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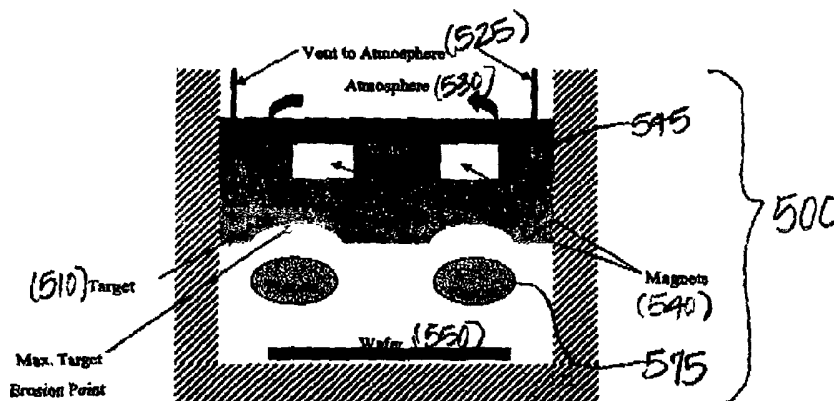
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(54) Title: SENSOR SYSTEM AND METHODS USED TO DETECT MATERIAL WEAR AND SURFACE DETERIORATION



(57) Abstract: A sensor system has been developed for measuring erosion of a sputtering target (510) in a vacuum chamber that includes: a) a sputtering target, b) a wafer, c) a vacuum atmosphere located between the sputtering target and the wafer, and d) a sensor device (525) directly coupled to the sputtering target (510), wherein the sensor device (525) is exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure. A method of detecting erosion in a sputtering target (510) has also been developed that includes: a) providing a sputtering target (510), b) providing a wafer (550), c) initiating a vacuum atmosphere and a plasma that are located between the sputtering target (510) and the wafer (550), d) providing a sensor device (525) directly coupled to the sputtering target (510), wherein the sensor device (525) is partly exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure, e) collecting data from the data collection apparatus; and f) automatically terminating the operation of the plasma once the data collection apparatus determines that the sputtering target (510) has sufficiently eroded.



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SENSOR SYSTEM AND METHODS USED TO DETECT MATERIAL WEAR AND SURFACE DETERIORATION

FIELD OF THE INVENTION

5 The field of the invention is sensor systems for detecting material wear and surface deterioration.

DESCRIPTION OF THE SUBJECT MATTER

10 Material wear and surface deterioration of components and various devices is or at least should be a major concern in many industries, including the electronic and semiconductor industry and the automotive and transportation industries.

 In the automotive and transportation industries, material wear and surface deterioration can be a major safety issue with respect to components that tend to wear down with use or deteriorate because of manufacturing and/or materials defects.

15 In the electronics and semiconductor industries, there are additional issues aside from those mentioned for the automotive and transportation industries. Electronic and semiconductor components are used in ever-increasing numbers of consumer and commercial electronic products, communications products and data-exchange products. Examples of some of these consumer and commercial products are televisions, computers, cell phones, pagers, palm-type or handheld
20 organizers, portable radios, car stereos, or remote controls. As the demand for these consumer and commercial electronics increases, there is also a demand for those same products to become smaller and more portable for the consumers and businesses.

 As a result of the size decrease in these products, the components that comprise the products must also become smaller and/or thinner. Examples of some of those components that need to be
25 reduced in size or scaled down are microelectronic chip interconnections, semiconductor chip components, resistors, capacitors, printed circuit or wiring boards, wiring, keyboards, touch pads, and chip packaging.

When electronic and semiconductor components are reduced in size or scaled down, any defects that are present in the larger components are going to be exaggerated in the scaled down components. Thus, the defects that are present or could be present in the larger component should be identified and corrected, if possible, before the component is scaled down for the smaller electronic products.

In order to identify and correct defects in electronic, semiconductor and communications components, the components, the materials used and the manufacturing processes for making those components should be broken down and analyzed. Electronic, semiconductor and communication/data-exchange components are composed, in some cases, of layers of materials, such as metals, metal alloys, ceramics, inorganic materials, polymers, or organometallic materials. The layers of materials are often thin (on the order of less than a few tens of angstroms in thickness). In order to improve on the quality of the layers of materials, the process of forming the layer – such as physical vapor deposition of a metal or other compound – should be evaluated and, if possible, modified and improved.

In order to improve the process of depositing a layer of material, the safety of an automobile tire, the wear of a set of brake pads or the quality of any other surface or material, the surface or material composition must be measured, quantified and defects or imperfections detected. In the case of the deposition of a layer or layers of material, it's not the actual layer or layers of material that should be monitored but the material and surface of that material that is being used to produce the layer of material on a substrate or other surface that should be monitored. For example, when depositing a layer of metal onto a surface or substrate by sputtering a target comprising that metal, the target must be monitored for uneven wear. Uneven wear of a sputtering target is inevitable and can lead to uneven deposition, and in some cases no deposition, of the metal on the surface of a substrate. In the case of an automobile tire or a set of brake pads, both take the role of the sputtering target in the previous example from the standpoint that they could wear out or wear unevenly leading to safety and efficiency issues for the operator and any passengers.

During conventional manufacturing and/or use of either electronic and/or semiconductor components or those components used by the automotive and/or transportation industries, the wear of materials cannot be easily checked, because such checks either require that the operation be

interrupted, or that an experienced operator be at hand or on an equipment monitoring schedule, both of which are costly. This often results in scheduled (rather than on demand) replacement of such materials, which again leads to costly waste of material, especially if the material is expensive to obtain or replace or if the material is not compromised in the first place.

- 5 To this end, it would be desirable to develop and utilize a sensing system that would a) comprise a simple device/apparatus and/or mechanical setup and a simple method for determining wear and/or deterioration of a surface or material; b) would notify the operator when maintenance is necessary, as opposed to investigating the quality of the material on a specific maintenance schedule; and c) would reduce and/or eliminate material waste by reducing and/or eliminating premature
- 10 replacement or repair of the material.

SUMMARY OF THE SUBJECT MATTER

A sensor system has been developed for measuring erosion of a sputtering target in a vacuum chamber that includes: a) a sputtering target, b) a wafer, c) a vacuum atmosphere located between the sputtering target and the wafer, and d) a sensor device directly coupled to the sputtering target, wherein the sensor device is exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure.

A method of detecting erosion in a sputtering target has also been developed that includes: a) providing a sputtering target, b) providing a wafer, c) initiating a vacuum atmosphere and a plasma that are located between the sputtering target and the wafer, d) providing a sensor device directly coupled to the sputtering target, wherein the sensor device is partly exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure, e) collecting data from the data collection apparatus; and f) automatically terminating the operation of the plasma once the data collection apparatus determines that the sputtering target has sufficiently eroded.

15

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a contemplated sputtering target.

Figure 2 shows a contemplated sputtering target.

Figure 3 shows a contemplated sputtering target.

5 Figure 4 shows a contemplated embodiment of a sensor system.

Figure 5 shows a contemplated embodiment of a sensor system.

Figure 6 shows a contemplated embodiment of a sensor system.

Figure 7 shows a contemplated embodiment of a sensor system.

Figure 8 shows a contemplated embodiment of a sensor system.

10 Figure 9 shows a contemplated embodiment of a sensor system.

Figure 10 shows a contemplated embodiment of a sensor system.

Figure 11 shows a contemplated embodiment of a sensor system.

Figure 12 shows a contemplated embodiment of a sensor system.

Figure 13 shows a contemplated embodiment of a sensor system.

15 Figure 14 shows a contemplated embodiment of a sensor system.

DETAILED DESCRIPTION

A sensing/sensor system has herein been developed that a) comprises a simple device/apparatus and/or mechanical setup and a simple method for determining wear and/or deterioration of a surface or material; b) notifies the operator when maintenance is necessary, as
5 opposed to investigating the quality of the material on a specific maintenance schedule; and c) reduces and/or eliminates material waste by reducing and/or eliminating premature replacement or repair of the material.

A sensor system has been developed for measuring erosion of a sputtering target in a vacuum chamber that includes: a) a sputtering target, b) a wafer, c) a vacuum atmosphere located between
10 the sputtering target and the wafer, and d) a sensor device directly coupled to the sputtering target, wherein the sensor device is exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure.

A sensing/sensor system has been designed that utilizes a change in a signal registered by a sensor system, such as a change in the pressure or flow of a gas, to notify the operator of wear and/or
15 deterioration of a surface or material. The sensing/sensor system may comprise a sensor device that comprises a fiberoptic assembly, an ultrasonic assembly, an optical transmission assembly, a vacuum integrity vent line (flow of gas) assembly, a magnetometer assembly, a height gauge assembly, a thumper assembly and/or a combination thereof, which are all described and disclosed in detail in the following Examples section.

20 The sensing/sensor system is triggered when the target or material deteriorates enough to expose the "triggering mechanism" to the vacuum chamber. The triggering mechanism may be a vent that releases the pressure in the chamber, a fiberoptic probe and/or optical transmission assembly that measures the photons coming from the plasma in the vacuum chamber, an ultrasonic sensor or magnetometer that measures a change in stability or a change in the magnetic field in the
25 chamber and/or a height gauge assembly that measures the simple height from a point on the wafer to a point on the surface of the target.

In one embodiment, a gas at a particular pressure is contained in a space adjacent to the material, such as a sputtering target or an automotive component. When the material wears down or deteriorates enough to open up the space where the gas is contained, there is a change in the pressure

of the gas resulting in a signal or notification to the operator. The change in pressure of the gas can alert the operator of material wear and/or surface deterioration in several ways, including by setting off an alarm system, light or other type of signal, by automatically shutting down the system or by generating a message to the operator.

5 For electronic and semiconductor applications and components, such as components and materials that comprise a layer of conductive material, the sensor system, such as one that includes a gas stream or chamber, can be located behind or adjacent to the working and/or useful area of a sputtering target or other similar type of component that is used to lay down or apply the conductive layer of material. Since sputtering targets can wear unevenly, a gas chamber or gas stream would be
10 useful to indicate when a portion of the sputtering target has been compromised to the point that it should be replaced in order to ensure that the conductive layers continue to be even and continuous, if necessary. A typical sputtering target and the associated wear of the target is shown in **Figures 1-3**. Figure 1 shows a new target (10) with an original, unused surface. Figure 2 shows a non-uniformly worn sputtering target (110). Figure 3 shows a profile of a worn Ti Endura target after
15 1229.2 kWh of "usage", of 0.311 inches initial thickness.

 In another contemplated embodiment, a hole, such as a microfine hole (which can be defined as at least 1 mil in diameter), is drilled from the back of the target area through the backing plate and to the atmosphere. The hole is designed in such a way as to avoid the introduction of water into the hole. When the sputtering target wears thin in one or more areas, there is a distinct and measurable
20 vacuum leak in the sputtering gun, such that the sputter chamber cannot operate. Basically, the vacuum pressure conditions in the sputter chamber are compromised and the chamber cannot be pumped back down to vacuum pressure conditions.

 A method of detecting erosion in a sputtering target has also been developed that includes: a) providing a sputtering target, b) providing a wafer, c) initiating a vacuum atmosphere and a plasma
25 that are located between the sputtering target and the wafer, d) providing a sensor device directly coupled to the sputtering target, wherein the sensor device is partly exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure, e) collecting data from the data collection apparatus; and f) automatically terminating the operation of the plasma once the data collection apparatus determines that the sputtering target has sufficiently
30 eroded.

For automotive and/or transportation-related components, such as tires and brake pads, the gas stream or chamber can be located at such a spot as to provide a signal to the operator when the stream or chamber is compromised, while allowing for the operator to continue operation of the vehicle (car, plane, truck, etc) for a limited amount of time. This method of providing a safe environment for the operator can be accomplished by placing the gas stream or chamber at a point in the material where there is a limited amount of material behind the gas stream or chamber. In other words, a change in the pressure of the gas stream or gas chamber in this case would not result in the complete inability to operate the vehicle, but would result in a signal to the operator that maintenance should be addressed as soon as possible.

As used herein, any references to the term "gas" means that environment that contains pure gases, including nitrogen, helium, or argon, carbon dioxide, or mixed gases, including air. For the purposes of the present subject matter, any gas that is suitable to use in an automotive, transportation, electronic or semiconductor application is contemplated herein.

Sputtering targets contemplated herein comprise any suitable shape and size depending on the application and instrumentation used in the PVD process. Sputtering targets contemplated herein also comprise a surface material and a core material (which includes the backing plate), wherein the surface material is coupled to the core material through and/or around a gas chamber or gas stream. As used herein, the term "coupled" means a physical attachment of two parts of matter or components (adhesive, attachment interfacing material) or a physical and/or chemical attraction between two parts of matter or components, including bond forces such as covalent and ionic bonding, and non-bond forces such as Van der Waals, electrostatic, coulombic, hydrogen bonding and/or magnetic attraction. The surface material and core material may generally comprise the same elemental makeup or chemical composition/component, or the elemental makeup and chemical composition of the surface material may be altered or modified to be different than that of the core material. In most embodiments, the surface material and the core material comprise the same elemental makeup and chemical composition. However, in embodiments where it may be important to detect when the target's useful life has ended or where it is important to deposit a mixed layer of materials, the surface material and the core material may be tailored to comprise a different elemental makeup or chemical composition.

The surface material is that portion of the target that is exposed to the energy source at any measurable point in time and is also that part of the overall target material that is intended to produce atoms that are desirable as a surface coating.

Sputtering targets may generally comprise any material that can be a) reliably formed into a sputtering target; b) sputtered from the target when bombarded by an energy source; and c) suitable for forming a final or precursor layer on a wafer or surface. Materials that are contemplated to make suitable sputtering targets are metals, metal alloys, conductive polymers, conductive composite materials, conductive monomers, dielectric materials, hardmask materials and any other suitable sputtering material. As used herein, the term "metal" means those elements that are in the d-block and f-block of the Periodic Chart of the Elements, along with those elements that have metal-like properties, such as silicon and germanium. As used herein, the phrase "d-block" means those elements that have electrons filling the 3d, 4d, 5d, and 6d orbitals surrounding the nucleus of the element. As used herein, the phrase "f-block" means those elements that have electrons filling the 4f and 5f orbitals surrounding the nucleus of the element, including the lanthanides and the actinides. Preferred metals include titanium, silicon, cobalt, copper, nickel, iron, zinc, vanadium, zirconium, aluminum and aluminum-based materials, tantalum, niobium, tin, chromium, platinum, palladium, gold, silver, tungsten, molybdenum, cerium, promethium, thorium or a combination thereof. More preferred metals include copper, aluminum, tungsten, titanium, cobalt, tantalum, magnesium, lithium, silicon, manganese, iron or a combination thereof. Most preferred metals include copper, aluminum and aluminum-based materials, tungsten, titanium, zirconium, cobalt, tantalum, niobium or a combination thereof. Examples of contemplated and preferred materials, include aluminum and copper for superfine grained aluminum and copper sputtering targets; aluminum, copper, cobalt, tantalum, zirconium, and titanium for use in 300 mm sputtering targets; and aluminum for use in aluminum sputtering targets that deposit a thin, high conformal "seed" layer of aluminum onto surface layers. It should be understood that the phrase "and combinations thereof" is herein used to mean that there may be metal impurities in some of the sputtering targets, such as a copper sputtering target with chromium and aluminum impurities, or there may be an intentional combination of metals and other materials that make up the sputtering target, such as those targets comprising alloys, borides, carbides, fluorides, nitrides, silicides, oxides and others.

The term "metal" also includes alloys, metal/metal composites, metal ceramic composites, metal polymer composites, as well as other metal composites. Alloys contemplated herein comprise gold, antimony, arsenic, boron, copper, germanium, nickel, indium, palladium, phosphorus, silicon, cobalt, vanadium, iron, hafnium, titanium, iridium, zirconium, tungsten, silver, platinum, tantalum, tin, zinc, lithium, manganese, rhenium, and/or rhodium. Specific alloys include gold antimony, gold arsenic, gold boron, gold copper, gold germanium, gold nickel, gold nickel indium, gold palladium, gold phosphorus, gold silicon, gold silver platinum, gold tantalum, gold tin, gold zinc, palladium lithium, palladium manganese, palladium nickel, platinum palladium, palladium rhenium, platinum rhodium, silver arsenic, silver copper, silver gallium, silver gold, silver palladium, silver titanium, titanium zirconium, aluminum copper, aluminum silicon, aluminum silicon copper, aluminum titanium, chromium copper, chromium manganese palladium, chromium manganese platinum, chromium molybdenum, chromium ruthenium, cobalt platinum, cobalt zirconium niobium, cobalt zirconium rhodium, cobalt zirconium tantalum, copper nickel, iron aluminum, iron rhodium, iron tantalum, chromium silicon oxide, chromium vanadium, cobalt chromium, cobalt chromium nickel, cobalt chromium platinum, cobalt chromium tantalum, cobalt chromium tantalum platinum, cobalt iron, cobalt iron boron, cobalt iron chromium, cobalt iron zirconium, cobalt nickel, cobalt nickel chromium, cobalt nickel iron, cobalt nickel hafnium, cobalt niobium hafnium, cobalt niobium iron, cobalt niobium titanium, iron tantalum chromium, manganese iridium, manganese palladium platinum, manganese platinum, manganese rhodium, manganese ruthenium, nickel chromium, nickel chromium silicon, nickel cobalt iron, nickel iron, nickel iron chromium, nickel iron rhodium, nickel iron zirconium, nickel manganese, nickel vanadium, tungsten titanium and/or combinations thereof.

As far as other materials that are contemplated herein for sputtering targets, the following combinations are considered examples of contemplated sputtering targets (although the list is not exhaustive): chromium boride, lanthanum boride, molybdenum boride, niobium boride, tantalum boride, titanium boride, tungsten boride, vanadium boride, zirconium boride, boron carbide, chromium carbide, molybdenum carbide, niobium carbide, silicon carbide, tantalum carbide, titanium carbide, tungsten carbide, vanadium carbide, zirconium carbide, aluminum fluoride, barium fluoride, calcium fluoride, cerium fluoride, cryolite, lithium fluoride, magnesium fluoride, potassium fluoride, rare earth fluorides, sodium fluoride, aluminum nitride, boron nitride, niobium nitride, silicon nitride, tantalum nitride, titanium nitride, vanadium nitride, zirconium nitride, chromium silicide, molybdenum silicide, niobium silicide, tantalum silicide, titanium silicide, tungsten silicide,

vanadium silicide, zirconium silicide, aluminum oxide, antimony oxide, barium oxide, barium titanate, bismuth oxide, bismuth titanate, barium strontium titanate, chromium oxide, copper oxide, hafnium oxide, magnesium oxide, molybdenum oxide, niobium pentoxide, rare earth oxides, silicon dioxide, silicon monoxide, strontium oxide, strontium titanate, tantalum pentoxide, tin oxide, indium oxide, indium tin oxide, lanthanum aluminate, lanthanum oxide, lead titanate, lead zirconate, lead zirconate-titanate, titanium aluminide, lithium niobate, titanium oxide, tungsten oxide, yttrium oxide, zinc oxide, zirconium oxide, bismuth telluride, cadmium selenide, cadmium telluride, lead selenide, lead sulfide, lead telluride, molybdenum selenide, molybdenum sulfide, zinc selenide, zinc sulfide, zinc telluride and/or combinations thereof.

Thin layers or films produced by the sputtering of atoms or molecules from targets discussed herein can be formed on any number or consistency of layers, including other metal layers, substrate layers dielectric layers, hardmask or etchstop layers, photolithographic layers, anti-reflective layers, etc. In some preferred embodiments, the dielectric layer may comprise dielectric materials contemplated, produced or disclosed by Honeywell International, Inc. including, but not limited to:

a) FLARE (poly(arylene ether)), such as those compounds disclosed in issued patents US 5959157, US 5986045, US 6124421, US 6156812, US 6172128, US 6171687, US 6214746, and pending applications 09/197478, 09/538276, 09/544504, 09/741634, 09/651396, 09/545058, 09/587851, 09/618945, 09/619237, 09/792606, b) adamantane-based materials, such as those shown in pending application 09/545058 ; Serial PCT/US01/22204 filed October 17, 2001; PCT/US01/50182 filed December 31, 2001; 60/345374 filed December 31, 2001; 60/347195 filed January 8, 2002; and 60/350187 filed January 15, 2002; c) commonly assigned US Patents 5,115,082; 5,986,045; and 6,143,855; and commonly assigned International Patent Publications WO 01/29052 published April 26, 2001; and WO 01/29141 published April 26, 2001; and (d) nanoporous silica materials and silica-based compounds, such as those compounds disclosed in issued patents US 6022812, US 6037275, US 6042994, US 6048804, US 6090448, US 6126733, US 6140254, US 6204202, US 6208014, and pending applications 09/046474, 09/046473, 09/111084, 09/360131, 09/378705, 09/234609, 09/379866, 09/141287, 09/379484, 09/392413, 09/549659, 09/488075, 09/566287, and 09/214219 all of which are incorporated by reference herein in their entirety and (e) Honeywell HOSP® organosiloxane.

The wafer or substrate may comprise any desirable substantially solid material. Particularly desirable substrates would comprise glass, ceramic, plastic, metal or coated metal, or composite material. In preferred embodiments, the substrate comprises a silicon or germanium arsenide die or wafer surface, a packaging surface such as found in a copper, silver, nickel or gold plated leadframe, a copper surface such as found in a circuit board or package interconnect trace, a via-wall or stiffener interface ("copper" includes considerations of bare copper and its oxides), a polymer-based packaging or board interface such as found in a polyimide-based flex package, lead or other metal alloy solder ball surface, glass and polymers such as polyimides. In more preferred embodiments, the substrate comprises a material common in the packaging and circuit board industries such as silicon, copper, glass, or a polymer.

Substrate layers contemplated herein may also comprise at least two layers of materials. One layer of material comprising the substrate layer may include the substrate materials previously described. Other layers of material comprising the substrate layer may include layers of polymers, monomers, organic compounds, inorganic compounds, organometallic compounds, continuous layers and nanoporous layers.

Contemplated polymers may comprise a wide range of functional or structural moieties, including aromatic systems, and halogenated groups. Furthermore, appropriate polymers may have many configurations, including a homopolymer, and a heteropolymer. Moreover, alternative polymers may have various forms, such as linear, branched, super-branched, or three-dimensional. The molecular weight of contemplated polymers spans a wide range, typically between 400 Dalton and 400000 Dalton or more.

Examples of contemplated inorganic compounds are silicates, aluminates and compounds containing transition metals. Examples of organic compounds include polyarylene ether, polyimides and polyesters. Examples of contemplated organometallic compounds include poly(dimethylsiloxane), poly(vinylsiloxane) and poly(trifluoropropylsiloxane).

The substrate layer may also comprise a plurality of voids if it is desirable for the material to be nanoporous instead of continuous. Voids are typically spherical, but may alternatively or additionally have any suitable shape, including tubular, lamellar, discoidal, or other shapes. It is also contemplated that voids may have any appropriate diameter. It is further contemplated that at least some of the voids may connect with adjacent voids to create a structure with a significant amount of

connected or "open" porosity. The voids preferably have a mean diameter of less than 1 micrometer, and more preferably have a mean diameter of less than 100 nanometers, and still more preferably have a mean diameter of less than 10 nanometers. It is further contemplated that the voids may be uniformly or randomly dispersed within the substrate layer. In a preferred embodiment, the voids are
5 uniformly dispersed within the substrate layer.

Among other things, the subject matter contemplated herein can perform and provide the following functions and actions:

- 10 a) Monitoring change in gas flow through or pressure in a network of microchannels embedded in a wearable material as a means to sensing when the wear in the material has reached the level of the microchannels
- b) Applying this wear sensor concept to monitoring wear of sputter targets in semiconductor processing applications
- 15 c) Applying this wear sensor concept to monitoring wear of automotive tires, whereby the source of gas is the tire air itself, with the microchannels being small enough that the flow will still provide days of "life"
- d) Applying this wear sensor concept to monitoring wear of brake shoes in automotive, motorcycle, rail or airplane braking systems
- 20 e) Monitoring the change in capacitance as a means to sensing when the wear in the material has reached the maximum level
- f) Monitoring the change in proximity or distance of individual surface elements to a reference point, either via conventional optics, "light-radar" or holography, as a means to sensing when the wear in the
25 material has reached the maximum level
- g) Monitoring the change in time-of-flight of a sound wave between one (of many) target-back-side transducers and the target front surface, as

a means to sensing when the wear in the material has reached the maximum level.

- 5 h) An optical fiber approach, whereby an optical fiber is coiled and bonded on the back side of the target or between that target and its substrate, and as soon as the wear reaches the outer cladding of the fiber, such intrusion can be sensed by SOA optical instrumentation.
- 10 i) As noted, some of the proposed wear sensing methods are analog (acoustic- and optical-radar, capacitive approach) while others are digital and only provide and an alarm at one point or not (optical fiber and the gas-flow or-pressure approaches).
- 15 j) Providing an optimal cost-benefit tradeoff via a hybrid approach between our preferred flow/pressure digital approach and an analog approach (e.g. the addition of one or more sensors, such as an ultrasonic sensor) to provide an optimal technical solution with both analog monitoring and a digital alarm.

Some of the contemplated benefits and advantages of the subject matter disclosed herein include:

- 20 a) Over the capacitive approach: The GCN (Gas Channel Network or Vacuum Vent System) does not require electrical connections to hundreds of electrodes and the GCN approach can be used with metallic (electronically conductive) targets.
- 25 b) Over the optical radar proximity approach: The GCN does not require complex imaging and adjustment for hundreds of target sub-areas, not optical access to the target surface.
- c) Over not using a wear sensor: Cost savings to the user on two counts: Minimizes the waste associated with premature replacement of the device with the wearing material (tire, brake or target) of an overly cautious user,

and minimizes the cost of "unplanned" events such as tire blow-out, brake failure or sputtering unacceptable (substrate material rather than high-purity target) material on costly ICs.

EXAMPLES

EXAMPLE 1 – CONTEMPLATED VACUUM VENT LINE ASSEMBLIES

An example of an electronic and/or semiconductor application of this embodiment is shown in **Figure 4**. The sputter or sputtering target (410) is provided with a set of interconnected
5 microchannels (420) (e.g. 0.1 mm in diameter), which are connected to a gas flow (415) or pressure sensor (the black box (430) in Figure 4) on one end (e.g. slightly pressurized, or preferably under-pressurized relative to the vacuum chamber (400), in order to prevent contamination) and to a valve on the other.

Under normal operation, while the sputter target thickness is larger than the diameter of the
10 microchannels, no flow or change in pressure is observable. But as soon as the wear reaches any part of the micro-channel network, a change in gas flow or pressure will be monitored and used to trigger a warning that the target is near the end of its useful life.

The gap (450) between the target material and the water-cooled substrate (440, wherein the cooled water flow is represented as (445)) holding the target should be gas and vacuum tight, so that
15 the test gas (415) does not leak out into the vacuum, or "vacuum gas" is not lost to the external pump connected to the test gas pipe "inlet" (not shown in Figure 4).

As mentioned, Figure 4 shows a black box (430) to represent a flow or a pressure sensor that monitors the flow of the test gas. In addition, a valve (435) is shown on the other end of the gas network. This valve (435) is intended for use by the user or control system to periodically check the
20 proper function of the alarm system, e.g. via a short period of opening the valve to induce a flow to simulate the "end-of-life" of the target or wearing material, which should then trigger the alert mechanism, such as an alarm signal.

Figure 5 shows another embodiment of the sensor system disclosed herein having a vacuum integrity vent line. Vacuum chamber (500) contains a target (510) having vents (525) to the
25 atmosphere (530), a wafer or surface (550) and a plasma source (575). The chamber (500) further comprises at least one magnet (540) that is/are surrounded by a cooling fluid (545), which is represented as water in this Figure. When the maximum erosion point area breaks through to the vent or vent channel (525), a leak from the atmosphere causes a large pressure rise in the chamber.

The vacuum chamber shuts down until a new target is installed. This sensor system provides for a “hard off” fail-safe end of target life detector.

EXAMPLE 2 – CONTEMPLATED FIBEROPTIC ASSEMBLIES

5 An example of an electronic and/or semiconductor application of this embodiment is shown in **Figures 6 and 7**. **Figure 6** shows the front view of the vacuum chamber (600) that comprises a target (610) coupled to a fiberoptic cable (625), which is coupled to a fiberoptic sensor (620), a wafer or surface (650) and a plasma source (675). The chamber (600) further comprises at least one magnet (640) that is/are surrounded by a cooling fluid (645), which is represented as water in this
10 Figure. Light enters through the very thin remaining target material – after significant wear – and is sensed by the receiver. The sensor the provides a STOP signal to control.

Figure 7 shows an above view of the fiberoptic embodiment. The embedded fiberoptic cable (725) is located at the bond line. The spacing is exaggerated for the purposes of the illustration. The estimate of the spacing of the loops is approximately 0.25 inches. The fiberoptic cable connection
15 block allows manual insertion of the cable (725) into the union of the target material (610) and the rotating magnet apparatus (740), which provides a water tight seal. A fiberoptic sensor (720) is also shown.

EXAMPLE 3 – CONTEMPLATED ULTRASONIC ASSEMBLIES

20 An example of an electronic and/or semiconductor application of this embodiment is shown in **Figure 8**. **Figure 8** shows the front view of the vacuum chamber (800) that comprises a target (810) coupled to a transducer (825) and an oscilloscope (835), which measures the remaining thickness of the target, a wafer or surface (850) and a plasma source (875). The chamber (800) further comprises at least one magnet (840) that is/are surrounded by a cooling fluid (845), which is
25 represented as water in this Figure. The oscilloscope is adjustable to any given sputter depth (remaining target thickness), therefore a shut off signal is easily established. Lead wires from the transducers may be located between the target and the rotating magnet. Lead wires should be shielded from the magnet, so as not to perform the performance of the magnet.

EXAMPLE 4 – CONTEMPLATED OPTICAL TRANSMISSION DETECTOR ASSEMBLIES

An example of an electronic and/or semiconductor application of this embodiment is shown in **Figure 9**. **Figure 9** shows the front view of the vacuum chamber (900) that comprises a target (910) coupled to at least one fiberoptic waveguide (925) and a monochromator (935), a wafer or surface (950) and a plasma source (975). The chamber (900) further comprises at least one magnet (940) that is/are surrounded by a cooling fluid (945), which is represented as water in this Figure. The metal films are transparent to various frequencies of photons, and the light generated by the plasma can be used to detect the endpoint of the target without punch through by knowing the absorption coefficient of the metal film.

EXAMPLE 5 – CONTEMPLATED MAGNETOMETER ASSEMBLIES

An example of an electronic and/or semiconductor application of this embodiment is shown in **Figure 10**. **Figure 10** shows the front view of the vacuum chamber (1000) that comprises a target (1010) coupled to at least one magnetometer that is located behind the deepest erosion groove (1025), a wafer or surface (1050) and a plasma source (1075). The chamber (1000) further comprises at least one magnet (1040) that is/are surrounded by a cooling fluid (1045), which is represented as water in this Figure. The magnetometer can detect the inductance of the moving plasma. The empirical data can establish a relationship between the erosion depth and the strength of the magnetic field collapse. The lead wires from the magnetometer are located between the target and the rotating magnet.

EXAMPLE 6 – CONTEMPLATED HEIGHT GAUGE ASSEMBLIES

Examples of electronic and/or semiconductor applications of this embodiment are shown in **Figures 11-13**. **Figure 11** shows the front view of the vacuum chamber (1100) that comprises a target (1110) coupled to at least one micromechanical probe (1125), a wafer or surface (1150) and a plasma source (1175). The chamber (1100) further comprises at least one magnet (1140) that is/are surrounded by a cooling fluid (1145), which is represented as water in this Figure. The

micromechanical probe that measures the distance between the wafer and the target surface. **Figure 12** shows another contemplated embodiment of the height sensor by utilizing a radar sensor (1225) that measures the distance between the wafer surface and the target surface. At appropriate intervals, the height gauging wafer is loaded into the chamber, is activated to measure the height, records the height and is removed from the chamber. This type of apparatus works with any type of system and with any type of target. There are no modifications needed to the target or the chamber, and there is no interference with magnets, heat conduction or cooling water.

Figure 13 shows a height gauge apparatus where an IR camera (1325) measures the temperature profile in the chamber. In this height gauging apparatus, the gauge is loaded into the chamber and is activated to measure and record the temperature. There are no modifications needed to the target or the chamber, and there is no interference with magnets, heat conduction or cooling water.

EXAMPLE 7 – CONTEMPLATED “THUMPER” ASSEMBLIES

An example of an electronic and/or semiconductor application of this embodiment is shown in **Figure 14**. **Figure 14** shows the front view of the vacuum chamber (1400) that comprises a target (1410) coupled to at least one piezoelectric transducer (1425), a wafer or surface (1450) and a plasma source (1475). The chamber (1400) further comprises at least one magnet (1440) that is/are surrounded by a cooling fluid (1445), which is represented as water in this Figure. At appropriate intervals, the piezoelectric transducer emits vibration and “listens” for the return vibrations. Empirical data can establish a relationship between erosion and resonance of returned vibrations. The transducer can be attached to the target and sold as an assembly. Lead wires from the transducers are located between the target and the rotating magnet or on the OD of the target.

Thus, specific embodiments and applications of sensor systems and methods used to detect material wear and surface deterioration have been disclosed. It should be apparent, however, to those skilled in the art that many more modifications besides those already described are possible without departing from the inventive concepts herein. The inventive subject matter, therefore, is not to be restricted except in the spirit of the specification and claims disclosed herein. Moreover, in interpreting the specification and the claims, all terms should be interpreted in the broadest possible

manner consistent with the context. In particular, the terms “comprises” and “comprising” should be interpreted as referring to elements, components, or steps in a non-exclusive manner, indicating that the referenced elements, components, or steps may be present, or utilized, or combined with other elements, components, or steps that are not expressly referenced.

CLAIMS

We claim:

1. A sensor system for measuring and detecting erosion of a sputtering target in a vacuum chamber, comprising:
5 a sputtering target,
a wafer,
a vacuum atmosphere located between the sputtering target and the wafer, and
a sensor device directly coupled to the sputtering target, wherein the sensor device is exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed
10 to atmospheric pressure.
2. The sensor system of claim 1, wherein the sensor device comprises a vacuum vent line and the data collection device measures the change in pressure in the vacuum chamber.
3. The sensor system of claim 1, wherein the sensor device comprises a fiberoptic cable.
4. The sensor system of claim 1, wherein the sensor device comprises a transducer and the data
15 collection apparatus comprises an oscilloscope.
5. The sensor system of claim 1, wherein the sensor device comprises a fiberoptic waveguide and the data collection apparatus comprises a monochromator.
6. The sensor system of claim 1, wherein the sensor device comprises a magnetometer.
7. The sensor system of claim 1, wherein the sensor device comprises a height gauge coupled to
20 the wafer and the sputtering target.
8. The sensor system of claim 1, wherein the sensor device comprises at least one piezoelectric transducer.
9. The sensor system of claim 1, wherein the wafer comprises a silicon wafer.
10. A method of detecting erosion in a sputtering target, comprising:

providing a sputtering target,

providing a wafer,

initiating a vacuum atmosphere and a plasma that are located between the sputtering target and the wafer,

5 providing a sensor device directly coupled to the sputtering target, wherein the sensor device is partly exposed to the vacuum atmosphere and comprises a data collection apparatus that is exposed to atmospheric pressure,

collecting data from the data collection apparatus; and

10 automatically terminating the operation of the plasma once the data collection apparatus determines that the sputtering target has sufficiently eroded.

11. The method of claim 10, wherein the sensor device comprises a vacuum vent line and the data collection device measures the change in pressure in the vacuum chamber.

12. The method of claim 10, wherein the sensor device comprises a fiberoptic cable.

13. The method of claim 10, wherein the sensor device comprises a transducer and the data
15 collection apparatus comprises an oscilloscope.

14. The method of claim 10, wherein the sensor device comprises a fiberoptic waveguide and the data collection apparatus comprises a monochromator.

15. The method of claim 10, wherein the sensor device comprises a magnetometer.

16. The method of claim 10, wherein the sensor device comprises a height gauge coupled to the
20 wafer and the sputtering target.

17. The method of claim 10, wherein the sensor device comprises at least one piezoelectric transducer.

18. The method of claim 10, wherein the wafer comprises a silicon wafer.

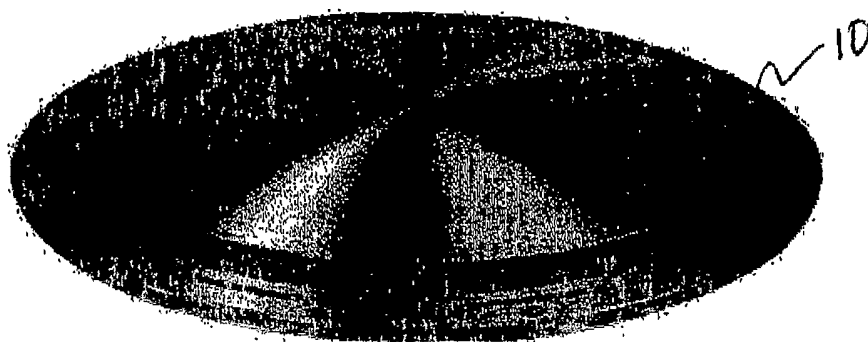


Fig 1. Photo of new target - showing original flat surface

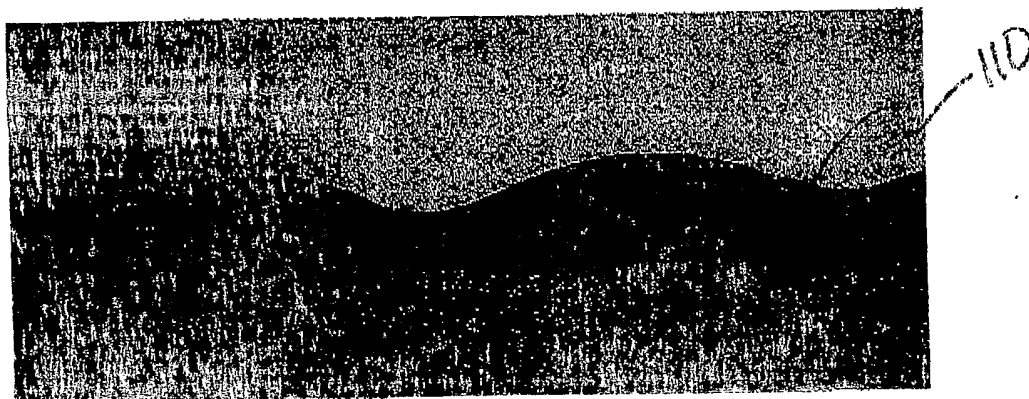


Fig 2. Photo of a non-uniformly worn sputter target

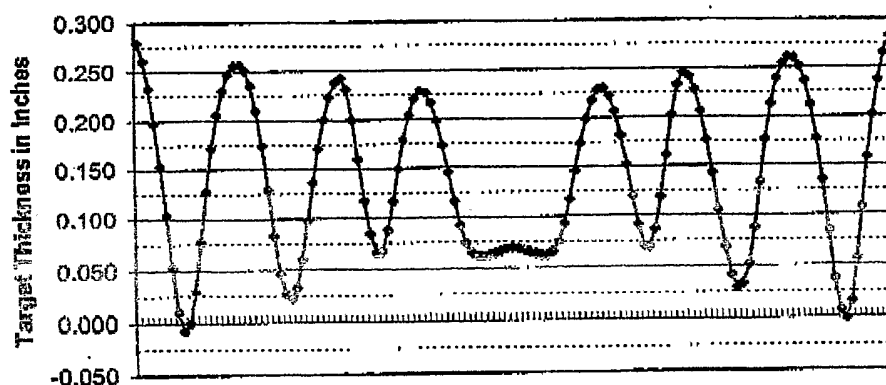


Fig 3. Profile of a worn TiEndura target after 1229.2 kWh of "usage", of 0.311" initial thickness
and 15-20" in diameter

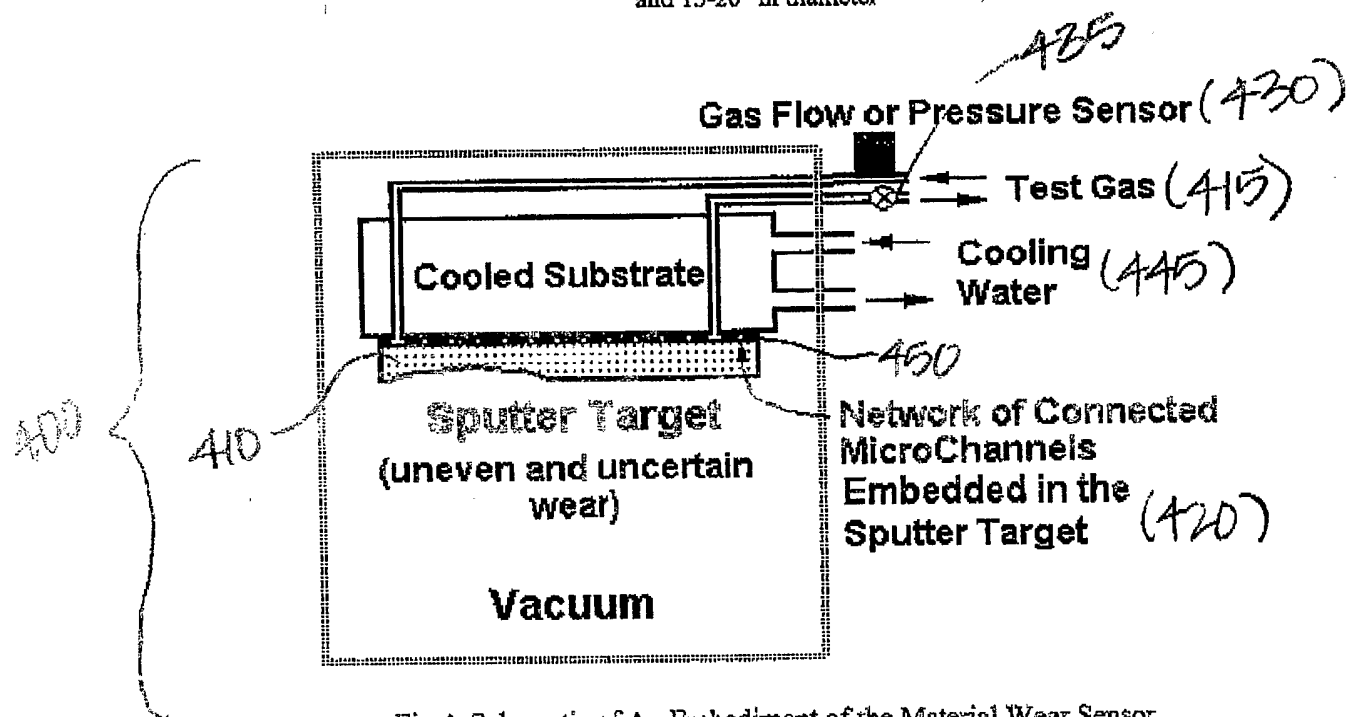


Fig.4. Schematic of An Embodiment of the Material Wear Sensor

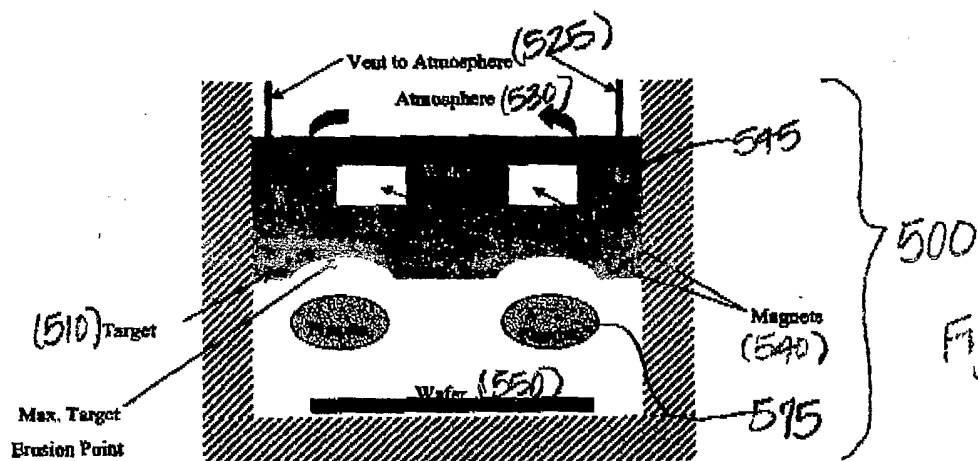


Figure 5

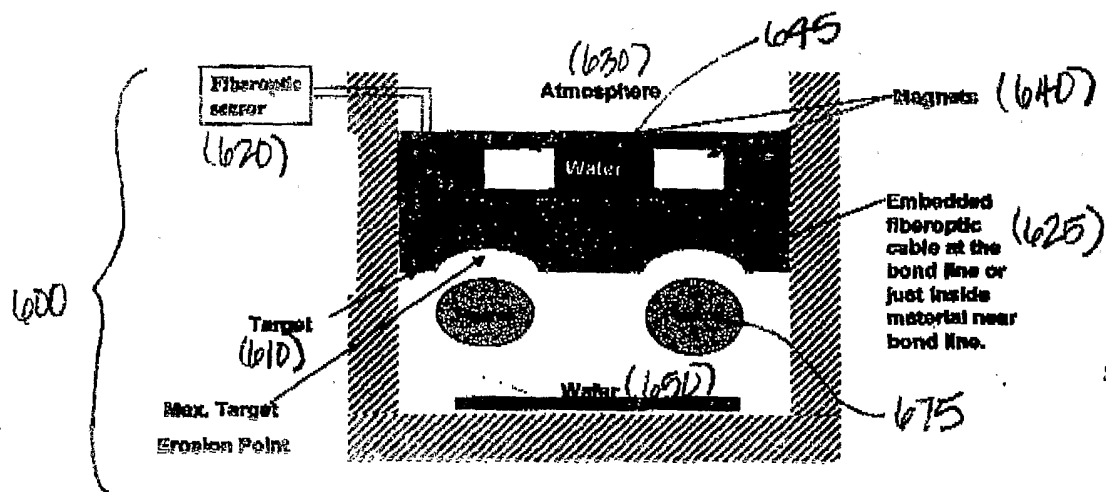


Figure 6

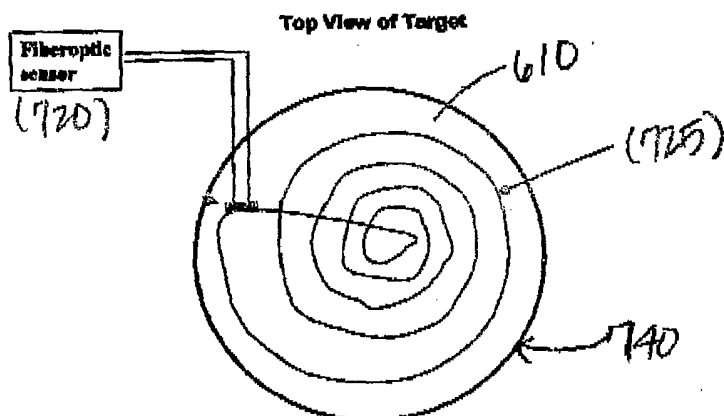


Figure 7

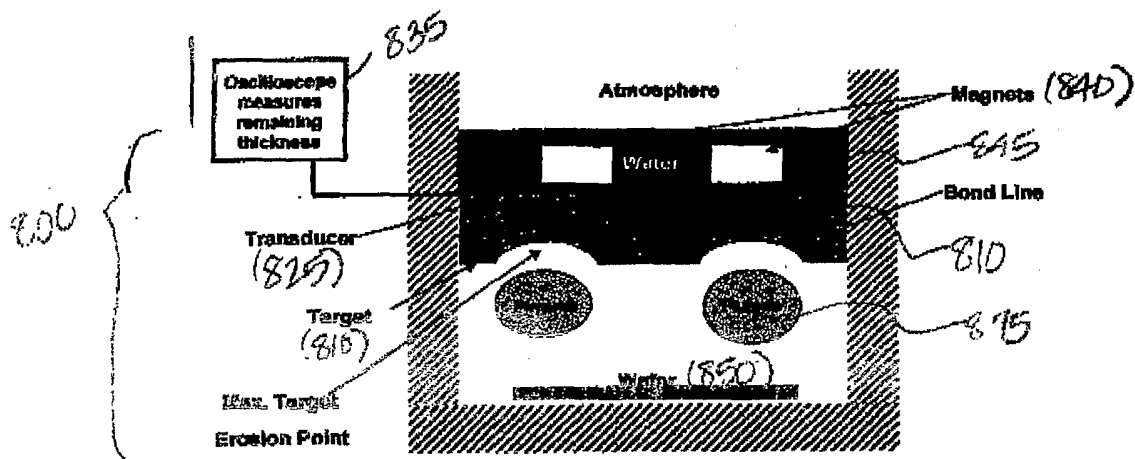


Figure 8

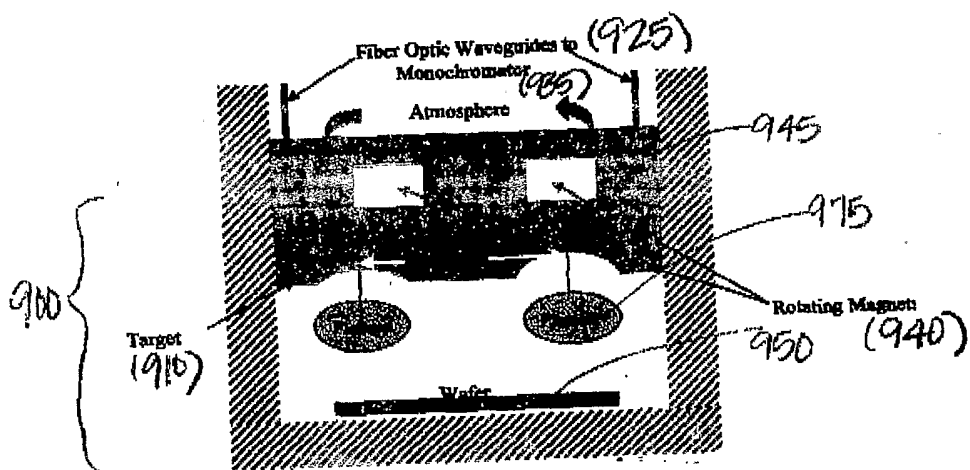


Figure 9

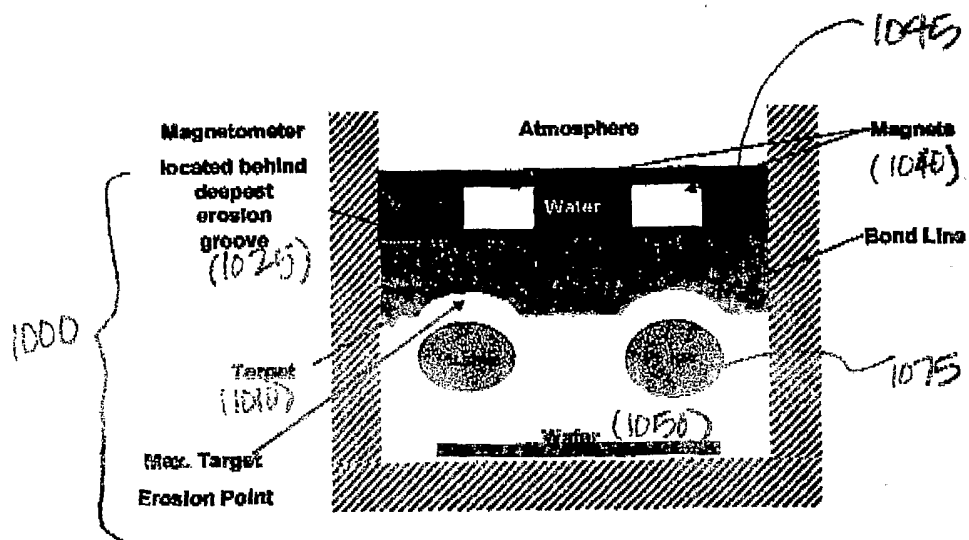
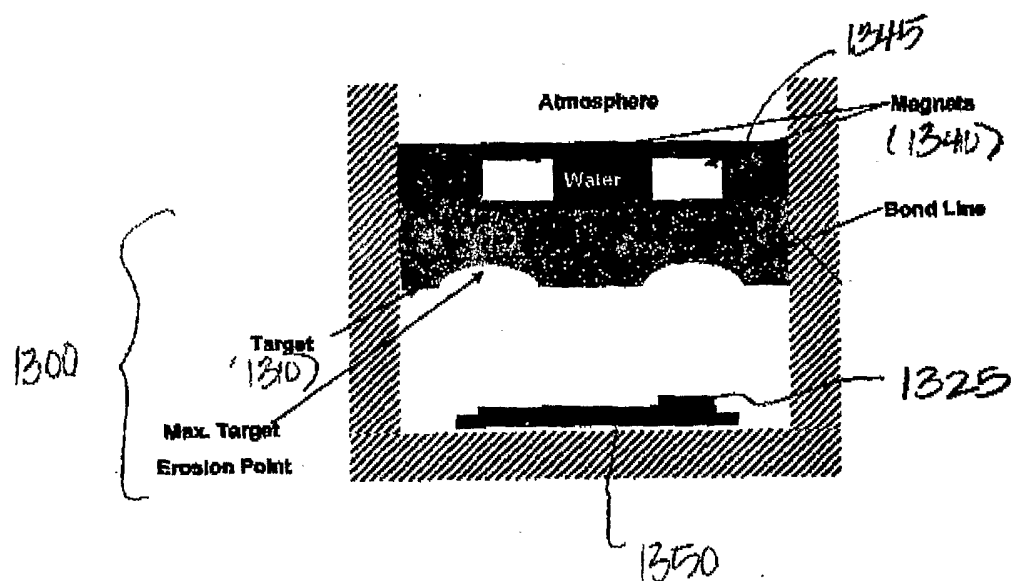
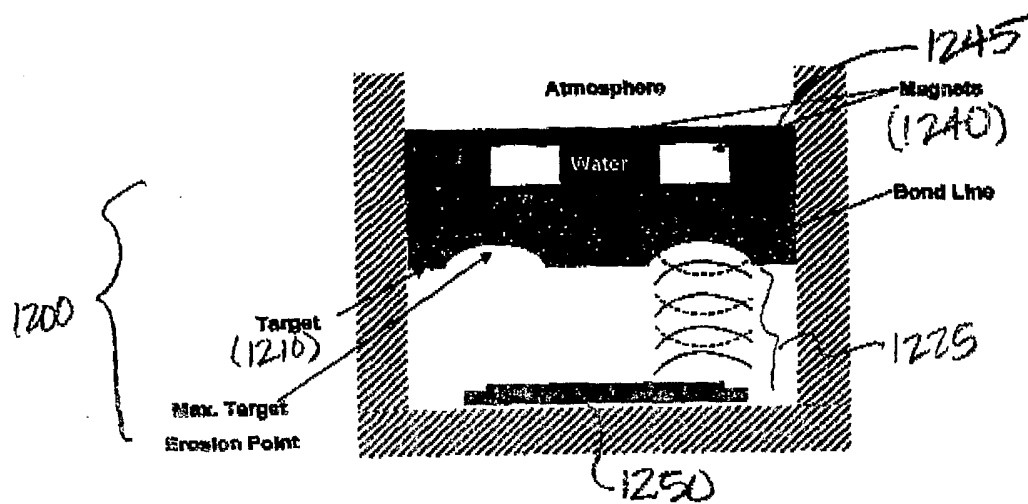
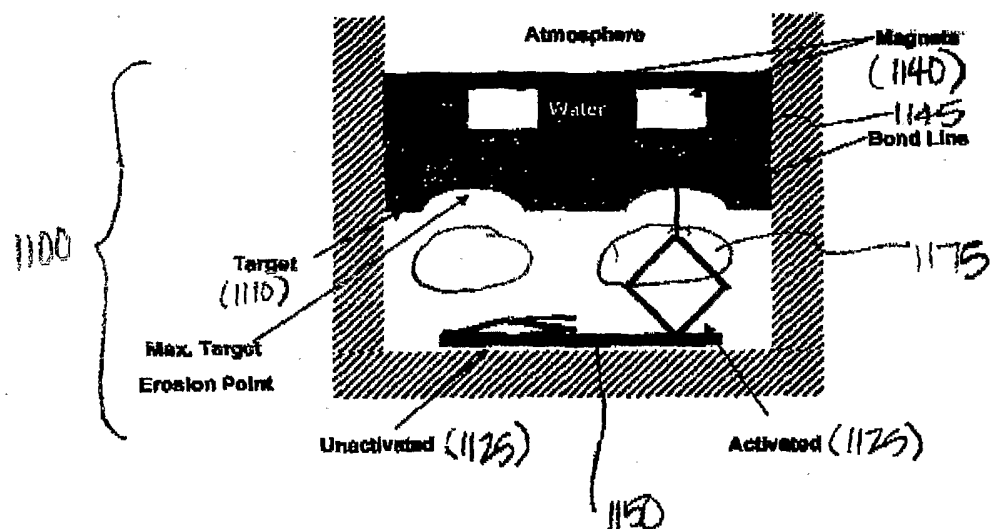


Figure 10



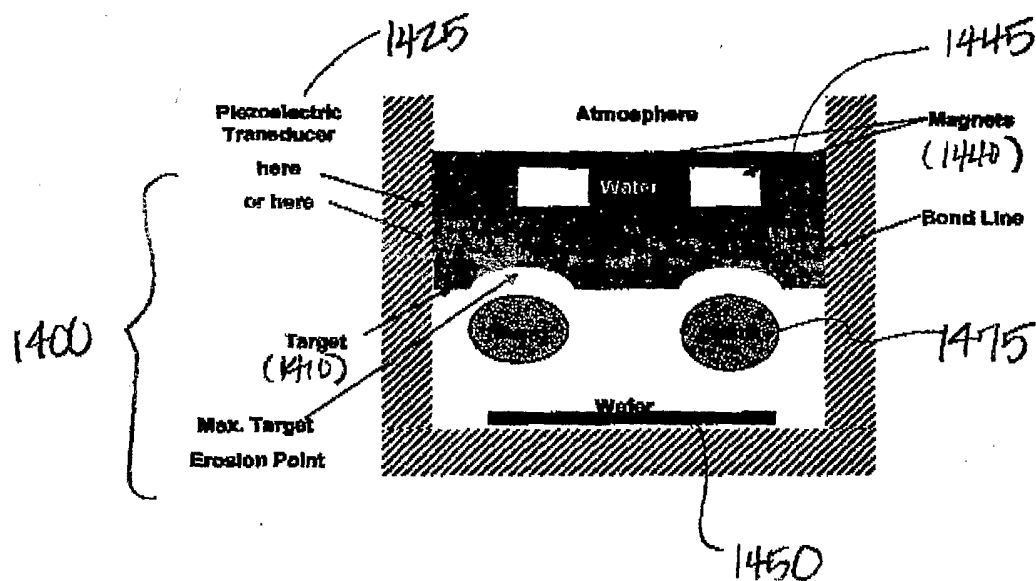


Figure 14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US03/28832

A. CLASSIFICATION OF SUBJECT MATTER																										
IPC(7) : C23C 14/34																										
US CL : 204/192.13, 298.03																										
According to International Patent Classification (IPC) or to both national classification and IPC																										
B. FIELDS SEARCHED																										
Minimum documentation searched (classification system followed by classification symbols) U.S. : 204/192.13, 298.03																										
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched NONE																										
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) NONE																										
C. DOCUMENTS CONSIDERED TO BE RELEVANT																										
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.																								
X	JP 07-292472 A (MIWA) 07 November 1995 (07.11.95), Abstract; Figures 1-4.	1, 2																								
X	JP 07-224377 A (SAITOU et al) 22 August 1995 (22.08.1995), Abstract; Figures 1-4.	1, 7																								
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Y		16																								
X	US 5,380,419 A (EGGERS et al) 10 January 1995 (10.01.1995), Abstract; Column 2 lines 48-60; Column 4 lines 31-68; Column 5 lines 1-9; Column 5 lines 57-68; Column 6 lines 1-15.	1, 2, 10, 11																								
X	US 4,983,269 A (WEGMANN) 08 January 1991 (08.01.1991), See Abstract; Column 3 lines 20-52; Column 4 lines 64-68; Column 7 lines 25-66; Column 12 lines 13-68; Column 13 lines 1-32; Column 13 lines 59-68; Column 14 lines 1-8.	1, 3, 10, 12																								
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Y		5, 14																								
Y	WO 90/10947 A (WEGMANN) 20 September 1990, (20.09.1990), See Abstract.	4, 8, 13, 17																								
☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.																										
<table border="0"> <tr> <td colspan="2">* Special categories of cited documents:</td> <td>"T"</td> <td>later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"A"</td> <td>document defining the general state of the art which is not considered to be of particular relevance</td> <td>"X"</td> <td>document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"B"</td> <td>earlier application or patent published on or after the international filing date</td> <td>"Y"</td> <td>document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"L"</td> <td>document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"&"</td> <td>document member of the same patent family</td> </tr> <tr> <td>"O"</td> <td>document referring to an oral disclosure, use, exhibition or other means</td> <td></td> <td></td> </tr> <tr> <td>"P"</td> <td>document published prior to the international filing date but later than the priority date claimed</td> <td></td> <td></td> </tr> </table>			* Special categories of cited documents:		"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"B"	earlier application or patent published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family	"O"	document referring to an oral disclosure, use, exhibition or other means			"P"	document published prior to the international filing date but later than the priority date claimed		
* Special categories of cited documents:		"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention																							
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"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family																							
"O"	document referring to an oral disclosure, use, exhibition or other means																									
"P"	document published prior to the international filing date but later than the priority date claimed																									
Date of the actual completion of the international search 20 January 2004 (20.01.2004)		Date of mailing of the international search report 06 FEB 2004																								
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US Commissioner for Patents P.O. Box 1450 Alexandria, Virginia 22313-1450 Facsimile No. (703) 305-3230		Authorized officer Rodney G. McDonald <i>Rodney McDonald</i> Telephone No. 703-308-0661																								

INTERNATIONAL SEARCH REPORT

PCT/US03/28832

C. (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4,500,409 A (BOYS et al) 19 February 1985 (19.02.1985), See Abstract; Column 1 lines 15-56; Column 7 lines 13-28; Column 8 lines 51-68; Column 10 lines 56-68; Column 11 lines 1-2.	6, 9, 15, 18