



US 20080006294A1

(19) **United States**

(12) **Patent Application Publication**
SAXENA et al.

(10) **Pub. No.: US 2008/0006294 A1**

(43) **Pub. Date: Jan. 10, 2008**

(54) **SOLDER COOLING SYSTEM**

Publication Classification

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(51) **Int. Cl.**
C23G 1/00 (2006.01)
C23G 3/00 (2006.01)
C23G 5/00 (2006.01)
(52) **U.S. Cl.** **134/2; 134/82**

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(57) **ABSTRACT**

(21) Appl. No.: **11/766,847**

(22) Filed: **Jun. 22, 2007**

Related U.S. Application Data

(60) Provisional application No. 60/805,935, filed on Jun. 27, 2006.

A system for processing a substrate having solder bumps includes a first region having a first pressure and adapted to receive the substrate for heating; a second region having a second pressure greater than the first pressure and adapted to receive the substrate for cooling; a support member constructed and arranged for supporting the substrate in the first region and the second region, the support member adapted to conductively cool the substrate disposed thereon; and a spray assembly disposed in the second region for providing a cooling spray to the second region and the substrate.

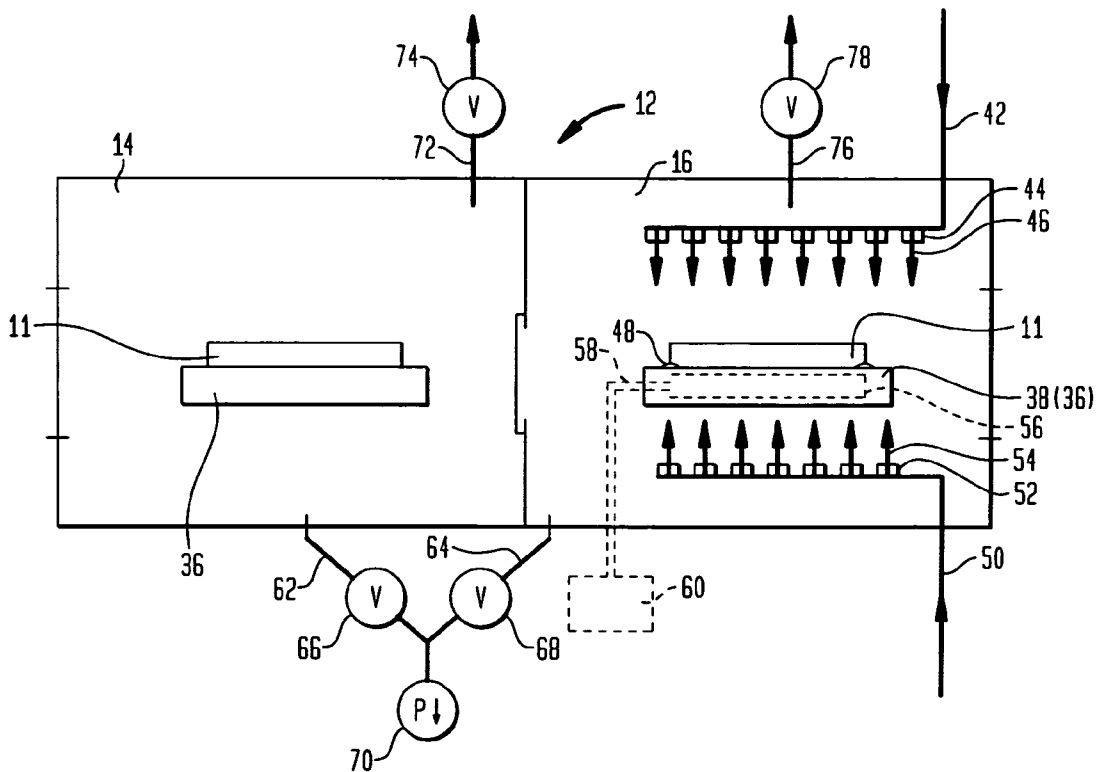
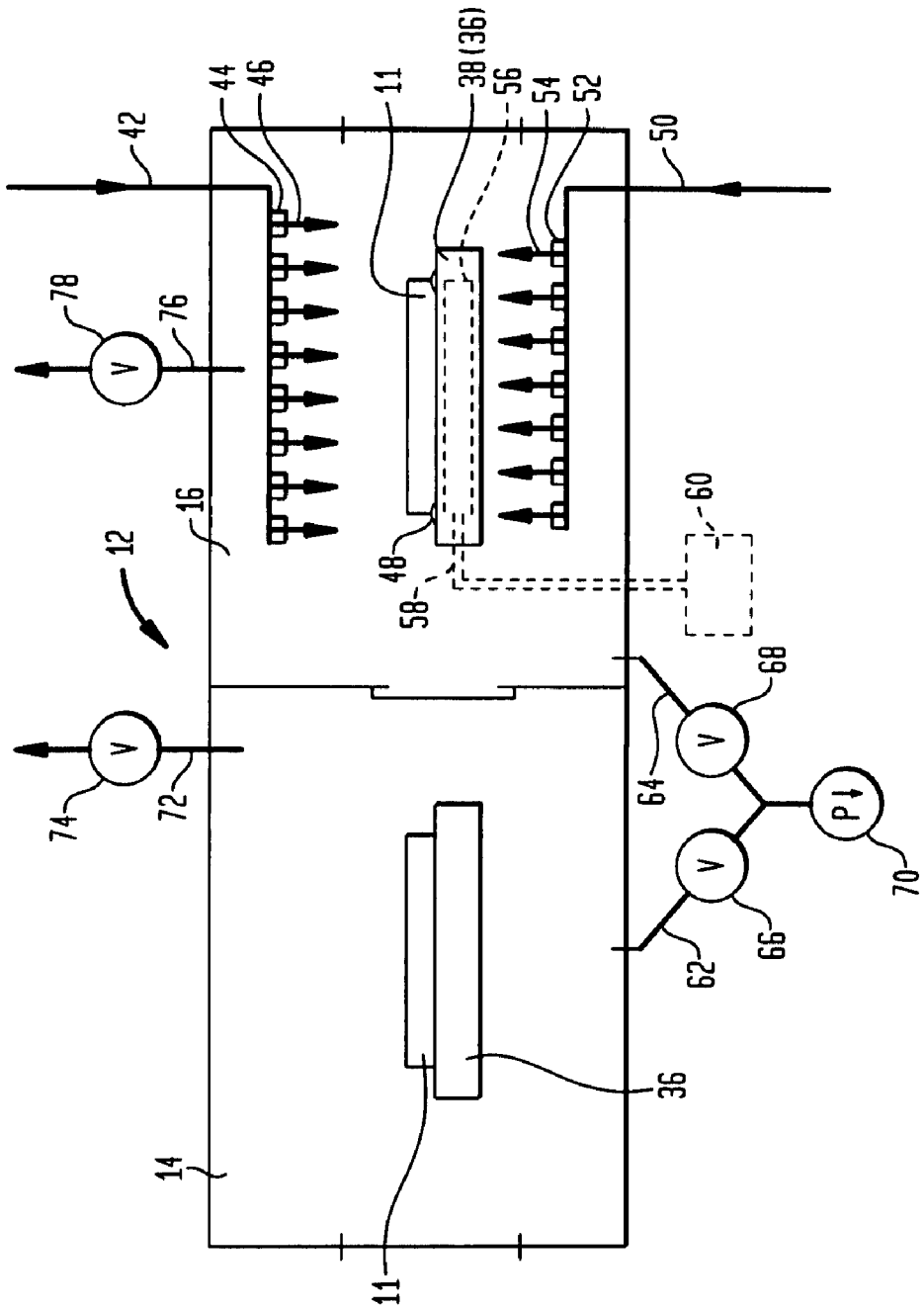


FIG. 2



SOLDER COOLING SYSTEM

BACKGROUND OF THE INVENTION

[0001] The present invention relates to cooling of for example solder bumps during formation of electronic devices and components.

[0002] To achieve flux-free soldering of solder bumps to the substrate, hydrogen plasmas can be used to reduce the metal oxides on the surface of the solder metal and the substrate before the two metal surfaces are heated sufficiently to create a molten liquid allowing joining of the solder bump to substrate. During hydrogen plasma reflow of solder balls on wafers, such as semiconductor wafers, it has been observed that such solder balls have a rough exterior surface, thereby contributing to their rough shape. Past attempts to improve solder ball shape have focused more on adjusting the plasma or hydrogen dosage to obtain a better surface finish, or by adjusting the cooling rate of the entire substrate.

[0003] Conventional cooling systems and machines typically consist of a single or dual chambers. In single chamber systems, cooling is achieved by having the substrate positioned on a carbon plate which is first heated electrically to cause reflow, and then cooled at a desired rate using a coolant flow to achieve the substrate cooling. The primary cooling mechanism in such case is conduction. In dual chamber systems, the cooling plate, such as a carbon plate, is kept at a specified cold temperature in the cooling chamber, and the substrate is moved to the cooling chamber from the first or reflow chamber (heating chamber). In some systems, the cooling chamber includes hydrogen or nitrogen, which may exist despite a vacuum, which is circulated to allow for cooling through convection as well.

[0004] While overall, substrates can be effectively cooled using such known techniques, the surface of the solder joints are often the last region to be cooled; thus causing uncontrolled and an unnecessarily slow cooling rate of the solder. Lead free solders have dendritic structure and metallurgy and accordingly, if the dendrites are permitted to cool too slowly, i.e. in an uncontrolled manner, the result is that the dendrites become coarse and therefore lead to surface roughness, the very condition to be avoided.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] For a more complete understanding of the present invention, reference may be had to the following drawings taken in conjunction with the detailed description, of which:

[0006] FIG. 1 shows the solder cooling system of the present invention.

[0007] FIG. 2 shows other features of the system of FIG. 1.

DESCRIPTION OF THE INVENTION

[0008] The present invention of solder bump cooling calls for use of a cooling medium selected from the group consisting of gas, liquid or mixed phase jets directed at the substrate to be used to improve cooling of the substrate. The forced convection cooling jets can be directed at the substrate from above and/or below the substrate. It has been discovered that the highest heat transfer rate for cooling can

be achieved using hydrogen at the highest possible velocity. For example, gas cooling jets provided at about 1 bar pressure at the jet nozzle tip will provide a gas velocity of a hundred meters per second (100 m/s), which can provide optimum results in terms of gas usage and cooling rate for hydrogen-only systems. Cooling of the substrate, such as a vertically positioned jet or a plurality of jets with respect to the substrate surface, will substantially reduce if not eliminate significant sideways or transverse jet forces that would displace the substrate with respect to solder processing. In that regard, means is employed to controllably position and maintain the substrate in place during cooling and subsequent processing of the substrate.

[0009] Hydrogen (H₂), nitrogen (N₂), carbon dioxide, (CO₂) or combinations of both may be used in the cooling gas jet. Nitrogen has lower heat transfer capability. Nitrogen is less expensive and safer to use than hydrogen and therefore, depending upon the solder processing being employed, nitrogen may be a more cost-effective alternative.

[0010] The number of gas jets—using N₂, H₂, CO₂ and/or combinations thereof—and their placement, and the liquid N₂ jets, can be optimized, i.e. using a select number of jets at a select distance from the substrate and having a particular flow rate and pattern, depending upon the substrate being processed.

[0011] The cooling gas jet can subsequently be vented from the solder processing assembly without significant cost or risk to operating personnel.

[0012] A higher pressure, greater than 100 Torr and up to 1 atmosphere, can be maintained during this operation of cooling (compared to pressures used for plasma reflow conditions of less than 100 Torr).

[0013] Referring to the FIG. 1, there is shown generally at 10 a solder cooling system of the present invention for processing a component such as a substrate 11 for example. The system 10 includes a housing 12 having a plasma reflow chamber 14 and a cooling chamber 16 with a passage 18 interconnecting the chambers 14, 16. The chamber 14 provides for a heating region and the chamber 16 provides for a cooling region in the housing 12. A door 20 at the passage 18 controls ingress and egress between and among the chambers 14, 16. The plasma chamber is provided with an inlet 22 and a door 24 in registration therewith. The cooling chamber 16 is provided with an outlet 26 and a door 28 in registration therewith. The doors 24, 28 are constructed and arranged to secure the respective one of the inlet 22 and outlet 26 as processing requires. The doors 20, 24, 28 are all constructed for airtight closure.

[0014] While the housing 12 is shown to contain both of the chambers 14, 16, an alternative embodiment would obviate the need for a single housing 12 by having separate housings for the plasma reflow chamber 14 and the cooling chamber 16, with the passage 18 interconnecting same through respective openings of the two separate housings.

[0015] In the plasma chamber 14, there is disposed a support member 36 such as a platform or plate, upon which the substrate 11 is supported to be subjected to plasma reflow 32 from a plasma generator 34. The door 24 of the plasma reflow chamber 14 effectively seals the chamber 14, while the door 20 seals the passage 18 between the plasma reflow chamber 14 and the cooling chamber 16. Such sealing of the

plasma reflow chamber **14** controls and restricts the atmosphere in the chamber **14** for purposes of safety of the operator and atmosphere control in the chamber **14**.

[0016] In one embodiment, the substrate **11** supported on a platform **36** or other type support member in the plasma reflow chamber **14** may be removed from the chamber **14** and then redeposited in the cooling chamber **16** on cooling platform **38** or other type of support member. In another embodiment, the support member **36** with the substrate **11** disposed thereon is moved from the plasma reflow chamber **14** through the passage **18** into the cooling chamber **16**, the door **20** being open to permit such transfer. Alternatively, the substrate **11** can be transferred by a conveying means **40**, such as a conveyor belt, from the plasma reflow chamber **14** to the cooling chamber **16**.

[0017] Regardless of whether the same support member **36** or the other support member **38** is used in the cooling chamber, the support member **36**, **38** may be a carbon-type plate and function as a heating/cooling block, depending upon the processing being used. The pressure in the cooling chamber **16** is at a higher pressure than the pressure in the plasma chamber **14** in order to facilitate a more effective and controlled cooling of the substrate **11** and to prevent the atmosphere in the plasma reflow **14** chamber from escaping through the passage **18** into the cooling chamber **16**. By way of example but not limitation, the cooling chamber **16** can be at a pressure of one atmosphere, while the plasma reflow chamber **14** is at a pressure of 10 Torr or less. (10 Torr approximately equal to 0.01 atmosphere).

[0018] The support member **36**, **38** is able to cool the substrate **11** by conduction, in view of the contact between the support member and the substrate. A cooling liquid or gas can be circulated through the support members **36**, **38**. The support members **36**, **38** may be constructed and arranged to receive a cooling flow of fluid such as water or cryogen gas, to facilitate the conductive cooling of the substrate **11**. The cooling by the support member **36**, **38** is discussed further with respect to FIG. 2.

[0019] A line **42** or a conduit is connected to a remote source of cooling medium, such as a gas or liquid of, for example nitrogen (N_2), Hydrogen (H_2), and or combinations of such and extends into the cooling chamber **16** for communication therewith. The line **42** delivers the gas and or liquid to the cooling chamber **16** where it is dispensed by at least one and where necessary a plurality of spray nozzles **44** disposed in the cooling chamber **16** to direct jet sprays **46** of the cooling medium to the substrate **11**. In effect, the substrate **11** in the cooling chamber **16** is cooled in an atmosphere at a higher pressure than the pressure in effect at the plasma reflow chamber **14**.

[0020] Cooling by the gas jets **46** occurs from above the substrate **11**. The jets **46** may be vertically positioned with respect to the substrate **11** such that the jets are perpendicular to the substrate.

[0021] The support members **36**, **38** may be constructed, either integrally or otherwise provided, with retaining members **48** such as for example fingers, flanges, ears, bosses or projections. The members **48** releasably retain the substrate **11** at a select position on the support members **36**, **38** to stabilize the substrate and retain same on the members **36**, **38** when subjected to the jets **46**. Only two members **48** are shown in FIGS. 1 and 2, due to the perspective of such drawing views.

[0022] There is shown in FIG. 2 other features of the present invention. A line **50** or conduit is connected to a remote source of cooling medium, such as a gas or liquid of, for example, nitrogen (N_2), hydrogen (H_2), and/or combinations of such and extends into the cooling chamber **16** for communication therewith. The line **50** delivers the gas and/or liquid to the cooling chamber **16** where it is dispensed by at least one and where necessary a plurality of spray nozzles **52** disposed in the cooling chamber **16** to direct jet sprays **54** of the cooling medium to the chamber **16** and the substrate **11**. In effect, the substrate **11** in the cooling chamber **16** is cooled in an atmosphere at a higher pressure than the pressure in effect at the plasma reflow chamber **14**.

[0023] As shown in FIG. 2, the support member **36**, **38** may be formed with a cavity **56** therein. The cavity **56** is constructed and arranged within the support member to receive a cooling medium, such as a gas or liquid to transfer by conduction the cooling effect of the medium to the substrate **11**. This cooling zone of the support member **36**, **38** enables same to function as a heat exchanger. A conduit or passageway **58** interconnects the cavity **56** to a remote source **60** of the cooling medium. The cooling medium can be any of water, other cooling fluids, and combinations thereof.

[0024] A vacuum may also be applied to chambers **14**, **16**, either individually or concurrent with each other. The vacuum may be applied simultaneously to the chambers **14**, **16** or in any sequence. The vacuum will assist with retaining the substrate **11** on the support member **36**, **38** in lieu of using retaining members **48**, or in combination therewith. The vacuum assembly consists of a conduit or passageway **62** in communication with the chamber **14**, and a conduit or passageway **64** in communication with the chamber **16**. Each of the conduits **62**, **64** are provided with a corresponding valve **66**, **68**, respectively. The passageways **62**, **64** are connected to a pump **70** which is used to draw the vacuum at a select one or both of the chambers **14**, **16**, simultaneously or in any sequence.

[0025] Exhaust line **72**, with corresponding valve **74**, is connected to chamber **14**, and exhaust line **76**, with corresponding valve **74**, is connected to chamber **16**. At least one or both of the exhaust lines **72**, **76** should be used to exhaust gas and the atmosphere as necessary from the chambers **14**, **16**.

[0026] Any combination of the features shown in FIG. 2 can be used with each other, as well as the features shown in FIG. 1 for operation in the present invention.

[0027] In summary, an embodiment of the system **10** includes a plasma reflow or heating chamber **14** and a cooling chamber **16** interconnected by a passageway **18** having a movable door **20**; the cooling chamber **16** being at a higher pressure than the plasma reflow chamber **14**; the support members **36**, **38** for the substrate being able to cool the substrate **11** by conduction; and a gas and or liquid spray of cooling jets **46** of nitrogen, hydrogen, carbon dioxide or combinations thereof is provided to the cooling chamber **16** and hence the substrate **11**.

[0028] The system is also used to cool and facilitate a flip chip attachment connection, wherein a circuit board with solder bumps thereon is attached to another circuit board or wafer having electronic connections in registration with the solder bumps for contact and connection therewith as necessary.

[0029] The system substantially reduces the amount of time necessary to cool the solder, thereby increasing cost-effectiveness of the solder process and unit yield.

[0030] It will be understood that the embodiments described herein are merely exemplary and that a person skilled in the art may make many variations and modifications without departing from the spirit and scope of the invention. All such variations and modifications are intended to be included within the scope of the invention as described herein. The embodiments described above may be not only in the alternative, but may be combined.

What is claimed is:

1. A system for processing a substrate having solder bumps comprising:

a first region having a first pressure and adapted to receive the substrate for heating;

a second region having a second pressure greater than the first pressure and adapted to receive the substrate for cooling;

support means constructed and arranged for supporting the substrate in the first region and the second region, the support means adapted to conductively cool the substrate disposed thereon; and

spray means disposed in the second region for providing a spray of a cooling medium to the second region and the substrate.

2. The system according to claim 1, further comprising exhaust means in communication with at least one of the first region and the second region.

3. The system according to claim 1, wherein the support means comprises a longitudinal member having a cooling zone for conductively cooling the substrate.

4. The system according to claim 3, wherein the cooling zone comprises a cavity formed in the longitudinal member for receiving a cooling medium selected from water, other fluids and combination thereof.

5. The system according to claim 1, further comprising: a first chamber for containing the first region and having a sealable inlet associated therewith; a second chamber for containing the second region and having a sealable outlet associated therewith; and a sealable passageway interconnecting the first and second chambers and through which the substrate is transferred between the first and second chambers.

6. The system according to claim 1, wherein the spray means is disposed above the support means.

7. The system according to claim 6, wherein the spray means comprises a plurality of jet spray nozzles.

8. The system according to claim 1, wherein the cooling medium is selected from carbon dioxide, nitrogen, hydrogen, and combinations thereof.

9. The system according to claim 1, wherein the support means comprises retaining members for releasably retaining the substrate positioned on the support means during exposure to the spray means.

10. The system according to claim 9, wherein the retaining means comprises projections constructed and arranged to releasably receive and position the substrate for being subjected to the spray means.

11. The system according to claim 1, wherein the second pressure is from 100 Torr up to 1 atmosphere.

12. The system according to claim 5, further comprising a passageway door constructed and arranged at the first chamber and the second chamber to control movement of the substrate between the first and second chambers and to segregate an atmosphere of the first region from an atmosphere of the second region.

13. The system according to claim 1, further comprising a gas conduit having one end in communication with the spray means and another end in communication with a source of the cooling medium.

14. The system according to claim 1, further comprising a pressure differential assembly in communication with the first and second regions for providing a vacuum therein for facilitating retaining the substrate on the support means.

15. The system according to claim 7, wherein the plurality of jet spray nozzles are disposed above and below the support means.

16. A system for processing a substrate having solder bumps comprising:

a first region having a first pressure and adapted to receive the substrate for heating;

a second region having a second pressure greater than the first pressure and adapted to receive the substrate for cooling;

cooling means constructed and arranged for cooling the substrate by conduction and spray means for providing a spray of a cooling medium to the second region and the substrate.

17. A method of processing a substrate having solder bumps, comprising:

heating the substrate at a first pressure; and

cooling the substrate at a second pressure greater than the first pressure, the cooling by conduction and by convection cooling jets.

18. The method according to claim 17, wherein the convection cooling jets are provided from above the substrate.

19. The method according to claim 17, wherein the convection cooling jets are provided from above and below the substrate.

20. The method according to claim 17, further comprising providing a pressure differential proximate the substrate to stabilize the substrate during exposure to the convection cooling jets.

21. The method according to claim 17, further comprising exhausting atmosphere proximate the substrate after the heating and cooling steps.

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