Increased High-Temperature Reliability and Package Hardening of Commercial Integrated Circuits (Through Die Extraction, Electroless Nickel/Gold Pad Reconditioning, and Ceramic Re-Assembly)

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Abstract

There is an ever-increasing demand for electronics in higher temperature applications, both in variety and volume. In many cases, the actual integrated circuit within the plastic packaging can support operation at higher temperatures, although the packaging and connectivity is unable to do so. Ultimately, there still remains a significant gap in the volume demand required for high temperature integrated circuit lines to justify support of more expensive ceramic solutions by the original component manufacturer vs. the cheaper, high-volume PEM flows. Global Circuit Innovations, Inc. has developed a manufacturable, cost-effective solution to extract the integrated circuit from any plastic encapsulated device and subsequently re-package that device into an identical ceramic footprint, with the ability to maintain high-integrity connectivity to the device and enabling functionality for 1000's of hours at temperatures at 250C and beyond. This process represents a high-value added solution to provide high-temperature integrated circuits for a large spectrum of requirements: low-volume, quick-turn evaluation of integrated circuit prototyping, as well as medium to high-volume production needs for ongoing production needs. Although both die extraction and integrated circuit pad electroless nickel/gold plating have both been performed successfully for many years in the semiconductor industry, Global Circuit Innovations, Inc. has been able to combine the two in a reliable, volume manufacturing flow to satisfy many of the stringent requirements for high-temperature applications.

Key words

Die Extraction and Re-Packaging, Die Thinning, Die Stacking, UBM Pad Re-Conditioning, High-Temperature Integrated Circuits, High Temperature Hardening of Commercial Die, Electroless Nickel/Gold or Nickel/Palladium Pad Plating

I. Introduction

Ceramic packaging generally provides a higher reliability semiconductor solution relative to PEM (plastic encapsulated microcircuits) for the same die. Although the demand for ceramic packaged semiconductor product has increased over the recent past due to higher temperature down-hole drilling applications and military program obsolescence requirements, it has not been sufficiently large for OCM's (original component manufacturers) to support the excessive cost in maintaining or developing the relatively low-volume product line demand as compared to the more lucrative high-volume commercial PEM flows.

Many semiconductor devices can operate at temperatures in excess of their current plastic packaging maximum specifications of 125C. How well the device functions over the increased substrate's temperature range depends on both the design and process upon which the silicon was originally manufactured, although many high-temperature application customers have the ability to accommodate increased leakage and/or slower clock speeds to compensate for higher ambient temperatures, up to and including 200+C.

However, because die are not readily available in low volumes due to high minimum order quantities, or within required lead times, die extraction and re-assembly (DER) can support assemblies for these applications by providing the ability to remove any die from its current plastic encapsulation, and in any volume, while also repackaging it into the ceramic equivalent footprint necessary to provide a microcircuit solution for harsher environments.

The DER process also provides the added value of working with and producing singulated, known-good die (KGD) as well as added visual inspection capability for counterfeit mitigation. Depending on the application, each extracted die can be thinned down to as little as 75 um while maintaining functionality, for packaging miniaturization requirements.

If the final bond intermetallic requires a bonding surface other than aluminum for high-temperature reliability applications, the original gold ball can be removed, followed by a under-bump metallic deposition process (UBM) of electroless nickel/gold or electroless nickel/palladium (ENIG or ENIPG, respectively). In either case, higher volume production of bare die scales extremely well with respect to extraction, original gold ball removal, and, if necessary, subsequent reconditioning of the pads.

II. Volume Die Extraction

Die extraction is a proven manufacturing procedure which removes the actual silicon chip from the original package so as to make the integrated circuit (IC) available for re-assembly into another package footprint, package type (ceramic or plastic), or to maintain it in die form for subsequent thinning and/or multi-chip assembly (see Figures 1a and 1b below).

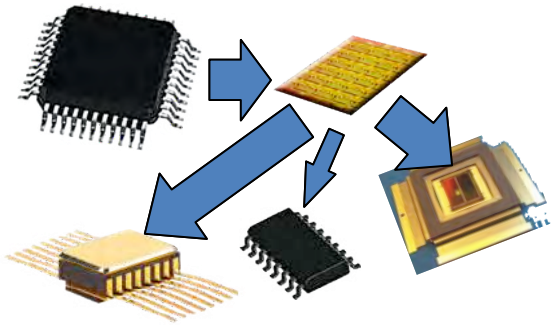

Fig. 1a – Silicon Die Extracted From Original Plastic Package and Re-Assembled Into New Plastic Footprint or Ceramic Package

Fig. 1b – Extracted Silicon Die Re-Assembled Into MCM Hermetic Package

In short, the silicon die can be removed from any plastic or ceramic package without damaging the die and with no change to the electrical performance. The functional, extracted die can then be re-mapped into any footprint of interest (plastic/ceramic package, or hybrid module).

This technology has been repeatedly proven to be scalable in high volumes for the general commercial industry, and specifically for high-temperature industrial applications. The chemical and mechanical processes used are no more aggressive than those experienced in the original wafer fabrication.

Figures 2a and 2b demonstrate both the cleanliness and controlled processing during extraction to eliminate inadvertent pad etching.

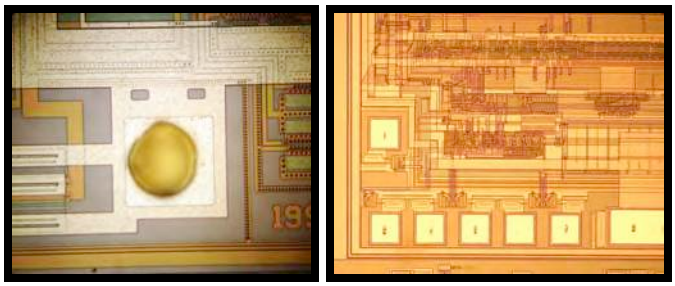

Fig. 2a **Fig. 2b** – Extracted Die with Gold Ball Still in Place (Fig. 2a), and Bare Die as Diced from a Manufactured Wafer (Fig. 2b). Aluminum Pad Integrity is Identical for Both.

To further illustrate this point, Figure 3 depicts the very clean silicon backside, which is routinely achieved prior to re-assembly.

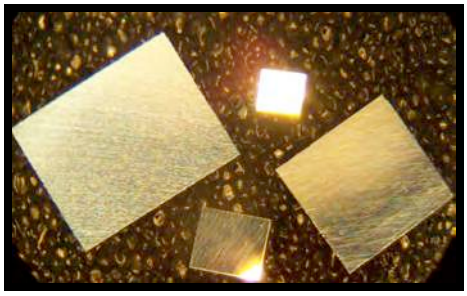

Fig. 3 – Silicon Die Backside Following Extraction

III. Die Thinning & Re-Mapping

Die thinning is an option, which enables low profile packages, or die stacking within a package cavity. The die thickness can be targeted down to 75 um routinely, and in some cases, as thin as 50 um, while maintaining functionality. Figure 4 below depicts the type of equipment typically used for such processes.

Fig. 4 – Die Thinning Equipment

Figure 5 demonstrates how the thinned die can be stacked within a package cavity or MCM substrate to achieve higher density packaging, or package miniaturization, if necessary.

Fig. 5 – Extracted and Thinned Die Following Die Attach and Wire Bonding.

In some cases, bond re-mapping is necessary to achieve variations in capability for a given die family. For example, some memory die can be reconfigured in x8, x16, or x32 I/O capability, all dependent on the bonding configuration. Certain FPGA families contain the identical die, but I/O count and overall capability is dependent on the final bond out of the die. Figure 6 shows the very powerful flexibility that is obtained using the DER process.

As can be seen in Figure 6, there are four potential re-bond options during the DER process: 1.) Originally non-bonded pads, which remain non-bonded (red), 2.) Originally non-bonded pads, which are newly bonded (green), 3.) Originally bonded pads, which subsequently are not required to be bonded (yellow), and 4.) Originally bonded pads, which are again bonded (purple).

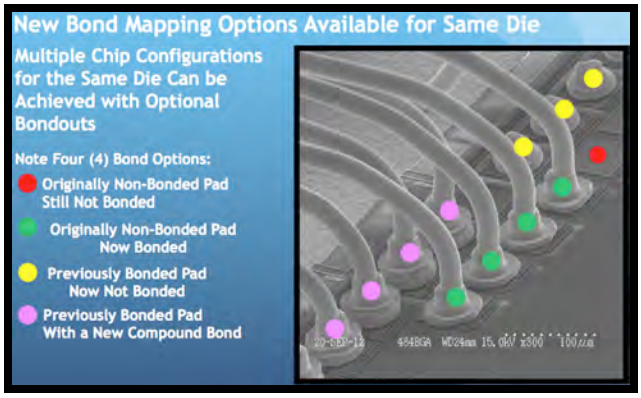

Fig. 6 – Bond Mapping Flexibility with Die Extraction and Re-Assembly (DER)

In this manner, obsolete die configurations within a given family (memory or FPGA, for example), can be easily recreated if any part within the family is still available.

IV. Original Bond Removal and Pad Reconditioning – Also Available in Volume Manufacturing

Although there currently exist hermetic ceramic assembly flows for extracted product which can vastly increase the high-temperature reliability of extracted product, while retaining the gold ball/aluminum pad bond interface, removal of the original gold bond for subsequent bond pad re-conditioning/plating provides a metallic stack-up which is not sensitive to Kirkendall voiding. Specifically, once the original bond has been removed, the remaining aluminum (or copper) pad can be reconditioned by plating an electroless nickel base, followed by either an electroless gold finish (ENIG) or a palladium/gold finish (ENIPG).

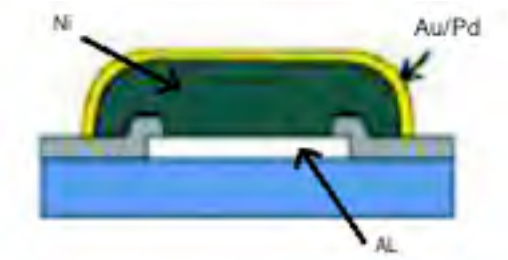

Fig. 7 – New Pad Metallization Stack-Up Illustration

Some of the obvious and less obvious benefits for performing this additional processing include, but are not limited to, the following:

1.) The original bond for the extracted die has been found to either be insufficient or compromised (i.e., bond lifts during subsequent re-assembly bonding)
2.) The end user is unable to accept compound bonding due to assembly constraints (typical in most military assembly flows MIL-STD 883J). [1]
3.) The end application requires removal of the original gold ball bond on aluminum pad to mitigate and/or eliminate Kirkendall voiding as seen during high-temperature applications.[2]

Figures 8 – 12 provide Scanning Electron Microscope (SEM) imagery to show the progression of a die as seen initially following conventional DER processing (through wire dressing/removal), following gold ball bond removal, after UBM aluminum pad reconditioning, and finally after final bonding of the finished die.

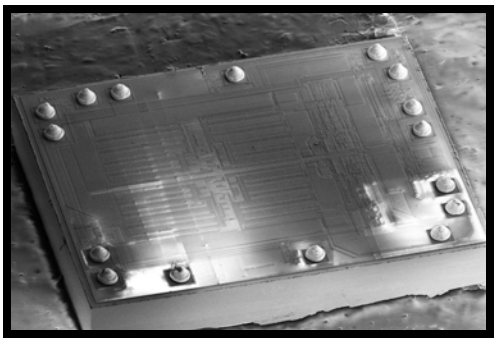

Fig. 8 – Extracted Die Following Wire Dressing

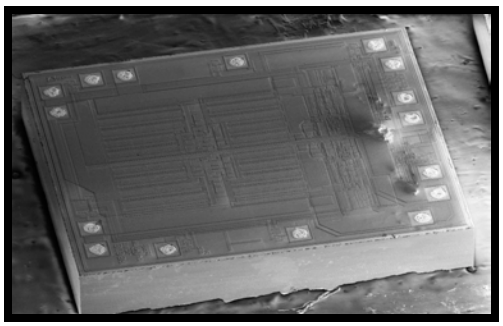

Fig. 9 – Die Following Gold Ball Removal

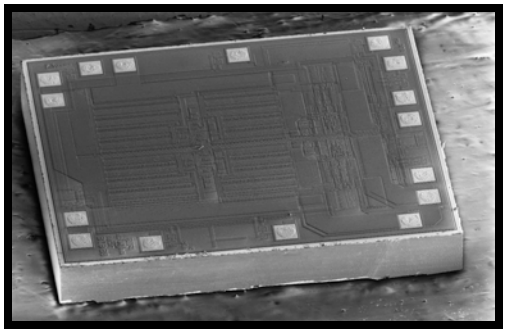

Fig. 10 – Die Following Pad Reconditioning with ENIG UBM Processing.

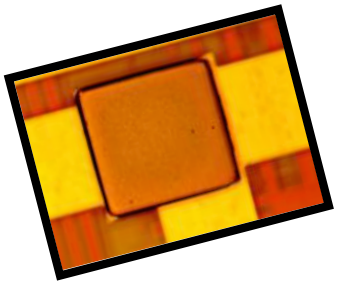

Fig. 11 – Optical Photo of Die Following Ni/Au Electroless Pad Re-Conditioning (Gold Finish)

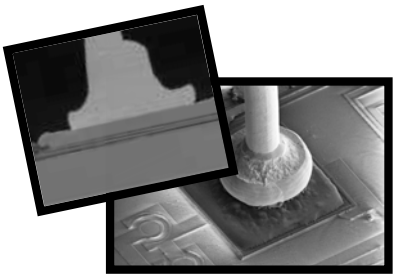

Fig. 12 – SEM Cross-Section and Top-Down Images of Subsequent Bond Following Pad Re-Conditioning.

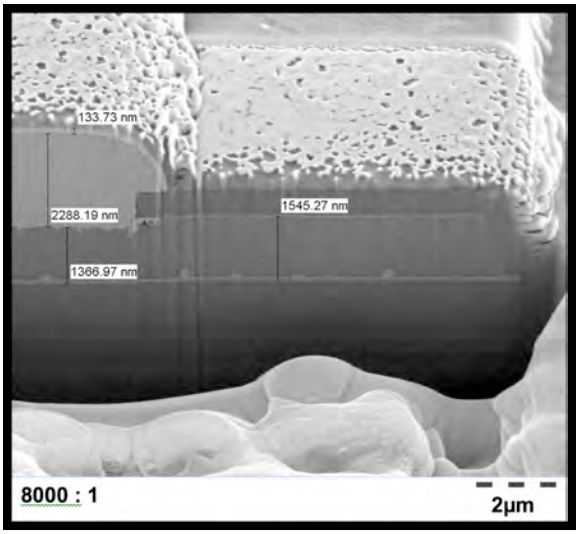

Fig. 13 – Cross-Section of Pad Re-Plating with Electroless Nickel and Palladium. All Measurements are 40% larger than Posted due to Oblique Angle.

Under careful process control, the final bonding on a reconditioned pad is not only more consistent (lower standard deviation as a percentage of average bond pull strength), but also of higher bond pull strength in general [3,4]. The following data* is taken directly from testing performed on identical devices before and after gold ball removal/pad reconditioning (ENIG):

	Avg. Bond Pull Strength	Std. Dev.	Mean-3 SD
Device as Received:	7.154g	1.03g	4.06g
Device After Pad Re-Conditioning:			
T=0	13.302g	1.52g	8.74g
T=168 (250C)	12.650g	1.255g	8.89g
T=1000 (250C)	11.540g	0.897g	8.50g
T=2000 (250C)	10.913g	0.755g	8.65g

*Data Reflects 16 Points Each

Table 1 – Bond Pull Strengths (Mean - 3D) for OCM Die and GCI Pad Re-Conditioned Die.

Thus, with optimization and controlled processing, average bond pull strengths can be increased, while also increasing the consistency, ultimately providing for a higher quality bonded device. Nominal breaking force of Gold 0.001" wire is 10 – 14 grams. [5]

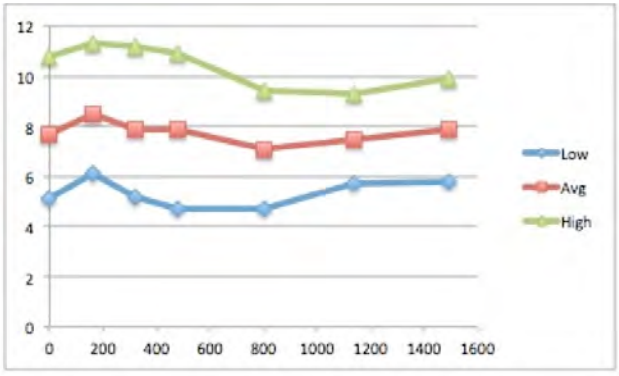

Fig. 14 – 250C Accelerated Life Test Data [1 mil Gold Wire on Re-Conditioned Pad - Bond Pull (g) vs. Time]

V. Conclusion

Die extraction and re-assembly (DER) can be performed in a controlled manufacturing environment to not only readily produce bare die, but also allow for subsequent die thinning and UBM pad processing, ultimately providing superior solutions for prototype development, device miniaturization, resolving integrated circuit obsolescence, and enabling high-temperature packaging performance for down-hole applications. Each of the processes involved with the associated technology is sufficiently scalable to provide economical solutions to commercial, industrial, and military demands/requirements with high-yield/high-volume manufacturing economically achievable.

Acknowledgment

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References

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[2] George G. Harman, *Wire Bonding in Microelectronics: Materials, Processes, Reliability, and Yield*, McGraw-Hill, 1997, pp. 122–125.

[3] R. Wayne Johnson, M. Palmer, M. J. Bozack and T. Isaac-Smith, "Thermosonic Gold Wire Bonding to Laminate Substrates with Palladium Surface Finishes," IEEE Transactions on Electronics Packaging Manufacturing 22 (1999)

[4] Kuldip Johal, Sven Lamprecht and Hugh Roberts, "Electroless Nickel / Electroless Palladium / Immersion Gold Plating Process for Gold and Aluminum-Wire Bonding Designed for High-Temperature Applications", Atotech Deutschland GmbH, Berlin, Germany Atotech USA Inc., Rock Hill, SC, USA

[5] Kulicke and Soffa; AW-14 Gold Bonding Wire for Universal Use: http://neu.aeroweb.net/weblog/wp-content/uploads/2010/01/aw14_datasheet1.pdf