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Epitaxial Growth of Al(100) on Si(100) by Gas-Temperature-Controlled Chemical Vapor Deposition

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Epitaxial Al(100) film was deposited on Si(100) by low-pressure chemical vapor deposition with the use of tri-isobutylaluminum(TIBA) at the substrate temperature of 380-400℃ with the deposition rate of 400nm/min. For the epitaxial film growth it was concluded that preheating the TIBA gas just before the incidence onto the substrate was very important (gas-temperature controlling). The specular reflectance of the1μm-thick Al film on Si was the same level as that of the sputtered film. The X-ray diffraction peak was very narrow and only Al(100) orientation was observed. The TED patterns of Al(100) films showed clear spots.

Today, aluminum and aluminum alloy films are widely used for metallization in VLSI processing. These films are currently deposited by the sputtering technique. However, this results in insufficient step coverage for a narrow and deep hole of sub-micron size (via and contact holes) because of the increasing integration density of IC's. And the sputtered films are poly-crystal and the troubles from the migration are frequently occurred.

A new deposition technique which provides conformal step coverage has been eagerly desired. The low pressure chemical vapor deposition (LPCVD) of aluminum films has been investigated as a potential technology for several years.[1-5] However, it has been difficult to obtain a smooth-surfaced film. Kato et al. improved the surface flatness by using magnetron plasma CVD with tri-methylaluminum, but the film contained a large amount of carbon, about 5%.[6] Amazawa and Nakamura improved the flatness with LPCVD and tri-isobutylaluminum(TIBA), and showed the possibility of selective deposition on silicon wafers with silicon dioxide patterns.[7] But the deposition rate was relatively low, about 10-20nm/mim.

On the other hand, the epitaxial growth of aluminum films were attempted with the use of TIBA by a newly developed LPCVD technique referred to as gas-temperature-controlled CVD(GTC-CVD).[8,9]

In this work, the epitaxial growth of aluminum films on Si(100) wafers were attempted by GTC-CVD. Epitaxial growth of Al(100) on Si(100) by GTC-CVD was found to be possible for the first time. The film properties were characterized by specular reflectance, scanning electron microscope (SEM), transmission electron diffraction (TED), X-ray diffraction, and secondary ion mass spectroscopy (SIMS) measurements.

Figure 1 shows a schematic diagram of the experimental system. The TIBA kept in a evaporator at 35℃ was bubbled by Ar, and was introduced into the cold wall-type reactor. These gases were preheated just before their arrival to the Si substrate by a gas temperature controller. This controller consisted of a Cu cylinder and two Cu plates with many small holes and was heated up to 230℃. This preheating had an important role on the epitaxial growth. A load lock chamber combined with the reactor was used. The deposition chamber was 30cm in diameter and 30cm in height and made of stainless steel. It was pumped by a turbomolecular pump whose punping speed was 550 l/sec. The pressure wasmonitored by a capacitance manometer.
The substrate holder was 15cm in diameter and could be heated to 430℃. Disilane could be added to TIBA before it was injected into the chamber.
The background pressure before the deposition was lower than $3x10^{-6}$Torr.
Substrates were 4-in. Si wafers having (100) orientation. Surfaces were precleaned with dilute HF. No other substrate treatment was employed. Pressure during the deposition was kept at 2 Torr automatically with the variable conductance valve. The typical growth rate was about 400nm/min at an Ar flow rate of 30sccm.

The aluminum film structure on Si(100) was categorized in these different region corresponding to different substrate temperatures as shown in Fig.2. It was found that the substrate temperature of 380-400℃ was neccesary for epitaxy.
Near 410℃, the surfaces became rough and the mixed structure of (100) and (110) preferred orientation was observed by X-ray diffraction measurement. At higher temperature, the film showed only (110) orientation. Below 380℃, the surface became rough and the structure was polycrystalline.

The aluminum films oriented in two different directions could grow on Si (100) by GTC-CVD. One was Al(110) on Si (100) and the other was Al(100) on Si(100). Two types of aluminum films had much different surface topography. It was observed that Al(110) films on Si(100) were polycrystal consisted by two types of grain crossed perpendicularly with each other. This structure was very similar to Al(110) film grown on Si(100) by ICB.[10] A single crystalline Al(110) film on Si(100) was not obtained. But we could make a single crystalline Al(100) film on Si(100).
The relations models of crystal orientation are shown in Fig.3.

The specular reflectance of the GTC-CVD aluminum film is shown in Fig.4 with that of the sputtered aluminum film as a function of wavelength. The GTC-CVD aluminum film gave a little higher values than these of the spattered film.

Figure 5 shows the TED patterns of epitaxial Al(100) films. These patterns showed clear spots. This meaned the film was singlecrystal oriented in (100).

Carbon, oxygen and hydrogen contents were measured by SIMS. Their contents were lower than 0.05 at.%.

In summary, the epitaxial Al(100) film was grown on Si(100) substrate by GTC-CVD for the first time. The film had a very smooth surface.

The epitaxial aluminum film deposited by GTC-CVD is expected to be applicable to migration-free and hillock-free IC interconnects.

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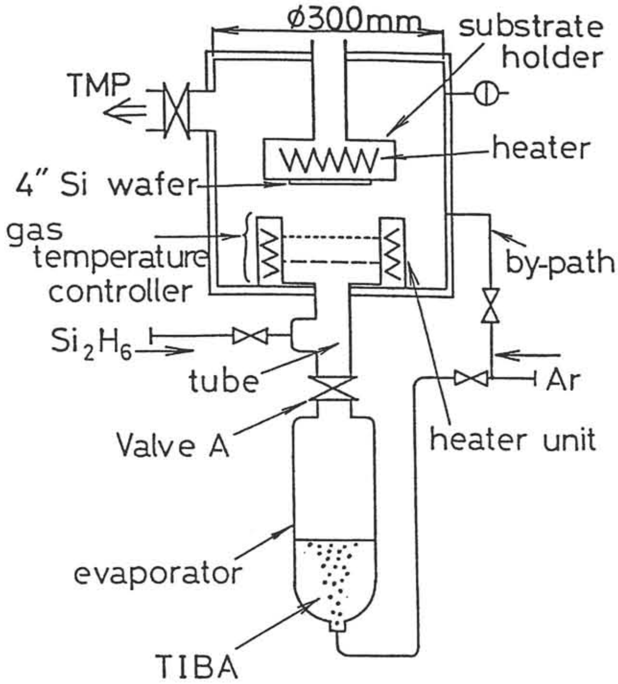
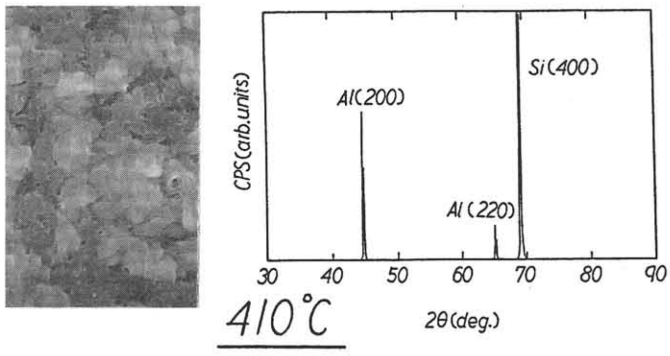
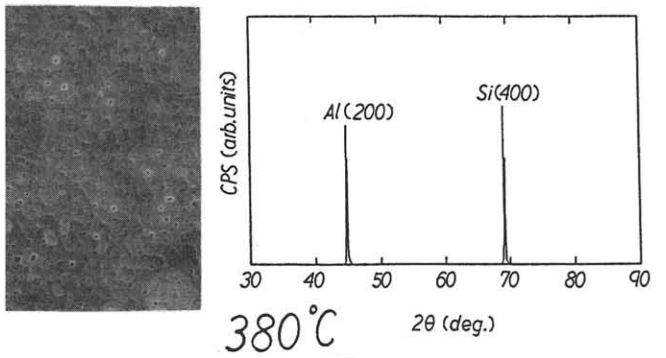


Fig.1. Experimental system of GTC-CVD





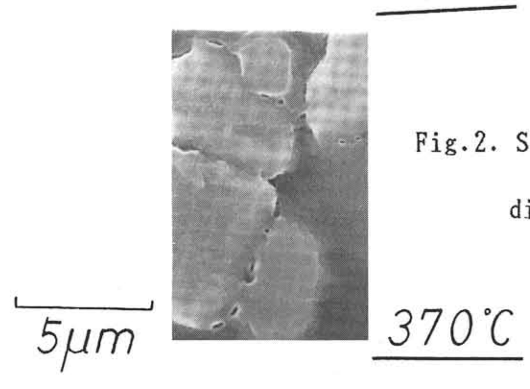


Fig.2. SEM photos and X-ray diffraction patterns

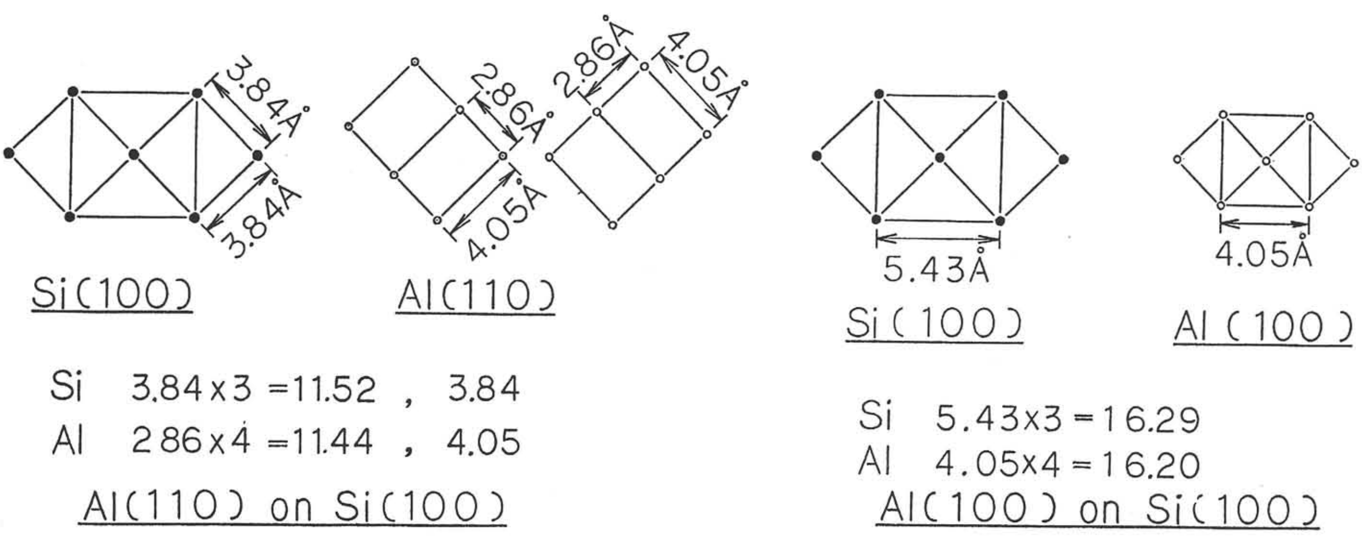


Fig.3. The relations models of crystal orientation

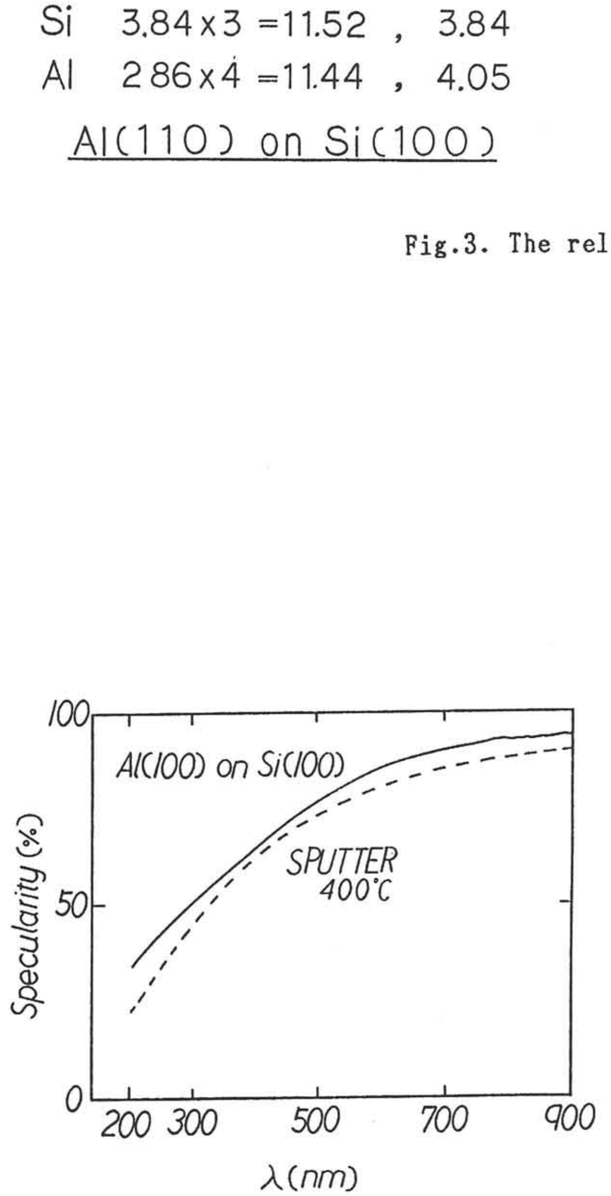


Fig.4 The specular reflectance of the GTC-CVD aluminum film

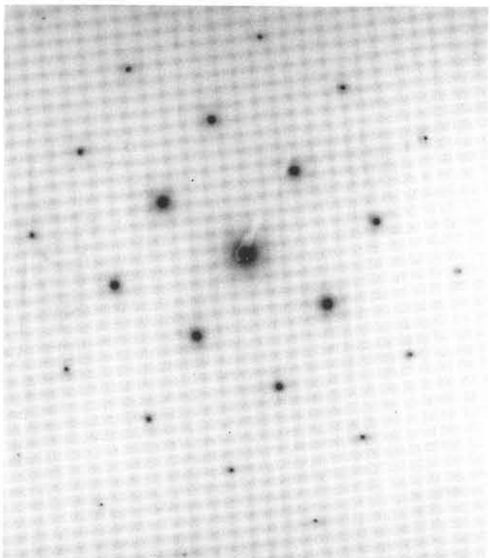


Fig.5. The TED patterns of the GTC-CVD aluminum film