Phase identification of gold-aluminum intermetallic compounds (IMCs) by electron diffraction

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Gold wire bonding on aluminum pads plays still an important role in microelectronic packaging. The reliability and the lifetime of these bonds is often determined by the intermetallic compounds (IMC) at the aluminum gold interface. Since several decades the analysis of aluminum-gold IMCs in gold wire bonded interconnects is in focus of scientific investigations. Five intermetallic compounds play a major role in the Al-Au system: the aluminum rich Al_2Au ($Al_{11}Au_6$) phase [1], AlAu [1], the polymorphic $AlAu_2$ (space groups 58 and 62) [2], as well as the gold rich phases Al_3Au_8 [3] and $AlAu_4$ [4]. They differ in composition and structure.

The aim of this investigation is the development of a fast and reliable method to unambiguously distinguish between the different Al-Au intermetallic phases in bonded interconnects. Due to very similar chemical compositions, especially for the gold rich compounds, and the small single phase areas a differentiation by EDXS does not seem to be helpful. Due to the very small diameters (~50nm) of IMC crystallites, electron diffraction is an applicable method for phase analysis. Furthermore, the electron backscatter diffraction (EBSD) technique is a promising approach for phase identification in future applications, since the time-consuming TEM analysis, as well as the specimen preparation may be omitted.

For studying the different diffraction techniques reference specimens have been produced. To grow the intermetallic phases under controlled conditions, thin layers of gold and aluminum with a defined thickness ratio of 4:1 have been deposited onto silicon single crystal wafer substrate with a platinum protective layer (~100nm). After exposure to elevated temperatures (~200°C) within nitrogen atmosphere for several hours (2h, 5h, 7.5h, 12h), the evolution of intermetallic Al-Au phases by diffusion controlled solid state reaction has been observed (Figure 1).

The sample preparation for TEM investigations was done by focused ion beam technique (FIB). The specimen preparation for EBSD measurements was carried out by ion polishing. Furthermore, specimen preparations by FIB, as well as manual microsectioning have been examined with regard to EBSD image quality.

SEM investigations of sample cross-sections exhibit the formation of several layers with different microstructure (grain morphology) and mass contrast, respectively (Figure 1). This result leads to the assumption that different Al-Au phases have formed. To assign the according IMC, electron backscatter diffraction (EBSD) with automatic indexing was carried out (Figure 2). In addition, the recorded EBSD patterns have been compared with computed ones (Figure 3).

To confirm the correct phase identification by EBSD, TEM inspections, especially selected area electron diffraction (SAED) helped to obtain the appropriate results (Figures 4 and 5).

1.   Journal of the Less-Common Metals, 160 (1990) 143-152
2.   Journal of the Less-Common Metals, 35 (1974) 259-266
3.   Journal of the Less-Common Metals, 154 (1989) 251-260
4.   Journal of the Less-Common Metals, 161 (1990) 347-354
5.   This research is supported by the project NanoStress. Thanks to A. Winkelmann for providing the computed EBSD patterns.
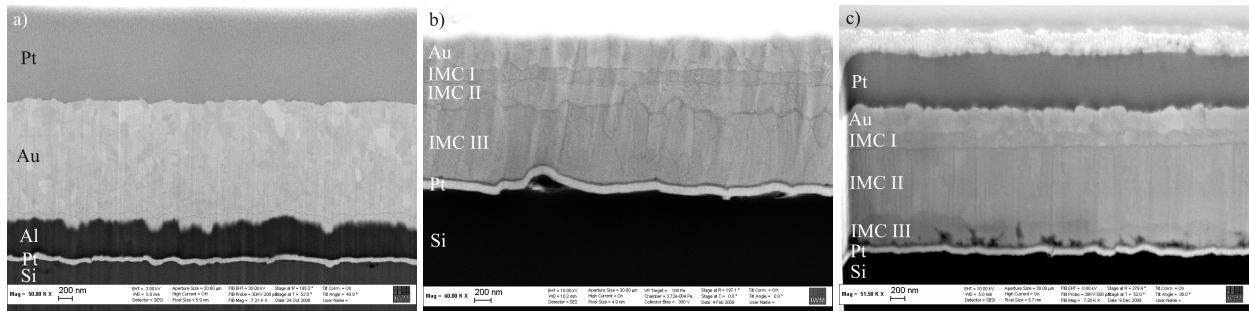
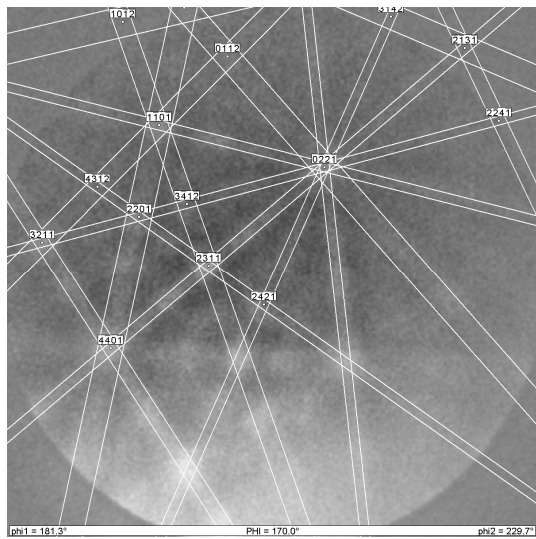**Figure 1.** Sample cross sections in SEM a) as deposited, b) after 5h at 200°C, c) after 7,5h at 200°C

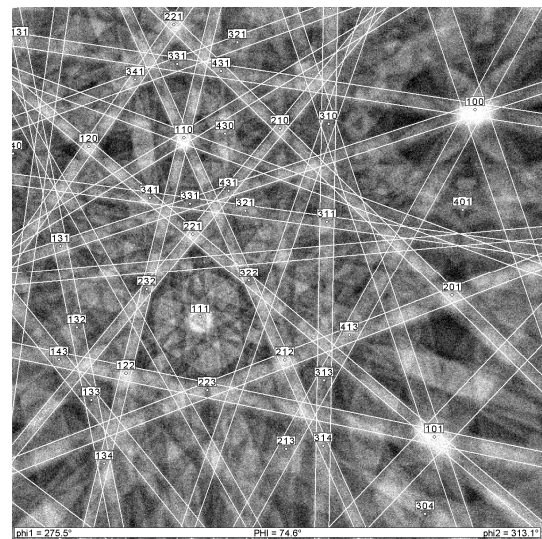**Figure 2.** EBSD pattern of Al-Au IMCIII (indexing for Al_3Au_8)

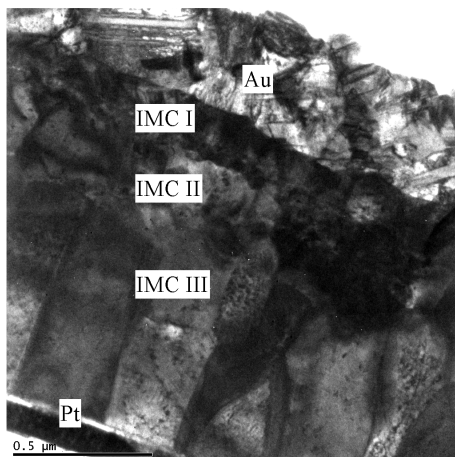**Figure 3.** Dynamically simulated and indexed EBSD pattern of $AlAu_4$
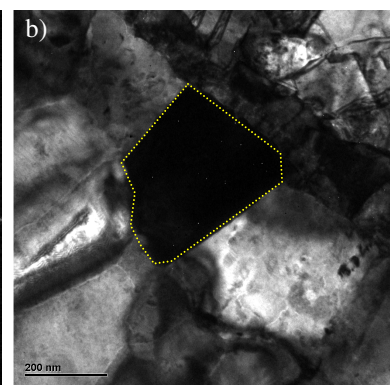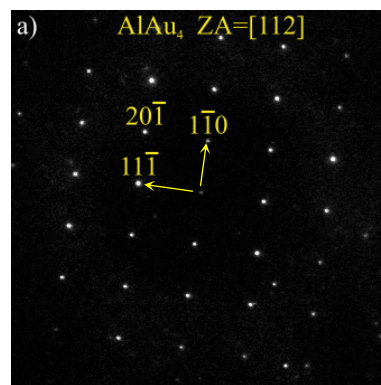

Figure 4. TEM bright field (5h/200°C)

Figure 5. a) SAED pattern of $AlAu_4$, b) Observed grain (located in IMC II area in Fig.4)