

METHOD AND APPARATUS FOR REMOVING MATERIAL FROM A SUBSTRATE SURFACE

The present invention relates to methods and apparatus for removing material from a
5 substrate surface and in particular to methods and apparatus for the cleaning or
etching of surfaces of electronics components and components related to the
manufacture thereof. However, as will be understood by the skilled addressee, the
invention is not limited to such uses.

10 Failure of electronics circuits due to problems experienced during manufacture is
common. While there may be several sources of problems, a typical problem is
commonly attributed to the existence of material such as residual surface organic
contaminants (eg dirt, finger prints, etc), or residual material from different
manufacturing stages, such as solvent residue and epoxy bleed-outs.

15 Integrated circuits (ICs) are manufactured in a multi-layered process of moulding and
bonding of component parts. Bonding typically includes wire bonding, where two
adjacent IC components are bonded by fusing wires between mounting pads of the
adjacent components. Problems can occur in the bonding process if the mounting
20 pads are not clean, resulting in a non-integral or weak bond, and thus a defective IC.

One proposed solution for improving the wire bonding is cleaning the mounting pads
prior to the bonding process. Two cleaning methods are known: capacitive cleaning
using a radio frequency (RF) power source; and ion cleaning using an ion beam in an
25 Ar/O₂ environment at 1500eV. RF cleaning is achieved by applying RF to an
electrode in a vacuum chamber which also contains a component requiring surface
cleaning. A source of Ar is introduced into the chamber and a plasma is formed.
The plasma ions chemically react with the material on the surface of the component.
There are several problems associated with RF cleaning. Firstly, it is only possible to
30 control the power input to an RF cleaning system. Secondly, there are significant
health and safety requirements associated with operating high powered RF
equipment, as well as ensuring any RF leakage doesn't affect nearby people and
equipment. Thirdly, RF generators require complex matching networks to allow
greater flexibility in cleaning regimes. Different matching networks are required for

different applications or different operating pressures. Both RF and ion cleaning may also damage the components being cleaned by voltage discharge or arc formation.

Other problems may arise due to lack of cleanliness of parts related to the

- 5 manufacture of an IC. For example, moulds used during the moulding process may have residual epoxy films which eventually need to be cleaned from the mould.

Current cleaning processes for moulds include the use of wire brushes or chemical baths. However wire bath cleaning damages the mould and shortens its lifecycle, and chemical baths are relatively slow. One proposed method for extending the
10 mould life is to coat the mould surface with 3-10 μ m of CrN, or "hard chrome", to increase resistance to damage from wire brush cleaning. While extending the life of the mould by increasing resistance to wear, such coatings have the disadvantage of reducing the accuracy of the intended mould dimensions.

- 15 It is an object of at least one of the embodiments of the present invention to ameliorate or overcome at least one of the above problems associated with the prior art, or at least to provide a suitable alternative thereto.

According to a first aspect of the present invention there is provided a method of
20 removing material from a substrate surface comprising the steps of:

providing a plasma using a power source; and
contacting the substrate surface with one or more of ions, atoms or free radicals of the plasma,
wherein the power source is supplied as a variable voltage.

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According to a second aspect of the present invention there is provided a method of removing material from a substrate surface comprising the steps of:

placing the substrate in an evacuable chamber having an electrode therein;
providing a variable voltage to the electrode to provide a plasma in the
30 chamber between the electrode and the substrate; and
contacting the substrate surface with one or more of ions, atoms or free radicals of the plasma to remove at least a portion of the material on the surface.

Advantageously, by supplying the power source as a variable voltage, the problems of arcing are prevented, and therefore the substrate is not unnecessarily damaged.

Preferably, the variable voltage is a pulsed voltage, and more preferably the voltage
5 is pulsed in consecutive 3-30kHz periods. By providing the voltage in a pulse, a plasma can be formed without providing an arc and without unnecessarily heating the environment in which the material removing method is provided.

Preferably the variable voltage is pulsed from 0V to a voltage between -300V and
10 -1000V, and more preferably from 0V to a voltage between -380V and -600V. Also preferably, the voltage is applied in a 3 to 20 μ s pulse. Preferably, the pulse is provided once per 3-30kHz period. Alternatively, the pulse may be provided more than once per period. For example, a pair of 3 μ s pulses, 5 μ s apart, may be provided per 3-30kHz period.

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Preferably there are two opposed electrodes, wherein the power source is supplied to one of the electrodes and the other electrode is floating, and wherein the substrate is on the floating electrode. Alternatively, the other electrode is grounded, or the other electrode is either grounded, floating or of generally equal potential to the one
20 electrode, and the substrate is on the one electrode.

Preferably, the plasma is provided in an O₂ environment, and more preferably the plasma is provided in an O₂/CF₄ environment.

25 Preferably the plasma is provided in a chamber evacuated to about 80 to 1500mTorr.

Alternatively two substrates are provided on respective electrodes. In another alternative arrangement there are a plurality of spaced electrodes, at least some of which respectively support a respective one of a plurality of said substrates. In
30 another alternative arrangement, at least one of the electrodes supports at least two said substrates on one or both of its opposing sides.

Preferably the substrate is one of an IC, IC component, IC mould, die, wafer, ball grid array, IC package, leadframe, PCB, microvia, disk holder, reader arm, or hard disk. Also preferably, the material is one of an organic substance, organic contaminant, solvent residue or epoxy resin.

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According to a third aspect of the present invention there is provided an apparatus for removing material from a substrate surface comprising:

- a vacuum chamber;
- an electrode in the vacuum chamber; and
- 10 a power source for providing a variable voltage to the electrode, such that a plasma is formable within the chamber and one or more of ions, atoms or free radicals of the plasma contact the substrate surface,
- wherein the power source is supplied as a variable voltage.

- 15 Preferably the variable voltage is provided as a pulsed voltage.

- Preferably there are two opposed electrodes, wherein the power source is supplied to one of the electrodes and the other electrode is floating, and wherein the substrate is on the floating electrode. Alternatively, the other electrode is grounded, or, the
- 20 other electrode is either grounded, floating or of generally equal potential to the one electrode, and the substrate is on the one electrode.

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Preferably the chamber comprises an opening for hermetic abutment with a surface of a conveyor, the substrate being positioned on the conveyor.

For the purposes of the specification, the terms "cleaning" and "etching" when used in the specification are to be considered the same as "material removal" or "removal of material", also as used in the specification.

- 30 Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a simplified schematic view of an apparatus according to the present invention;

Figure 2 is a graph representing an example of a pulsed voltage used in the present invention;

- 5 Figures 3 and 4 are simplified schematic views of alternative embodiments of apparatus according to the present invention; and

10 Figures 5a and 5b are simplified schematic views of another alternative embodiment of apparatus according to the present invention, with the chamber in respective retracted and in use positions.

Referring to Figure 1, a preferred embodiment of the invention is a method and apparatus for removing material from a substrate surface. While not intended to be an exhaustive list, examples of the substrate include electrical components, such as
15 an IC, IC package, ball grid array, or a component of an IC or IC package. Such components may include wafers, chips, dies or moulded parts. Another example of the type of substrate whose surface may be cleaned by the invention includes the surfaces of moulds described above in relation to the prior art, and as used in IC package manufacture, or media holders for holding hard disks, etc, during
20 manufacturing coating processes.

A preferred embodiment of the apparatus comprises a vacuum chamber 10 and an electrode 12a therein connected to a power source in the form of a DC power supply 14. A second electrode 12b is provided in a floating configuration. An inlet port 16 is
25 provided on the chamber 10 for the introduction of gas into the chamber. An outlet port 18 is also provided on the chamber 10 for connection to an external vacuum pump. A controller (not shown) is provided in communication with the power supply 14 to control the power supply's output, to provide a variable voltage, in the form of a pulsed negative voltage supply as illustrate in Figure 2, which is described below in
30 more detail. In alternative arrangements, any power configuration can be used to provide the variable voltage. For example, a rectified AC power supply or a monostable multivibrator circuit may be used as or as part of the controller.

In use, a substrate 22 is positioned in the chamber 10 on the second electrode 12b with a surface 24 to be cleaned facing toward the electrode 12. Material 26 to be cleaned from the surface 24, illustrated schematically in the relevant Figures, may include general organic substances, surface organic contaminants, having C-H and
5 C-C bonds, solvent residue or epoxy resin.

In this embodiment, the distance between the electrodes 12a and 12b is about 5 mm, but in other embodiments may range from 3 to 100mm, depending on the substrate to be cleaned, and the cleaning regime.

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The chamber 10 is then evacuated via outlet port 18 to a pressure of about 10-50mTorr, and gas introduced into the chamber 10 via inlet port 16 to increase the pressure to about 150mTorr, though in alternative embodiments the increased pressure may be in the range of 80 to 1500mTorr. The introduced gas is typically a
15 mix of $O_2:CF_4$ at a ratio of 4:1, where the CF_4 acts as a catalyst to improve the formation of a plasma. In alternative embodiments, the ratio may be different, or CF_4 may not be present. In yet another embodiment, the gas may be Ar.

In this embodiment, the gas is continually passed through the chamber 10 during the
20 cleaning process at a flow rate of 200sccm, though in alternative embodiments the flow rate may range from 50 to 1000sccm. Aside from keeping a relatively consistent quality of gas and therefore plasma in the chamber 10, the flow of gas also acts to sweep or flush out any material 26 residue removed during the cleaning process from the substrate surface 24.

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The controller then activates the power supply 14 to provide a pulsed voltage to the electrode 12. Figure 2 illustrates an example of a pulsed voltage waveform for use with this embodiment, where -800V is pulsed once for 5 μ s during 10kHz periods. The pulsed voltage builds up a capacitance-type charge between the electrodes 12a
30 and 12b and the substrate surface 24, and a plasma is formed. Atoms and radical species of the plasma contact the substrate surface and chemically react with the material 26 thereon. The chemical reaction breaks down the material 26. For example, plasma atom and radical species formed from the O_2 gas present in the chamber during plasma formation can contact and break, for example, C-C and C-H

bonds of the unwanted material 26. Also, ions of the plasma bombard the substrate surface 24 further resulting in removal of unwanted material 26 from the substrate surface 24.

- 5 It is important to reduce the risk of arc discharge between the electrodes 12a and 12b and the substrate 22, as discharge may damage the surface 24 of the substrate 22 on the second electrode 12b and render the substrate 22 unusable. On the other hand, if the voltage is too low, either the plasma will not form, or will not provide species of sufficient energy to remove the material 26 from the substrate surface.
- 10 The use of a pulsed voltage is therefore advantageous in that a plasma with ions of sufficient energy for cleaning may be formed, while the risk of discharge is reduced. Furthermore, since the risk of discharge is reduced, the electrodes can be positioned closer together, resulting in more efficient cleaning, and more efficient use of space in the chamber 10. Furthermore, unlike prior art RF cleaning where only power can
- 15 be modified to control the process, in the present invention the parameters of voltage, frequency and pulse width can be independently controlled to optimise the cleaning process.

In the embodiment described above, the second electrode 12b is floating. By

20 floating the electrode, risk of discharge between the electrodes 12a and 12b damaging the substrate surface 24 is relatively reduced. However, the cleaning effectiveness of the plasma is also relatively reduced. For this reason, this embodiment is suited to cleaning the surface of more sensitive components, as described above. In an alternative embodiment, the substrate is still placed on the

25 second electrode, but the second electrode is grounded. By grounding the second electrode, discharge risk is increased, however voltage magnitude and pulsing parameters may be adjusted for relatively more effective and more aggressive cleaning. Hence, this embodiment is more suited to less sensitive components than would be cleaned using the embodiment described above in detail. In other

30 alternative embodiments which provide a more aggressive cleaning regime than those embodiments previously described, the substrate is positioned on the first electrode 12a, and the second electrode 12b is either floating or grounded. In yet another alternative embodiment, the substrate is on the first electrode 12a, and the second electrode 12b has a generally equal negative potential to the first electrode.

This embodiment may be optimised for the cleaning of, for example, IC moulds, media holders or associated tools. In this embodiment, the gap between component and opposed electrode can be as small as 3mm to 8mm, which allows for more uniform plasma distribution. For example, it is possible in this embodiment to remove
5 20µm -100µm of epoxy moulding compound from a mould surface in less than 10 minutes, compared with 1 hour for chemically based prior art methods, or to remove 3nm of diamond-like carbon (DLC) coating from a media holder in less than 10 seconds.

10 Figures 3 and 4 illustrate alternative embodiments of the invention where like reference numerals denote like parts, and where multiple substrates and/or electrodes are employed. In Figure 3, two substrates 22a and 22b are placed in the chamber 10 on respective grounded electrodes 12b. They are positioned such that they face an electrode 12a therebetween, the electrode 12a being negatively biased
15 by having provided thereto a pulsed negative voltage, as described in relation to previous embodiments. Figure 4 illustrates an embodiment comprising two such negatively biased electrodes 12a and three floating electrodes 12b with substrates 22a-d positioned thereon. The cleaning method of both these embodiments is performed as described above in relation to the embodiment illustrated in Figure 1.

20 IC packages are manufactured in several stages and may be manufactured in batched arrays or conveyor lines. One or several dies are attached to a package substrate, such as a wafer, printed circuit board (PCB), leadframe or flex circuit board. The die is then wire bonded to the package substrate by attaching wire
25 strands between respective corresponding mounting pads on the package substrate and the die. An epoxy layer is then moulded over the die, wire bonds and package substrate to form the IC package. A secondary layer may also be attached to the package and wire bonded thereto via secondary wire bonding mounting pads.

30 Preferred embodiments of the invention may be used to clean:

- the package substrate prior to attaching the die;

- the mounting pads prior to wire bonding (for example in a chamber of pressure 100-200mTorr with only O₂ present as introduced gas and with the substrate positioned on a floating electrode);
- 5 • the package after wire bonding and prior to moulding, to improve mould adhesion (for example in a chamber of pressure of about 100mTorr with only O₂ present as introduced gas and with the substrate positioned on a floating electrode);
- 10 • the moulded package prior to attaching the secondary layer to clean epoxy bleed from the moulding process which may be covering the secondary wire bonding pads (for example in a chamber of pressure 700-800mTorr with 9:1 of O₂:CF₄ present as introduced gas and with the substrate positioned on a floating electrode); and
- 15 • the mould itself either after one moulding process or more typically after 600-1000 uses (for example in a chamber of pressure of about 200mTorr with 9:1 of O₂:CF₄ present as introduced gas and with the substrate positioned on one of two opposed electrodes, where both electrodes are provided with a pulsed negative voltage power supply).

20 Figures 5a and 5b illustrate another alternative embodiment of the invention where like reference numerals denote like parts. This embodiment is configured for in-line substrate surface cleaning during manufacture of IC packages, the process of which is described immediately above. In this embodiment, the chamber 10a, has an open side 28 which is sealed when the chamber 10a comes into contact with a conveyor 30. A leading edge 32 of the chamber 10a may be lined by a seal, such as a silicon or rubber seal, to aid in producing an hermetic seal with the conveyor. In this
25 embodiment, the vacuum pump, gas and power supply (not shown) would typically be positioned on the outside surface of a top sidewall 34 of the chamber 10a.

30 The conveyor 30 carries substrates 22 to be cleaned. Once the substrates are in position to be cleaned, as illustrated in Figure 5b, the chamber 10 is lowered, either mechanically, hydraulically or pneumatically, over the substrates 22 to form an evacuable vacuum chamber with the conveyor 30. The cleaning process then

proceeds as described above, but without the use of a second electrode, and thus with the substrate 22 electrically floating upon the conveyor 30.

- 5 This apparatus can be used for cleaning after any or each stage of the IC package manufacturing process described above. The apparatus may either be built into new manufacturing equipment or, due to its small size, retrofitted for use with existing equipment. An example of dimensions of the chamber 10a are as follows: 80mm (depth) x 250mm (width) x 20mm (height). The same chamber 10a design can be used to clean in-line, for example, IC package moulds. For such an application,
- 10 since the mould cavities would be facing relatively downwardly, the chamber's 10a open face would face relatively upwardly, and be configured to be moved upwardly to form the vacuum chamber with the mould and about the mould surface to be cleaned.
- 15 The embodiment of Figures 5a and 5b shows two substrates for cleaning. As will be apparent, in alternative embodiments, the chamber 10a can be adapted to accommodate fewer or more than two substrates for simultaneous cleaning.

20 In another alternative embodiment, the power supply may be connected to the substrate, and an electrode positioned in the chamber opposed to the substrate surface, the electrode being either grounded or floating.

As will be understood by the skilled addressee, the present invention has several advantages over the prior art. For example:

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- the risk of forming an arc is reduced;
 - operating temperature is kept to a minimum, thus reducing the risk of heat damage to the component;
 - the system is less complicated compared with prior art RF cleaning systems, since no matching network is required, and there are no similar concerns with
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- regard to health, safety and effect on neighbouring equipment;
 - there is greater and easier parameter control compared with RF systems;
 - when used for cleaning moulds, the working life of the mould is increased, due to less damage to the mould, and the quality of moulded components is

improved, since a thinner hard nickel protective coating can be used on the mould surface;

- cleaning times are relatively faster than those of the prior art;
- operating costs are lower compared to known cleaning systems; and
- 5 • due to low operating costs and simplicity of operation, the invention can be used at more stages during the manufacture of IC packages, thus increasing integral package production yield.

10 While the preferred embodiments have been described mainly with reference to IC components and their manufacture, it will be understood that the invention is not limited to the cleaning of such products. For example, the invention may be used for cleaning hard disk surfaces; magnetic reader arms of disk drives, prior to coating by protective or other layers; microvias; sidewalls of PCB drill holes, and so on. Furthermore, the invention may be used to modify component surfaces, such as
15 polyimide surfaces to improve their adhesion properties.

While the invention has been described in reference to its preferred embodiments, it is to be understood that the words which have been used are words of description rather than limitation and that changes may be made to the invention without
20 departing from its scope as defined by the appended claims.

Hence, methods and apparatus for removing material from a substrate, such as an IC component, are disclosed. The methods include creating a plasma in an evacuable chamber, by providing a power source to an electrode in the chamber,
25 and contacting the substrate surface with at least one of ions, atoms and free radicals of the plasma. The power source, preferably DC, is supplied to the electrode as a variable, and preferably a pulsed voltage to prevent arcing.

CLAIMS:

- 1 A method of removing material from a substrate surface comprising the steps
of:
- 5 providing a plasma using a power source; and
contacting the substrate surface with one or more of ions, atoms or free
radicals of the plasma,
wherein the power source is supplied as a variable voltage.
- 10 2 A method of removing material from a substrate surface comprising the steps
of:
placing the substrate in an evacuable chamber having an electrode therein;
providing a variable voltage to the electrode to provide a plasma in the
chamber between the electrode and the substrate; and
- 15 contacting the substrate surface with one or more of ions, atoms or free
radicals of the plasma to remove at least a portion of the material on the surface.
- 3 The method of claim 1 or 2 wherein the variable voltage is a pulsed voltage.
- 20 4 The method of any preceding claim wherein the voltage is pulsed once per
consecutive 3-30kHz periods.
- 5 The method of any preceding claim wherein the variable voltage is pulsed
from 0V to a voltage between -300V and -1000V.
- 25 6 The method of any preceding claim wherein the variable voltage is pulsed
from 0V to a voltage between -380V and -600V.
- 7 The method of any preceding claim wherein the voltage is applied in a 3 to
30 20 μ s pulse.
- 8 The method of any preceding claim comprising two opposed electrodes,
wherein the power source is supplied to one of the electrodes and the other electrode
is floating, and wherein the substrate is on the floating electrode.

- 9 The method of any of claims 1 to 7 comprising two opposed electrodes,
wherein the power source is supplied to one of the electrodes and the other electrode
is grounded, and wherein the substrate is on the grounded electrode.
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- 10 The method of any of claims 1 to 7 comprising two opposed electrodes,
wherein the power source is supplied to one of the electrodes, and the other
electrode is floating, wherein the substrate is on said one of the electrodes.
- 10 11 The method of any of claims 1 to 7 comprising two opposed electrodes,
wherein the power source is supplied to one of the electrodes, and the other
electrode is grounded, wherein the substrate is on said one of the electrodes.
- 12 The method of any of claims 1 to 7 comprising two opposed electrodes,
15 wherein the power source is supplied to both of the electrodes, and the other
electrode is floating, wherein the substrate is on the one of the electrodes.
- 13 The method of any preceding claim wherein the plasma is provided in an O₂
environment.
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- 14 The method of any of claims 1 to 12 wherein the plasma is provided in an
O₂/CF₄ environment.
- 15 The method of any preceding claim wherein the plasma is provided in a
25 chamber evacuated to about 80 to 1500mTorr.
- 16 The method of any of claims 8 to 15 comprising two said substrates located on
respective electrodes.
- 30 17 The method of any of claims 8 to 15 comprising a plurality of spaced
electrodes, at least some of which respectively support a respective one of a plurality
of said substrates.

18 The method of claim 18 wherein at least one of the electrodes supports at least two said substrates on one or both of its opposing sides.

19 The method of any preceding claim wherein the substrate is one of an IC, IC
5 component, IC mould, die, wafer, ball grid array, IC package, leadframe, PCB, microvia, disk holder, reader arm, or hard disk.

20 The method of any preceding claim wherein the material is one of an organic substance, organic contaminant, solvent residue or epoxy resin.

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21 Apparatus for removing material from a substrate surface comprising:
a vacuum chamber;
an electrode in the vacuum chamber; and
a power source for providing a variable voltage to the electrode, such that a
15 plasma is formable within the chamber and one or more of ions, atoms or free radicals of the plasma contact the substrate surface,
wherein the power source is supplied as a variable voltage.

22 The apparatus of claim 21 wherein the variable voltage is configured to be
20 provided as a pulsed voltage.

23 The apparatus of claim 21 or 22 comprising two opposed electrodes, wherein the power source is supplied to one of the electrodes and the other electrode is floating, and wherein the substrate is on the floating electrode.

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24 The apparatus of claim 21 or 22 comprising two opposed electrodes, wherein the power source is supplied to one of the electrodes and the other electrode is grounded, and wherein the substrate is on the grounded electrode.

30 25 The apparatus of claim 21 or 22 comprising two opposed electrodes, wherein the power source is supplied to one of the electrodes, and the other electrode is floating, wherein the substrate is on said one of the electrodes.

- 26 The apparatus of claim 21 or 22 comprising two opposed electrodes, wherein the power source is supplied to one of the electrodes, and the other electrode is grounded, wherein the substrate is on said one of the electrodes.
- 5 27 The apparatus of claim 21 or 22 comprising two opposed electrodes, wherein the power source is supplied to both of the electrodes, and the other electrode is floating, wherein the substrate is on the one of the electrodes.
- 10 28 The apparatus of any of claims 21 to 27 comprising a plurality of spaced electrodes, at least some of which respectively support a respective one of a plurality of said substrates.
- 15 29 The apparatus of any of claims 21 to 28 wherein the chamber comprises an opening adapted for hermetic abutment with a surface of a conveyor, the substrate being positioned on the conveyor.
- 20 30 The apparatus of any of claims 21 to 29 wherein the substrate is one of an IC, IC component, IC mould, die, wafer, ball grid array, IC package, leadframe, PCB, microvia, disk holder, reader arm, or hard disk.
- 31 The apparatus of any of claims 21 to 30 wherein the material is one of an organic substance, organic contaminant, solvent residue or epoxy resin.
- 25 32 A method or apparatus substantially as herein described with reference to the accompanying drawings.