Extended Abstracts of the 1993 International Conference on Solid State Devices and Materials, Makuhari, 1993, pp. 543-545

Improvement of the Interface between Selectively Deposited Al and Si by Annealing

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The interaction between Al deposited selectively by CVD and Si has been investigated. The structure of Al depended on the size of contact holes. Al was single-crystalline in 0.7μm contact holes, but polycrystalline in 1.2μm and 2.0μm holes. In the case of single crystalline Al, Si at the bottom of contact holes was eroded uniformly by Al after deposition and after annealing at 400°C. In the case of polycrystalline Al, Si was eroded nonuniformly and Al spikes were formed. However, after annealing at 400°C, the Al spikes disappeared and the surface of eroded Si became extremely flat. Junction leakage current of the 2.0μm n^+ contact was found to increase after Al deposition. However, after annealing at 400°C, the increase of junction leakage current was not found to 10V. The change may be due to the improvement of the interface. These results indicate that selective Al-CVD can be used safely as a contact-hole-filling method.

§1 Introduction

In multilevel interconnections for ULSI, filling narrow holes of high aspect ratio has been one of the main difficulties. For this purpose, selective deposition of Al onto contact holes is very attractive and has been investigated by several researchers. In recent years, selective Al CVD has been achieved by controlling the deposition temperature.[1)-3)] However, in the case of filling holes by this method, an Al-Si direct contact was formed. It is well known that an interaction between Al and Si occurs in an Al-Si direct contact, i.e., Si is eroded by Al and Al spikes are formed.

In this study, we investigated the interaction between selectively deposited Al and Si and proposed a method for improving the interface between Al and Si.

§2 Experimental conditions

Si(111) wafers with orientation of about 3° off-angle were used. These wafers were covered with SiO_2 films, and 0.7μm, 1.2μm, and 2.0μm contact holes were formed. Before deposition of Al, the wafers were dipped in 1% HF solution for 45s and rinsed in deionized water. After these treatments, Al was deposited by low-pressure CVD using dimethylaluminum hydride (DMAH). The substrate temperature was 340°C and the deposition time was 60s. Under these conditions, Al was selectively deposited. After the deposition, these samples were annealed in H_2 ambient at 400°C for 30 min.

The morphologies of selectively deposited Al and the Si surface at contact holes were characterized by scanning electron microscopy (SEM) and atomic force microscopy (AFM). Electrical properties, such as junction leakage current and contact resistance, were measured using n^+/p diodes whose junction depths (x_j) were 230nm and 330nm (simulated).

§3 Results and discussion

3-1 Improvement of the Al-Si interface

Figure 1 shows the SEM photographs of selectively deposited Al and Si surface after removal of Al and SiO_2 films by wet etching. After deposition, contact holes were completely filled with Al, as shown in Fig 1(a). The structure of Al depends on the size of holes. Al was single-crystalline in 0.7μm holes, but polycrystalline in 1.2μm and 2.0μm holes. Si at the bottom of holes was eroded laterally and vertically during deposition, as shown in Fig 1(b). The shape of holes became hexagonal for all sizes of holes. The behavior of vertical erosion depends on whether deposited Al is single crystalline or polycrystalline. In 0.7μm holes, Si was eroded uniformly, while in 1.2μm and 2.0μm holes, nonuniform erosion occurred and Al spikes were formed. The erosion pattern is similar to that at the grain boundary of Al. Figure 1(c) shows Si surfaces after 400°C annealing. The erosion pattern (Al spikes) disappears in 1.2μm and 2.0μm holes. The shape of 0.7μm holes did not change, but that of 1.2μm and 2.0μm hole reverted to the initial shapes before deposition. The profile of the Al-Si interface was measured for 2.0μm holes by AFM and is shown in Fig 2. After deposition (a), the size of holes was larger than that before the deposition and the depth of the spike was

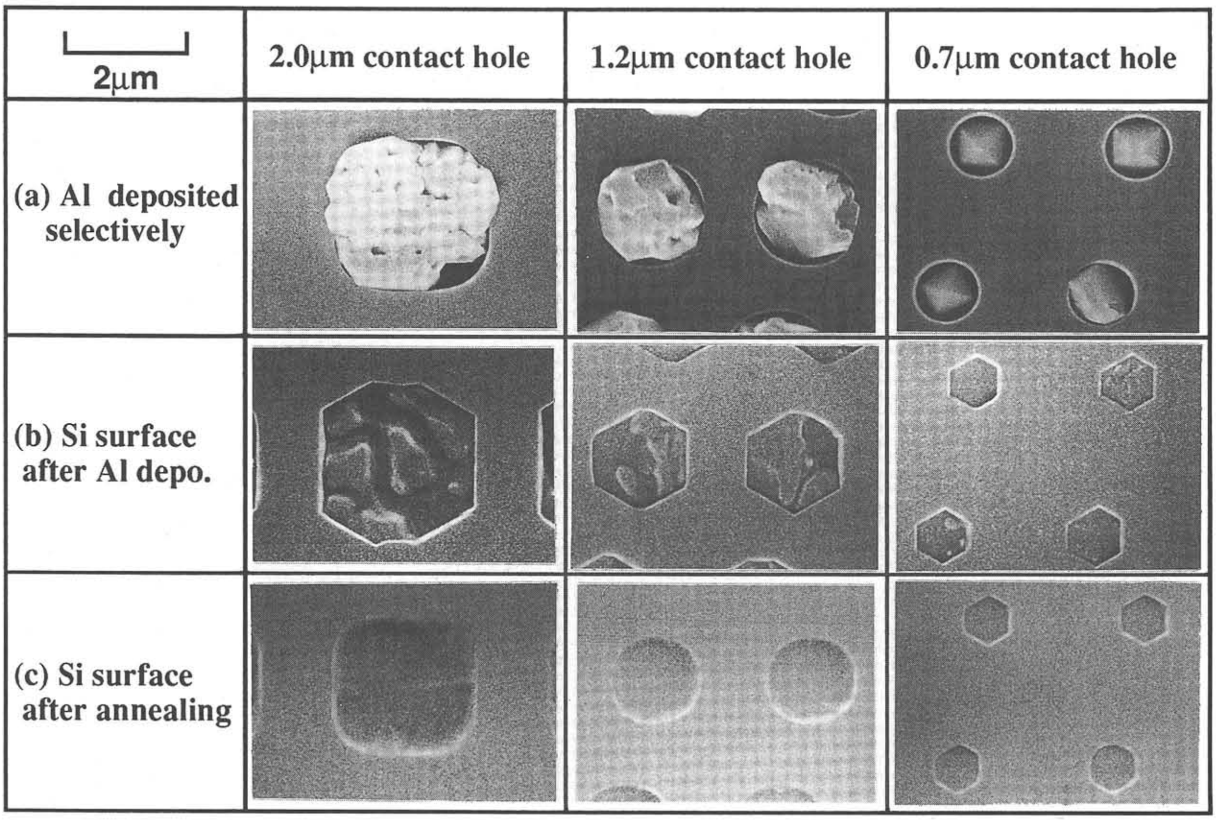

Fig. 1 SEM photographs of selectively deposited Al and Si surface after removal of Al and SiO_2

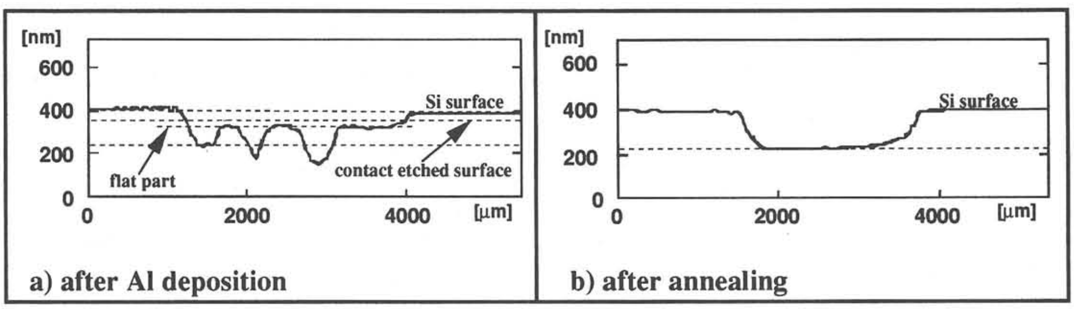

Fig. 2 AFM profiles of eroded Si surface of 2.0μm contact hole

190nm. However, after annealing (b), the size was almost the same as that before deposition and the interface between Al and Si became extremely flat. The same result was obtained with 1.2μm holes. Table I shows the depth of eroded Si (x_{er}), which was estimated from AFM measurement. Here, the depth was measured from the etched surface at contact-etching. In the 1.2μm and 2.0μm holes, x_{er} after annealing was shallower than x_{er} at spikes but deeper than x_{er} at the flat part before annealing. x_{er} in the 0.7μm hole became deeper with annealing, but was much shallower than x_{er} in 1.2μm and 2.0μm holes. Tsubouchi et. al. reported that erosion-free and spike-free Al-Si direct contact was realized through selective deposition of single-crystal Al

Table I The depth of eroded Si (x_{er}), which was estimated from AFM measurement

		2.0μm contact hole	1.2μm contact hole	0.7μm contact hole
as-deposited	flat part	**15nm**	**10nm**	**12nm**
	spike	**190nm**	**150nm**	——
after annealig at 400°C	flat part	**100nm**	**70nm**	**39nm**

using DMAH.[4] Our result is inconsistent with their result. Based on our results, the mechanism of the improvement of the Al-Si interface in the case of polycrystalline Al is considered as follows. Al spikes are

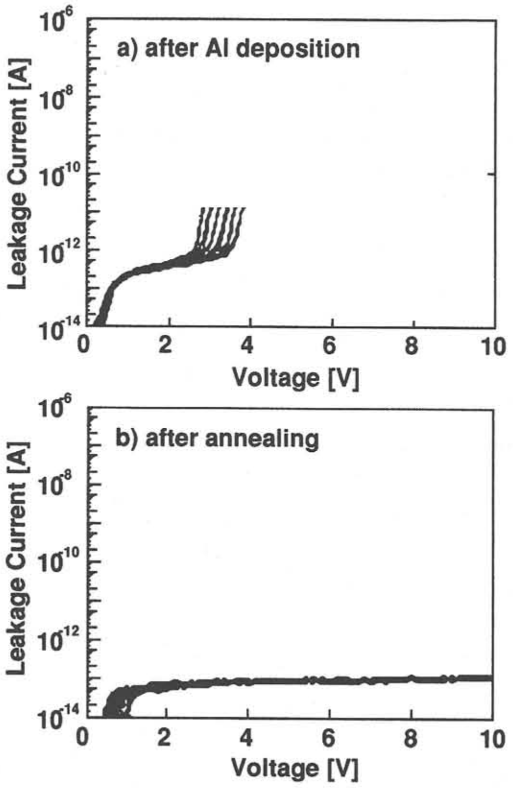

Fig. 3 Leakage current of 2.0μm n+ contact

formed locally by dissolution of Si at the grain boundary of Al. During annealing at 400°C, Si in the grain boundary of Al is swept out and grows epitaxially into spike regions of the Si substrate.

3-2 Electrical properties of n+/p diode

Figure 3 shows junction leakage current of 2.0μm n+ contact holes at x_j of 230nm. The deepest Al spike was formed in this case. After Al deposition (a), junction leakage current was found to increase from about 2V. However, after annealing at 400°C (b), the increase of junction leakage current was not found to 10V. This change may be due to the improvement of the interface. Contact resistance (ρ_c) of 2.0μm contact holes was measured by the Kelvin method and is shown in Table II. With 400°C annealing, ρ_c at x_j of 230nm increases and is much larger than ρ_c of sputtered Al-1%Si, while ρ_c at x_j of 330nm increases slightly but is the same as ρ_c of sputtered Al-1%Si. At the spikes, Si grows epitaxially with annealing, and there was the fear that this epitaxial Si induces increase of ρ_c but the above findings exclude this possibility. The impurity concentration at the eroded Si surface (n_s) depends on x_j and x_{er}, as shown in this table. The large increase of ρ_c at x_j of 230nm due to annealing is explained by the large decrease of n_s.

Table II Contact resistance (ρ_c) and impurity concentration (n_s) of 2.0μm contact hole of as-deposited and after annealing at 400°C

		depth of eroded Si	junction depth (simulated)			
			230nm		330nm	
			ρc	ns	ρc	ns
CVD-Al	as-deposited	**15** [nm]	**12.9** [Ω]	**3.26×10^{20}** [cm^2]	**14.9** [Ω]	**2.17×10^{20}** [cm^2]
	after annealing at 400°C	**100** [nm]	**73.9** [Ω]	**7.21×10^{19}** [cm^2]	**15.7** [Ω]	**2.00×10^{20}** [cm^2]
sputtered - Al	as-deposited	—	—	**3.26×10^{20}** [cm^2]	—	**2.17×10^{20}** [cm^2]
	after annealing at 400°C	—	**16.8** [Ω]	**3.26×10^{20}** [cm^2]	**15.6** [Ω]	**2.17×10^{20}** [cm^2]

§4 Conclusions

The interaction between Al deposited selectively by CVD and Si have been investigated. The structure of selectively deposited Al depends on the contact hole size. After deposition, Si was eroded uniformly by single-crystalline Al and nonuniformly by polycrystalline Al. However, after annealing at 400°C, the interface between Al and Si was improved and became extremely flat. Low leakage current is obtained in the Al-Si direct contact after this annealing. The result of ρ_c measurement shows that epitaxially grown Si at the spikes, which gives the very flat Al-Si interface, does not influence ρ_c. These results indicate that the selective CVD Al has potential for use in the Al-Si direct contact.

References

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