

## TEM observations of Aluminum/Ceramic Interfaces

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Al circuit substrate has been widely used in power electronic devices especially for high reliable applications. Past studies have been focused on the aluminum (Al)/alumina bonding mechanism and strength [1]. In other applications of high-density electrical circuit substrate, aluminum nitride substrate is used with the added advantage of high thermal conductivity and good mechanical performance [2]. In line with this, a model system of Al/sapphire ( $\alpha$ -Al<sub>2</sub>O<sub>3</sub>), which was manufactured near actual industry process conditions, plays a vital role in understanding the basics of Al/ceramic interface structures. In this study, transmission electron microscopy (TEM) is used to investigate the stable orientation relationships and atomic structures of Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interfaces with different bonding process conditions.

A “sandwich” structure of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001)/Al or Al-Silicon (Si) alloy/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001) was fabricated using a hot-press process. Figure 1 shows the schematic of the sample. The sandwiched structure of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001)/Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001) was fabricated at 675°C, which is above the Al melting point. While the sandwiched structure of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001)/Al-Si alloy/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001) was fabricated at 645°C, which is above the melting point of Al-Si alloy. The cross-sectional interface atomic structure observation and diffraction analysis were performed using TEMs (JEOL JEM-4010, JEM-2010) operated at 400KV and 200KV, respectively. Compositional analysis of the interfaces were performed by a scanning transmission electron microscope (JEOL JEM-2100F) combined with energy dispersive X-ray (EDX) analysis and electron energy loss spectroscopy (EELS) analysis.

Figure 2 shows the TEM and HRTEM images of pure Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface fabricated in this study. The TEM image clearly showed that the step structures of sapphire, ranging from a few nanometers to ~80nm, are formed at the interface. The detailed diffraction analysis showed that there seems to be no epitaxial orientation relationship (OR) between Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, although the HRTEM images showed that the Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface was atomically sharp in between steps of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. Similar step structures of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> were shown by a TEM study reported by X.S. Ning et. al [1]. The present results suggest that  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> surface and molten Al have reacted with each other during the bonding processes. Figure 3(a) shows the TEM image of Al-Si alloy/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface. It is clear that the step structures were formed at the interface but the step height was significantly smaller compared with the pure Al case. The detailed diffraction analysis also showed that there seems to be no epitaxial relationship between Al-Si alloy and  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. However, in specific areas at the interface, silicon precipitates were observed in the HRTEM images. A typical HRTEM image of the epitaxial silicon precipitate on sapphire is shown in Figure 3(b). These precipitates were confirmed to be Si by electron diffraction and STEM-EELS analyses. The OR between the epitaxial Si and the  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> substrate is determined to be [1-10]Si // [1-100]  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, (111)Si // (0001)  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>. The same OR was also reported for epitaxial silicon thin film on sapphire using high vacuum evaporation [3]. This orientation relationship was predicted to be the most stable one by the coincidence of reciprocal lattice point (CRLP) calculation, which calculates the maximum

geometrical coherency between two crystals in reciprocal space [4]. The present results suggest that Si may segregate to the interface and affect the interface reaction between Al and  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>.

References

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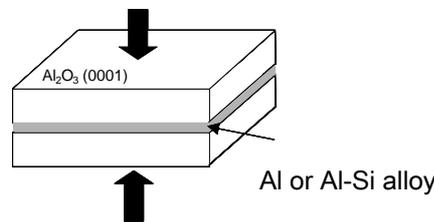


FIG. 1. Schematic of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> (0001)/Al or Al-Si alloy/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub>(0001) sandwiched samples.

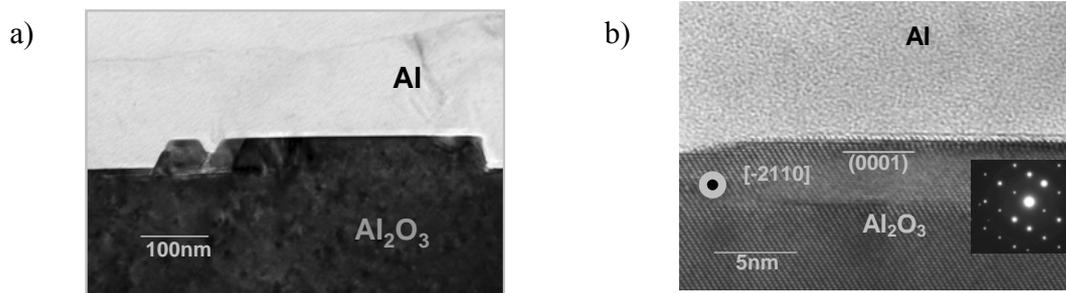


FIG.2. (a) TEM image of Al/  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface. Step structures are clearly observed at the interface. (b) HRTEM image of the interface in (a). Al/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface showed atomically sharp structure in between steps.

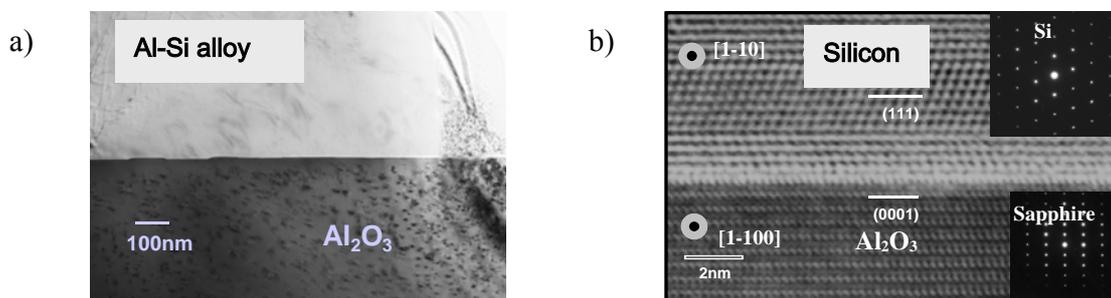


FIG. 3. (a) TEM image of Al-Si alloy/ $\alpha$ -Al<sub>2</sub>O<sub>3</sub> interface. Smaller steps and Si precipitate can be seen at the interface. (b) HRTEM image of the interface between Si precipitate in (a) which shows epitaxial relationship with  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>.