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(54) Title: COMPOSITE TRANSDUCER APPARATUS AND SYSTEM FOR PROCESSING A SUBSTRATE AND METHOD OF CONSTRUCTING THE SAME

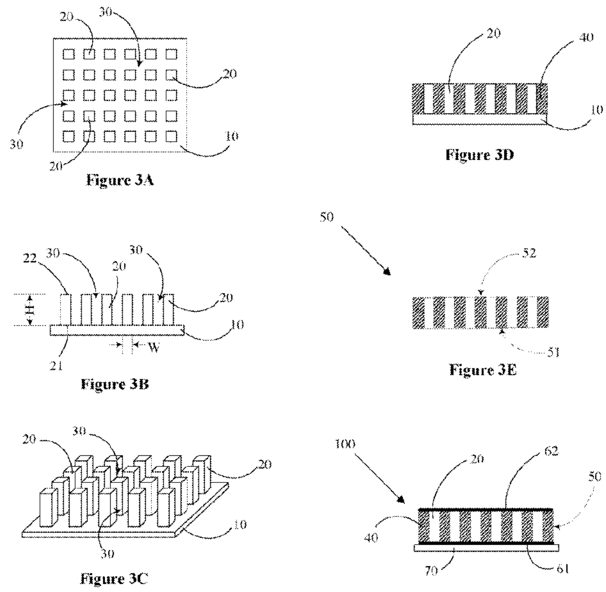

Figure 3A
Figure 3B
Figure 3C
Figure 3D
Figure 3E
Figure 3F

(57) Abstract: A transducer, system and method of constructing the same that utilizes a composite of piezoelectric pillars. In one embodiment, the invention is an apparatus for generating acoustic energy comprising: a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced- apart manner so that spaces exist between adjacent pillars; the pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars, and the spaces filled with a resilient material so as to form a composite assembly.

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COMPOSITE TRANSDUCER APPARATUS AND SYSTEM FOR PROCESSING A SUBSTRATE AND METHOD OF CONSTURCTING THE SAME

Cross-Reference To Related Patent Applications

[0001] The present patent application claims the benefit of United Stated Provisional Patent Application Serial No. 60/985,947, filed November 6, 2007 and United Stated Provisional Patent Application Serial No. 61/034,142, filed March 5, 2008, the entireties of which are hereby incorporated by reference.

Field of the Invention

[0002] The present invention relates generally to an apparatus and system for generating acoustic energy for the processing of substrates, such as semiconductor wafers, raw silicon substrates, flat panel displays, solar panels, photomasks, discs, magnetic heads or any other item that requires a high level of processing precision. Specifically, the invention relates to an acoustic generating apparatus, or a system incorpoating the same, that can provide high levels of particle removal efficiency from substrates containing delicate devices that minimizes damage to the delicate devices.

Background of the Invention

[0003] In the field of semiconductor manufacturing, it has been recognized since the beginning of the industry that removing particles from semiconductor wafers during the manufacturing process is a critical requirement to producing quality profitable wafers. While many different systems and methods have been developed over the years to remove particles from semiconductor wafers, many of these systems and methods are undesirable because they cause damage to the wafers. Thus, the removal of particles from wafers must be balanced against the amount of damage caused to the wafers by the cleaning method and/or system. It is therefore desirable for a cleaning method or system to be able to break particles free from the delicate semiconductor wafer without resulting in damage to the device structure.

[0004] Existing techniques for freeing the particles from the surface of a semiconductor wafer utilize a combination of chemical and mechanical processes. One typical cleaning chemistry used in the art is standard clean 1 ("SC1"), which is a mixture of ammonium hydroxide, hydrogen peroxide, and water. SC1 oxidizes and etches the surface of the wafer. This etching process, known as undercutting, reduces the physical contact area to which the particle binds to the surface, thus facilitating removal. However, a mechanical process is still required to actually remove the particle from the wafer surface.

[0005] For larger particles and for larger devices, scrubbers have been used to physically brush the particle off the surface of the wafer. However, as device sizes shrank in size, scrubbers and other forms of physical cleaners became inadequate because their physical contact with the wafers cause catastrophic damage to smaller devices.

[0006] The application of acoustic energy during wet processing has gained widespread acceptance to effectuate particle removal, especially to clean sub-micron particles off wafers (or plates) undergoing fabrication in the semiconductor process line. The acoustic energy used in substrate processing is generated via a source of acoustic energy. Typically, this source of sonic energy comprises a transducer which is made of piezoelectric material, such as a ceramic or crystal. In operation, the transducer is coupled to a source of electrical energy. An electrical energy signal (i.e. electricity) is supplied to the transducer. The transducer converts this electrical energy signal into vibrational mechanical energy (i.e. acoustic energy) which is then transmitted to the substrates being processed. The transmission of the acoustic energy from the transducer to the substrates is typically accomplished by a fluid that acoustically couples the transducer to the substrate. It is also typical that a material capabale of acoustic energy transmission be positioned between the transducer itself and the fluid coupling layer to avoid "shorting" of the electrical contacts on the piezoelectric material. This transmitting material can take on a wide variety of structural arrangements, including a thin layer, a rigid plate, a rod-like probe, a lens, etc. The transmitting material is usually produced of a material that is inert with respect to the fluid coupling layer to avoid contamination of the substarte.

[0007] The applciation of acoustic energy to substrates has proven to be a very effective way to remove particles and to improve the efficiency of other process steps, but as with any mechanical process, damage to the substarates and devices thereon is still possible. Thus, acoustic cleaning of substrates is faced with the same damage issues as traditional physical cleaning.

[0008] The acoustice energy generated by existing transducer assemblies is often energetic enough to cause some of the fragile structures that make up the electrical circuit to be damaged (i.e., removed or partially removed causing the circuit to no longer function). Through long-term study of existing transducer assemblies and the associated acoustic properties, the current inventors have determined that a myriad of problems exist both with the structure of the piezoelectirc material and the direction and orientation of the acoustice waves propogated by existing tranducer assemblies.

Summary of the Invention

[0009] It is therefore an object of the present invention to provide a system and method of cleaning substrates using sonic energy.

[0010] Another object of the present invention is to provide a system and method of processing substrates using sonic energy that reduces damage to devices on the substrates.

[0011] Still another object of the present invention is to provide a system and method of cleaning substrates using sonic energy that reduces damage to devices on the substrates while achieving suitable particle removal efficiency.

[0012] Yet another object of the present invention is to provide a system and method of processing substrates using sonic energy that controls cavitation within the processing fluid.

[0013] A yet further object of the present invention is to provide a system and method for processign substrates that results in less energy loss between the transducer and the substrate to be processed.

[0014] Another object of the present invention is to provide a system and method for processing substrates that results in a more uniform energy distribution on the surface of the substrate.

[0015] This invention is of an acoustic generation device formed using ceramic piezoelectric material formed into a radial section and segmented such that it is composed of individual acoustic generating pillars that can be interconnected to generate an acoustic wave that efficiently and precisely couples into a fluid acoustic transmission media applied to either the front and /or the back of a wafer. The radial nature of the piezoelectric element is designed so that the acoustic energy is directed into the acoustical transmission fluid and on to the wafer (or plate) surface and reflects away from the generating source, suppressing standing waves which contain nodes of very high energy and very low energy. The high energy regions can lead to structure damage and the low energy regions can lead to reduced removal of particles . Both these conditions are unwanted in the use of these transducers.

[0016] In one aspect, the invention can be an apparatus for generating acoustic energy comprising: a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced-apart manner so that spaces exist between adjacent pillars; the pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars; and the spaces filled with a resilient material so as to form a composite assembly.

[0017] In another aspect, the invention is an apparatus for processing articles with acoustic energy comprising: a transducer assembly comprising: a transmitting structure having a concave inner surface and a convex outer surface; a first transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure; a second transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure, the second active transducer spaced from the first active transducer so that a non-active acoustic energy area exists on the transmitting structure between the first and second transducers.

[0018] In yet another aspect, the invention is a method of constructing a device for generating acoustic energy comprising: providing a layer of supporting material; positioing a piezoelectric material atop the layer of adhesive material; cutting the piezolectric material into a plurality of pillars so that spaces exist between adjacent pillars; and filling the spaces with a resilient material to form a composite assembly.

[0019] In a further aspect, the invention can be a method of processing an article comprising: supporting an article on a support; providing a transducer assembly comprising a transmitting structure having a concave inner surface and a convex outer surface; a first transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure; a second transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure, the second active transducer spaced from the first active transducer so that a non-active acoustic energy area exists on the transmitting structure between the first and second transducers; positioning the trasnducer assembly adjacent to a surface of the article on the support and in an orientation wherein the non-active acoustic area of the transmitting structure faces the surface of the article; applying fluid to the surface of the article so that the convex bottom surface of the transmitting structure is fluidly coupled to the surface of the article; and activating the first and/or second transducers, thereby generating acoustic are propagated at the surface of the article at a non-normal angle that results in refelected acoustic waves travelling away from the transducer assembly.

Brief Description of the Drawings

[0020] Figure 1 is a schematic of a prior art transducer.

[0021] Figure 2 is a schematic illustrating an acoustic wave generated by the prior art tranducer of FIG. 1 having nodes and antinodes.

[0022] Figure 3A is a top view of an array of piezoelectric pillars supported on a wax base and used to create a transducer according to one emboidment of the present invention.

[0023] Figure 3B is a side view of the array of piezoelectric pillars of FIG. 3A.

[0024] Figure 3C is a perspective view of the array of piezoelectric pillars of FIG. 3A.

[0025] Figure 3D is a side view of the array of piezoelectric pillars of FIG. 3A with the spaces between pillars filled with a resilient material, according to one emboidment of the present invention.

[0026] Figure 3E is a side view of a composite assembly comprising the piezoelectric pillars with the spaces between pillars filled with a resilient material as shown in FIG. 3D, wherein the wax base has been removed, according to one emboidment of the present invention.

[0027] Figure 3F is a side view of a transducer incorpoarting the composite assembly of FIG. 3E according to one embodiment of the present invention, wherein a transmitting material is bonded to the bottom electrode.

[0028] Figure 4A is a schematic representation of the transducer of FIG. 3F wherein the electrodes are energized so that the individual pillars are generating acoustic energy waves, according to one embodiment of the present invention.

[0029] Figure 4B is a schematic representation of the transducer of FIG. 3F wherein the electrodes are energized so that the individual acoustic energy waves of the pillars effectively combine to forrm a plane wave profile, according to one ambodiement of the present invention.

[0030] Figure 5 is a side view of a composite transducer according to one embodiment of the present invention wherein an impedance matching layer has been added.

[0031] Figure 6 is a cross-sectional side view of a curved composite transducer according to one embodiment of the present invention.

[0032] Figure 7 is a perspective view of an acoustic processing system according to one emodiment of the present invention.

[0033] Figure 8 is a cross-sectional view of the transducer assembly of the acoustic processing system of Figure 7 along perspective VIII-VIII.

[0034] Figure 9 is a diagram of the tranducer assembly of FIG. 8 showing one set of preferred dimensions.

[0035] Figure 10 is a perspective view of an acoustic processing system according to a second emodiment of the present invention wherein a small composite transducer assembly is moved across the surface of a wafer by a support rod.

[0036] Figure 11 is a perspective view of an acoustic processing system according to a third emodiment of the present invention wherein a composite transducer assembly extends acroos the entire diameter of a wafer.

[0037] Figure 12 is a perspective view of the acoustic processing system of FIG. 11 processing a rectangular panel.

[0038] Figure 13 is an illustration of different shapes in which a curved composite trasnducer according to the present invention can be constructed.

[0039] Figure 14 is a graph comparing acoustic levels generated at varoious distances along a wafer for a transducer assembly according to the present invention and three prior art transducer configurations.

Detailed Description of the Drawings

[0040] Refernng to FIG. 1, a typical prior art transducer **1** used in existing acoustic processing systems is illustarted. While the exact shape and orientation of the prior art transducer **1** used in the industry varies, all known prior art transducers **1** are large flat plate structures. It has been discovered that these prior art transducers **1** have an issue in that when they are driven with electrodes **2, 3** on opposite sides the plate and the piezoelectric material **4** is set into oscillation by its inherent piezoelectric effect, the resulting oscillations tend to be multi-nodal depending on the exact shape of the flat plate structure. As can be seen in FIG. 2, this in effect launches a complicated acoustic wave **5**. This acoustic wave 5 has a non uniform energy pattern.

[0041] In addition, if the transducer **1** is positioned so that its major surfaces are parallel to a substarte to be processed (i.e., the acoustic wave **5** propogates in a direction perpendicular to the surface of the substarte), the acoustic wave **5** reflects off the surface of the wafer and returns toward the transducer **1**. This creates a standing wave. In fact, the standing wave problem has been discovered to exist even in transducer arrangements where the acousic energy wave is transmitted parallel to the surface of the wafer but has a radial component that is normal to the wafer.

[0042] A standing wave consists of nodes and antinodes and therefore in terms of energy, subjects the wafer to localized areas of high and low energy points. The wave returning to the transducer **1** dissipates heat into the transducer **1** and consequently requires some form of cooling, either liquid and/or gas. Without cooling, some of the components associated with the construction can be quickly degraded. The impedance of a typical ceramic or crystal piezoelectric material also changes as a function of temperature. If the temperature changes from the temperature at which it was matched to the power supply (fixed match to 50 ohm load) the piezoelectric material dissipates additional energy in the material as heat. This further heats the transducer **1** causing still more changes in impedance. Left unchecked, this will lead to failure of the transducer **1**.

[0043] Referring now to FIGS. 3A-3F, a composite transducer **100** and its construction at according to one emboidment of the pressent inevntion will be decribed. To begin, a typical flat stock piece of a piezoelectric material is provided (not shown). The piezoelectric material can be a ceramic, crystal or any other material capable of converting electrical energy to mechanical energy. The flat stock piece of piezoelectric material is then placed on a wax base **10** or other supporting material, such as an adhesive. In soe emboidment, the supporting material may be an electrode (discussed later). The supporting material can be any material or structure capable of performing the supporting function described below.

[0044] Referring now to FIGS. 3A-3C exclusively, once the flat stock piezoelectric material is placed on the wax base **10**, the piezoelectric material is cut into pieces in both x and y planes, thereby forming an array of pillars **20** of the piezoelectric material. During the cutting process the saw preferably cuts only through the flat stock piezoelectric material, and not the wax base **10**. The wax base **10** holds the pillars **20** in place in their spaced apart and generally upright orientation. A plurality of intersecting channels are formed between the pillars **20** thereby providing spaces **30** between adjacent pillars **20**. While the pillars **20** are in an euqally spaced-apart array configuation in the illustarted emboidment, other configurations and geometric patterns can be achieved. Moreover, if desired, the pillars **20** can take on other geometric shapes, including cylindical, radial segemnt, eyc. In order to avoid clutter, only a few of the pillars **20** and spaces **30** are numerically identified in the drawings.

[0045] Each of the pillars **20** has a height **H** defined by the distance between its bottom surface **21** and its top surface **22**. Each of the pillars also has a width **W**. It is preferable that the height H of the pillars **20** be greatern than the width **W**. It is even more prefered that the height **H** be twice the width **W** or greater. It is also preferred that pillar width **W** and the width of spaces **30** be approximately equal, or at the very least of the same magntude. In other embodiments, it may be preferred that the width of the spaces **30** be smaller than the width **W** of the pillars **20**.

[0046] Moreover, from a functionality standpoint, it is also preferred that the width **W** of the pillars **20** and the width of the spaces **30** be less than a wavelength of the acoustic energy waves to be generated by the composite transducer **100**. For the example, for a pillar **20** operating at a 1MHz frequency, the preferred dimensions are that the height **H** of the pillar **20** be approximately 1.6mm, the width **W** of the pillar **20** be approximately 0.8mm or less, and thw width of the surrounding spaces **30** be less than or equal to 0.8mm in the active areas. In other embodiments which are described later, it may be desirable to have not acoustically active areas. There are various means to create active and non-active acoustical generating areas described later.

[0047] Referring now to FIG. 3D, once the pillars **20** are created, the spaces **30** are backfilled with a curable filler **40**. In one emboidment, the curabel filler is preferably a resilient material **40**. Other examples of curable fillers include elastomers and epoxies. Once the filler **40** cures, the wax base **10** is removed, thereby resulting in a composite assembly **50** formed by the pillars **20** of piezoelectric elements separated by the filler **40**. The composite assembly is shown in FIG. 3E.

[0048] Referring now to FIG. 3E, the composite assembly **50** comprises a bottom surface **51** and a top surface **52**. As will be describe din detail below, the composite assembly **50** can be formed or later shaped so as have curvature.

[0049] Referring now to FIG. 3F, once the composite assembly **50** is in the desired shape (which is flat in the illustarted embodiment), an electrically conductive material is applied to the bottom and top surfaces **51, 52** of the composite asembly **50**, thereby forming electrodes **61, 62**. As a result, a transducer **100** according to one emboidment of the present invention is formed. The electrcially conductive material used to form the electrodes **61, 62** can be a metal, such as silver, an electrically conductive epoxy, or any material that can conduct an electric current to excite the piezoelectric pillars **20**.

[0050] As will described in gerater detail below, in certain situations it may be desirable to only energize a certain one or subsets of the piezoelectric pillars **20**. Thus, while the electrcodes **61, 62** are shown as being applied to entirety of the bottom and top surfaces **51, 52** of the composite assembly **50**, in other emboidments the electrodes **61, 62** may cover only selected areas that are electrically isoltaed from one another (as shown in the embodiment of FIG. 6).

[0051] When the transducer **100** is to be used in conjunction with the wet processing of articles, it may be desirable to shield the transducer **100** (and its electrodes) from the processing liquid so as to avoid shorting and/or contamination of the processing fluid. This can be achieved by bonding a transmitting structure **70** (generically illustrarted) to the transducer **100**. As illustrated in FIG. 3F, the transmitting structure **70** is bonded directly to the transducer **100**. The transmitting structure **70** can be constructed of a wide varierty of materials, shapes and dimensions. Depending on the intended fuction, the transmitting structure can be a rigid structure or a thin film or foil. Suitable materials for the transmitting structure **70** include polymers, quartz, sapphire, boron nitride vitreous carbide, stainless steel, or any other material that can effectively transmit acoustic energy to facilitate the intended processing.

[0052] In one emboidment, it may be preferred that the transmitting structure **70** be a polymer film. Suitable polymers include materials like Halar (ECTFE), Polyvinylidene Fluoride (PVDF), Polysulfone or other polymers. The thickness of the polymer film can preferably range from 0.1 mil to 18 mil, and more preferably range from 1 mil to 5 mil. These polymer films may be treated chemically or other wise manufactured to improve the surface characteristics of the material to provide a low surface tension toward the processing fluid.

[0053] Referring now to FIG. 4A, a schematic representation of the transducer **100** energized so as to generate acoustic energy. Electricity is supplied to the electrodes **61, 62** by wires that are operably connected to a source of electricity. The electricity is converted by each of the piezoelectric pillars **20** into independent acoustic waves **80**. As can be seen, the pillars **20** act as independent pistons, each generating its own independent acoustic wave **80** in a direction that is substantially parallel to its height **H**.

[0054] However, as can be seen in FIG. 4B, the summary effect of the acoustic waves **80** is the launching of a plane wave that is free of nodes of anti-nodes. As the pillars **20** extend in their axial direction (i.e., vertically along their height **H**) by the piezoelectric effect, the pillars **20** contract by Poisson's ratio in the lateral direct (i.e., horisontally along their width **W**). Similarly, when the pillars **20** contract in their axial direction by the piezoelectric effect, the pillars **20** expand by Poisson's ratio in the lateral direct. However since the spaces **30** are filled with a resilient material, any waves generated in the lateral direction are greatly dampened or suppressed. This in effect launches the plane wave from the surface of the transducer **100**.

[0055] As mentioned above, the pillars **20** can be energized independently or grouped in subsets to create acoustically active areas and acoustically inactive areas. Pillars **20** that have no opposing electrodes or do not have thier electrodes energized, do not have the piezoelectric effect and do not launch an acoustic wave. Thus the extent of the acoustically active area can be tailored to the precise situation desired. In addition, if areas of the transducer **100** (or assmebly in which the device is to be used) are not required to be acoustically active, these sections can have the piezoelectric pillars **20** removed from the composite and filled with a resilient material or left as a void.

[0056] Referring now to FIG. 5, an emboidment of the transducer **100** is illustared wherein a matching layer **75** is added between the transmitting structure **70** and the electrode. Thematching layer**75** (or layers) are preferably chosen to act as impedance matching layers to reduce energy loss during transmission of acoustic energy to the processing fluid. In other words, the matching layer **(75)** is designed acoustically so that the acoustic wave is efficiently coupled into the transmission fluid and not reflected at the interface. As an example, a ¼ wave epoxy matching layer (Approximately 0.029") and a very thin polymer (Halar film) which is acoustical transparent can be used as the matching layer **75** and the transmitting structure **70** respectively. In design variations, as the external polymer film thickness is increased and is seen as part of the acoustical layers; then the polymer film is included as a matching layer and all layer thickness and properties are adjusted to efficiently transfer the acoustical energy from the piezoelectric pillars **20** to the processing fluid

[0057] Referring now to FIG. 6, a transducer **100** having a radius of curvature is illustarted according to one embodimet of the present invention. In certain processing applications of articles, it may be desirable for the trasnducer **100** to take a curved shape to effectuate acoustic energy control and fluid coupling to the article.

[0058] The curved transducer **100** of FIG. 6 can be formed by either forming the composite assembly **50** to have a radius of curvature during the the setps discussed above or manipulating the composite assembly **50** subsequent to being formed in a flat shape. The electrodes **61, 62** and the transmitting structure **70** (and any matching layers) can be bonded to the composite assembly **50** before or after the curvature is formed. In Figure 6, these materials were bonded prior to forming the curvature. As an alternate order of construction, the composite assembl **50** alone can be formed in a curved form and then the electrodes **61, 62** and transmitting structure **70** (and impedance matching layers if any) can be bonded in later steps. The transmitter structure **70** is typically included after the curvature forming process and in the next steps of assembly.

[0059] The transmitting structure **70** comprises a convex outer surface **71** and a concave inner surface **72**. The transducer **100** is bonded to the concave inner surface **71**. As can be seen, the top electrodes **62** are applied as two isoltaed regions on the top surface of the composite assmebly **50**. Thus, when the trasnducer is energized by applying an electrical signal to the electrodes **61, 62**, only those pillars **20** covered by the electrodes **62** will generate acoustic energy, thereby resulting in two separate acoustically active regions **A, B**. Because the central region of the composite assembly **50** does not receive an electric signal as a result of there being no electrode **62** in that region, the pillars **20** in that region do not generate acoustic energy, thereby resulting in an acoustically inactive area **C**. The acoustically active regions **A, B** are circumferantially separated by the acoustically inactive area **C**.

[0060] The pattern of the electrodes **61, 62** to create the active piezoelectric pillars **20** can be varied to change the acoustical energy pattern to any desired configuration. Reduced electrode pattern area can also reduce the effective acoustical strength in a given area. In addition, areas of the composite assembly **50** where no acoustical energy is required may be made inactive by not ony omitting electrodes in that area, but also may have electrodes that do not receive power, or these areas can have the composite assembly **50** removed and/or lefta s void or replaced with a resilient material. In alternate embodiments, the piezoelectric pillars **20** can be grouped, and each group would have its own electrode(s) **61, 62** and power/control wire. This would allow each group of pillars **20** to be controlled independently by an outside controller. This allows for each group of pillars to have its own power level, operating frequency, on/off cycle time. In other embodiments, the outer electrode can be divided into multiple regions. Each electrode would have its own power/control wire. This is an alternate method to control the active region(s) of the device.

[0061] Referring now to FIG. 7 , a megasonic system **1000** for processing a flat article **400** is illustarted. The megasonic system **1000** comprises a rotary support (not visible) upon which the artcile is supported in a generally horizontal orienattion and rotated. The megasonic system **1000** also comprises a transducer assembly **200** that is positioned adjacent to and opposing an upper surface **401** of the artcile **400**. The trasnducer assembly **200** is supported in a cantilevered fashion by the support mechanism, generically illustarted at block **210**. If desired, the support mechanism can be capable of translational and/or pivotal movement. The transducer assembly **200** is supported sufficiently close to the surface **401** of the article so that when the dispenser **300** applies a liquid to the surface of the wafer, a liquid film of the liquid couples the trasnducer assembly **200** to the surface **401** so that acoustic energy generated by the transducer assembly **200** can be transmitted to the article **400**. The general concept of such single-article acoustic-assisted processing systems are known in the art and disclosed in such patents at U.S. Patent 6,684,891, to Mario Bran, the entirety of which is incorporated by reference.

[0062] The trasnducer assembly **200** is supported substantially paralle to the surface **401** of the artcile **400**. While the trasnducer assembly **200** is illustarted as an elongated rod-like probe, the invention is not so limited. It is to be understood that the tranducer assembly can take on a wide variety of shapes, orientations, and structural arrangements.

[0063] Referring now to FIG. 8, a cross-sectional view of the transducer assembly **200** is illustrated. The transducer assembly **200** incorpoates the curved transducer described in FIG. 6 above except that a impedance matching layer **75** has been incorpoated and the transmitting structure **70** is in the shape of a tubular element. In this emboidment, the transmitting structure **70** is a protective polymer film extended over a supporting structure **90** that plays no role acoustically in the device, but supplies rigidity and structural integrity. In an alternative emboidment, the transmitting structure **70** can be constructed of a material and/or thicknes that is sufficiently rigid to provide the necessary structural integrity for supporting. For example, the trasnmitting structure **70** can be constructed of quartz, sapphire, fused silica, or other materials that are inert to the chemicals and/or liquid used. in the processes.

[0064] The transmitting structure **70** is the form of a cylindrical tube and comprises an outer surface **71** and inner surface **72**. Of course, the transmitting structure **70** can take other curved embodiemnts, such as a lens, a curved plate, a par-cylindrical trough, etc.

[0065] Electrical wires **63, 64** are operably connected to the electrodes **61, 62** and routed through the transducer assembly **200** to the outside where they are connected to a source of an electircal signal. The source of electricity provides an electical signal that drives the piezoelectric pillars **20** located in the active areas **A, B** of the composite tranducer **100** to geenrate waves **80** of acoustic energy. Preferably, the wave **80** of acoustic energy have a frequency that is in the megasonic range, and more preferably between 500KHz and 5MHz.

[0066] The composite trasnducer **100** is bonded to the inner surface **71** of the transmitting stcurture **70** at the bottom circumferential prtion so that the waves **80** of acoustice energy generated by the acoustically active sections **A, B** of the composite transducer **100** are transmitted into the layer of liquid **310** on the article surface **401**. Through a combination of the rotational orientation of the transducer assembly **200** and the circumferential spacing between the acoustically active sections **A, B** of the piezoelectric pillars **20**,the plane waves **80** of acoustic energy are transmitted through the liquid layer **310** to the surface **401** of the article **400** at an angle so that the waves **80** do not reflect back into the transducer assembly **200**. Instead, the waves **80** reflect off the article **400** and angle harmlessly away from the tranducer assembly **200**.

[0067] In other words, by having only those pillars **20** on the two upper edges electrically active, acoustic waves launched from these pillars **20** do not reflect back to the transducer **100**, thereby suppressing standing waves. The pillars **20** that would generate a standing wave (those in acoustically inactive region **C**) are not electrically connected with electrodes.

[0068] The transmitting structure **70** forms an internal cavity **95**, may be left as a void filled with air or another gas, or optionally may be filled with a dampening material which dampens acoustic energy that may be applied to the backside of the transducer **100** inside of this construction. The presence of a dampening material suppresses any undesirable acoustical energy. The transmitting structure **70** is sealed such that the liquid **310** cannot breach the cavity **95** and the material inside of the cavity **95** cannot get outside to contaminate the liquid **310** and potentially the article, which may be a semiconductor wafer or solar panel having deleciate structures.

[0069] It may also be desirable to have the outer surface of the transmitting structure **70** treated or altered to have a low surface tension toward the transmission liquid **310** so at least partial wetting occurs. Air pockets, bubbles or voids will cause reflections of acoustical energy back to the transducer.

[0070] Referring to FIGS. 7 and 8 concurrently, a method of clean[illegible] a semiconductor wafer **400** using the system **1**[illegible]ill be described. First, a semiconductor wafer **400** is positioned on the rotatable support where it is supported in a generally horizontal orienttaion. The wafer **400** is then rotated, as indicated by the arrow. A liquid medium **31**[illegible]n dispensed via the dispenser [illegible] onto the top surface **401** of the wafer **400**. The liquid can be any chemical, solution or the like used in processing wafers, such such as DI water, SC1, SC2 ozonoated DI water, etc.

[0071] The transducer assembly **200** is p[illegible]ed adjacent the surface **401** of the wafer so [illegible] a small gap exists between the bottom of the transmitting structure **70** and the surface **401** of the wafer **400**. The trasnducer assembly is just larger than a radius of the wafer **400**. For example, for a 300 mm silicon wafers, the transducer assembly 200 would be rod like [illegible]mm long rod with 150mm of active acoustical length.

[0072] As the wafer **400** rotates, the liquid **310** supplied to the surface **401** forms a layer of liquid **310** that fluidly couples the transducer assembly **200** to the wafer **400**. Electricity is then supplied via the wires, **63, 64** to excite the pillars **20** in the active regions **A, B**, thereby geenrating acoustic energy waves **80** at the desired frequency and power level. The waves **80** of acoustic energy are then transmitted outward through the trasnducer assembly **200** in an angled amnner and enter the liquid layer **310**, eventually contacting the wafer surface **401**. Rotating the wafer **400** on the chuck beneath the trasnducer assembly **200** provides complete acoustic coverage of the surface **401**. The acoustic energy waves **80** dislodge particles from the wafer surface **401**, thereby effectuating cleaning.

[0073] As shown in FIG. 9, the acoustically active areas **A, B** are spearated by an acoustically inactive area **C** of at least 45 degrees or more. This ensures that the waves **80** do not reflect abck into the transducer assembly **200**. Of course, the size of the inactive area **C** will be dictated by the curvature of the structure and other characteristics. Furthermore, while the inner and outer surfaces **71, 72** of the transmitting structure **70** are shown as curved surfaces, it is possible that the angled wave application technique of the present invention can be accomplished by using planar surfaces that are angled to one another. Thus, the terms curved, convex, and concave are intended to cover embodiments wherein planar surface are angulalary oriented with respect to one another to acheiev the same effect.

[0074] Referring now to FIG. 10, a second embodiment of a system **2000** according to the present invention is illustrated. In this emboidment, the composite transducer assembly **200** is a short segment of the transducer assembly of the first system **1000**. This short segment transducer **200** is is attached to a support arm **90** that traverses the rotating chuck in a radial manner. The radial scan can be programmed to account for the area of the wafer increasing as the transducer moves toward the outer edge. The acoustical transmission media **310** would be dispensed onto the wafer surface **401** as set forth above to achieve the fluid coupling. The acoustical device **200** would be rod like 24mm long with 20mm of active acoustical length.

[0075] Referring now to FIGS. 11-12, a third embodiment of a system **3000** according to the present invention is illustarted processing articles of different shape. In this emboidment, the composite transducer **200** is a full diameter (or width) of the object **400** to be treated. The transducer **200** could be held in place and the object (wafer, plate etc.) could be linearly scanned beneath the transducer **200**. The acoustical transmission media would be dispensed onto the wafer/plate surface.

[0076] In each instance the desired goal is to suppress structure damage from the acoustic energy applied to the surface, yet having sufficient energy to remove particles. Using composite piezoelectric material, it is also possible to make a transducer that is made up of many segments (extending the composite pattern) so that the length can be any dimension in principal. Furthermore, the general shape is not required to be a round rod, alternative variations in the shape of the device can enhance the characteristics of the device, as shown in FIG. 13.

[0077] The foregoing description of the preferred embodiment of the invention has been presented for the purpose of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto.

Claims

What is claimed is:

1. An apparatus for generating acoustic energy comprising:

a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced-apart manner so that spaces exist between adjacent pillars;

the pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars; and

the spaces filled with a resilient material so as to form a composite assembly.

2. The apparatus of claim 1 wherein the spaces between adjacent pillars and the width of the pillars are substantially equal.

3. The apparatus of claim 1 wherein the height of the pillars is at least twice the width of the pillars.

4. The apparatus of claim 1 wherein the height of the pillars is about twice the width of the pillars.

5. The apparatus of claim 1 further comprising:

a first electrode on the bottom surface of the pillars;

a second electrode on the top surface of the pillars; and

a source of electricity operably coupled to the first and second eletcrodes so that each one of the pillars generate an acoustic wave from the bottom surface.

6. The apparatus of claim 1 wherein the spaces between adjacent pillars and the width of the pillars are of the same magnitude.

7. The apparatus of claim 1 further comprising:

a first electrode on the bottom surface of the pillars;

a second electrode on the top surface of the pillars;

a source of electricity operably coupled to the first and second eletcrodes so that each one of the pillars generate an acoustic wave having a frequency and a wavelength from the bottom surface; and

wherein the width of the pillars and the spacing between adjacent pillars is less than the wavelength of the acoustic wave.

8. The apparatus of claim 7 wherein the frequency of the acoustic wave is in the megasonic range.

9. The apparatus of claim 1 further comprising:

electrodes on the top and bottom surfaces of the array of pillars;

a source of electricity operably coupled to the eletcrodes; and

the electrodes arranged in a manner that allows either individual pillars or subsets of the plurality of the pillars to be operated independently to generate isolated acoustic waves.

10. The apparatus of claim 1 wherein the bottom surfaces of the pillars have a radius of curvature.

11. The apparatus of claim 1 further comprising:

a first electrode on the bottom surface of the pillars;

a second electrode on the top surface of the pillars;

a source of electricity operably coupled to the first and second electrodes and adapted so that each one of the pillars generate an independent acoustic wave in a manner such that the indpendent acoustic waves together act as a plane wave.

12. The apparatus of claim 1 further comprising a transmitter material bonded to a bottom surface of the composite assembly.

13. The apparatus of claim12 wherein the transmitter material is a polymer film.

14. The apparatus of claim 12 further comprising an impedance matching layer between the transmiter material and the bottom surface of the composite assembly.

15. The apparatus of claim 14 wherein the impedance matching layer is an epoxy.

16. The apparatus of claim 1 wherein the composite assembly has a bottom surface having a radius of curvature.

17. The apparatus of claim 16 further comprising a transmitter material bonded to a bottom surface of the composite assembly and an impedance matching layer between the transmiter material and the bottom surface of the composite assembly.

18. The apparatus of claim 16 wherein an outer surface of the transmitter material which comes into contact with a coupling fluid is treated to decrease surface tension toward the coupling fluid.

19. The apparatus of claim 1 further comprising:

the composite assembly having a bottom surface having a convex radius of curvature and a top surface;

electrodes operably connected to the top and bottom surfaces of the composite assembly; and

a transmitting structure having a convex outer surface and a convex inner surface, the composite assembly incuding the electrodes bonded to the concave inner surface of the transmitting structure.

20. The apparatsu of claim 19 wherein the composite assembly is located within an enclosed space.

21. The apparatus of claim 20 wherein the enclosed space is filled with an acopustic dampening material.

22. The apparatus of claim 19 wherein the transmitter structure is a hollow rod-like structure.

23. An apparatus for processing articles with acoustic energy comprising:

a transducer assembly comprising:

a transmitting structure having a concave inner surface and a convex outer surface;

a first transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure;

a second transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure, the second active transducer spaced from the first active transducer so that a non-active acoustic energy area exists on the transmitting structure between the first and second transducers.

24. The apparatus of claim 23 wherein the first and second transducer are spaced from one another by at least 45 degrees of the concave inner surface.

25. The appataus of claim 23 further comprising:

a support for supporting an article to be processed;

a conduit for applying a fluid to a surface of the article;

the transducer assembly positioned adjacent to and opposing the surface of the article so when the fluid is applied to the surface of the article by the conduit, the convex bottom surface of the transmitting sturcture is fluidly coupled to the surface of the article; and

the transducer assembly oriented so that the non-active acoustic area of the transmitting structure faces the surface of the article.

26. The apparatus of claim 25 wherein the support is a rotatble support.

27. The apparatus of claim 25 wherein the support is a translational motion support.

28. The apparatus of claim 25 wherein the transducer assembly is oriented so that acoustic waves generated by the first and second transducers are propagated at the surface of the article at a non-normal angle that results in refelected acoustic waves travelling away from the transducer assembly.

29. The apparatus of claim 23 wherein each of the first and second transducers are formed by a composite assembly comprising a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced-apart manner so that spaces exist between adjacent pillars; the pillars having a width and a height extending between a top surface and a bottom surface,

wherein the height of the pillars is greater than the width of the pillars; and the spaces filled with a resilient material so as to form a composite assembly.

30. A method of constructing a device for generating acoustic energy comprising:

providing a layer of supporting material;

positioning a piezoelectric material atop the layer of adhesive material;

cutting the piezoelectric material into a plurality of pillars so that spaces exist between adjacent pillars; and

filling the spaces with a resilient material to form a composite assembly.

31. The method of claim 30 wherein the pillars have a width and a height, the height being greater than the width.

32. The method of claim 30 wherein the height of the pillars is at least twice the width of the pillars.

33. The method of claim 30 further comprising:

applying an electrically conductive material to at least a portion of a top surface of the composite assembly; and

applying an electrically conductive material to at least a portion of a bottom surface of the composite assembly.

34. The method of claim 30 wherein the supporting material is a wax or an adhesive.

35. The method of claim 30 further comprising:

forming the composite assembly so that a bottom surface of the composite assembly has a radius of curvature.

36. The method of claim 35 further comprising:

applying an electrically conductive material to at least a portion of a top surface of the composite assembly; and applying an electrically conductive material to at least a portion of the curved bottom surface of the composite assembly.

37. The method of claim 35 further comprising:

bonding a transmitting material to the electrically conductive material on the bottom surface of the composite assembly.

38. The method of claim 37 wherein the transmitting material is sapphire or quartz.

39. The method of claim 37 wherein the transmting material is a polymer film.

40. The method of claim 37 wherein the transmitting material has a convex outer surface.

41. The method of claim 40 wherein the electrically conductive material applied to the top surface of the composite assembly in two electrically isoltaed sections separated by a non-active area.

42. The method of claim 40 further comprising:

treating the outer surface of the transmitter material to decrease its surface tension with a fluid.

43. The method of claim 40 wherein the transmitting material forms an internal cavity in which the composite assembly is located, the method further comprising: filling the internal cavity with a dampening material.

44. A method of processing an article comprising:

supporting an article on a support;

providing a transducer assembly comprising a transmitting structure having a concave inner surface and a convex outer surface; a first transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure; a second transducer having a convex bottom surface bonded to the concave inner surface of the trasmitting structure, the second active transducer spaced from the first active transducer so that a non-active acoustic energy area exists on the transmitting structure between the first and second transducers;

positioning the trasnducer assembly adjacent to a surface of the article on the support and in an orientation wherein the non-active acoustic area of the transmitting structure faces the surface of the article;

applying fluid to the surface of the article so that the convex bottom surface of the transmitting structure is fluidly coupled to the surface of the article; and

activating the first and/or second transducers, thereby generating acoustic are propagated at the surface of the article at a non-normal angle that results in refelected acoustic waves travelling away from the transducer assembly.

45. The method of claim 44 wherein each of the first and second transducers are formed by a composite assembly comprising a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced-apart manner so that spaces exist between adjacent pillars; the pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars; and the spaces filled with a resilient material so as to form a composite assembly.

46. The method of claim 44 wherein the support is capable of rotation or tranlsation of the article.

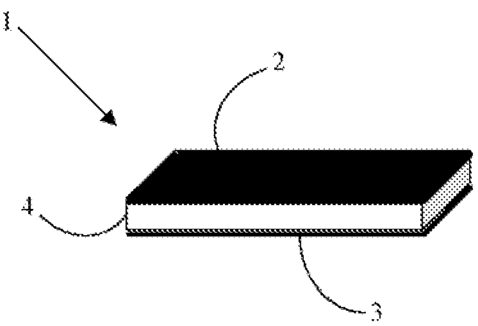

Figure 1 (Prior Art)

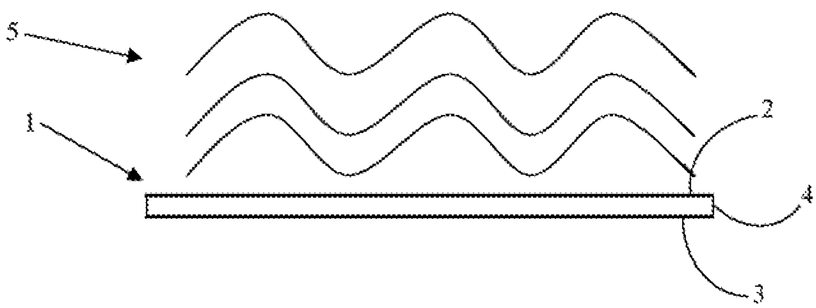

Figure 2 (Prior Art)

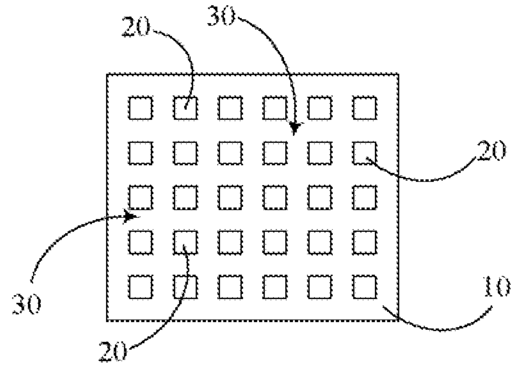

Figure 3A

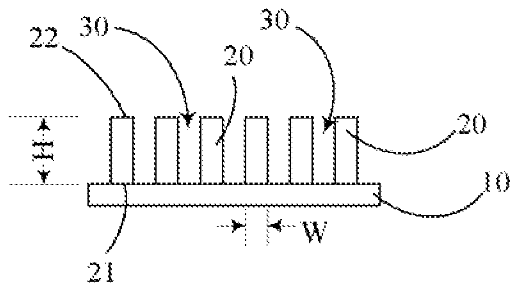

Figure 3B

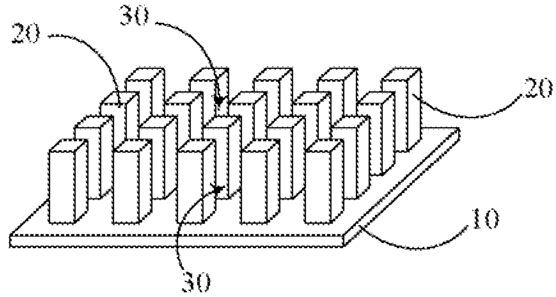

Figure 3C

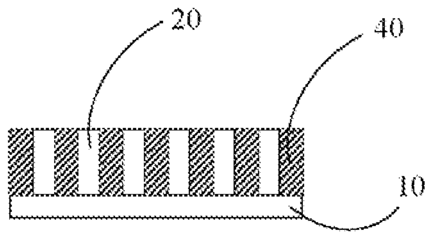

Figure 3D

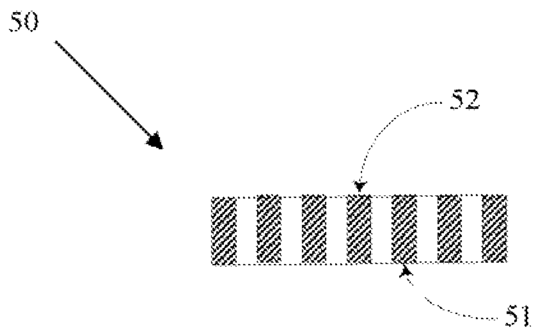

Figure 3E

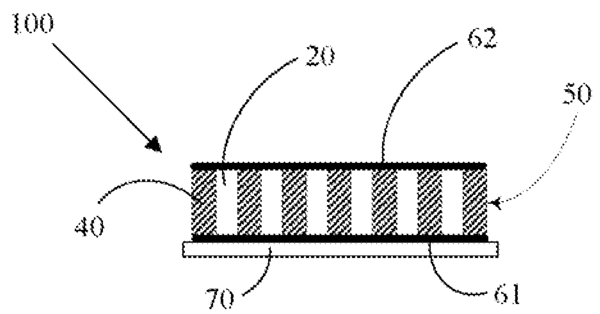

Figure 3F

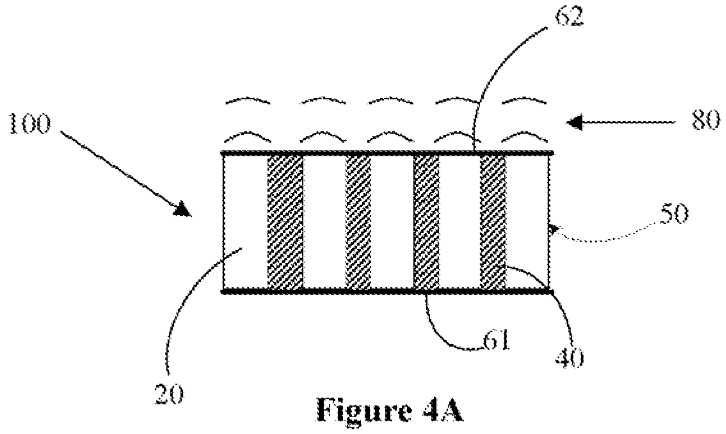

Figure 4A

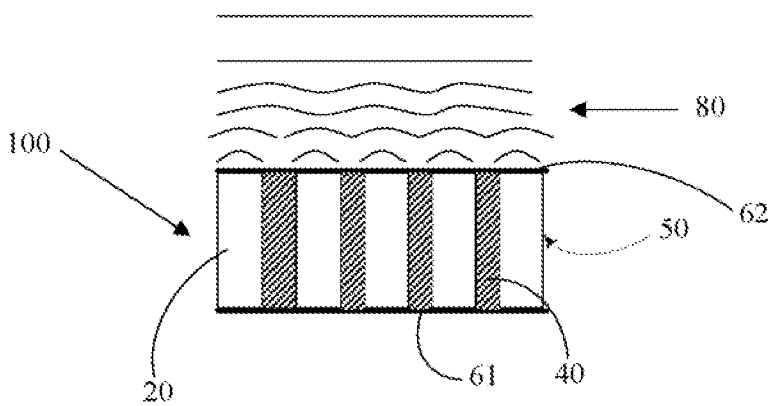

Figure 4B

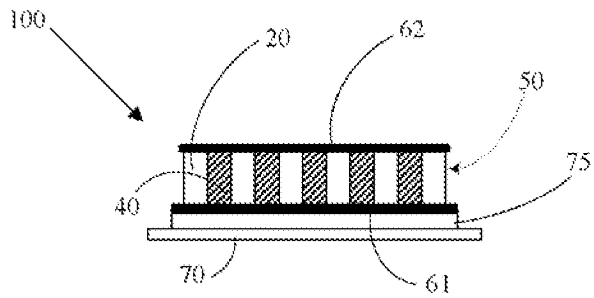

Figure 5

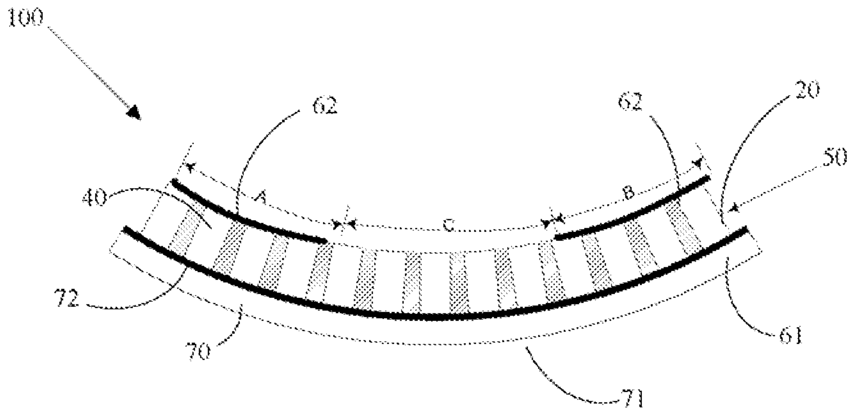

Figure 6

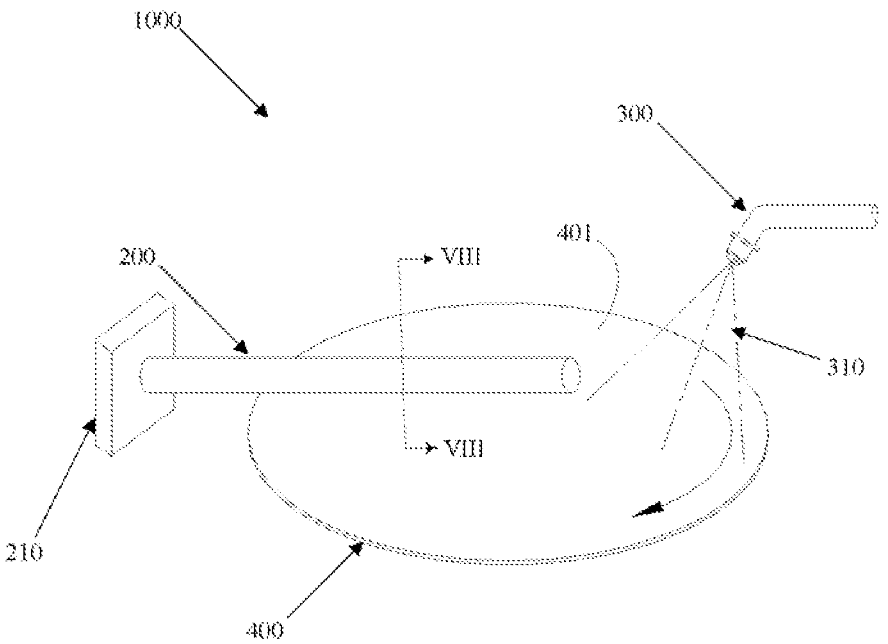

Figure 7

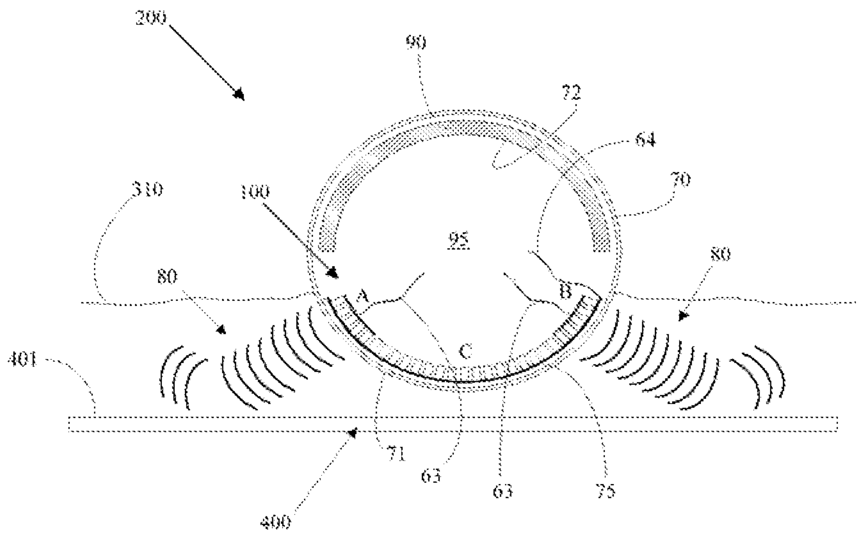

Figure 8

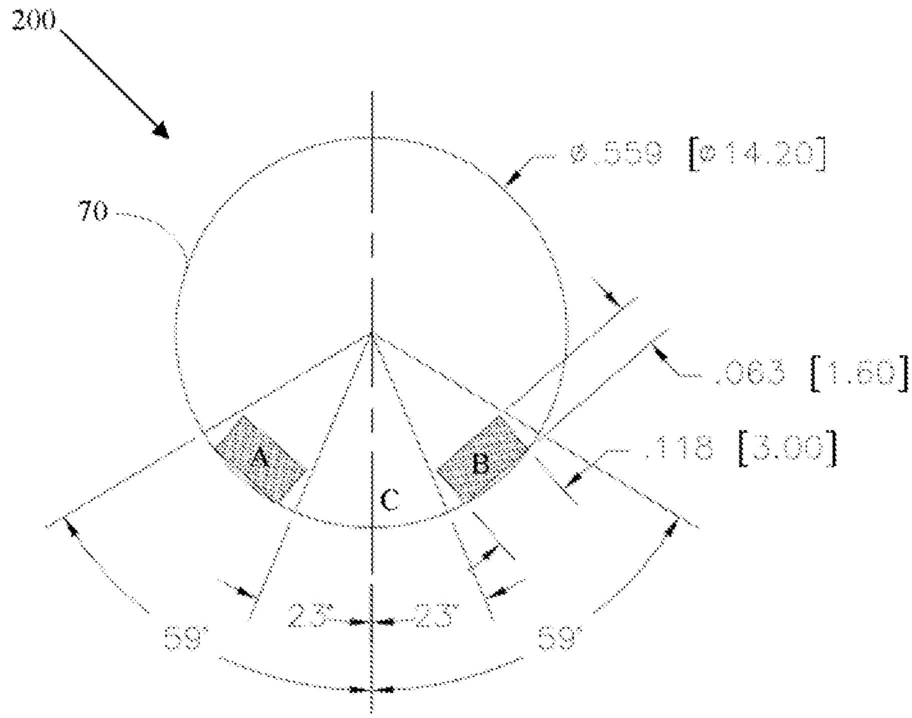

Figure 9

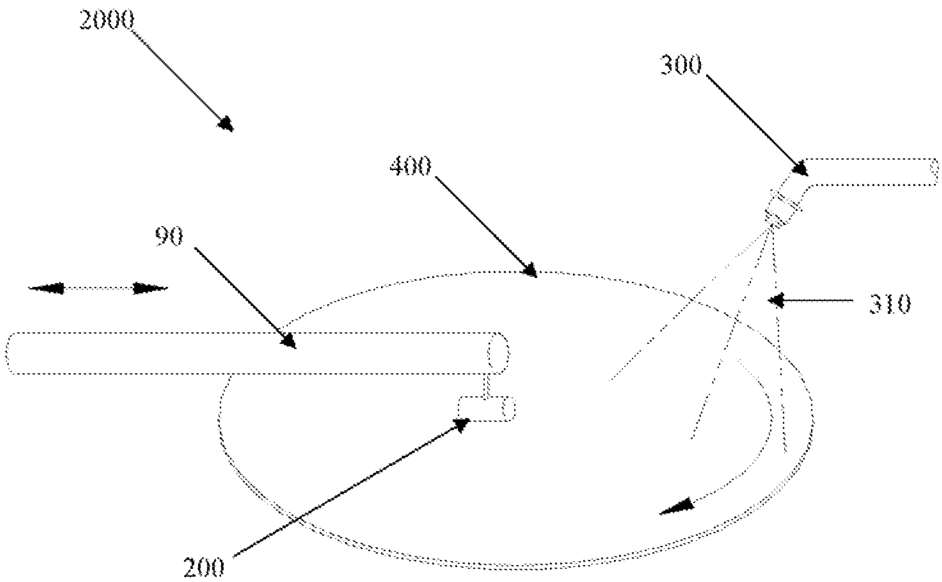

Figure 10

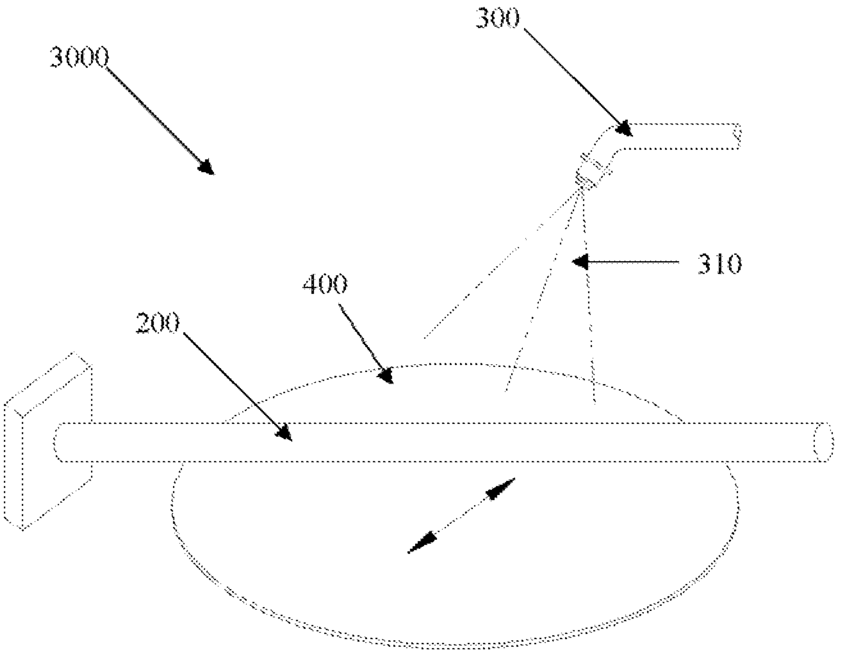

Figure 11

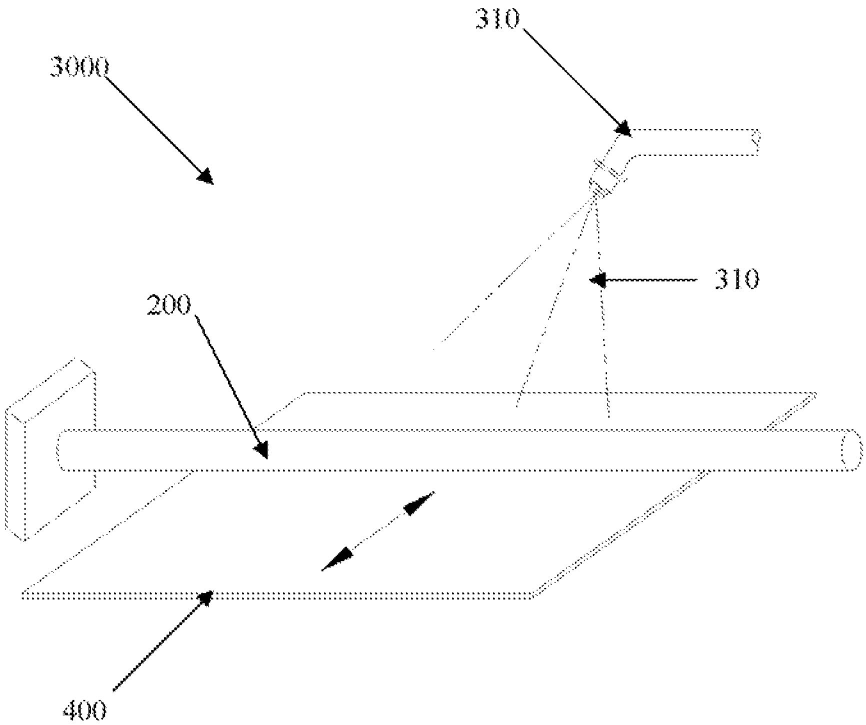

Figure 12

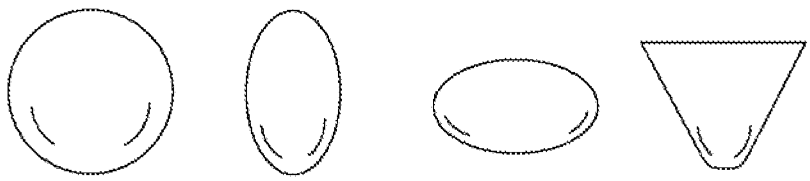

Figure 13

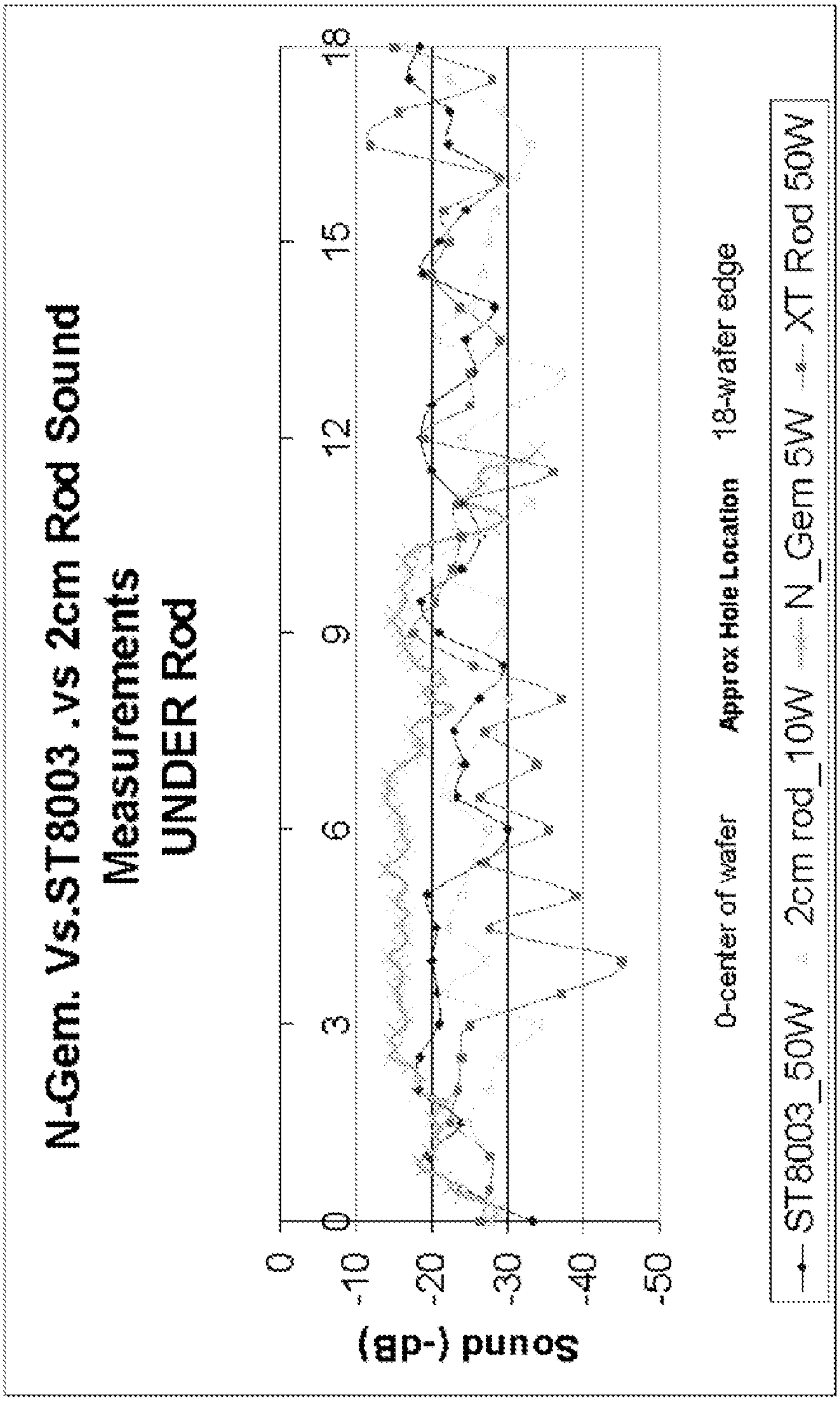
N-Gem. Vs.ST8003 .vs 2cm Rod Sound Measurements UNDER Rod
Sound (-dB)
0
-10
-20
-30
-40
-50
0
3
6
9
12
15
18
0-center of wafer
Approx Hole Location
18-wafer edge
ST8003_50W
2cm rod_10W
N_Gem 5W
XT Rod 50W

Figure 14

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 08/82701

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B06B 1/06, G10K 11/00 (2009.01)
USPC - 73/632, 310/334, 310/336
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)
USPC: 73/632, 310/334, 310/336

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 73/632, 310/334, 310/336 (text search)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Electronic Databases Searched: USPTO WEST (PGPUB, EPAB, JPAB, USPT), Google Patent, Google Scholar.
Search Terms Used: electrically adj conduct$, inner surface, outer surface, sapphire, fill$ or composite, electrically adj conduct$, fill$ or composite, second adj transducer, concave or convex, transmit$, concave

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 6,758,094 B2 (Miller et al.) 06 July 2004 (06.07.2004), entire document especially abstract; figure 2 A-B; col 4, ln 14-40; col 6, ln 06-08; col 5, ln 51-64; col 4, ln 15-18; col 6, ln 01-12; col 4, ln 02-08; col 3, ln 60-62	1-22, 30-43
Y	US 3,260,991 A (Laakmann et al.) 12 July 1966 (12.07.1966), especially col 5, ln 17-21	1-22, 30-43
Y	US 4,672,591 A (Breimesser et al.) 09 June 1987 (09.06.1987), col 2, ln 6-8	15
Y	US 6,755,352 B1 (Toda) 29 June 2004 (29.06.2004), especially figure 2; col 4, ln 8-29; col 5, ln 23-41; col 5, ln 23-41	5, 7-9, 11, 19-22, 41
Y	US 5,629,578 A (Winzer et al.) 13 May 1997 (13.05.1997), especially col 5, ln 42-47; col 7, ln 01 -09	33, 36-43
Y	US 5,317,618 A (Nakahara et al.) 31 May 1994 (31.05.1994), especially col 5, ln 08-14	38-43

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"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)
"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
"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
"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
"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
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
02 March 2009 (02.03.2009)	20 MAR 2009

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 08/82701

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

(please see extra sheet)

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-22, 28-30, 32, and 34-43

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Continuation of Box No. III -- Observations where unity of invention is lacking

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-22, 28-30, 32, and 34-43 is directed to an apparatus for generating acoustic energy comprising: a plurality of pillars constructed of a piezoelectric material, the pillars arranged in a spaced-apart manner so that spaces exist between adjacent pillars; the pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars; and the spaces filled with a resilient material so as to form a composite assembly.

Group II: Claims 23-27 and 44-46 are directed to an apparatus for processing articles with acoustic energy comprising: a transducer assembly comprising: a transmitting structure having a concave inner surface and a convex outer surface; a first transducer having a convex bottom surface bonded to the concave inner surface of the transmitting structure; a second transducer having a convex bottom surface bonded to the concave inner surface of the transmitting structure, the second active transducer spaced from the first active transducer so that a non-active acoustic area exists on the transmitting structure between the first and second transducers

The inventions listed as Groups I-II do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Group I does not include the inventive concept of administration of a transmitting structure having a concave inner surface and a convex outer surface; a first transducer having a convex bottom surface bonded to the concave inner surface of the transmitting structure; a second transducer having a convex bottom surface bonded to the concave inner surface of the transmitting structure, as required by group II.

Group II does not include the inventive concept of pillars having a width and a height extending between a top surface and a bottom surface, wherein the height of the pillars is greater than the width of the pillars; and the spaces filled with a resilient material so as to form a composite assembly, as required by Group I.

Groups I-II therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.

Note: claims 31 and 33 are not present in the application