Technical Note

Influence of Fluoride Ions Contamination in Front Opening Unified Pod (FOUP) Generating Defective Bonding Pad

Soon Seok Kwon\textsuperscript{1}, Sung Min Hwang\textsuperscript{1}, Hyoung Ryeun Kim\textsuperscript{1}, Hee Chang Jang\textsuperscript{1}, Jeong Hoon Hong\textsuperscript{1}, Gil Joo Song\textsuperscript{1}, Hyun Yul Park\textsuperscript{1}, Minsoo Kim\textsuperscript{2}, Youhwan Shin\textsuperscript{3}, Jin Young Kim\textsuperscript{3}, Tae Yong Noh\textsuperscript{4}, Seoung-Kyo Yoo\textsuperscript{4*}

\textsuperscript{1}Contamination Quality Engineering, Manufacturing and Technology Division, SK Hynix Semiconductor Inc., Icheon-si, Gyeonggi-do 467-701, Korea
\textsuperscript{2}Center for Urban Energy Research, Korea Institute of Science and Technology, Seongbuk-gu, Seoul 02792, Korea
\textsuperscript{3}Fuel Cell Research Center, Korea Institute of Science and Technology, Seongbuk-gu, Seoul 02792, Korea
\textsuperscript{4}WITHTECH INC., Yuseong-gu, Daejeon 34036, Korea

ABSTRACT

We analyzed defective bonding pad in various ways and determined the causes of defects that boosts oxidation of aluminium by fluoride residue on surface of pad with moisture. Additionally, we compared and evaluated methods to minimize pad defects in aspects such as etching and wafer storage environment. In case of wafers after pad open etching process using common CF\textsubscript{4} stored in FOUP, the concentration of fluoride ions in FOUP was 230 ng L\textsuperscript{-1} and it decreased down to 170 ng L\textsuperscript{-1} when Ar sputtering step was added after using CF\textsubscript{4}. Also under the same condition, fluoride ion concentration in FOUP decreased down to 20 ng L\textsuperscript{-1} when nitrogen purge was introduced for 10 minutes to the FOUP where wafers were stored and the moisture also decreased from 40% before purge to 10% after purge. As a result of observation on pad surface after storing wafers in FOUP for 120 hours under each condition, negligible amount of defects were found when nitrogen was purged. Therefore, we conclude that defects on pad were generated by existing fluoride ions after etching process and moisture in the air.

Keywords: Bonding pad; Fluoride ion; Etching process; Contamination; Front opening unified pod (FOUP).

INTRODUCTION

According to miniaturization, speed acceleration and mass storage in semiconductor, not only manufacturing process to form chip on wafer but also packaging process to install the completed chip on circuit is continuously being developed (Mönch \textit{et al.}, 2011; Nakamura \textit{et al.}, 2013; Joyce \textit{et al.}, 2015). There is not a single part unimportant in packaging process, but interconnecting technology connecting chip and package which enables to interact electrically and structurally is considered as most the important. Among these techniques, the wire bonding technology is a technique which connects aluminium pad of chip with lead frame of package by gold wire and is already a very commonly used technology. But recently defects in this wire bonding are increasing (Tan \textit{et al.}, 2002; Goh \textit{et al.}, 2013). As well known, many kinds of chemicals are used and various kinds of particles form in the semiconductor manufacturing process and airborne molecular contaminations (AMCs) from these chemicals. Particles with moisture in the air not only contaminate wafer itself but also have effect on wire bonding which can generate product defects (Kikyuama \textit{et al.}, 1991; Den \textit{et al.}, 2006; Lin \textit{et al.}, 2010; Lee \textit{et al.}, 2015). To prevent this kind of contamination by exposure to the air, wafers on which chip is formed are stored or moved in the enclosed carrier called front opening unified pod (FOUP) and particles or AMCs remaining on wafers may diffuse into FOUP and contaminate it (Frickinger \textit{et al.}, 2000; Hu \textit{et al.}, 2005; Hu \textit{et al.}, 2009). Particles or AMCs adsorb onto inside of FOUP which can contaminate other wafers and FOUPs like a “contagious disease” and therefore various researches on FOUP cleaning and purge are in progress (Hu and Tsao, 2006; Hu \textit{et al.}, 2007; Yoo \textit{et al.}, 2012). The aluminium pad of chip for wire bonding is a part that is exposed to the outside after wafer process, which can be continuously affected by the surrounding atmosphere until it is insulated from packaging. Especially, it can be contaminated by molecular contamination due to silicon
dust from die sawing process which cuts off chips from silicon wafer, oxidation on pad surface by atmospheric moisture, and chemical contamination by silicon wafer protective layer or residual chemicals of etchant (Corum et al., 1993; Hsu, 2001). Contamination by etchant is highly likely due to the residual fluoric etchant solution or gas remaining after the etch process (Hua et al., 2014; Song et al., 2015). Contamination on pad surface can cause abnormal failure having various defects on the surface in black colour and Non-Stick-on-Pad (NSOP) failure having wire ball to be detached after wire bonding, and these failures can increase contact resistance with probe used in chip inspection which causes damage on probe pin or degrade electrical feature of the chip (Kim et al., 2003; Dan et al., 2015).

In this research, pads failed in actual manufacturing process were collected and inspected. The surfaces and composition were checked to figure out the causes of contamination. The correlation between pad contamination effect by open pad etch process condition and AMCs according to inner environment of FOUP is reported.

METHODS

Chips with defects, found in the inspection in actual manufacturing process were collected to analyse the images of surfaces, cross sections, and substances according to the thickness of thin layers. The surfaces of normal and abnormal pad for visual inspection were observed by Microscope (CX-21, Olympus), and images of surfaces and cross sections were obtained by scanning electron microscopy with Energy Dispersive x-ray Spectroscopy (SEM-EDX, S-5200, Hitachi) and transmission electron microscopy (TEM, CM200, Philips), respectively. The substance analysis according to the thickness of thin layer was conducted by Auger Electron Spectroscopy (AES, PHI-670, Perkin Elmer).

The etching condition for pad open process was divided into as-is using carbon tetrafluoride (CF₄) condition and introducing an argon sputtering step after using CF₄ by pad etch facility (Producer, Applied Materials, Inc.) for investigating an etchant influence. To investigate the cause of defect on bonding pad surface, different etching process for pad opening was applied. For the first nine wafers, typical CF₄ etching process was applied. Then three from these nine wafers were selected and each one was stored in three different pre-cleaned FOUPs. The other rest six wafers had additional argon sputtering process and each one was stored in six different pre-cleaned FOUPs. And finally, nitrogen purge was applied to only the three FOUPs from the latter six FOUPs had both CF₄ etching and argon sputtering. As for nitrogen purge, it remained for 10 minutes with 10 mL min⁻¹ of flow rate and the measured moisture concentration inside of FOUP during purge was measured by a humidity sensor (Datalogger 177-H1, Testo). After storing each wafer in FOUPs for 2 hours under each condition, fluoride ion concentration inside of three FOUPs at each condition was measured and averaged by online AMCs monitoring system (proFast-2000, WITHTECH Inc.) and three pad surfaces at each condition were analysed by EDX for comparison. Also, defect occurrence on the pad surface stored in FOUP for 2 hours and the pad surface stored in FOUP for 120 hours under each condition was observed by microscopically.

RESULTS AND DISCUSSION

When an abnormally failed pad from pad open etching process was collected and inspected visually, the normal pad surface was bright but many defects with black colour were observed on the surface of abnormal pad as shown in Fig. 1. The results of observation on abnormal pad surfaces by SEM-EDX and TEM were shown in Fig. 2. From the result of SEM-EDX observation, defects on pad surfaces were in bump shape and Al, O and F elements were detected by EDX from these bumps with different contents. Also, as a result of diffraction pattern of defects part by TEM, it was found that defects have crystal structures, not amorphous. Fig. 3 shows the analytic result of substance according to the depth profile on the surface represented as sputtering time using AES, which shows the fact that F and O elements were located in deeper position on abnormal pad than normal pad. The depth profile of AES is calculated by sputter time and the thickness of Rutherford backscattering. From this method, 1 minute of sputter time is 100 Å of depth profile. Fig. 3(a) shows normal pad has fluoride ion from pad surface to 40 Å and Fig. 3(b) shows abnormal pad had fluoride ion to deeper area as 330 Å. When aluminium oxide layer (Al₂O₃) of each normal pad and abnormal pad were analyzed by SEM-EDX, it was found that the thicker the Al₂O₃ layer is, the higher the concentration of fluoride.

Fig. 1. Microscopic images of pad surfaces of normal (a) and abnormal (b), and bonding pads (c).
ion on pad surface is as shown in Fig. 4. The defects on pad surface were not observed if the thickness of Al₂O₃ layer is under 80 Å and the fluoride ion concentration on the surface was 4%. On the other hand, defects were observed when the thickness of Al₂O₃ layer is over 180 Å with the higher the concentration of fluoride ion on pad surface. From this, it is regarded that Al₂O₃ layer abnormally becomes thicker due to presence of fluoride ion. Alberici et al. (2003) reports that the normal pad surface has Al₂O₃, fluorine used in pad etching process and aluminium from pad combines to form AlFₓ, and reaction with moisture in exposed environment to outside develops crystalized compounds, AlFₓ.H₂O, Al(OH)ₓ, Al(OF)ₓ, and AlF(OH)ₓ. Chen et al. (2001) also reports that the humidity with fluoride ion was effective in acceleration of the growth of crystal defects. From these results and reports, it is considered that fluoride ion boosts oxidization of aluminium with moisture in the air and this growth forms a thick oxidization layer.

To investigate the influence of fluoride ion on this abnormal growth of Al₂O₃ layer, wafers after pad open etching process were stored in FOUP and fluoride ion substance inside of FOUP and on the pad surfaces was
analysed. Also to split fluoride ion concentration, argon sputtering step (CF$_4$ + Ar) other than common CF$_4$ etching process (CF$_4$) and nitrogen purge step (CF$_4$ + Ar + N$_2$) into FOUP were introduced. Table 1 shows result from each online AMCs monitoring system and EDX measured fluoride ion inside of FOUP and on pad surfaces under each condition. The fluoride ion concentration when using as-is CF$_4$ was 230 ng L$^{-1}$, decreased down to 170 ng L$^{-1}$ upon introduction of argon sputtering step and to ng L$^{-1}$ upon nitrogen purge. Fluoride ion concentration on pad surfaces also decreased down to each 23%, 11% and 4%. From this result, it was found that the fluoride ion concentration adsorbed onto wafer can be reduced by argon sputtering and also fluoride ion contamination diffused into FOUP from wafer can be reduced by nitrogen purge. This result supports the theoretical background of Fick’s 2nd law shown as Eq. (1), which insists that nitrogen purge can decrease fluoride ion concentration in FOUP and relatively higher fluoride ion concentration on wafer is diffused into FOUP to remove fluoride ion on wafer.

$$ R_{des} = D_0 \cdot \exp\left(\frac{E_a}{kT}\right) \cdot \frac{dC}{dx} \quad (1) $$

$R_{des}$: Desorption rate [moles cm$^{-2}$ s$^{-1}$],
$D_0$: Rate constant,
$E_a$: Desorption Enthalpy (Activation Energy),
$T$: Temperature,
$dC/dx$: Concentration gradient,
(dC/dx): Concentration gradient between wafer and surround ↑, Removal rate ↑.

Furthermore, changes in moisture concentration were observed during nitrogen purge to investigate the moisture effect when pad is exposed. As a result, moisture concentration was approximately 40% initially and decreased down to 10% level within 10 minutes after nitrogen purge, as shown in Fig. 5. Fig. 6 is image from observation of defect occurrence on pad surfaces after storing wafers in FOUP for each 2 hours and 120 hours under each condition. Under two conditions, a case used as-is CF$_4$ and the other case added argon sputtering step, defects occurred on pad surfaces with slight differences even after storing 120 hours and in case nitrogen purge was introduced, there were barely any defects after 120 hours of storage. This can be interpreted that defect could occur due to existing fluoride ions on pad surfaces (4%) even after introducing nitrogen purge, but nitrogen purge could additionally remove moisture and restrain defect occurrence. From these results, it was found that the introduction of nitrogen purge can restrain defect occurrence on pad surfaces by removing over 90% of fluoride ion and it is necessary to remove not only fluoride ion but also moisture to prevent defect occurrence.

**CONCLUSIONS**

We investigated the cause of defects on aluminium pad which often occurs in packaging process. Firstly, pad on which defects occurred was analyzed and found that the thickness of Al$_2$O$_3$ layer had abnormally increased, which is because of Al$_2$O$_3$ layer growing into an abnormal crystal structure due to fluoride ions existing on the surface and in the layer and moisture in the air. After pad open etching using common CF$_4$, wafers are stored in FOUP and fluoride ions which is one of chemicals used in etching adsorbed onto wafer diffused into FOUP at 230 ng L$^{-1}$. When argon

<table>
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<th>Condition</th>
<th>Pad Open Etch and N$_2$ Purge Process</th>
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<tr>
<td></td>
<td>CH$_4$</td>
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<tr>
<td>F Conc. in FOUP (ng L$^{-1}$)</td>
<td>230</td>
</tr>
<tr>
<td>F Conc. on Pad (Atomic %)</td>
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sputtering step was added to as-is pad open etching process using only CF₄, fluoride ion concentration in FOUP decreased down to 170 ng L⁻¹ and that on the pad surface decreased from 25% to 10%. After storing wafers through each of two kinds of etching conditions for 120 hours in FOUP, plenty of defects were observed on pad surfaces under both conditions. When nitrogen purge into FOUP in which stores wafers after argon sputtering step adding to etching using CF₄ was introduced for 10 minutes, fluoride ion concentration in FOUP decreased down to 20 ng L⁻¹ and so did moisture down to 10% level each, and defects barely occurred on pad surfaces after storing for 120 hours. From this, it was understood that when wafers are stored in FOUP after pad open etching process, fluoride ions, the one of chemicals used in etching adsorbed onto wafer diffuses into FOUP to exist at certain concentration, and this fluoride ion in FOUP causes defects on pad surfaces with moisture. It was discovered that, to prevent defect occurrence on aluminium pad surface which is only part exposed to the air until packaging process is completed after wafer process, it is necessary to manage fluoride ion and moisture content upon storing or moving wafers.

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