diffraction spectrum had a strong (111)Al peak. The crystal orientation of Al was confirmed to be changed into (111) after the annealing. The diffraction spot A and C in Fig. (B2) were 111 and 202 diffraction spots, respectively. The diffraction spot 111 appeared when the sample surface was parallel to (111) plane, and the 202 spot appeared when the sagittal plane of the incident beam was parallel

Table 1. Single crystallization of aluminum on SiO_2 by thermal annealing.

		Before annealing (As deposited)	After annealing (645°C, 15min)
Conventional RHEED pattern (JEOL, JEM-2000FX)		(A1)  Polycrystal ring pattern.	(B1)  Spot pattern with weak ring.
Scanning μ-RHEED observation	μ-RHEED pattern	(A2)  Nonselectively deposited Al film on SiO_2 via-hole pattern. Weak spot pattern.	(B2)  Nonselectively deposited Al film on SiO_2 checker pattern. (111)Al single crystal pattern.
	Scanning μ-RHEED image	(A3)  Nonselectively deposited Al film on SiO_2 via-hole pattern. Polycrystal grain structure was observed. (Grain size : 3–10μm)	(B3)  (B4)  X : Al film on SiO_2 checker pattern. Y : Al film on SiO_2. SiO_2 was not patterning.
		No micrograin structure was observed in Al on SiO_2 checker pattern, i. e., the Al on SiO_2 checker pattern was single crystallized by the thermal annealing.	

to $(\bar{1}2\bar{1})$ plane. In the region where the intensities of 111 and 202 spots are both strong, each of planes parallel and perpendicular to the sample surface is directed to the same direction, i. e., single crystal region. Figures (B3) and (B4) show the scanning μ-RHEED images using the spot A and spot C in Fig. (B2), respectively. In X region of Fig. (B3) and (B4), the intensities of diffraction spot A and C were both strong. Hence, the Al film in X region was confirmed to be (111) single crystal. In X region, Al film was deposited on SiO_2 checker pattern and the checker size was 1μm□.

Figure 3 shows a low magnification superimposed scanning μ-RHEED image using the spot A and C of Fig. (B2) in Table 1. In the gray region, spot A was strong and spot C was weak. The gray region was the rotated grain among {111} planes. In the white region the spot A and spot C were both strong, i. e. , single crystallized region. In the white region, Al film was deposited on 10μm wide SiO_2 checker arrays of 1μm□. It was confirmed that Al films on SiO_2 checker pattern arrays were single crystallized over several hundred μm length on several 10 μm wide checker pattern arrays.

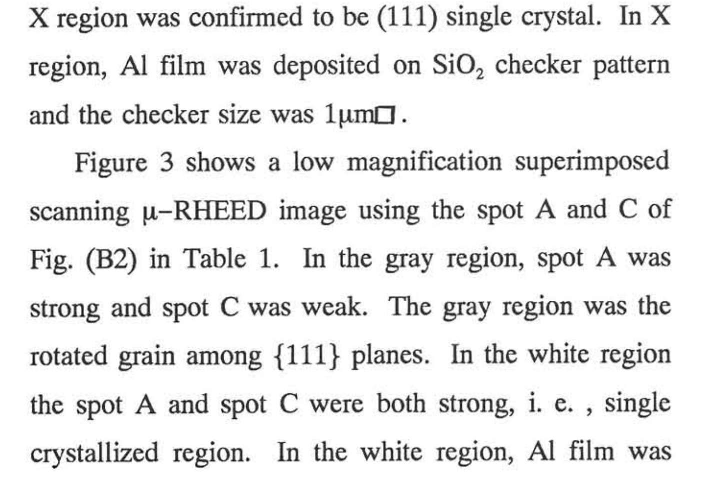


Fig. 3. Low magnification superimposed scanning μ-RHEED image using spot A and spot C of Fig. B2 in Table 1. The intensities of the diffraction spot A and C were both strong in the white regions. The white regions were single crystallized (111)Al region. The gray regions were rotated {111} grains.

We found that Al film on SiO_2 was single crystallized by thermal annealing when the selectively deposited single crystal Al existed beneath the nonselectivery deposited Al film. The selectively deposited Al on (111)Si was (100) single crystal and the nonselectively deposited Al was (100) oriented polycrystal before the annealing. (100) oriented polycrystal Al on SiO_2 pattern was completely changed into (111)Al after the annealing at 645°C. We estimate that, since the sample was annealed from the back side, the selectively deposited single crystal (100)Al was changed into stable (111)Al and then the nonselectively deposited Al was changed into single crystal (111)Al.

4. Summary

We found that Al film on SiO_2 via-hole patterned Si wafer was single crystallized by thermal annealing. SiO_2 via-holes were completely planarized with Al by selective and nonselective chemical vapor deposition using dimethylaluminum hydride and H_2. Single crystallization of Al on SiO_2 was observed with the scanning μ-RHEED microscope. The single crystal Al on SiO_2 is the most promising candidate for high reliable interconnection in submicron VLSI.

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References

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