The Delamination Defect Improvement of High Transmittance Dielectric (HTD) Film on BSI Image Sensor Manufacturing

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***Abstract* –A new high transmittance dielectric (HTD) films without plasma damage are implemented in BSI CMOS imager. It suffers from delamination problem, thus causes potential reliability issue. In this paper, the HTD film properties in regard with delamination defect have been studied. SEM, TEM, SIMS, TDS are employed to analyze the fundamental of film properties.**

I. INTRODUCTION

Silicon thinning process is indispensable for a BSI CMOS image sensor. However, grinding and chemical etch will damage silicon surface, leading to increase of dark current and white pixel [1]. Optical dielectric film deposition process, for example, PECVD oxide, makes the surface condition even worse due to plasma damage. A high transmittance dielectric (HTD) film deposition with low plasma damage is required. In this work, a non-plasma damage deposition process is employed. This new film show high transmittance without plasma damage. Besides, high refractive index property of the HTD film has higher flexibility in the design of optical film scheme for a BSI pixel structure. However, the wafers suffer delamination problems after thermal alloy. The delamination defect might be from the moisture absorption property of HTD film and poor adhesion between HTD film and silicon substrate [2]. In this paper, we use SEM, TEM, SIMS, and TDS data to analyze the HTD film properties and discuss about mechanism to the delamination.

II. EXPERIMENTAL

HTD film was deposited on blank wafers by a non-plasma damage process. Secondary Ion Mass Spectroscopy (SIMS) was used to analyze element profile. Thermal Desorption Spectroscopy (TDS) was employed to trace moisture absorption and outgassing behaviors of HTD film. Thermal baking was inserted after deposition of HTD film to minimize the effect of moisture absorption. In addition, DOE of film deposition was conducted to minimize the delamination. Finally, thermal stress of alloy (up to 5 times) was used by to assure the robustness of new HTD film.

III. RESULTS AND DISCUSSIONS

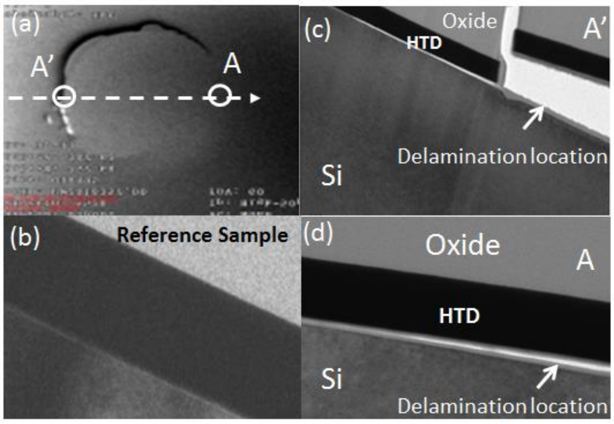

Fig. 1 (a) The SEM top-view of delamination of HTD film. (b) TEM cross section of reference sample without delamination. (c) TEM cross section of location A' and (d) location A.

Figure 1(a) shows SEM image of delamination defect. The delamination is between dielectric film and Si substrate as shown on the TEM images of Fig. 1(c) and 1(d).

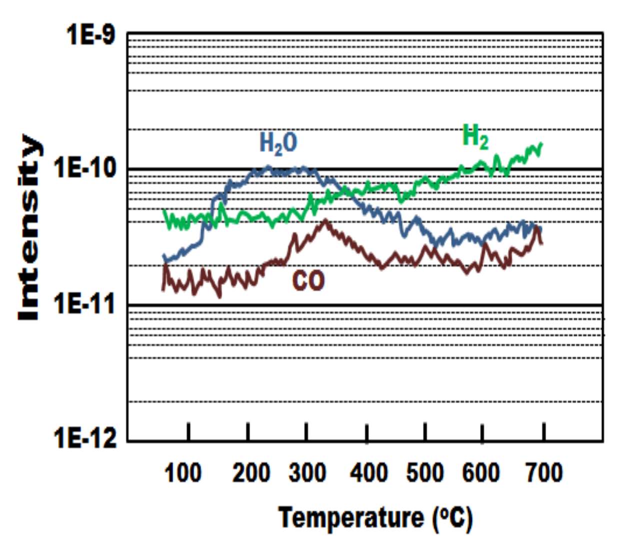

Fig. 2 Thermal Desorption Spectroscopy (TDS) as a function of temperature from 50 °C to 700°C.

Backside silicon surface will be exposed without protection of dielectric film, and lead to optical and potential reliability failures. TDS data of Fig. 2 show the outgassing molecules are majorly H_2O, H_2, and CO. It's reported that some dielectric films are susceptible to humidity and ambient gases, such as H_2O and CO [3]. The dielectric film might absorb H_2O and CO molecules in the environment during transferring to the next process stage. These molecules are chemically absorbed in the dielectric film. Thermal should be given to overcome the binding energy between molecules and dielectric film to desorb H_2O and CO molecules. Both H_2O and CO can be effectively disrobed under 200°C~400°C temperature regime as shown in Fig. 2. However, it's found that hydrogen signal increases with elevating temperature. Hydrogen might be from the dissociation of H_2O due to thermal energy.

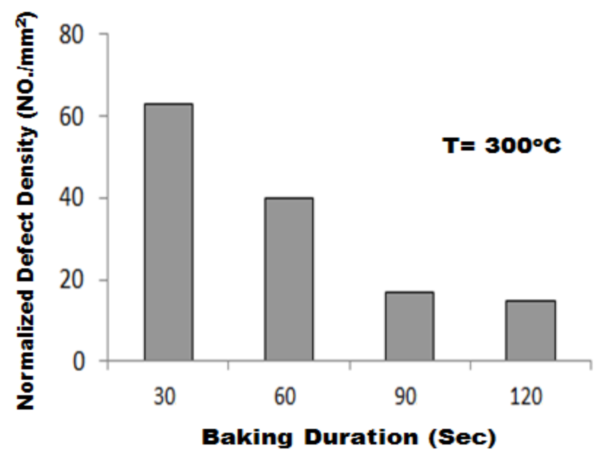

Fig. 3 Normalized defect density of control wafer under different baking duration at 300°C.

Figure 3 shows normalized defect density of the studied blank wafers under different baking duration at 300°C. It's observed the delamination defect density decreased with increasing baking duration. The H_2O and CO molecules are desorbed by the thermal energy. It's suspected that H_2O in the dielectric film will substantially expand in volume due to the thermal effect and then causes unbalanced stress between dielectric film and silicon substrate. However, the defect density does not further reduce with longer baking time than 90s. There should be another factor inside the dielectric film in addition to the moisture absorption from H_2O.

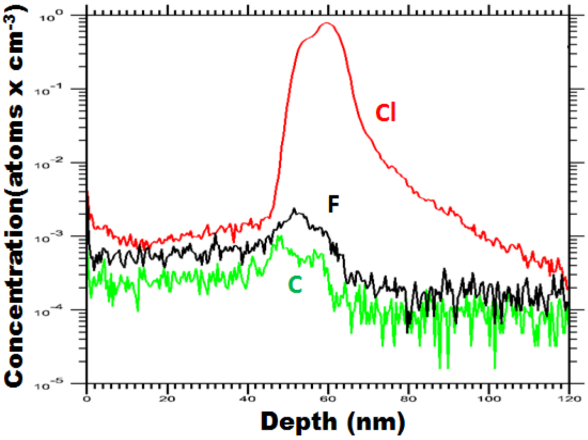

Fig. 4 SIMS profile of control wafer.

SIMS profile is illustrated in Fig. 4. Noticeably, the main element included Cl, F, and C in addition to the molecules of dielectric film (not illustrated). Cl and F are from the residue of precursor without full reaction. From literature, Cl might cause dielectric film damage with the combination of thermal alloy [4].

During thermal process, partial hydrogen molecules dissociates into H^+ and combine with Cl^- to form HCl, and the other hydrogen molecules vaporized to gas state. HCl corrosion effect will reduce the adhesion between dielectric film and Si substrate. The chemical bonding between oxygen (from dielectric film) and silicon is broke (corrodes) by HCl chemical. On the other hand, vaporized water causes unbalanced stress between dielectric film and silicon substrate due to volume expansion by thermal, and lead to the delamination.

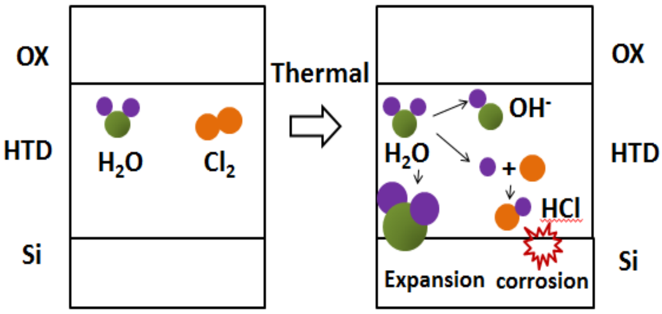

Fig. 5 Schematic view of mechanism to HTD film delamination

Therefore, an L9 DOE is conducted to minimize the Cl concentrations of HTD films as listed on Table I. Reducing Cl concentration effectively minimize delamination density. On the other hand, the defect density shows no dependence on the fluorine concentration. The optimized film (Condition No 9) combined with post baking passed thermal stress test by up to 5 times as illustrated in Fig.6.

Table I Design of Experiment (DOE) for HTD film

No	Cl concentration deviation (%)	F concentration deviation (%)	Pressure (Torr)	Process Time of STEP1 (Sec)	Process Time of STEP2 (Sec)	Defect Density ($NO./mm^2$)
1	+33%	+7%	L2	L1	L1	58
2	+94%	+10%	L3	L3	L1	60
3	+71%	-8%	L1	L2	L1	55
4	0%	0%	L2	L2	L2	16
5	-4%	+2%	L3	L1	L2	18
6	-1%	-18%	L1	L3	L2	14
7	-31%	+10%	L2	L3	L3	0
8	-48%	-4%	L3	L2	L3	0
9	-59%	-17%	L1	L1	L3	0

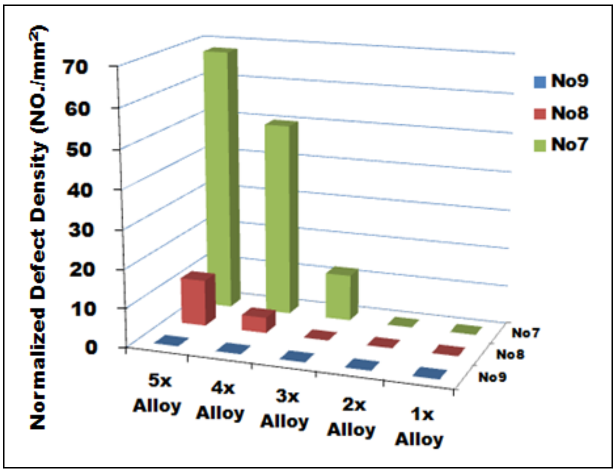

Fig. 6 Normalized defect density of sample No 7, 8, and 9 with different thermal process.

IV. CONCLUSIONS

The residue of Cl and chemisorbed H_2O, in HTD film, are the dominant factors to delamination defect. During thermal alloy, HCl corrosion effect leads to worse adhesion between HTD film and silicon surface. On the other hand, stress effect of H_2O volume expansion will cause the HTD film to delaminate from weakness point of adhesion. With optimized HTD film and post baking process, the defect can be eliminated, proven by thermal stress up to 5 cycles.

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