Fluxless soldering using Electron Attachment (EA) Technology

Proprietary, patented innovation for wafer level packaging applications including wafer bump and copper pillar reflow.

Air Products has partnered with Sikama International to introduce the Electron Attachment fluxless reflow system to the electronics wafer level packaging segment.

Building on our 25 years of proprietary and patented innovation for the global electronics packaging industry, Air Products introduces breakthrough technology that uses electron attachment or EA to activate hydrogen at ambient pressure and at a starting temperature as low as 100°C.

The Electron Attachment process:

Principle of EA

Electron Attachment is a novel flux-free technology based on electron attachment (EA), which can be operated at ambient pressure and normal solder reflow temperatures using non-flammable mixtures of hydrogen (<4 vol%) in nitrogen. The technology is invented by Air Products in recent years, which involves generating a large quantity of low-energy electrons. Some of the electrons can attach to hydrogen molecules, forming active species for oxide removal.

When low-energy electrons, such as below 10 eV, collide with gas molecules, some are captured by gas molecules, producing anions by dissociative or direct attachment. The following equation represents the dissociative attachment for hydrogen, where a hydrogen molecule (H_2) combines with an electron (e^-) to give an excited molecular hydrogen anion (H_2^{-*}) which dissociates to give an atomic hydrogen anion (H^-) and a neutral hydrogen atom (H).

$$H_2 + e^- \rightarrow H_2^{-*} \rightarrow H^- + H$$

The neutral hydrogen atom can further capture an electron, forming an excited atomic hydrogen anion (H^{-*}) by direct attachment as depicted in the equation below.

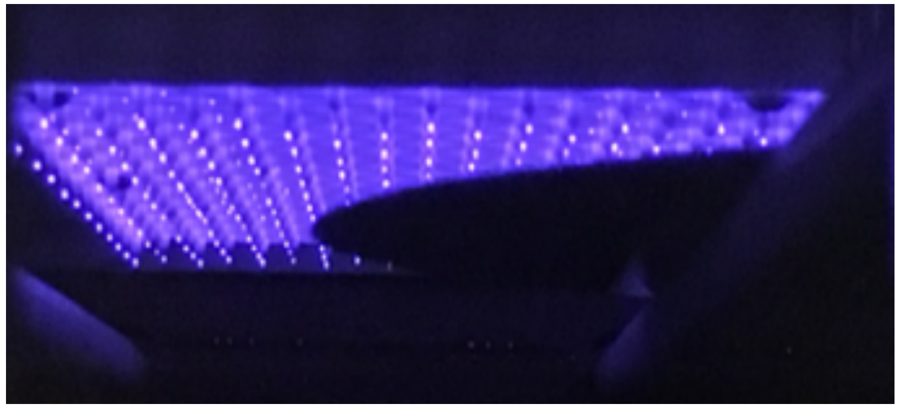
$$H + e^- \rightarrow H^{-*}$$

The excited atomic hydrogen anion can be stabilized by releasing a photon or colliding with a nitrogen molecule. Nitrogen as the dilution gas is inert to EA because its electron affinity is close to zero. Driven by an applied electrical field, the atomic hydrogen anions formed under EA can be directed to the soldering surfaces for oxide reduction.

Here is an example of reducing tin monoxide.

$$2H^- + SnO \rightarrow Sn + H_2O + 2e^-$$

As reduction by-products, water vapor can be easily vented out of the furnace and free electrons can be removed properly.



Wafer entering an EA zone for oxide removal.

Sikama International UP 1200 System Description for Electron Attachment Processing

Sikama International's UP1200 EA version furnace is a five heat zone, linear tunnel process oven. The furnace is designed to be used to remove metal oxides from solder bumps on UBM wafers and solder caps from copper pillar wafers via the electron attachment technology, which activates hydrogen to produce hydrogen anions and then reflow the solder to their final shape in the absence of traditional flux processes. The furnace is capable of operating at temperatures up to 400°C. The function principle is based on non-contact heating in combination with forced thermal convection. The system may be operated with an open air atmosphere or with a nitrogen (N_2) atmosphere or forming gases.

Air Products and Sikama International EA-enabled prototype furnace for production-scale wafer bump reflow

Roller-featured wafer transportation system

The EA UP1200 furnace is designed to accept semiconductor wafers up to 300 mm in diameter.

The wafers that are to be reflowed in the furnace are transported by means of a roller transport system with stainless steel rollers in the non-critical zones and ceramic rollers in the preheat electron attachment and reflow zones. This unique transport system allows for a stable, centered, and vibration-free transport of the wafer through each zone as described below and allows for electrical isolation of the working piece. Wafer throughput in the reflow furnace is one unit per minute, which matches the standard manufacturing throughput of 60 wafers per hour. The load and unload buffers have appropriate sensors to provide SMEMA interface connection to link into automated production lines.

The UP1200 furnace has eight (8) temperature controlled zones: one (1) liquid cooled entrance zone, five (5) individually controlled, electrically heated zones and two (2) liquid cooled zones at the furnace exit. The heated zones consist of two (2) pre heat zones, two (2) EA zones and one (1) reflow zone.

All heat zones utilize a modified Sikama's "thermal technology" to satisfy special needs for applying EA technology. The modified “thermal technology” is based on non-contact heating in combination with forced thermal convection. Heating (cooling) zones are heated (cooled) from the top and bottom of the furnace tunnel for all zones.

Each heated zone has individual set point controls and gas flow controls that maintain platen temperatures to within +/-2°C to ensure consistent and precise temperature for repeatable profiles and uniformity across the wafer surface. The forming gas is introduced into the preheat zone 2, the EA zones and the reflow zone through perforations in the conduction heating platens and enters the chamber at the same temperature set for each zone. Nitrogen gas is introduced in the other chambers in the same fashion. The O_2 level in all zones is below 10 ppm, nominally at 5 ppm. The internal liquid-cooled zones ensure controlled work item temperatures at the entrance and exit of the oven. Cooling zone temperatures are controlled by water systems external to the UP1200 furnace.

The EA UP1200 furnace is fully computer controlled. The proprietary software is useful for storing temperature profiles, monitoring individual heat zone temperatures, and displaying process status. Process profiles can be created on the computer and sent to the machine for execution.

Benefits of Electron Attachment

EA is considered to be promising for activating hydrogen for fluxless solder reflow due to the following reasons:

- The atomic hydrogen anion formed under EA is a strong reducing agent since it is free of a chemical bond and is a good electron donor for triggering an oxide reduction.
- Different to the conventional plasma, the charged environment created under EA is singly negative, which makes hydrogen anions repel each other and extends their lifetime at ambient pressure.
- Comparing with the random diffusion of neutral gas molecules or atoms, the hydrogen anions approaching to soldering surfaces under EA is driven by an electrical field, which is much faster and efficient.
- Ambient pressure is more favorable than vacuum for forming anions by EA because the increased collisions between electrons and gas molecules, which not only facilitates the formation of low energy electrons but also increases the probability of electrons approaching and attaching to gas molecules.

Customer Benefits of Electron Attachment Technology

The EA-based technology offers the following benefits for wafer bump reflow:

1) Enhanced bump reflow quality because the flux induced solder voids and wafer contaminations naturally disappear,

2) Improved productivity by having in-line process capability, eliminating post wafer cleaning, and avoiding furnace down time for cleaning,

3) Reduced cost of ownership to end users due to eliminated costs associated with cleaning equipment, cleaning solution, labor work, and flux,

4) Improved safety by eliminating flux exposure and using a non-toxic and non-flammable gas mixture, and

5) No environmental issues by eliminating organic vapors, hazard residues, and CO_2 emission.

Our studies suggest that the EA process promotes the formation of atomic hydrogen anions, a strong reducing agent that removes surface oxides on solder and base metals. Driven by electrical fields within the EA process, these atomic hydrogen anions move directly toward the soldering surface, making it possible to use hydrogen concentrations as low as a nonflammable range of 4 percent hydrogen in 96 percent nitrogen.

EA enables a variety of commonly used solder alloys in electronic assembly processes to reflow and wet at temperatures a few degrees above their melting points. Major benefits can include a large increase in the process-operating window, a complete elimination of flux residues, and a significant reduction of voiding tendency in solder joints.

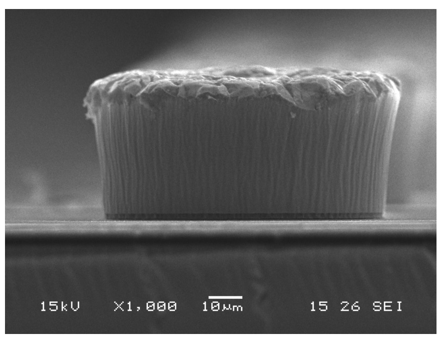
Wafer Level Packaging Applications for EA Technology

UBM Wafer Bump Reflow

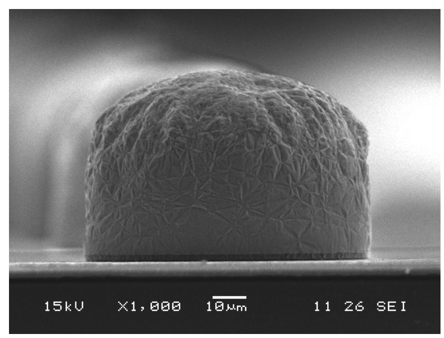
Wafer bumping is a critical step in wafer-level packaging. A reflow process is used to form homogeneous solder spheres on the wafer surface. The prevention of solder oxides during reflow is essential for bump shape uniformity and formation of strong metallic interconnect phases.

During the reflow heating cycle, an electron emission device is turned on to establish an EA environment surrounding the solder bumps.

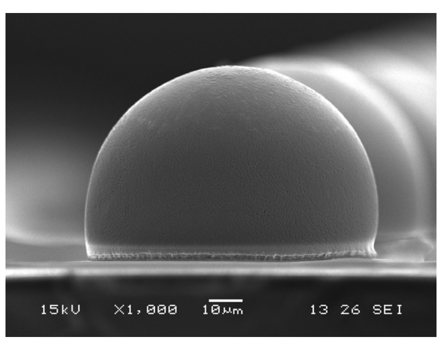
Solder bumps reflowed from 200 mm mechanical wafers (see photos below) under EA have a very smooth surface and spherical shape, driven by a high surface tension of the oxide-free molten solder. In the absence of electron attachment, the solder bump surfaces are quite wrinkled, and the bump height is small due to the restriction of the oxide skin on the molten solder during reflow.



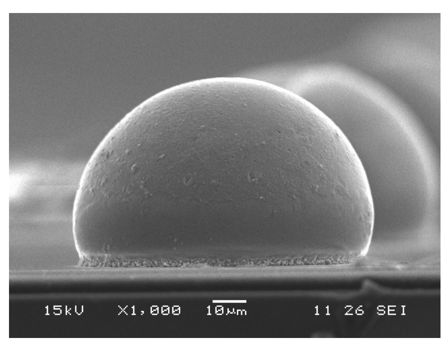
Before reflow



Reflow without EA

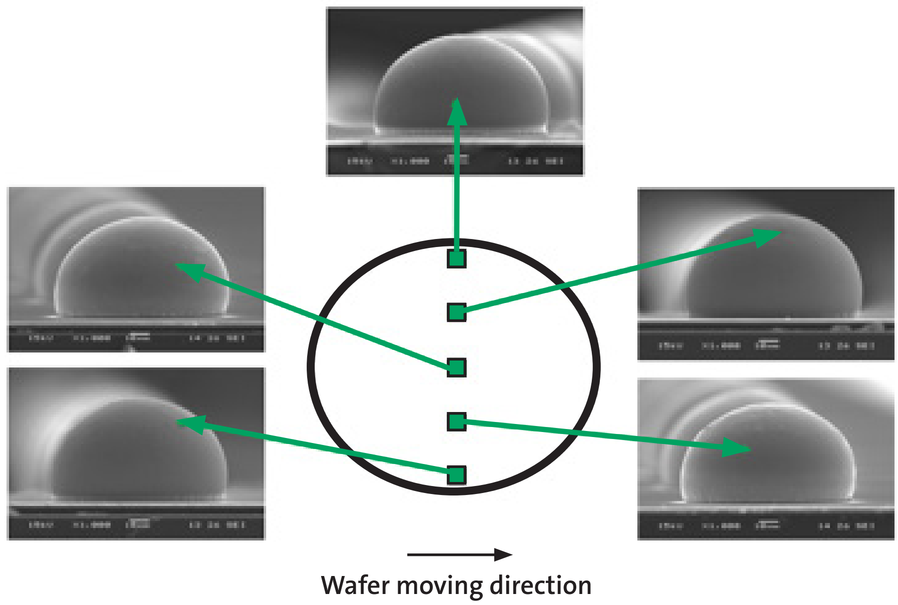


Reflow with EA

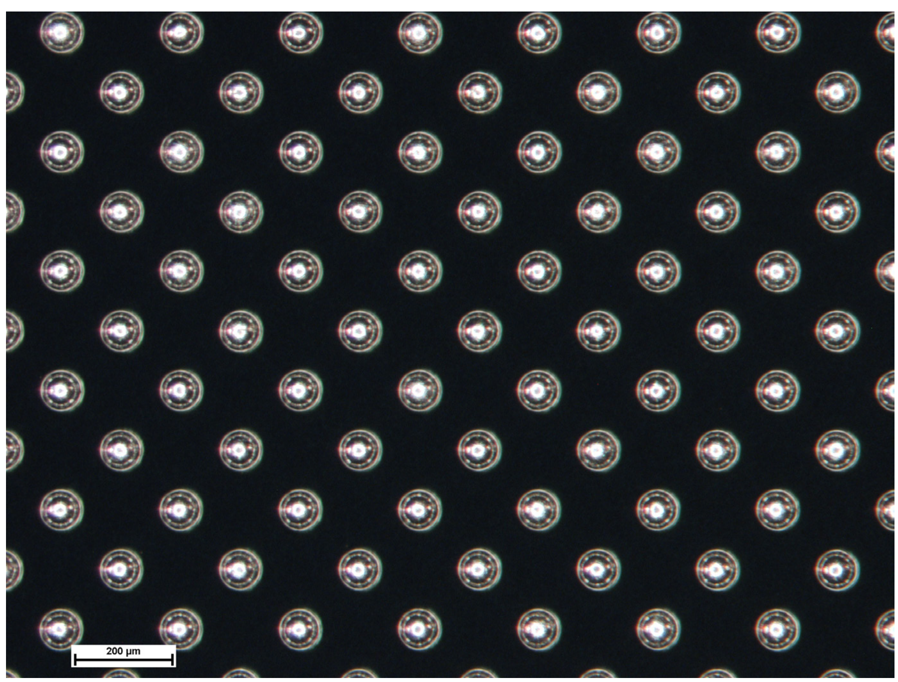


Reflow with flux

As shown in photograph below, the EA-based process can ensure a good bump uniformity across the width of a 12" moving wafer.



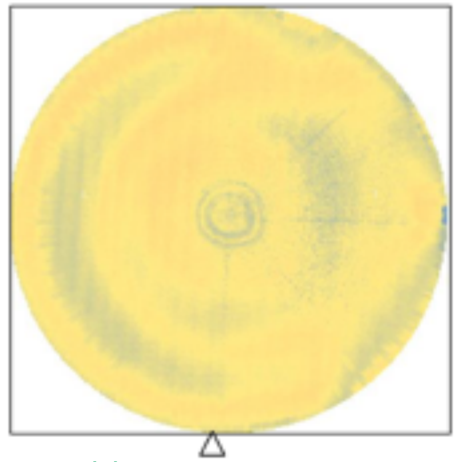
In addition, the surfaces of the post-reflowed wafers are free of extra solder and foreign materials as seen below.



Clean wafer surface after EA-based reflow

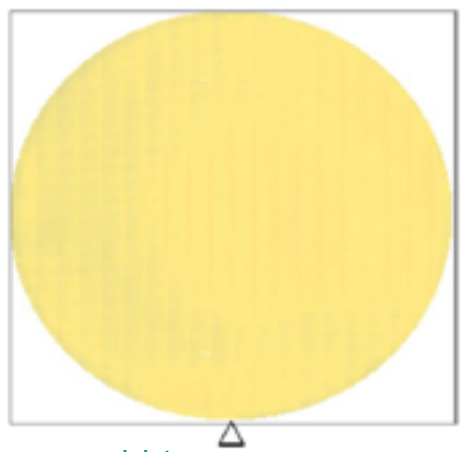
Standard quality inspection of the 200 mm mechanical wafer after EA-based reflow was performed by a leading OSAT company for bump height and bump diameter using AOI (Automated Optical Inspection) and demonstrated that the wafer processes with the EA technology was within their nominal specifications for their POR (Process of Record – flux with inert atmosphere). Ball shear and void inspection was also performed.

Spec	62 ± 15um
AVG BH	59.1um
Max BH	62.8um
Min BH	48.7um
BH Sigma	1.42um



Bump height distribution map and data

Spec	88um +20%/-10%
AVG BH	90.2um
Max BH	91.9um
Min BH	88.0um
BH Sigma	0.47um

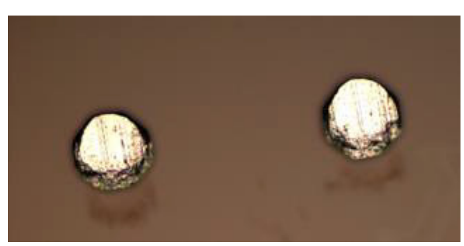


Bump diameter distribution map and data

All shear failures are within solder bumps and shear strengths well exceed the criterion (> 2 g/mil2).

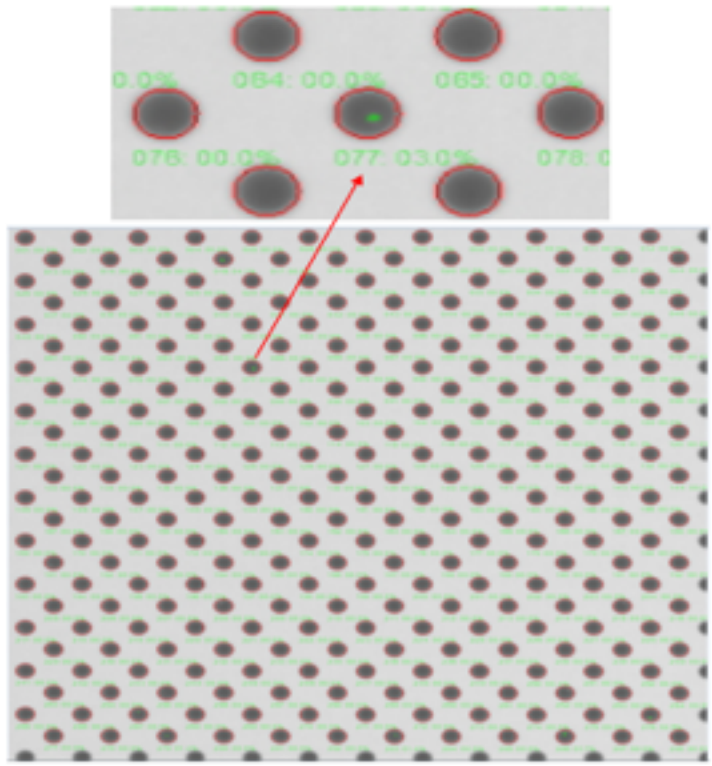
AVG	**Max**	**Min**
3.70	4.11	3.34

Spec >2 G/mil2



Bump shear failures and data

The x-ray image of a die on a reflowed wafer, which demonstrates that the number of bump voids (green) is quite low and the size of a typical void is 3% of the bump area, which is much below the specified upper limit (8% of the bump area).



X-ray image of a die showing low voids (green) and a tupical void size of 3% of the bump area.

We welcome the opportunity to show you how our latest breakthrough electron attachment technology can benefit your electronics packaging application.

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