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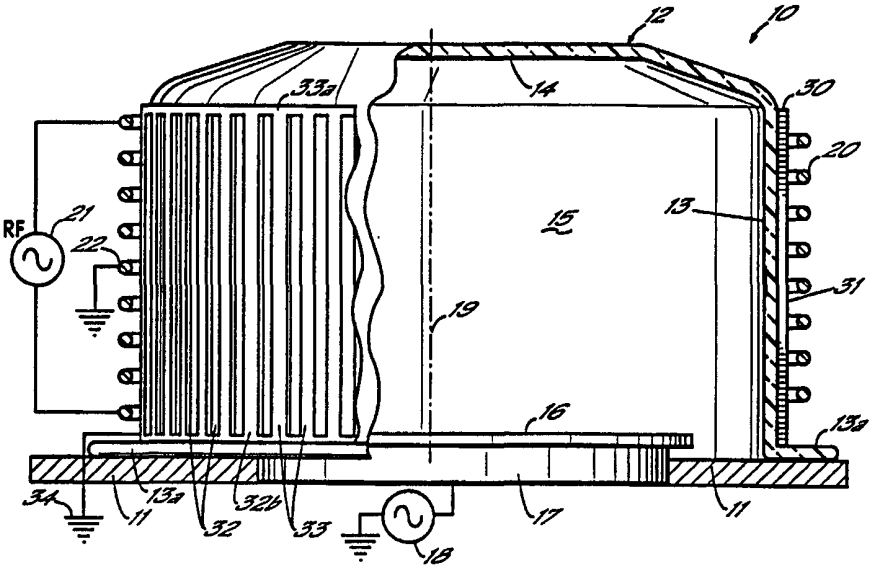
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(57) Abstract

A plasma etch apparatus (10) includes a vacuum chamber (15) surrounded by a cylindrical dielectric wall (13). A coil (20) surrounds the wall and is energized with medium frequency RF energy inductively coupled into the chamber to energize a plasma to etch a semiconductor wafer (16) on a support (17). A generally cylindrical Faraday shield (30) contacts the outside of the wall between the wall and the coil and has a plurality of axially oriented slits (32) closely spaced around the shield and extending less than the height of the shield. One slit (31) extends the full height of the shield and interrupts an otherwise continuous conductive path around the circumference of the chamber with a gap about 1/8 inch wide, so that, upon initial energization of the coil, a momentary peak–to–peak RF voltage across the gap generates an electric field in the chamber which ignites the plasma.

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APPARATUS AND METHOD FOR ELECTROSTATICALLY SHIELDING AN INDUCTIVELY COUPLED RF PLASMA SOURCE AND FACILITATING IGNITION OF A PLASMA

This invention relates to plasma processing and particularly to plasma etching with an inductively coupled plasma.

Background of the Invention:

In semiconductor wafer processing, inductively coupled plasmas (ICPs) have been used with success in plasma processing, particularly plasma etching, of semiconductor wafer substrates. One processing apparatus for etching semiconductor wafers with an ICP is disclosed in Bayer et al. U.S. Patent No. 5,569,363, hereby expressly incorporated by reference herein. In the Bayer et al. patent, RF energy is applied to a coil that surrounds a vacuum chamber outside of a chamber wall made of quartz. The coil generates a magnetic field within the chamber which excites electrons and forms a plasma. While the field is largely inductively coupled, the development of a high peak to peak voltage across the coil causes some degree of capacitive coupling of energy into the chamber. Such voltage has, in situations, developed a sheath of 900 to 1000 volts, for example, which imparts substantial energy to ions in the plasma. Such energy is enough to cause an undesirable degree of sputtering of the inside of the chamber wall and the sheath reduces the useful volume of the plasma.

It has been proposed to add a metal Faraday shield around the outside of the chamber, between the coil and the chamber wall. The proposed shield is provided with slits that extend axially but which leave a complete circumferential band around each edge of the shield. The shield is grounded to prevent capacitive coupling of voltage into the chamber while the slits prevent the inductive shielding of magnetic energy that is required to energize the plasma. Such a proposed shield, unfortunately, has the effect of preventing initial ignition of the plasma by the coil, requiring a separate electrode or discharge element to start the plasma.

There is a need, therefore, to provide for the shielding of a chamber from capacitive coupling effects when a coil is employed to inductively couple energy into a chamber, and to do so without interfering with plasma ignition.

Summary of the Invention:

An objective of the present invention is to provide shielding of a chamber from capacitive coupling. A particular objective of the invention is to provide efficient shielding from an RF coil that is provided around the chamber to inductively couple RF energy into plasma within the chamber. It is a further objective of the present invention to provide shielding that prevents capacitive coupling between a chamber and an exterior coil while facilitating plasma ignition.

In accordance with the principles of the present invention, a plasma processing chamber, particularly an etching chamber, is provided having an external loop-shaped RF inductor. The inductor is preferably a helical coil for inductively coupling RF energy into the chamber to form a plasma within the

chamber. In addition, a Faraday shield is provided outside of the chamber wall between the wall and the inductor. The shield is grounded so as to provide effective shielding of capacitive coupling of voltage from the coil to the plasma within the chamber and is slitted to allow inductive coupling of the RF energy into the chamber. The ground connection is localized to a limited section of the inductor so as to allow a peak-to-peak voltage to develop across the gap when the RF current is initially induced into the shield from the inductor.

In the preferred embodiment of the invention, a cylindrical shield is positioned against the outside of a quartz chamber wall between the wall and a helical coil that encircles the wall and is spaced slightly from the wall. The shield preferably has a plurality of closely spaced internal slits extending axially almost the height of the shield, but less than the entire height of the shield, leaving at least one edge of the shield uninterrupted by the slits, thereby leaving at least one circumferential path of uninterrupted metal conductor around almost the entire circumference of the chamber. At one point in the circumference, a full height slit or gap interrupts the entire height of the shield, thereby avoiding a continuous 360° circumferential conductive path formed by the shield around the chamber.

In the preferred embodiment, the coil, which surrounds the chamber outside of the shield, inductively couples RF energy into the chamber to energize a plasma. The shield is preferably grounded at only one point on its circumference, for example, at a point directly opposite or 180° from the full height gap. Preferably, the gap, as well as the internal slits, are approximately

1/8 inch wide, with strips of the metallic portion of the shield being about 1/8 inch wide between the slits and gap.

When the coil is initially energized with RF energy and before a plasma exists in the chamber, a peak-to-peak voltage develops across the coil. The energization of the coil couples an RF voltage onto the shield which results in a peak-to-peak voltage developing across the narrow full height gap. When the shield is grounded diametrically opposite the gap, the voltages on the opposite edges of the shield bordering the gap are equal and opposite relative to ground potential. This peak-to-peak voltage may be several thousand volts, for example, 5000 volts RF, peak-to-peak. This voltage produces a strong RF electric field that extends through the quartz chamber wall and into the chamber where, within a time interval in the order of one or a few milli-seconds, it ignites a plasma opposite the gap inside the chamber. The plasma, once ignited, propagates, also in a time interval in the order of a milli-second, around the perimeter of the chamber inside of and close to the chamber wall, where the plasma forms a belt of conductive ionized gas around the circumference of the chamber inside of the chamber. When this plasma belt forms, the voltage across the gap of the shield quickly drops to a nominal voltage in the order of 10 to 20 volts, for example, 14 volts, peak-to-peak.

With the present invention, a plasma is formed that fills the chamber with very low capacitive coupling of voltage from the coil to the plasma, resulting in a low plasma potential and small plasma sheath between the plasma and the circumferential quartz side wall of the chamber. At the same time, the shield

couples energy form the coil to quickly ignite a plasma upon the initial energization of the coil.

These and other objectives of the present invention will be readily apparent from the following detailed description of the present invention in which:

Brief Description of the Drawings:

Fig. 1 is a side view of a sputter etching apparatus, partially broken away, embodying principles of the present invention.

Fig. 2 is a top view, partially in cross-section, of the apparatus of **Fig. 1**.

Detailed Description of the Preferred Embodiments:

Fig. 1 illustrates a plasma etching apparatus 10 having a base 11 to which is sealed a quartz bell jar 12 having a circumferential side wall 13 and an integral top 14. The sidewall 13 is typically approximately 15 to 16 inches in diameter and about 3/8 inches thick. The bell jar 12 has a lip 13a which is sealed to the base 11 to provide a vacuum tight chamber 15 in which is processed a substrate, such as a wafer 16, supported on a substrate support 17. An RF generator 18, preferably a high frequency generator at, for example, 13.56 MHZ, is connected to the substrate support 17 to produce a negative bias on the substrate 16 and control the energy of positive ions from plasma in the chamber 12 for etching the substrate. The bell jar 12 and support 17 are centered on an axis of symmetry 19 of the chamber 145 and sidewall 13.

Surrounding the cylindrical side wall 13 of the bell jar 12, spaced a close distance of 1/16 to 1/4 inches, preferably about 1/8 inches, from the outside of the wall 13, is a helical coil 20. The coil 20 is connected across an RF generator 21 which operates to energize the coil with RF energy preferably at a

medium frequency of, for example, 460 KHz. The coil 20 in the illustrated embodiment is grounded at its center 22. The coil 20, when energized, couples RF energy into the chamber 15 to support a plasma for etching the substrate 16 on the support 17.

Also surrounding the cylindrical side wall 13 of the bell jar 12 and preferably in close proximity to or in contact with the outer surface of the wall 13 is a Faraday shield 30. The shield 30 is formed of a conductive sheet metal material and forms a loop that surrounds the wall 13 inside of the coil 20 which is spaced by a cylindrical space 29 from the shield 30. The shield 30 substantially surrounds the wall 13 but for a narrow gap 31 along one side of the wall 13 about 1/8 inches wide. The gap 31 is disposed parallel to the axis 19 of the cylindrical sidewall 13 of the bell jar 12. The gap 31 completely interrupts current paths around the circumference of the shield except for a small amount of capacitive conductivity of the RF energy across the gap 31. The shield 30 is also provided with a plurality of slits 32 that are separated by conductive strips 33, each about 120 in number and of approximately equal width. The slits 32 are disposed parallel to the gap 31 and parallel to the axis 19 of the chamber 15. The slits 32 each have a length which is approximately 1/4 inch less than the height of the shield 30, which in turn is preferably greater than the height of the coil 20. The conductive strips 33 each connect at their upper end to a horizontal band 33a and at their lower end to a horizontal band 33b, which bands each completely encircle the bell jar except where they are interrupted by the upper and lower ends of the gap 31. The shield 30 is grounded at a single angular position 34 on its circumference, preferably diametrically opposite the gap 31.

When the coil 20 is first energized by the energy from the RF generator 21, a circumferential RF current is induced in the shield 30 which is accompanied by a voltage that is neutral at the ground point 34 but is in the order of magnitude of 1000 peak-to-peak volts across the gap 31. This peak-to-peak voltage is further accompanied by an RF electrical field 35 at the gap 31 which extends through the wall 13 in the vicinity of the gap 31 into the chamber 12. In the vacuum of the chamber 12, which may contain, for example, an inert gas such as argon at a pressure of from 1 mTorr to 10 Torr, the electrical field 35 across the gap 31 on the inside of the chamber wall 12 ignites a plasma in the vicinity of the gap 31 within a millisecond or so after the coil 20 is first energized. This plasma results in the production, within a millisecond or so after plasma ignition, of a sheath of electrons about 2 centimeters in width encircling the chamber 12 and oscillating at the frequency of the RF energy, immediately inside of the cylindrical side wall 13, whereupon the voltage across the gap 31 drops to a voltage in the range of from 10 to 20 volts. Upon formation of the sheath, a plasma quickly fills the chamber 12.

The shield 30 effectively reduces or substantially eliminates capacitive coupling of energy from the coil 20 to the plasma in the chamber 12 that would impart a high potential and a correspondingly large surrounding plasma sheath to the plasma in the chamber 12. As a result, plasma etching of the quartz bell jar 12 is minimized. The shield 30 does so without interfering with the ignition of the plasma, and rather, functions to quickly and efficiently ignite a plasma in the chamber 12 upon the energization of the coil 20.

From the above description of the invention and the preferred embodiments, one skilled in the art will appreciate that variations and additions may be made to the processes and the equipment described without departing from the principles of the invention.

What is claimed is:

1. An apparatus for plasma processing a substrate comprising:

a vacuum chamber having a dielectric wall;

an inductor positioned outside of the chamber in proximity to the wall;

an RF energy source connected to the inductor;

a Faraday shield positioned between the inductor and the wall, the shield being in the shape of a loop having opposite ends and a circumference interrupted by at least one gap bordered by the opposite ends of the shield, whereby the opposite ends of the shield are in close proximity to each other across the gap;

the shield having a localized ground connection that allows RF current induced around the loop to develop a peak-to-peak voltage across the opposite ends of the loop and the gap that is sufficiently high, when no RF plasma is present in the chamber, to produce a plasma igniting electric field adjacent the gap inside of the wall of the chamber.

2. The apparatus of claim **1** wherein:

the gap is between approximately 1/16 and 1/8 inch wide.

3. The apparatus of claim **2** wherein:

the gap is approximately 1/8 inch wide.

4. The apparatus of claim **1** wherein:

the shield is in contact with the outside of the dielectric chamber wall.

5. The apparatus of claim **1** wherein:

the wall of the chamber is cylindrical and defines an axis of symmetry;

the inductor is a helical coil surrounding the cylindrical chamber wall; and

the shield is cylindrical and has a height at least as great as that of the coil with the gap extending the height of the shield and disposed substantially parallel to the axis of symmetry of the cylindrical chamber wall.

6. The apparatus of claim **5** wherein:

the shield has a plurality of closely spaced circumferentially-spaced slots therein extending only partially the height of the shield which are disposed generally parallel to the axis of symmetry of the cylindrical chamber wall.

7. The apparatus of claim **1** wherein:

the shield has a plurality of transverse slots therein closely spaced along the circumference of the shield, each slot extending partially across the loop.

8. The apparatus of claim 1 wherein:

the localized ground connection is located at one section of the circumference of the loop approximately midway between the opposite ends.

9. A plasma etching apparatus comprising:

a vacuum chamber having and axis and a dielectric side wall surrounding the axis;

a coil outside of the chamber and surrounding the dielectric side wall;

an RF energy source connected across the coil;

an electrically conductive Faraday shield extending in a loop circumferentially around the outside of the chamber adjacent the outside of the side wall between the coil and the side wall, the shield having at least one gap bordered by opposite ends of the shield and being grounded along a limited portion of its circumference such that RF current induced around the loop develops a peak-to-peak voltage across the loop that is sufficiently high to produce a plasma igniting electric field in the vicinity of the gap inside of the wall of the chamber.

10. The apparatus of claim **9** wherein:

the gap is between approximately 1/16 and 1/8 inch wide.

11. The apparatus of claim **9** wherein:

the shield is in contact with the outside of the chamber wall.

12. The apparatus of claim **9** wherein:

the wall of the chamber is cylindrical and defines an axis of symmetry;

the inductor is a helical coil surrounding the cylindrical chamber wall; and

the shield is cylindrical and has a height at least as great as that of the coil with the gap being an axial gap extending the height of the shield.

13. The apparatus of claim **12** wherein:

the shield has a plurality of closely spaced axial slots therein extending only partially the height of the shield.

14. The apparatus of claim **9** wherein:

the shield has a plurality of axial slots therein extending partially across the loop and closely spaced along the circumference of the shield.

15. The apparatus of claim **9** wherein:

the shield has a ground connection is located at one section of the circumference of the loop approximately midway between the ends.

16. A method of electrostatically shielding an inductively coupled RF plasma source and igniting a plasma in a vacuum processing chamber, the method comprising the steps of:

providing an inductor outside of the wall of a processing chamber in a position to inductively couple RF energy into a plasma in the chamber when energized therewith;

providing a shield between the inductor and the wall in a loop substantially encircling the chamber wall that is interrupted by at least one gap;

grounding the shield at only a selected limited portion of the loop so as to allow a peak-to-peak RF voltage to develop in the shield across the gap; and

igniting a plasma in the chamber by energizing the inductor with an RF energy to induce RF current momentarily in the shield and produce a peak-to-peak voltage across the gap of the shield to produce an electric field inside the wall of the chamber in the vicinity of the gap to ignite the plasma in the chamber.

17. The method of claim **16** wherein:

the inductor providing step includes the step of providing a helical coil outside of the wall and surrounding the processing chamber;

the shield providing step includes the step of providing a cylindrical shield located between the coil and the wall in contact with the wall; and

the at least one gap is a gap extending along one side of the chamber.

18. The method of claim **16** wherein:

the shield providing step includes the step of providing a shield having a gap that is between approximately 1/16 and 1/4 inches in width.

19. The method of claim **16** wherein:

the shield providing step includes the step of providing a shield having a plurality of spaced slits therein extending almost, but less than, entirely across the shield, the slits being approximately as wide as the gap and having spacings between the slits about as wide as the gap.

20. The method of claim **16**, further comprising the steps of:

providing a wafer in the chamber and sealing the chamber before energizing the inductor; and

following ignition of the plasma, continuing to energize the plasma with energy inductively coupled from the inductor, electrically attracting ions from the plasma onto the surface of the wafer and etching the wafer therewith.

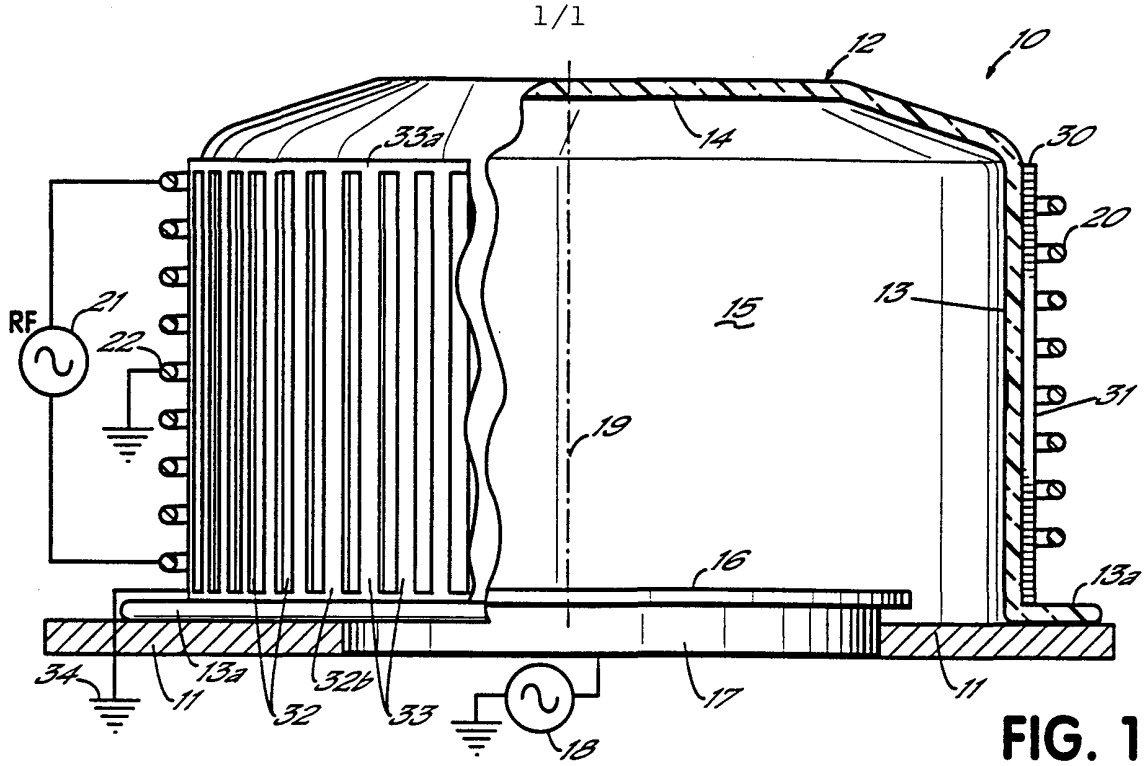

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FIG. 1

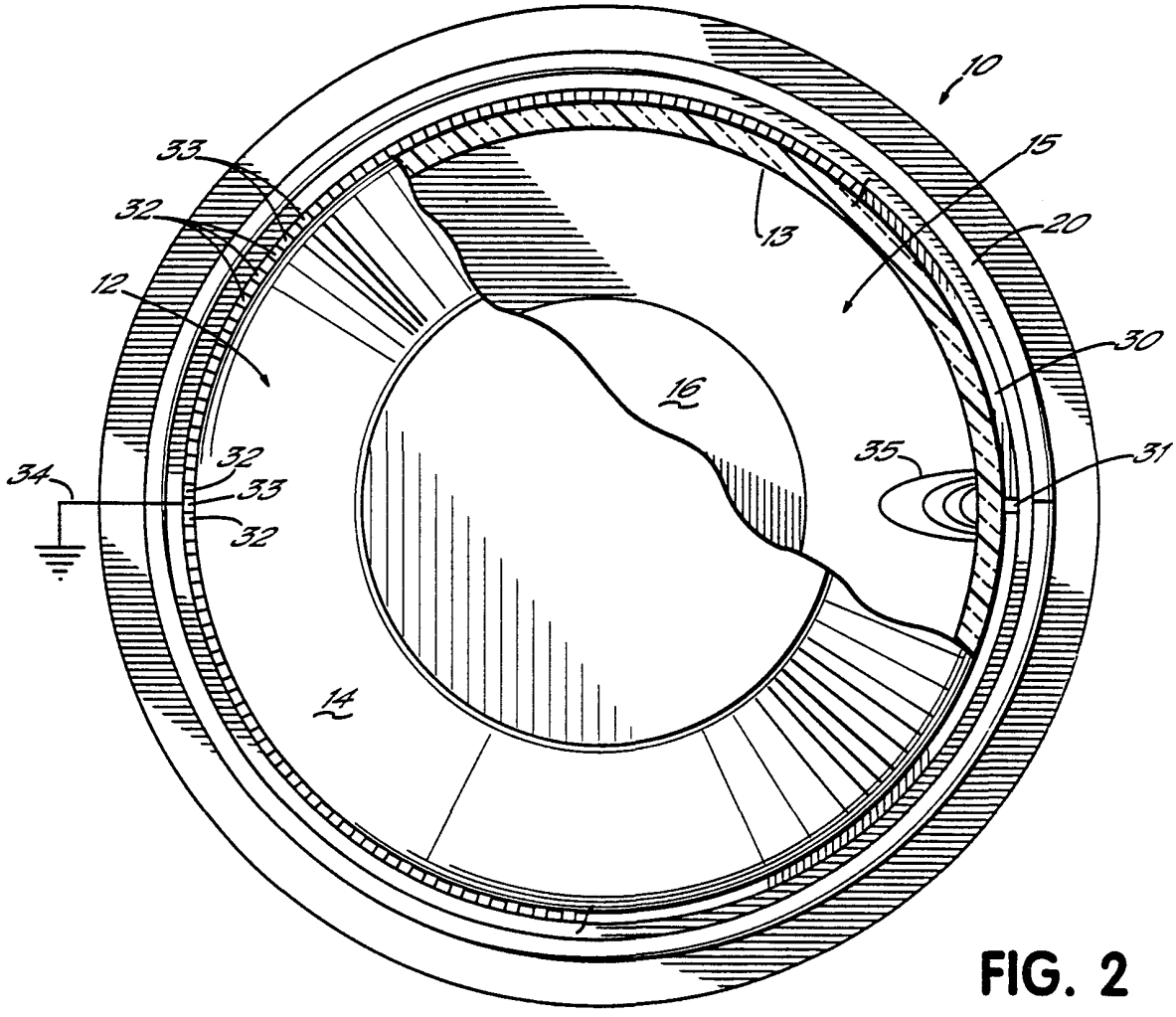

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FIG. 2

INTERNATIONAL SEARCH REPORT

Inte ›nal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01J37/32

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

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IPC 7 H01J

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 96 15545 A (MATTSON TECH INC) 23 May 1996 (1996-05-23) page 22, line 31 -page 23; figure 7 page 35, line 15 -page 36, line 21; figures 10,11 page 38, line 8 -page 45, column 12; figure 12	1-3,5,6, 9-13,16
A	WO 98 11594 A (CTP INC) 19 March 1998 (1998-03-19) page 11, line 11 - line 23; figure 2	1,9,16
A	EP 0 845 800 A (HITACHI LTD) 3 June 1998 (1998-06-03) column 3, line 3 - line 54; figure 2	1,9,16

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[X] Further documents are listed in the continuation of box C.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 234 529 A (JOHNSON WAYNE L) 10 August 1993 (1993-08-10) abstract; figures	1,9,16

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte nal Application No
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