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Formation of High Quality Epitaxial Silicon Films by Ultra Clean Technology

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An ultra clean CVD (Chemical Vapor Deposition) epitaxial growth system was developed to grow high quality epitaxial silicon films. Introduction of newly-developed ultra high vacuum compatible reactor having carbon susceptor with minimized contamination as well as the electrostatic wafer chucking/transfer mechanism working in high vacuum realized an ultra clean environment for epitaxy. As a result, defect-free epitaxial silicon films were obtained at such low temperatures less than 900°C, when substrates were heat-treated under the ultra high vacuum before epitaxial growth. The generation lifetime and the carrier concentration of epitaxial films grown in this system were typically 4.7 msec and 8×10^{12} cm^{-3}, respectively.

1. Introduction

There have been considerable interests in the formation of high quality epitaxial silicon films, since they are very important to realize high performance DRAM's and imaging devices. In such devices, leakage currents and dark currents must be suppressed as small as possible, since the amount of signal charges decreases with the scaling down of devices for ultra large scale integration. Dark currents are reduced inversely proportional to the generation lifetime of carrier in epitaxial films. To date, the generation lifetimes of epitaxial silicon films are usually very short, except special cases which exhibit good generation lifetimes such as 1 to 2 msec(1). In order to improve the quality of epitaxial films, i.e., to increase the generation lifetime, it is inevitably required to eliminate contaminations as low as possible such as oxygen, carbon, heavy metals, and etc. almost completely.

In the present work, an ultra clean CVD (Chemical Vapor Deposition) epitaxial growth system was developed by introducing an ultra high vacuum compatible RF heating quartz tube system, an ultra clean gas delivery system, and etc.(2-4).

2. Epitaxial Growth System

A newly-developed ultra clean CVD epitaxial growth system is shown in Fig. 1.

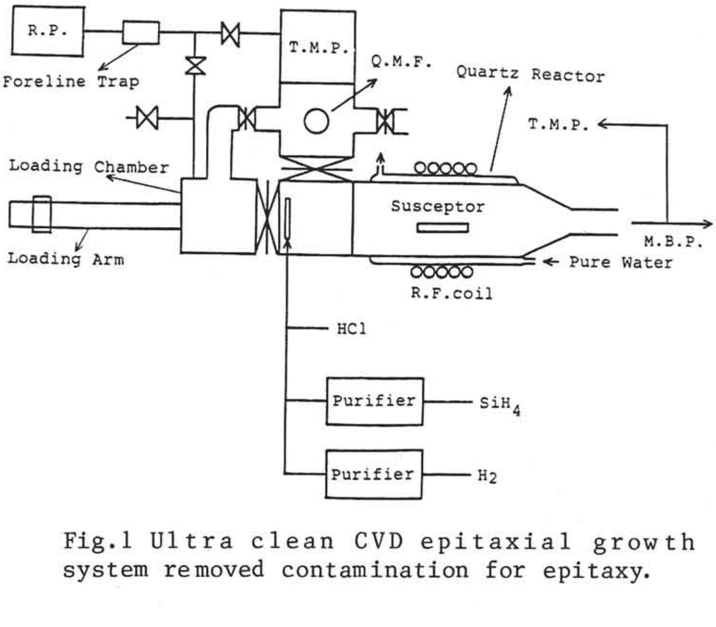

Fig.1 Ultra clean CVD epitaxial growth system removed contamination for epitaxy.

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In order to realize high quality epitaxial films, it is essential to eliminate all possible contamination sources from the processing environment completely. The new technique introduced to connect the quartz flange to the stainless flange has reduced the leakage level below the detection limit of $2x10^{-11}$ atm·cc/sec Extensive baking was conducted for outgassing of all stainless steel components of the system and also the quartz tube before the start of experiments. During epitaxy, the quartz tube was water-cooled by flowing ultra pure water in order to minimize the contamination from the heated quartz wall. One of the greatest contamination sources is the carbon susceptor. The conventional carbon susceptor, when RF heated, generates a lot of contaminations by releasing gases, such as water, nitrogen, carbon monooxide, and etc., through pin-holes in the SiC coating

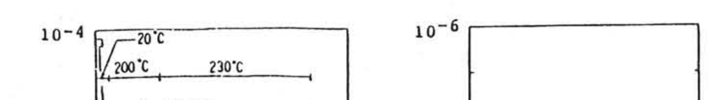

Fig.2 Outgassing characteristics of new and conventional susceptor.
(a) Time dependence of total pressures in reactor under high vacuum with outgassing of new and conventional susceptor.
(b) Time dependence of partial pressures for outgas species from the new susceptor.

layer. Therefore complete outgassing from the carbon susceptor is essential. A new carbon susceptor structure in which the SiC coating is partially removed was introduced to perform complete outgassing. The outgassing characteristics of the new susceptor are shown in Fig.2 in comparison with that of the conventional susceptor. It is seen that the outgas from the new susceptor decreases much faster than that of the conventional one. The outgas level at 888°C was below $1x10^{-8}$ Torr. After that, the new susceptor was etched by hydrochloric acid to remove the heavy metals on the surface, and then the surface was covered with polysilicon by silane thermal decomposition. To avoid the contamination from the atmosphere, load lock system was employed. Here, the transfer from loading chamber to reactor is performed using electrostatic wafer chucking mechanism under a high vacuum which is performed by oil-free turbo molecular pumping system. To introduce ultra clean gases into reactor, a leak-free, particle-free, and deadzone-free gas delivery system was employed.

3. Experimental

The epitaxial silicon films were grown using silane-hydrogen gas system, where the silane concentration is 1000 ppm, and total gas flow rate is 10 l/min. The substrates used were antimony-doped n-type silicon wafers of 0.05-0.18 Ω·cm, oriented 2.5° off the (111) plane. The growth rate was around 300 to 1000 A/min depending on the growth temperatures. The defect-free epitaxial growth conditions were investigated for various prebaking temperatures and pressures, and also growth temperatures by observing as-grown staking faults and OSF's using the Wright etching technique. The carrier concentrations and the generation lifetimes of the epitaxial films were evaluated by the MOS diode with a guard ring which suppresses the surface leakage current.

4. Results and Discussion

The relationship between the epitaxial growth conditions and the defect densities is shown in Table I. Here, it should be noted that all samples have shown Kikuchi-lines in the electron diffraction patterns. It is found that high vacuum prebaking of wafers at temperatures above 800°C is very effective to obtain defect-free epitaxial films. The present prebaking condition for defect-free epitaxial silicon films agrees well with the reported condition of removing native oxide(5). Table I shows that defect-free epitaxial films are obtained at growth temperatures above 890°C and the deposition rate of 1000 A/min. The typical high frequency C-V curve and the depth profile of the carrier concentration calculated from the C-V curve were shown in Figs. 3 and 4, respectively. It is found in Fig. 4 that the carrier concentration is about $8x10^{12}$ cm^{-3}. The generation lifetime was calculated from the C-t curve shown in Fig. 5. The generaion lifetime and the carrier concentration of the epitaxial films deposited under various conditions are shown in Fig. 6. The prebaking at the high vacuum made it possible for the epitaxial films to have the low carrier concentration ($8x10^{12}cm^{-3}$) and the longer generation lifetime (4.7 msec),

Table I Relationship between epitaxial growth conditions and defect densities.

Prebaking			Epitaxial Growth		Defect Density
Temp. (°C)	Time (min)	Press. (Torr)	Temp. (°C)	Press. (Torr)	(cm^{-2})
1157	10	760	960	80	$2.6x10^2$
1202					N.D.
1202			890		N.D.
			855		$2.4x10^2$
755	30	10^{-7}	890	80	$3.9x10^3$
805					N.D.
			855		$3.9x10^3$

*N.D. shows that the defect density is less than 80 cm^{-2}.

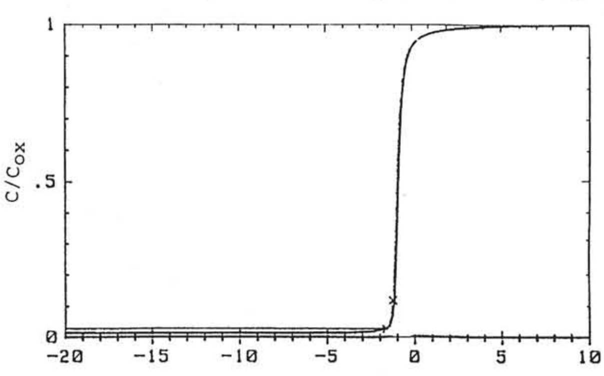

Fig.3 High frequency C-V characteristics of n^+ polysilicon gate MOS capacitor with 600 A oxide grown on the defect-free epitaxial films.

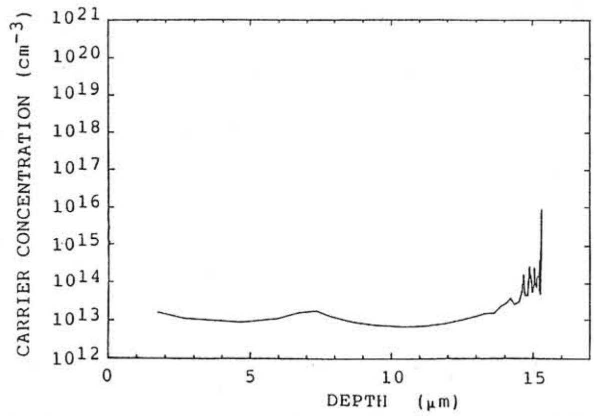

Fig.4 Depth profile of the carrier concentration in the epitaxial films calculated from the C-V characteristics.

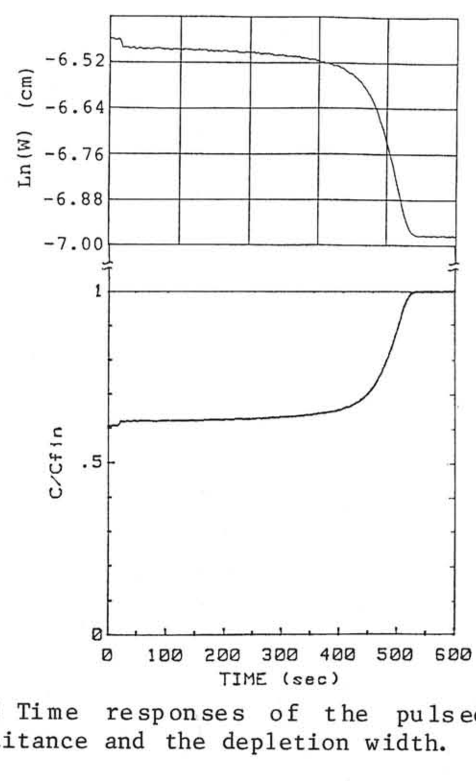

Fig.5 Time responses of the pulsed MOS capacitance and the depletion width.

compared with the datas reported by many workers. The improvement of the generation lifetime achieved here is due to the elimination of contaminants, such as oxygen, carbon, heavy metals, and etc., which have been introduced to epitaxial films from the reactor and also from the gases.

5. Conclusions

To improve the generation lifetime of the epitaxial silicon films, an ultra clean CVD epitaxial growth system has been developed. In this system, it is found that the prebaking under high vacuum made it possible to grow the defect-free epitaxial films at temperatures below 900°C when the deposition rate is 1000 A/min. The carrier concentration and the generation lifetime of the films were $8x10^{12}$ cm^{-3} and 4.7 msec, respectively. These results have made it practice to use epitaxial silicon films for DRAM's and imaging devices since dark currents have been suppressed well below the desired level.

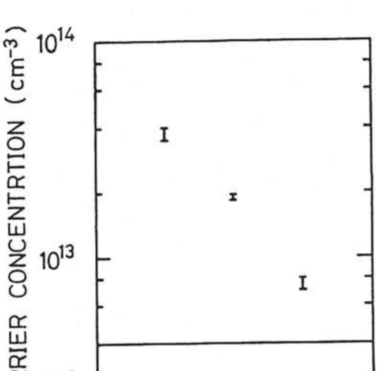

Fig.6 Comparison of the generation lifetimes and the carrier concentrations.
a: Epitaxial films on sale.
b: Epitaxial films prebaked at 1202°C in 760 Torr.
c: Epitaxial films prebaked at 805°C in 10^{-7} Torr.

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