

Inspection of Under Bump Metallisation – Solder Ball Interface by SEM, EDX and Moiré Interferometry

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ABSTRACT

Ball grid array (BGA) packaging is gaining popularity due to the insatiable demand for miniaturisation of devices, for higher I/O count and for more real estate on a package. As a result of this trend, solder balls used on different forms of BGA packaging are getting smaller and smaller. Traditionally the dominant failure mode in a well-designed and well-manufactured solder joint is low-cycle thermal fatigue. It is usually difficult to manufacture all perfect solder balls in a BGA package, especially as bump and pitch dimensions get smaller. Industry problems seem to concentrate on two points 1) either the solder ball itself is defective, e.g. has too many voids, or 2) the intermetallic between the solder bump and the under bump metallisation (UBM) is defective, e.g. partially formed or did not form at all. In this article, it is shown that a combination of inspection methods can be very effective in inspection of the interfaces and the solder bump for manufacturing defects. The analysis conducted in this study indicates that a lack of or a partial intermetallic compound layer between the solder bumps and UBM is very often the cause of the failure in the module.

INTRODUCTION

In this study a BGA module shown in Figure 1 was inspected for solder bump and UBM interface integrity right after manufacturing. SEM (scanning electron microscopy) and EDX (energy dispersive X-ray spectroscopy) techniques were used in conjunction with the Moiré interferometry technique. During the manufacturing process, after all modules are mounted on a printed circuit board (PCB), components are usually checked for electrical functionality. Once it is known that a certain component is dysfunctional, it is usually a guessing game to find where the actual problem is. Very often the scapegoat is the vendor for that specific component. At this stage choosing an inspection method is critical. The methods mentioned in this article provide a very powerful procedure to pinpoint the source of the failure point with great

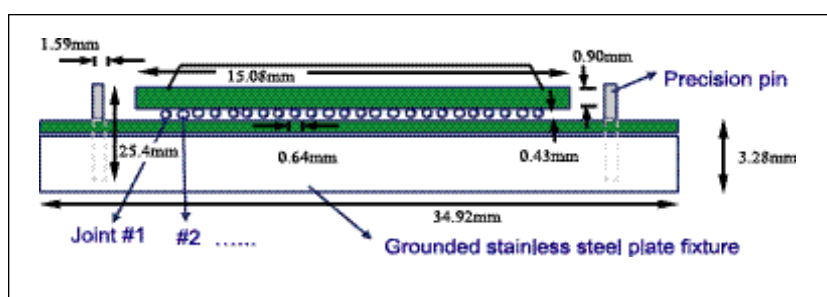


Figure 1
Tested BGA module on the fixture

accuracy. Moreover, these techniques provide much better quantitative information than most other inspection methods. Also, using these inspection methods costs a fraction of other typically used techniques.

PREPARING THE MODULE FOR INSPECTION

In order to inspect the solder bump and its interfaces, there is a need to have a good cross-section of the package including the PCB substrate. Hence, usually a section of the circuit board that contains the module is cut off from the rest of the PCB. A high precision diamond saw is used to section the module through the centre of the solder bumps. The sectioned surface is then polished with very fine silicon carbide paper to obtain a smooth surface.

SEM INSPECTION

The finely polished sections of solder bumps are first analysed under SEM. Both the SEM and SEM backscattered photos are taken. The SEM images suggest that there is a crack between the solder bump

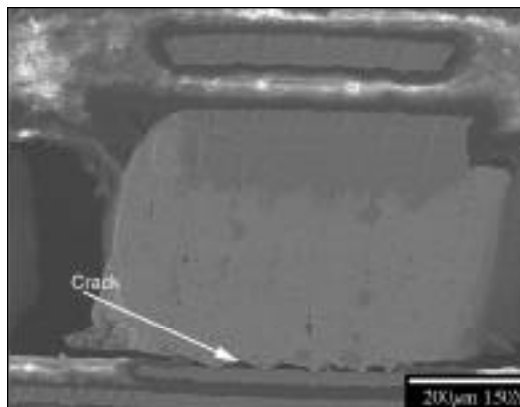


Figure 2
SEM photo of solder bump C1
on U28

Figure 3
SEM backscattered photo of solder bump C1 on U28

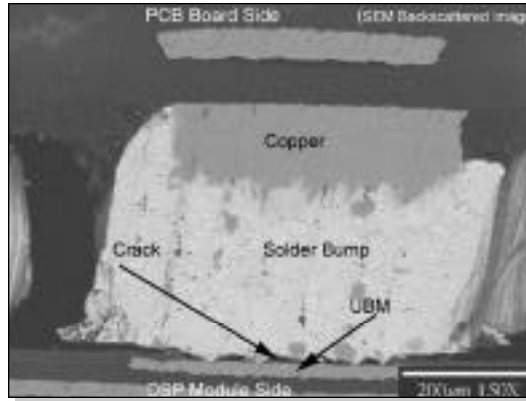
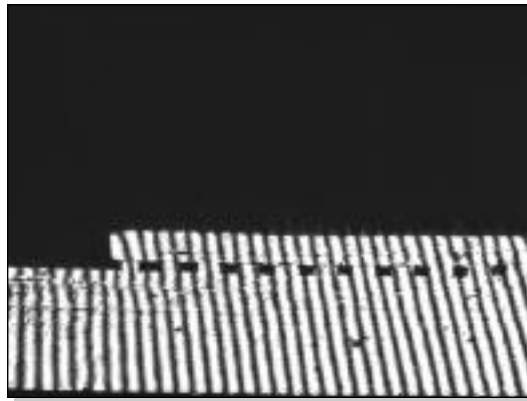


Figure 4
Initial whole U fringe field



and its UBM on the die side as shown in Figure 2. Cracks were observed in some solder bump-UBM interfaces and no cracks were observed in some other interfaces. No cracks were observed in the body of the solder joints, which usually are the stereotypical first suspects for

any device failure. It is well known that SEM images can be misleading unless inspected by highly experienced and trained personnel. SEM only provides information about the cross-section that is polished. Hence, one could get a well-manufactured looking section from a partially debonded bump with voids and cracks. Moreover, it is not possible to get any physical quantitative information from SEM images. This gap in inspection can be filled with the Moiré interferometry technique.

UB MOIRÉ INTERFEROMETRY TECHNIQUE

The Moiré interferometry technology developed at the University at Buffalo, Electronic Packaging Laboratory, allows measuring of the plastic strain field in a package during fatigue testing up to and including the failure point of the suspect area. The resolution of this advanced technique is typically $0.417 \mu\text{m}$ and goes up to $0.041 \mu\text{m}$ when the phase shifting option is used. By means of this method it is easy to pinpoint failure mechanisms and physically measure the plastic strain accumulation with sub-micrometer accuracy. Furthermore, this technique also permits pinpointing the interfacial delamination initiation as a function of thermal cycles.

Figure 4 shows the initial Moiré fringes for the U field. By inspecting the initial fringes shown in Figure 4 we see that fringes are continuous across the solder joints, because the displacement compatibility is satisfied at each solder bump. The existence of initial fringes indicates that there is small strain applied on the package during fixture mounting process. The interfaces that indicate cracks in SEM images are actually partial and some have asperity contact, hence still have mechanical shear strength. After applying thermal cycling, usually around 20 cycles of 100°C to 0°C with a 42-min period, a close

Figure 5
SEM photos of separated solder bumps.
Left: an array of solder bumps
Right: a close view of a single solder bump

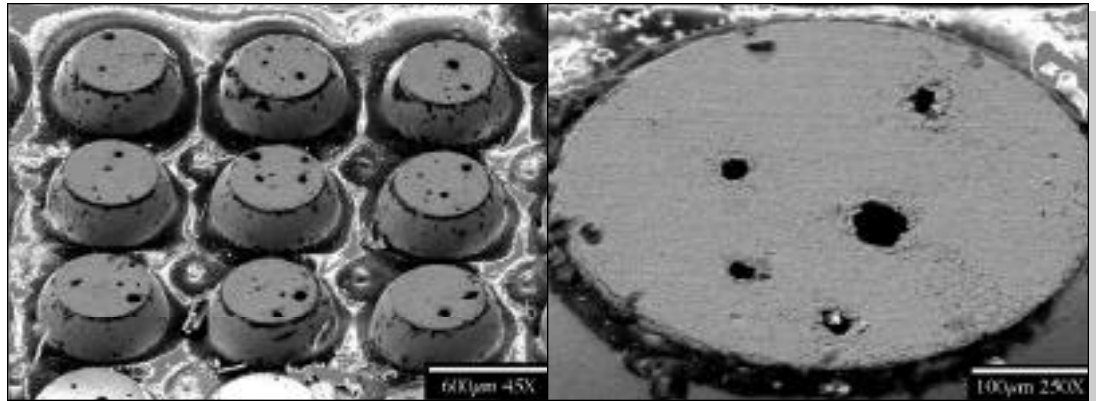
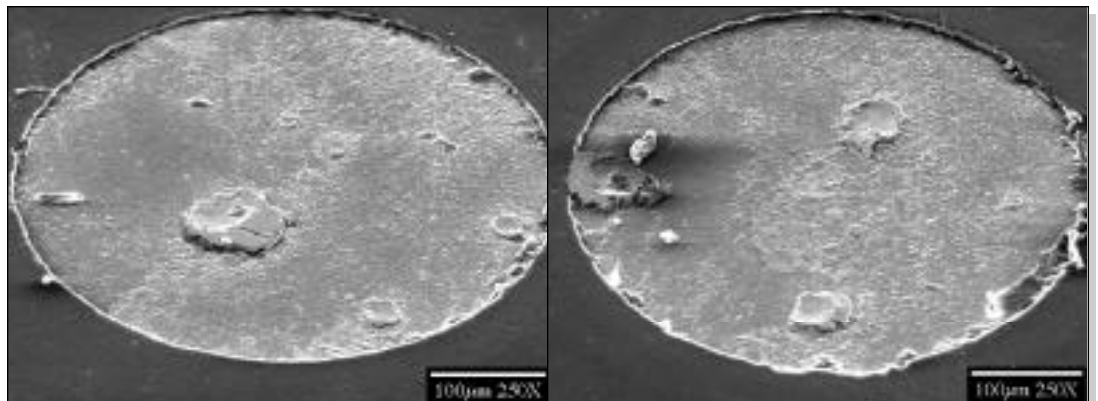


Figure 6
SEM photos of two of the UBMs on the DSP module side



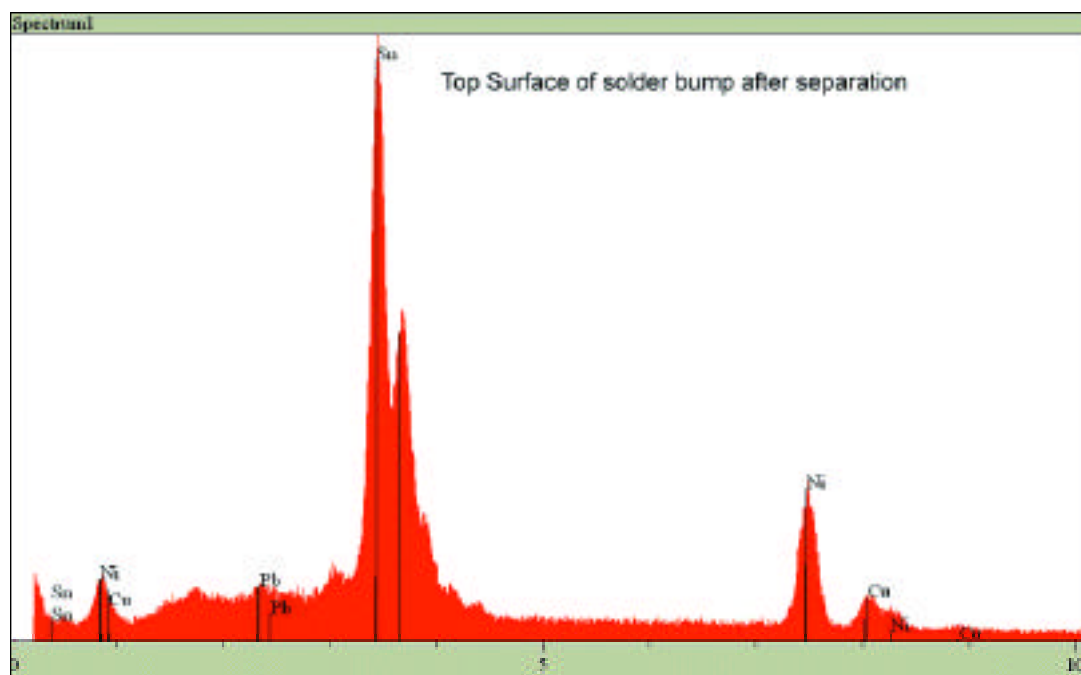


Figure 7
EDX spectrum of the top surface
of the solder bump after
separation

inspection of the fringe fields indicate that fringes become discontinuous at the solder joints that have cracks between the solder bump and the UBM.

Discontinuity of fringes indicates that there is a physical discontinuity between the solder and the UBM, as a result the solder bump does not develop any plastic strain. Moiré fringes can be thought of in a manner similar to an electrical potential field, they must be continuous unless there is a discontinuity. If there were not a discontinuity, the fringes would be continuous across a solid medium. If the bond between the solder bump and the UBM remained intact the Moiré fringes would remain continuous across the interfaces after thermal cycling.

Solder bumps with cracked interfaces do not develop any plastic strain and solder bumps with good interfaces develop plastic strain as a result of thermal cycling. The value of the plastic strain can easily be calculated from the fringes. The whole field optical fringe approach detects any initiation of interface delamination immediately with great accuracy.

An SEM image of the interface between the solder bump and the UBM may look like it is intact or delaminated depending on the cross-sectional position. However, Moiré interferometry can easily distinguish between a completely debonded interface and a partially debonded interface. In addition, a completely debonded or never formed interface will never develop any plastic strain starting from the first thermal cycle. On the other hand, a partial interface will develop plastic strain initially but will fail quickly and release the strain.

Moiré interferometry measurements are always supported by SEM observations.

ENERGY DISPERSIVE X-RAY SPECTROSCOPY (EDX)

The last step in the inspection process is the verification of the material composition. For this purpose EDX provides an excellent tool. In order to perform EDX inspection, the module must be separated manually or by thermal cycling failure. EDX is capable of providing elemental composition with a sampling depth of 1–2 μm . First, the top surface of the separated solder bump is measured.

Figure 5 shows the SEM photos of separated solder bumps. Smooth surfaces at the solder tops indicate that intermetallic never formed during reflowing process.

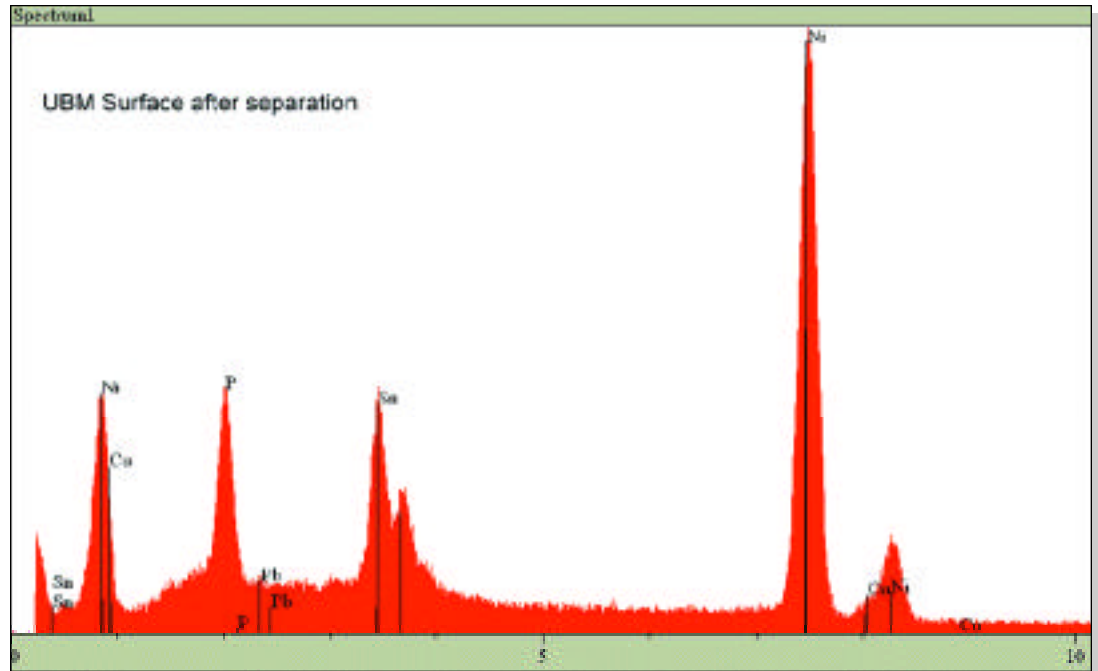
Figure 6 shows images of two separated UBMs. Features on the UBM surface correspond to fragments of solder torn from the base of voids in the solder. Mostly, however, there is a clean separation at the bump/UBM interface. The EDX spectrum shown in Figure 7 indicates that the dominant element on the solder bump surface is Sn (tin) as well as small amounts of Pb (lead) and Cu (copper). Ni (nickel) is also present. The UBM surface is predominantly Ni with P (phosphorus) with Cu, as indicated in Figure 8, corresponding to a plated nickel layer over copper. The tin observed originates from small tin particles remaining after fracture. Although there is no gold observed due to the thinness of the gold layer, there may be a gold flash on the surface of NiP. The purpose of Au flash is to protect the Ni from oxidation.

From the EDX spectra, we can conclude that the separation was located between the solder bumps and NiP UBM. Figure 7 also indicates that Ni has diffused into the solder bumps to form a partial intermetallic compound. This separation indicates that the failure of the module is solely because of the weakness of the intermetallic compound between UBM on the die side and the solder bump. These modules had separated after only a few thermal cycles. In this case the UBM is NiP, which has very low dissolution rate in Sn, about 0.0021 at 100 mm/s at 250 °C. Due to the low dissolution rate higher thermal energy is needed to form the intermetallic compound. In this case it is likely that the bumps and UBMs never received the adequate thermal energy needed to form the intermetallic compound.

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Figure 8
EDX spectrum of the UBM
surface



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