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Microdefect Elimination in Reduced Pressure Epitaxy on Silicon Wafer by Back Damage-Si_3N_4 Film Technique

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ABSTRACT

A gettering technique which prevents microdefect formation during oxidation processes after the growth of reduced pressure Si epitaxial layer for bipolar devices is described. A gettering process which consists of protection of the back damage layer with Si_3N_4 film is proposed. A microdefect density in epi-layers of $\sim 10^2$ cm^{-2} is obtained by back damage with the Si_3N_4 film coating technique, on the contrary, the microdefect density reaches $\sim 10^6$ cm^{-2} without the Si_3N_4 film. The critical thickness of Si_3N_4 film to elminate microdefects in epi-layers is obtained 2500 and 200Å for substrates without and with back damage, respectively. It is found that the gettering action is closely correlated with induced defects in the back surface (OSF, dislocation, damage line, etc.) by sandblast-damaging and/or Si_3N_4 film.

Reduced pressure (RP) silicon epitaxy is an especially important technique for bipolar devices with buried layer containing high concentration of As or Sb. The advantage of RP epitaxy has attracted special interest for shallow junction devices. It has been reported that RP silicon epitaxy has more advantage in characteristics of layer [autodoping, pattern shift, and uniformity of epitaxial layer, etc. (1-5)], than those of atmospheric silicon epitaxy.

In general, a variety of defects such as stacking faults, slip dislocations (6, 7), and microdefects correlated with impurities (8, 9) is introduced in epi-layer during epi-processing. The stacking fault density can be obtained less than ~ 10 cm^{-2} by gas etching prior to epitaxy and slip dislocations can be decreased to negligible extent by a radiant heating technique. However, the existence of microdefects in the epitaxial surface has become one of the most serious problems (*e.g.*, collector-emitter leakage) for device characteristics.

In order to suppress nucleation sites for microdefects in epi-layer, a variety of gettering techniques has been proposed. These gettering techniques are based on mechanical damage (10, 11), deposition of Si_3N_4 film on back surface (12), and intrinsic gettering (13-17), etc. (18-21). Although a number of workers have shown that stacking faults are produced in the atmospheric silicon epitaxial layer during thermal oxidation (22-26), none has reported the oxidation-induced stacking faults and gettering of microdefects in RP epi-layers.

Key words: gettering, tensile stress, bow of wafer, oxidation-induced stacking fault.

In RP epitaxy applying the microdefect gettering with a back-side damage technique, the gettering effect was found to be decreased by the reasons as follows (27): (*i*) the back damage layer is removed by HCl gas etching prior to epitaxial growth and by HCl gas produced from the SiH_2Cl_2 source during epitaxial growth; (*ii*) gas etching on the back surface is accelerated by a reduced pressure; and (*iii*) the back damage layer is annealed-out during a high temperature epitaxial process. Therefore, a protection of damage layer with Si_3N_4 films is proposed for a more effective gettering.

In the present paper, we describe the reduction of microdefects in RP epitaxial layer by sandblast-Si_3N_4 gettering technique and discuss the gettering mechanism on the basis of preferential etching and x-ray diffraction topography (XRT) data. In addition, we refer to the bow of substrates with Si_3N_4 film on the back surface.

Experimental Procedures

The p-type Si substrates used in this study were taken from a CZ-grown crystal with the resistivity of 10 $\sim$ 20 Ω-cm. The wafers were 75 mm diam and 0.4 mm thick with the surface oriented approximately 3° from the (111) plane along the <110> direction. The front surfaces were mechanically-chemically polished and the back with and without sandblast-damage.

The Si_3N_4 films were deposited on the back surface of silicon wafers prior to epitaxial growth by chemical vapor deposition using the system SiH_4-NH_3-N_2 at 770°C.

The silicon epi-layer was deposited in a commercial "AMC-7800-RP" cylindrical epi-reactor. The epi-layer was grown to the thickness of 2 ~ 3 μm at a rate of 0.3 μm/min at 1080°C in a reduced pressure of 80 Torr.

Finally, epitaxial substrates were annealed at 1140°C for 1 hr in wet O_2 for the evaluation of microdefects in epi-layers. Microdefects in an epi-layer were revealed using the Sirtl etchant for 15 ~ 30 sec and the XRT Lang method was also used to characterize the defects in an epi-layer and back surface.

The Si_3N_4 film thickness and bow were measured by an ellipsometer and a microsensor.

Results and Discussions

The sandblast gettering technique is commonly applied to reduce the microdefects in a substrate surface or epi-surface for MOS and bipolar devices. In the case of RP epitaxy, an annihilation of damage layer was confirmed by the decrease of oxidation-induced stacking fault (OSF) density in the back surface after gas etching and/or heat-treatment the same as the epi-process.

In general, a wafer surface is vulnerable to adsorbed oxygen or other impurities from the carbon susceptor. Metallic contamination is apt to take place as a result of the reaction between an SUS component and HCl gas or Cl gas dissociated from SiH_2Cl_2 source. Therefore, gettering processes are important for the suppression of microdefects caused by heavy metal contamination in the RP epitaxial layer. The damage layer can be protected by the deposited Si_3N_4 film which is an acid- and heat-stable material.

Gettering effect by Si_3N_4 film without back damage. —Figure 1 shows the correlation between the microdefect density in epi-layers and the Si_3N_4 film thickness.

In the Si_3N_4 gettering process, Petroff *et al.* (12) reported the elimination of nucleation centers and impurities which occur during oxide growth involved in the formation of SF by the preoxidation process prior to epitaxial growth. In the paper mentioned above, the Si_3N_4 film was deposited to 4000Å thick to eliminate microdefects in the substrate surface. In the deposition of a 4000Å thick Si_3N_4 film, we speculate that the bow of the substrate increases and many slip dislocations are introduced in the wafers.

As shown in Fig. 1, the microdefect density in an epi-layer drastically decreases from ~10^6 cm^{-2} to ~10^3 cm^{-2} when the 2500Å-Si_3N_4 film was deposited. Epitaxial defects were evaluated by Sirtl etching after a heat-treatment at 1140°C for 1 hr in wet O_2. Sirtl-etched figures of epi-layers and back surfaces after removing Si_3N_4 films by hot H_3PO_4 solution are shown in Fig. 2(a) and (b), respectively.

Typical epitaxial microdefects, triangular shaped etch pits in the ungettered region observed by an optical microscope are shown in Fig. 3.

Damage line and dislocation pits, as shown in the bottom of Fig. 2(b), are observable in the back surface of gettered epi-wafer with an Si_3N_4 film of more than 2000Å thickness. These damage lines and dislocations are considered to be due to the stresses by an Si_3N_4 film.

Figure 4 shows that the microdefects in epi-layers are gettered when the Si_3N_4 film more than 2250Å thick is deposited. The Sirtl-etched epi-layer and back surface with an Si_3N_4 film are shown in Fig. 4(a) and (b), respectively. These damage lines have the tendency to run toward a definite direction as shown in Fig. 4(b). The remarkable correlation between the gettered region in epi-layer and the damage lines in back surface was observed in Fig. 4.

Figure 5 represents XRT of slip dislocations and damage lines in the substrate with a 3000Å-thick Si_3N_4 film. It is apparent from the topography that disloca-

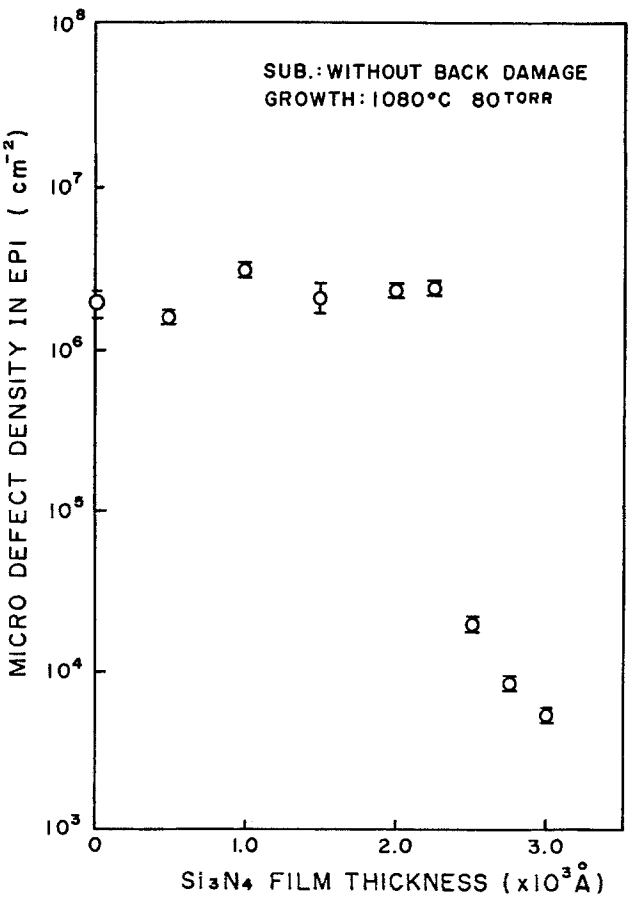

Fig. 1. Correlation between Si_3N_4 film thickness and microdefect density in epi-layer.

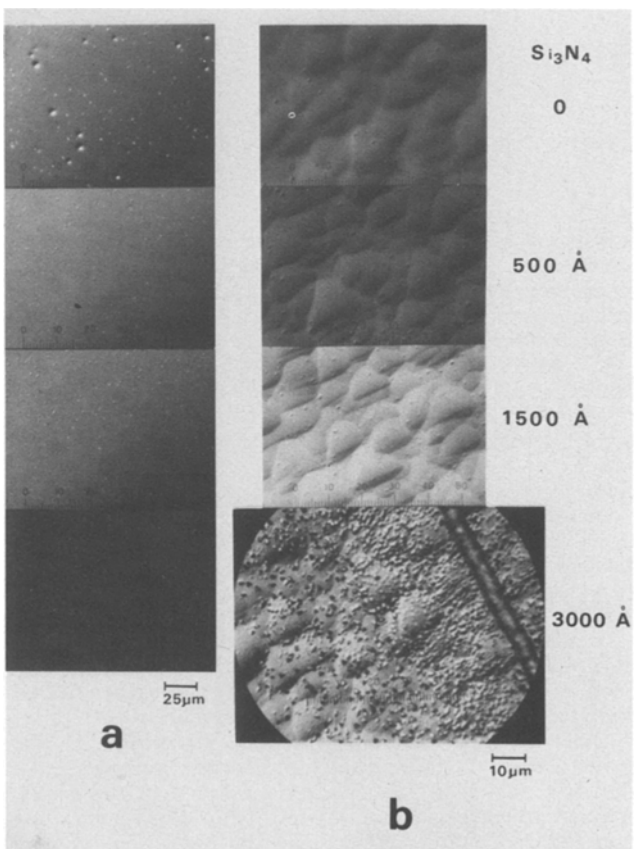

Fig. 2. Optical micrographs of defects in (a) epi-layer and (b) back surface removed Si_3N_4 film.

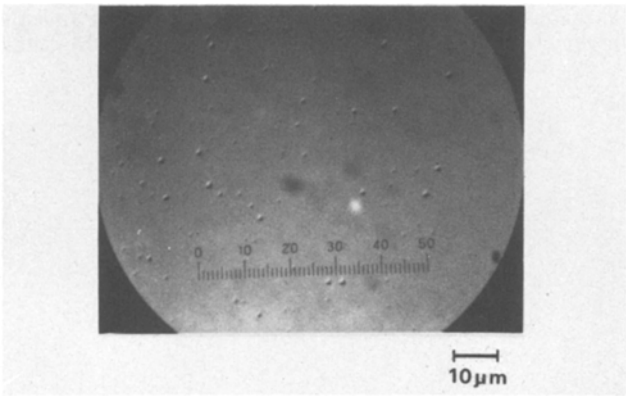

Fig. 3. Microdefects in RP epitaxial layer revealed by Sirtl etching.

tions are introduced around the damage lines, in accord with Fig. 2(b) (bottom).

The thick Si_3N_4 film is necessary to getter microdefects in an epi-layer with an Si_3N_4 film. That is, microdefects in epi-layer were reduced with Si_3N_4 films of 2500Å, 3000Å-thick without back damage, however the bow of the wafer becomes large in proportion to the Si_3N_4 film thickness as shown later and slip dislocations were introduced into the active layer as shown in Fig. 5. Consequently, the Si_3N_4 gettering technique without back damage has a problem which cannot be ignored for device processing.

Gettering effect by back damage with Si_3N_4 film.— In Fig. 6, the microdefect density in epi-layer is plotted as a function of the OSF density due to back damage by a sandblast technique prior to the deposition of a 1000Å-thick Si_3N_4 film. The microdefect density in an epi-layer is closely related to the density of OSF with back damage. It became evident that more than 5×10^5 cm^{-2} OSF's of density in the back-side damage is necessary to reduce epi-microdefects less than 10^3 cm^{-2} as shown in Fig. 6. Gettering experiments were

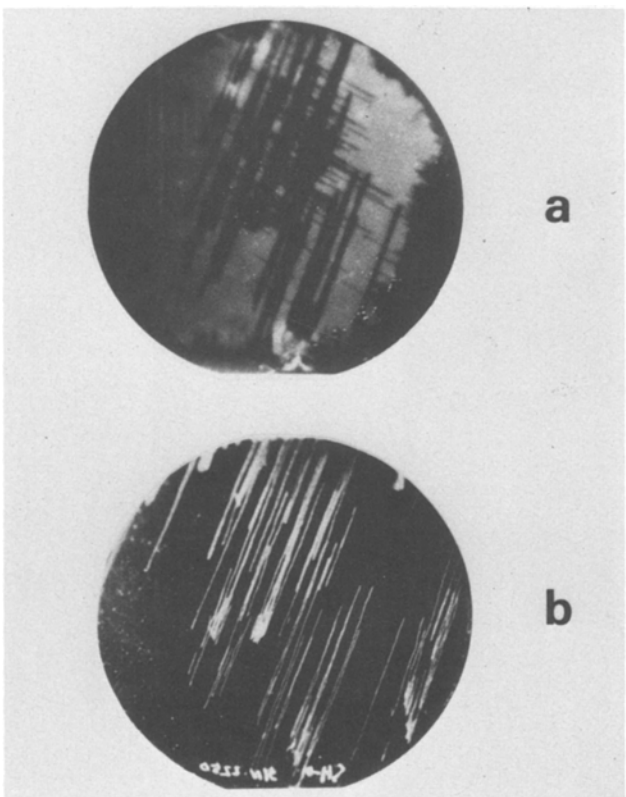

Fig. 4. (a) Sirtl-etched epi-surface and (b) its substrate back surface with 2250Å-thick Si_3N_4 film.

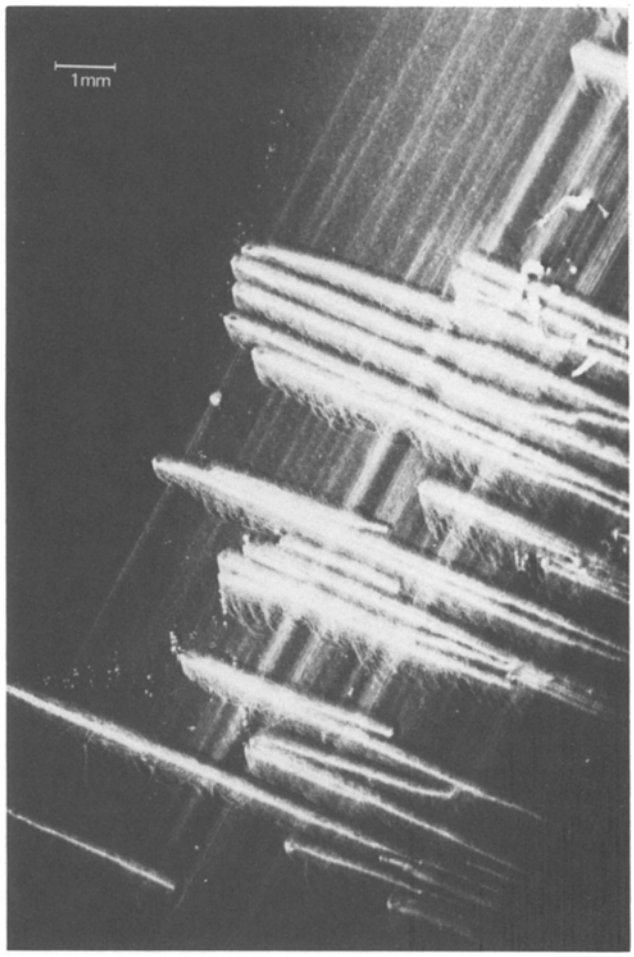

Fig. 5. X-ray diffraction topograph of epi-wafer with 3000Å-thick Si_3N_4 film. $g = [2\bar{2}0]$.

carried out using back-damaged wafers with OSF's more than 5×10^5 cm^{-2} in the same wafer lots.

Figure 7 shows the dependence of epi-microdefect density on the Si_3N_4 film thickness. The epi-microdefect density decreased remarkably from 10^6 cm^{-2} to 10^3 cm^{-2} with the 200Å-thick film. When the Si_3N_4 film of 1000Å thickness was deposited, the microdefects in the epi-layer were reduced to the density of 5×10^2 cm^{-2}.

Figure 8 shows etched figures of the epi-layer and back surfaces with sandblast damage. The Si_3N_4 film was removed by hot H_3PO_4 solution before Sirtl etching. The defects in the back surface (Fig. 8b) remarkably differ from those on the back surface shown in Fig. 2(b). OSF's due to sandblasting are observed in the back surface with Si_3N_4 films of more than 200Å thick as shown in Fig. 8(b). That is, the defect density in a back surface was kept with more than 10^5 cm^{-2} even after epitxial growth. This shows that the extent of back damage with sandblasting remained at the same level before epitaxy, even though wafers were annealed in epitaxy and oxidation processes. It is suggested that the gettering action by back damage occurred effectively by covering with a thin Si_3N_4 film.

Bow of substrate with Si_3N_4 film.—A tensile stress of 10^{10} dynes cm^{-2} has been reported for chemically vapor deposited (CVD) Si_3N_4 films on an Si wafer (28, 29). It is well known that Si substrates bend (30) with the stress of the Si_3N_4 film being vulnerable to cracks (31) with increasing Si_3N_4 film thickness and the process temperature. As a result of cracking due to Si_3N_4 film, dislocations are introduced into the wafers.

Figure 9 shows the bow dependence on the Si_3N_4 film thickness after the oxidation of the epi-layer at

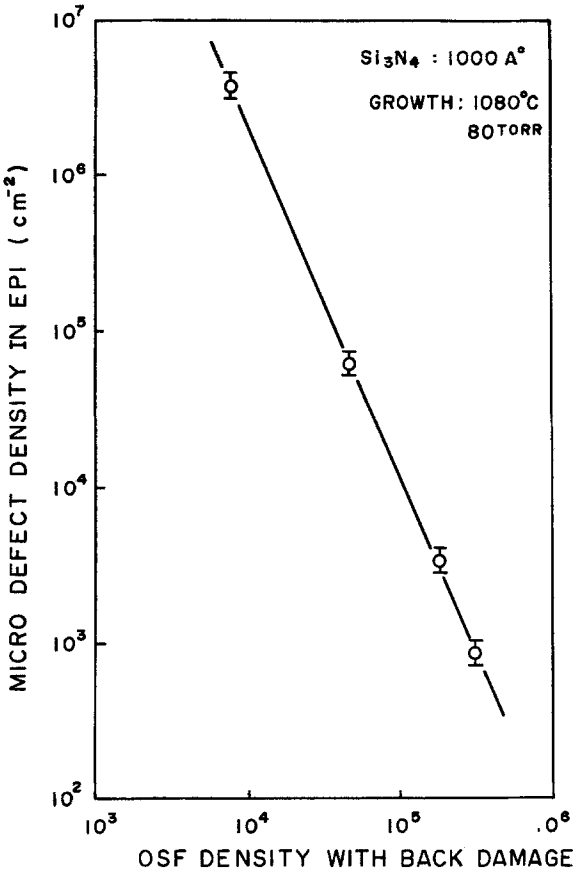

Fig. 6. Correlation between microdefect density in epi-layer and OSF density by back damage.

1140°C for 1 hr wet O_2. The cracks in Si_3N_4 films are observed after epitaxial growth and they accelerate, introducing dislocations into a substrate after an oxidation process. The minimum bow was found with the Si_3N_4 film of the thickness between 500 and 1000Å as shown in Fig. 9. In addition, the bow of wafers shows a tendency to approach a constant value with the Si_3N_4 film thickness above 2000Å which is the thickness of introducing cracks into a wafer. In the Si_3N_4 gettering without back damage, the constant bow region corresponds to the Si_3N_4 film thickness region with effective gettering in an epi-layer.

Since the bow of wafers becomes a serious problem in a photolithographic process after epitaxial growth, we may conclude that the effective thickness of an Si_3N_4 film with back damage is 500-1000Å for minimizing the bow of wafer and eliminating microdefects in an epi-layer.

Summary and Conclusion

The effective gettering of microdefects in an RP epitaxial layer has been shown in sandblast-wafers covering the back surface with a thin Si_3N_4 film. In both the gettering cases of applying Si_3N_4 film with and without back damage, it becomes clear that the elimination of the microdefects in an epi-layer is closely related to the induced defects in the back surface with sandblast-damage and Si_3N_4 film.

The conclusions reached are as follows.

1. The gettering of microdefects in an epi-layer occurs at the critical Si_3N_4 film thickness of 2500Å without back damage; however the bow of the wafer becomes large and many dislocations are introduced in the epi-layer.

2. The microdefect density in epi-layers shows a reciprocal correlaton with the density of OSF in the back surface and good linearity in log-log plotting.

3. The gettering of the microdefects in an epi-layer occurs with more than 200Å-thick Si_3N_4 film with back damage. The minimum microdefect density in an epi-layer obtained was 5×10^2 cm^{-2} with the 1000Å-thick Si_3N_4 film.

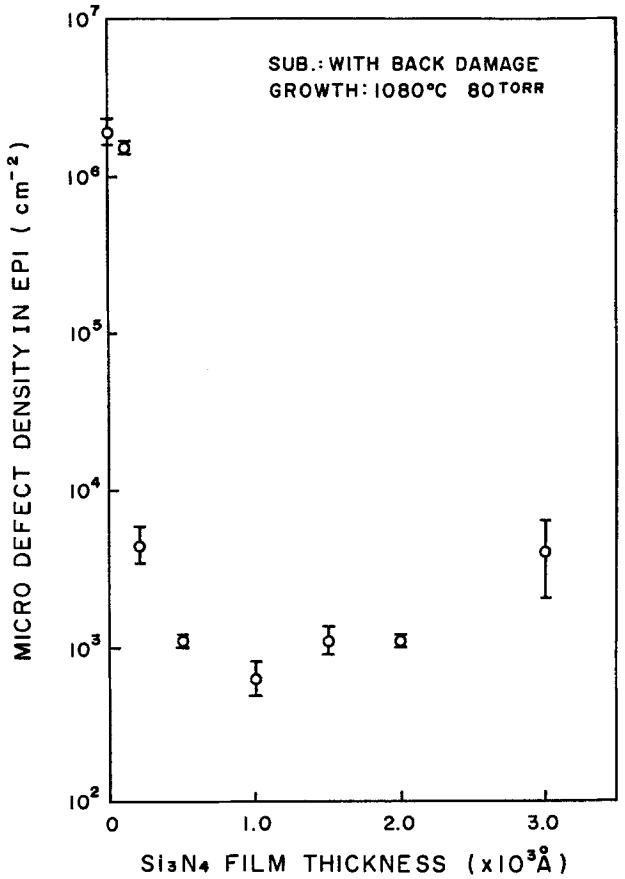

Fig. 7. Correlation between microdefect density in epi-layer and Si_3N_4 film thickness.

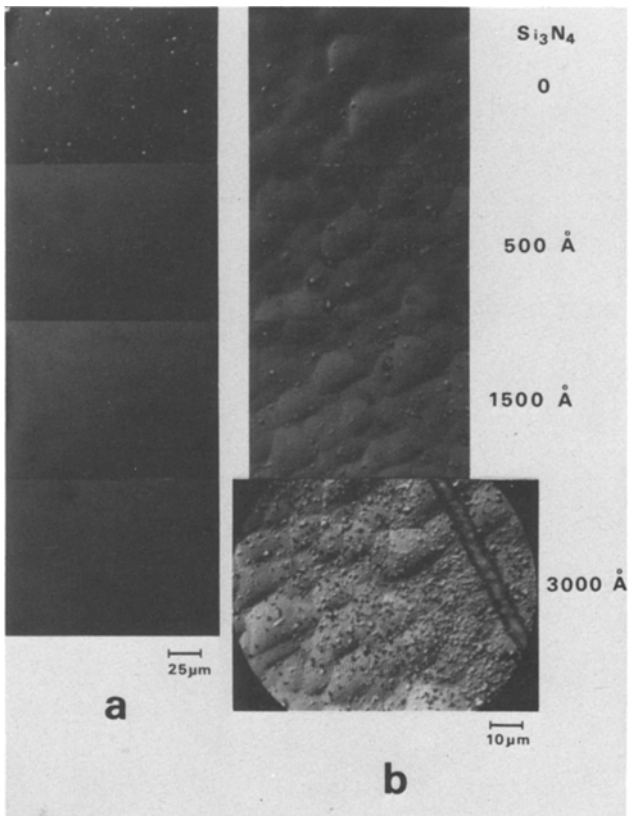

Fig. 8. Optical micrographs of defects in (a) epi-layer and (b) back surface removed Si_3N_4 film.

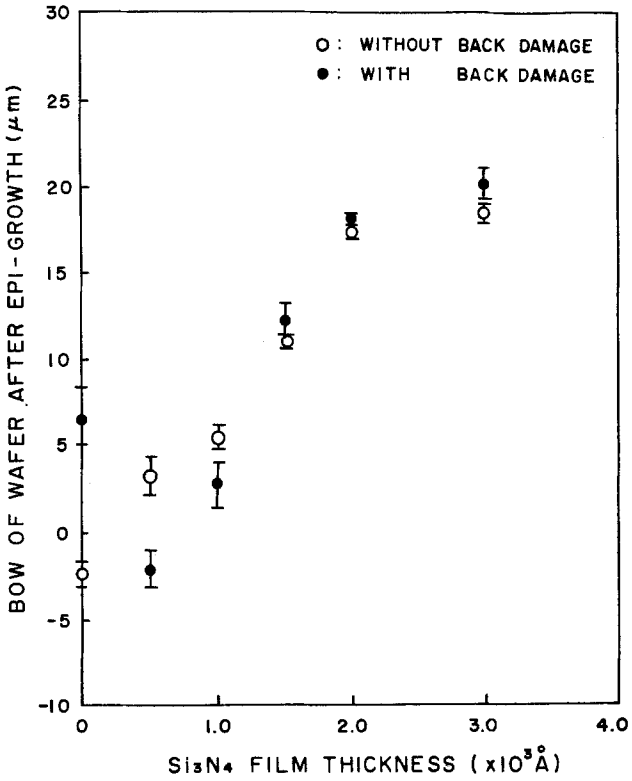

Fig. 9. Correlation between bow of wafer after epitaxial growth and Si_3N_4 film thickness.

4. The minimum bow of an epi-wafer with Si_3N_4-sandblast treatment after an epi-oxidation was found in the range of 500-1000Å in Si_3N_4 film thickness The bow was saturated at the Si_3N_4 film thickness more than 2000Å. This coincides with the Si_3N_4 film thickness which introduces cracks for effective gettering.

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