Solder joint assessment using X-ray diffraction at the ESRF: A brief formalisation

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Introduction

The EPSRC project 'Lead-free soldering for flip-chip assembly applications' involves the interconnection of microelectronic components (flip-chips) to printed circuit boards (PCB) using Pb-free solder materials. Two key objectives in the project are: the understanding of intermetallic compounds and void formation in the solder joints, and quantifying the internal stresses in the solder joint.

A solder joint is formed between the chip and surface pad, on the PCB, when the solder paste between the pad and chip is heated beyond the reflow temperature of the solder alloy (170°C for Sn/Pb alloys, 220°C for Pb-free alloys). During this reflow metallurgical reactions occur between the solder alloy and the PCB surface pad; the surface finishes for the PCB pads range from Cu, Ni/Au, Ag, Sn. Although the presence of intermetallics may indicate that a good metallurgical bond has been achieved, the drawback is that they are generally brittle; especially $Cu_6 Sn_5$, and this can lead to a loss in mechanical integrity of the joint. Therefore, it is key that these intermetallic compounds are identified and quantified. Historically, the study of dissolution of differing surface coatings, the formation of intermetallics and their growth is investigated through the use of micro-sectioning proceeded by optical microscopy, scanning electron microscopy and compositional analysis using the Auger Analysis technique. However, the micro-sectioning procedure is destructive, which basically ends the life of a sample, and may have an influence on the integrity of the analysis. Hence, a non-destructive technique for quantifying the intermetallic microstructure is sought after.

Voids in the solder joint are also formed in the reflow stage, whereby solvents in the solder pastes' flux medium are evaporated and can create bubbles which get trapped in the joint. This problem is exacerbated when using Pb-free solder alloys to create very small joints as Pb-free materials generally have larger surface tensions than Sn/Pb alloys and reflow in higher temperatures. These voids also need to be quantified in terms of their size, position and frequency in the solder joints as a function of different reflow profiles and alterations to the solder paste material, as the presence of voids will have a detrimental effect on the strength of the solder joint.

Internal strains within the solder joint also affect the joint strength and reliability. Strains are formed in the solder joint if the chip is misplaced prior to reflow. During the reflow, the molten solder will try to re-align due to surface tension and wetting effects, thus causing strains as the solder solidifies. Quantifying the strain distribution in the solder joint as a function of misalignment will yield invaluable information that can used in further mathematical modelling simulations that can predict time to failure of solder joints.

Experimental

We wish to use the X-ray diffraction technique (XRD) at the ESRF to identify micro intermetallics, voids and internal strains within solder joints made from Pb-free alloys. The desirability of this technique lies within its non-destructive nature and its capacity to map the interior of the solder joints using penetrating X-rays. Lab based XRD has previously been used to identify intermetallics in solder joints, i.e. [1]. However, the spatial resolution needed to investigate micro-solder joints (100-200µm square) can only be supplied by the X-rays from an insertion device at a synchrotron storage ring, such as the micro-focusing beamline ID13 at the ESRF.

Aims

We wish to analyse a variety of solder joints of different sizes, composition, ageing history etc. Initially, we would investigate the intermetallics and void content of solder bumps on different surface finishes, see figures one and two.

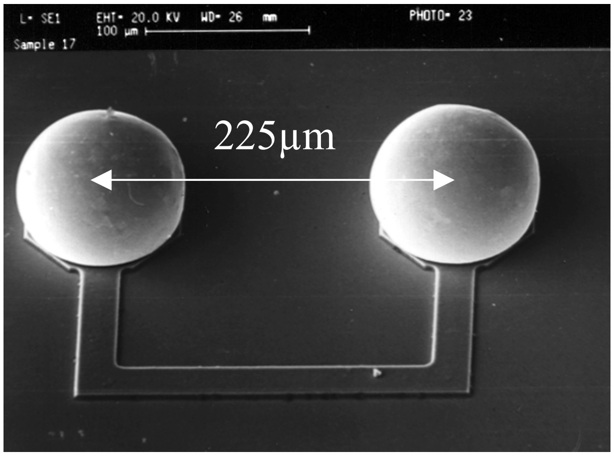

Figure 1 Solder bumped silicon wafer

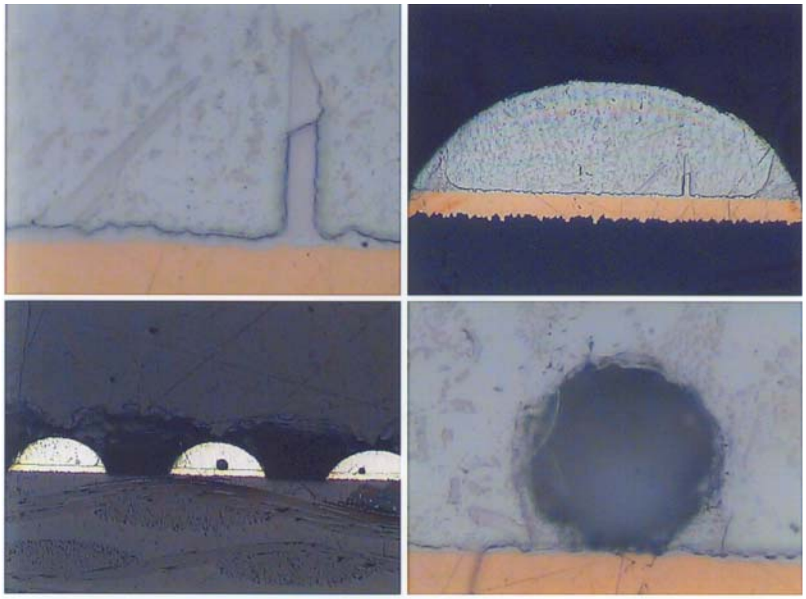

Figure 2 Micro-sections of solder bumps

Accelerated life testing is also planned in collaboration with the industrial partner ITRI using a single chamber (-25^{0}C< >+125^{0}C), and powered cycling (ambient < > +105^{0}C). This work-package will also study the mechanical properties of lead-free joints, and in particular, their mechanical strength and creep resistance. Although the presence of intermetallics may indicate that a good metallurgical bond has been achieved, the drawback is that they are generally brittle, especially Cu_6 Sn_5, and this can lead to a loss in mechanical integrity of the joint. After the thermal cycling experiments, details will be gathered on the growth rates observed for these intermetallics, as well as the changing microstructure.

Secondly, we would wish to analyse a solder joint connecting a flip-chip, or microelectronic component, to a PCB with the emphasis on mapping the internal strain and again, the intermetallic structure. We would use samples that have differing alignments and samples that have been subjected to different thermal aging cycles. Figure three displays the cross-section of an assembled flip-chip to a PCB.

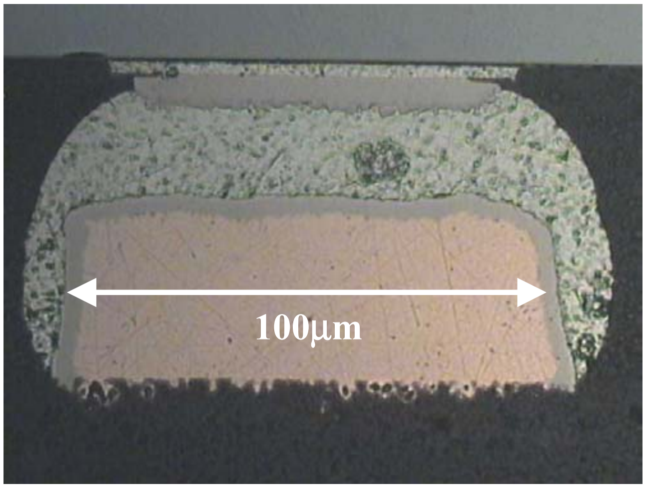

Figure 3 Cross-section of assembled solder joint

Details of Samples
Solder joint alloy – 95.5%Sn/3.8%Ag/0.7%Cu
Surface pad finish – Cu, Ni/Au, Sn, Ag
Size of joints (small) – 100 - 200μm square or diameter, 50μm in height
Size of joints (large) – 300 - 500μm square or diameter, 100μm in height
Pitch between joints – 200 - 300μm
Sample size – 5 – 10mm square, 1 – 5mm in height

Manpower
Dr. Gavin Jackson has extensive experience performing experiments on beamlines belonging to the storage rings of the ESRF (BL13/ID32) and Daresbury Laboratory (Station 6:1 and 6:3).

Relevant publications

[1] G. Y. Li and Y. C. Chan ‘Interactions between silver-palladium metallization and tin-lead-silver solder’, Physica Status Solidi, Rapid Research Notes, 98-015 (1998)

[2] Y. Y. Wei, J. G. Duh ‘Effect of thermal ageing on (Sn-Ag, Sn-Ag-Zn)/PtAg, Cu/Al2O3 solder joints’, J.Mat.Sci., Materials in Electronics (Oct. 1998) 373-381

Abstract

As-fabricated solders of eutectic Sn-Ag and ternary Sn-3.5 wt% Ag-1 wt % Zn alloys are coupled with metallized substrates including PtAg/Al2O3 and Cu/Al2O3 to simulate the solder joint in microelectronics. The growth mechanism of intermetallics and the mechanical properties of solder joints after thermal ageing (150 degrees C and 200 degrees C) are evaluated. In this study, a 1206 passive device/solder/metallization/Al2O3 surface mount technology (SMT) assembly is employed, and a Cu stud is attached on the ceramic substrate assembly to evaluate mechanical properties and the fracture morphology by the pull-off test. In addition, microstructure evolution of the interfacial morphology, elemental and phase distribution are probed with the aid of scanning electron microscopy (SEM), electron probe micro- analysis (EPMA) and X-ray diffraction (XRD) techniques. There are two intermetallics (Cu,Sn and Cu,Sn,) formed at the eutectic Sn-Ag solder/Cu metallized layer interface, while only Cu,Sn, is observed in the Sn-3.5 Ag-1Zn/Cu system. However, in the PtAg metallized substrate, only Ag,Sn is present, regardless of which solders are employed. Cu,Sn, and Ag,Sn in the Sn-3.5Ag-1Zn system contain 2-5 at % Zn due to the higher solubility of Zn in both Cu and Ag. The adhesion strength decreases as the time increases for all solder joint systems in the thermal ageing test. The solder joint with eutectic Sn-Ag alloy exhibits higher fracture load than that with Sn-3.5Ag-1Zn alloy. From the fracture surface analysis, as the ageing time increases, the fracture takes place from the solder/conductor interface toward the inside of the IMC (intermetallic compound). (C) 1998 Kluwer Academic Publishers.