

APPARATUS AND METHOD FOR UNIFORM METALLIZATION ON SUBSTRATE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention generally relates to an apparatus and a method for metallization on substrate from electrolyte solutions. More particularly, it relates to applying at least one ultra/mega sonic device to a metallization apparatus, incorporating a dynamical controlling mechanism of substrate motions for uniformly applying the acoustic wave across the substrate surface, to achieve highly uniform metallic film deposition at a rate far greater than a conventional film growth rate in electrolyte solutions.

2. The Related Art

[0002] Forming of a metallic layer onto a substrate bearing a thin conductive layer, usually copper, in an electrolyte environment, is implemented to form conductive lines during ULSI (ultra large scale integrated) circuit fabrication. Such a process is used to fill cavities, such as vias, trenches, or combined structures of both by electrochemical methods, with an overburden film covering the surface of the substrate. It is critical to obtain a uniform final deposition film because the subsequent process step, commonly a planarization step (such as CMP, chemical-mechanical planarization) for removing the excess conductive metal material, requires a high degree of uniformity in order to achieve an equal electrical performance from device to device at the end of a production line.

[0003] Currently, metallization from electrolyte solutions is also employed in filling TSV (through silicon via) to provide vertical connections to 3-D package of substrate stacks. In TSV application, a via opening has a diameter of a few

micrometers or larger, with a via depth as deep as several hundreds of micrometers. The dimensions of TSV are orders of magnitude greater than those in a typical dual damascene process. It is a challenge in TSV technology to perform metallization of cavities with such high aspect ratio and depth close to the thickness approaching that of the substrate itself. The deposition rates of metallization systems designed for use in the typical dual damascene process, usually a few thousand angstroms per minute, is too low to be efficiently applied in TSV fabrication.

[0004] To achieve the void-free and bottom-up gapfill in deep cavities, multiple organic additives are added in the electrolyte solutions to control the local deposition rate. During deposition, these organic additives often break down into byproduct species that may alter the desired metallization process. If incorporated into deposited film as impurities, they may act as nuclei for void formation, causing device reliability failure. Therefore, during the deposition process, high chemical exchange rate of feeding fresh chemicals and removing break-down byproducts in and near the cavities is needed. In addition, with high aspect ratio, vortex is formed inside the cavities below where steady electrolyte flow passes on top of the cavity openings. Convection hardly happens between the vortex and the main flow, and the transport of fresh chemicals and break-down byproducts between bulk electrolyte solution and cavity bottom is mainly by diffusion. For deep cavity such as TSV, the length of diffusion path is longer, further limiting the chemical exchange within the cavity. Moreover, the slow diffusion process along the long path inside TSV hinders the high deposition rate required by economical manufacturing. The maximum deposition rate by electrochemical methods in a mass-transfer limited case is related to the limiting current density, which is inversely proportional to diffusion double layer thickness for a given electrolyte concentration. The thinner the diffusion double layer is, the higher the limiting current density is, thus a higher deposition rate is possible. The PCT international application with the PCT publication number WO/2012/174732, and the PCT application number PCT/CN2011/076262 discloses an apparatus and method by using ultra/mega sonic in the substrate metallization to conquer the above issues.

[0005] In the plating bath with a piece of ultra/mega sonic device, the acoustic wave distribution across the ultra/mega sonic device length is not uniform, which is proved by the power intensity test of an acoustic sensor and other optical-acoustic inspection tool. If applying an acoustic wave on the substrate, the acoustic energy acts on each point of the substrate is not the same.

[0006] In addition, in the plating bath with an acoustic field, the wave energy lost occurs due to acoustic wave absorbed by the plating bath wall and diffraction around the additives and byproducts. So that the power intensity of acoustic wave in the areas near the acoustic source is different from the power intensity of acoustic wave in the areas far away from the acoustic source. A standing wave formed between two parallel planes maintains the wave energy within the plating bath to minimize the wave energy lost. And the energy transfer only occurs between the node and anti-node within a standing wave. However, the power intensity of acoustic wave at its node and anti-node are different, which leads to nonuniform acoustic performance across the substrate surface during process. What's more, it is difficult to control the standing wave formation during the process due to the difficulty in adjusting the parallelism and distance between the planes.

[0007] Therefore, a way of controlling uniformity of acoustic energy distribution further improving the uniformity of plating deposition is desired. And a way of controlling the acoustic field with low wave energy lost in the plating bath is further required.

SUMMARY

[0008] The present invention provides at least one ultra/mega sonic device in a metallization apparatus to achieve highly uniform metallic film deposition at a rate far greater than conventional film growth rate in electrolyte solutions. In the present invention, the substrate is dynamically controlled so that the position of the substrate passing through the entire acoustic wave field with different power intensity in each

motion cycle, guaranteeing each location of the substrate to receive the same amount of overall sonic energy during the process time, and to accumulatively grow a uniform deposition thickness at a rapid rate.

[0009] In an embodiment of the present invention, an apparatus for uniform metallization on substrate includes an immersion bath, at least one set of electrode, a substrate holder, at least one ultra/mega sonic device, a reflection plate, and a rotating actuator. The immersion bath contains at least one metal salt electrolyte. The at least one set of electrode connects to an independent power supply. The substrate holder holds at least one substrate and electrically connects with a conductive side of the substrate. The conductive side of the substrate is exposed to face the electrode. The at least one ultra/mega sonic device and the reflection plate are disposed parallel for generating ultra/mega sonic standing wave in the immersion bath. The rotating actuator rotates the substrate holder along its axis in the standing wave field, so as to result in a uniform overall power intensity distribution across the substrate in an accumulated time.

[0010] In another embodiment of the present invention, an apparatus for uniform metallization on substrate includes an immersion bath, at least one set of electrode, a substrate holder, at least one ultra/mega sonic device, and a rotating actuator. The immersion bath contains at least one metal salt electrolyte. The at least one set of electrode connects to an independent power supply. The substrate holder holds at least one substrate and electrically connects with a conductive side of the substrate. The conductive side of the substrate is exposed to face the electrode. The at least one ultra/mega sonic device generates ultra/mega sonic wave in the immersion bath. The rotating actuator rotates the substrate holder along its axis in the acoustic wave field, so as to result in a uniform overall power intensity distribution across the substrate in an accumulated time.

[0011] According to an embodiment of the present invention, a method for uniform metallization on substrate includes the following steps: supplying at least one

metal salt electrolyte into an immersion bath; transferring a substrate to a substrate holder that is electrically connected with a conductive side of the substrate and the conductive side of the substrate exposed to face an electrode connecting to an independent power supply; applying a first bias voltage to the substrate; rotating the substrate; immersing the substrate into the immersion bath; applying an electrical current to the substrate; turning on an ultra/mega sonic device; oscillating the substrate holder in the acoustic wave field, and meanwhile periodically changing the distance of space between the ultra/mega sonic device and a reflection plate; turning off the ultra/mega sonic device and stopping oscillation of the substrate holder and stopping periodically changing the distance of space between the ultra/mega sonic device and the reflection plate; applying a second bias voltage to the substrate; bringing the substrate out of the metal salt electrolyte; and stopping rotating the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The present invention will be apparent to those skilled in the art by reading the following description of embodiments thereof, with reference to the attached drawings, in which:

[0013] FIG. 1 shows power intensity distribution at the acoustic area at front of an ultra/mega sonic device.

[0014] FIGs. 2A to 2B show power intensity distribution along the space between an ultra/mega sonic device and a reflection plate in an exemplary apparatus, and FIG. 2C shows power intensity of a particular point within the space between the ultra/mega sonic device and the reflection plate in the exemplary apparatus.

[0015] FIG. 3 is a sectional view showing an apparatus for uniform metallization on substrate according to an exemplary embodiment of the present invention.

[0016] FIG. 4A shows the change of power intensity between an ultra/mega sonic device and a reflection plate along with the change of the distance of the space between the ultra/mega sonic device and the reflection plate, and FIG. 4B shows power intensity of a particular point within the space between the ultra/mega sonic device and the reflection plate in an exemplary apparatus while the distance of the space between the ultra/mega sonic device and the reflection plate changes.

[0017] FIGs. 5A and 5B show the change of the power intensity between an ultra/mega sonic device and a reflection plate with the motion of the substrate along Y axis and the motion of the reflection plate along X' direction.

[0018] FIG. 6 is a top view showing an apparatus for uniform metallization on substrate according to another exemplary embodiment of the present invention.

[0019] FIG. 7 is a sectional view showing an apparatus for uniform metallization on substrate according to further another exemplary embodiment of the present invention.

[0020] FIG. 8 is a sectional view showing an apparatus for uniform metallization on substrate according to further another exemplary embodiment of the present invention.

[0021] FIG. 9 is a sectional view showing an apparatus for uniform metallization on substrate according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

[0022] According to exemplary embodiments of the present invention, ultra/mega sonic devices are utilized, and an exemplary ultra/mega sonic device may be applied to a plating apparatus as described in US 6,391,166 or WO/2009/055992.

[0023] Referring to FIG. 1, FIG. 1 shows power intensity distribution at the acoustic area at front of a bar-shaped ultra/mega sonic device 102. FIG. 1 is obtained

by a hydrophone sensor. The dark area in FIG. 1 indicates low power intensity and the bright area indicates high power intensity. It can be seen from FIG. 1 that the power intensity distribution from the center to edge of the ultra/mega sonic device 102 is nonuniform. The power intensity distribution along D direction which is perpendicular to the surface of the ultra/mega sonic device 102 is also nonuniform. The power intensity is high at the area near the ultra/mega sonic device 102 and low at the area far away from the ultra/mega sonic device 102. In FIG. 1, letter “D” indicates the D direction, letter “C” means the center of the ultra/mega sonic device, letter “N” means a position near the center of the ultra/mega sonic device, letter “F” means a position far away from the center of the ultra/mega sonic device, numeral “104” indicates bright strips with high power intensity.

[0024] FIG. 2A shows a substrate which is processed in a plating bath with a standing wave across the surface of the substrate. As an acoustic wave propagating in a space between an ultra/mega sonic device and a reflection plate parallel with the ultra/mega sonic device, a standing wave is formed by the propagating wave interfering with its reflection wave when the distance of the space equals to

[0025]
$$N \cdot \frac{\lambda}{2}, N=1, 2, 3 \dots$$

[0026] where λ is the wavelength of the acoustic wave and N is an integer. The standing wave with highest power intensity is formed within the space. Under the condition that the distance of the space approximates integer times of half wavelength, the standing wave is also formed but the power intensity of the standing wave is not that strong. The standing wave maintains the wave energy within the space with high uniformity along the wave propagating direction. The wave energy lost caused by the wave propagation in the electrolyte is minimized. In this case, the uniformity of acoustic power intensity distribution from the area near the acoustic source to that far away from the acoustic source is enhanced, and the efficiency of the acoustic generator is enhanced as well. In FIG. 2A, numeral “202” indicates the ultra/mega

sonic device, numeral “204” indicates the reflection plate, numeral “206” indicates the substrate and letter “X” indicates X axis.

[0027] However, the energy distribution within a particular wavelength of the standing wave is nonuniform, due to the energy transferring between the node and antinode of the standing wave. FIG. 2B shows the substrate oscillating in the distance of a quarter of wavelength, from node to antinode, so as to get uniform overall wave power intensity across the surface of the substrate in an accumulation time. Further, in order to keep the total acoustic energy applied by the ultra/mega sonic wave on each point of the substrate be the same, the oscillating distance of the substrate equals to

[0028]
$$N \cdot \frac{\lambda}{4}, N=1, 2, 3 \dots$$

[0029] where λ is the wavelength of the ultra/mega sonic wave and N is an integer. Each point of the substrate obtains equal overall power intensity of the ultra/mega sonic wave during an accumulation plating time. As the uniform ultra/mega sonic wave working across the substrate with low wave energy lost, the high plating rate and uniformity of the plated film may be achieved. In FIG. 2B, numeral “202” indicates the ultra/mega sonic device, numeral “204” indicates the reflection plate, numeral “206” indicates the substrate and letter “X” indicates the X axis.

[0030] FIG. 2C shows power intensity of a particular point within the space between the ultra/mega sonic device and the reflection plate. The result is obtained by an acoustic sensor and the measurement is performed in a plating bath. It proves the power intensity changing periodically along the distance of the space between the ultra/mega sonic device and the reflection plate in the plating bath. The node to node distance is the half wavelength of the ultra/mega sonic wave and the node to antinode distance is a quarter of wavelength of the ultra/mega sonic wave.

[0031] FIG. 3 is a sectional view showing an apparatus for uniform metallization on substrate from electrolyte by using ultra/mega sonic according to an

exemplary embodiment of the present invention. The apparatus includes an immersion bath 3021, at least one set of electrode 3002, an electricity conducting substrate holder 3003, an ultra/mega sonic device 3004, a reflection plate 3005, rotating actuator 3030, a vertical actuator 3012 and a horizontal actuator 3013. The immersion bath 3021 contains at least one metal salt electrolyte 3020. The at least one set of electrode 3002 connects to an independent power supply. The electricity conducting substrate holder 3003 holds at least one substrate 3001 and electrically connects with a conductive side of the substrate 3001. The conductive side of the substrate 3001 is exposed to face the electrode 3002. The ultra/mega sonic device 3004 and the reflection plate 3005 are disposed parallel for generating ultra/mega sonic standing wave in the immersion bath 3021. The rotating actuator 3030 rotates the substrate holder 3003 along its axis in the standing wave field, so as to result in a uniform overall power intensity distribution across the substrate 3001 in an accumulated time. The rotation speed of the rotating actuator 3030 is in the range of 10 to 100rpm. The metal salt electrolyte 3020 flows from the bottom of the immersion bath 3021 to the top of the immersion bath 3021. At least one set of inlet and outlet is positioned in the immersion bath 3021 for circulation of the metal salt electrolyte 3020. The ultra/mega sonic device 3004 is mounted on the wall of the immersion bath 3021. The surface of the ultra/mega sonic device 3004 is immersed into the metal salt electrolyte 3020. An ultra/mega sonic generator is connected to the ultra/mega sonic device 3004 for generating the acoustic wave with a frequency from 20 KHz to 10 MHz and power intensity from 0.01 to $3\text{W}/\text{cm}^2$. The ultra/mega sonic device 3004 is made of at least one piece of piezo crystal. The acoustic wave field is formed in the space at front of the ultra/mega sonic device 3004. The reflection plate 3005 is facing and parallel to the ultra/mega sonic device 3004 to form a standing wave. The independent power supply connects to the electrode 3002 and works in a voltage-controlled mode or a current-controlled mode, and may switch between the two modes at desired time. The voltage-controlled mode and the current-controlled mode respectively have pre-programmed waveforms. The supplying electrical current is operable in DC mode or pulse reverse mode with pulse

period from 5ms to 2s. Each set of electrode 3002 may be made in one piece of electrode or multi pieces of electrodes with independent power supply for each piece of electrode. At least one piece of permeable membrane 3011 with one layer or multi layers is set between the electrode 3002 and the substrate 3001. The substrate holder 3003 is connected to the vertical actuator 3012 for loading or unloading the substrate 3001 into or out of the immersion bath 3021. The horizontal actuator 3013 horizontally oscillates the substrate 3001 in the acoustic wave field with an amplitude from 1 to 300mm and a frequency from 0.001 to 0.5Hz, The horizontal oscillating

distance is $N \cdot \frac{\lambda}{4}$, $N=1, 2, 3, \dots$, where λ is the wavelength of the ultra/mega sonic wave and N is an integer. The substrate 3001 is horizontally oscillated along propagation direction of the ultra/mega sonic standing wave and at the same time rotating in the standing wave field, based on the theory disclosed in FIGS. 2A to 2C, the power intensity on each point of the substrate 3001 is uniform over the course of process. The horizontal actuator 3013 is a linear actuator or a swing actuator.

[0032] FIG. 4A shows the change of the power intensity between an ultra/mega sonic device and a reflection plate with the change of the distance of the space between the ultra/mega sonic device and the reflection plate. The power intensity distribution map of the space between the ultra/mega sonic device and the reflection plate is measured by an acoustic testing station, wherein the dark area indicates low power intensity and the bright area indicates high power intensity. The alternative dark and bright lines along Y axis in the power intensity distribution map disclose the formation of the standing wave, wherein the node is at the darkest line and the antinode is at the brightest line. The dark strips along X axis in the power intensity distribution map disclose a nonuniform power intensity distribution across the ultra/mega sonic device length. The distance of space between the ultra/mega sonic device and the reflection plate is marked as d. To change the distance d from d1 to d2 ($d1 \neq d2$), the power intensity distribution map changes from brightest to darkest; herein d2-d1 is integer times of a quarter wavelength of the ultra/mega sonic wave. It

discloses that the standing wave formation in the plating bath is different when the distance of the space between the ultra/mega sonic device and the reflection plate is varied. In FIG. 4A, numeral “402” indicates the ultra/mega sonic device, numeral “404” indicates the reflection plate. FIG. 4B shows power intensity of a particular point within the space between the ultra/mega sonic device and the reflection plate in an exemplary apparatus while the distance of the space between the ultra/mega sonic device and the reflection plate changes. The result is obtained by an acoustic sensor and the measurement is performed in a plating bath with an ultra/mega sonic source while the distance of the space between the ultra/mega sonic device and the reflection plate decreases from d_n to d_m ($d_n \neq d_m$, $d_n < d_m$) or increases from d_m to d_n . It discloses that the power intensity changes periodically while the distance of the space between the ultra/mega sonic device and the reflection plate changes. The peak power intensity is achieved when the plating bath meets the condition of standing wave formation that the distance of the space between the ultra/mega sonic device and the reflection plate is integer times of half-wavelength. The energy is maintained between the ultra/mega sonic device and the reflection plate with minimum energy lost. In order to achieve uniform ultra/mega sonic energy intensity distribution in the space between the ultra/mega sonic device and the reflection plate and minimize the energy lost in the plating bath, the motion controlling mechanism for adjusting the distance of the space between the ultra/mega sonic device and the reflection plate is critical in the plating bath.

[0033] FIGS. 5A and 5B show the change of the power intensity between an ultra/mega sonic device and a reflection plate with the motion of the substrate along Y axis and the motion of the reflection plate along X' direction. The power intensity distribution map of the space between the ultra/mega sonic device and the reflection plate is measured by an acoustic testing station, wherein the dark area indicates low power intensity and the bright area indicates high power intensity. The alternative dark and bright lines along the Y axis in the power intensity distribution map disclose the formation of the standing wave, wherein the node is at the darkest line and the

antinode is at the brightest line. The dark strips along X' direction in the power intensity distribution map disclose a nonuniform power intensity distribution across the ultra/mega sonic device length. The substrate is oscillated along Y axis with an amplitude of

$$\Delta Y = \frac{N \bullet \frac{\lambda}{4}}{\sin \theta}, N=1, 2, 3 \dots$$

[0034]

[0035] where λ is the wavelength of the ultra/mega sonic wave and N is an integer. The lateral component movement along Y' direction, an angle $\theta (0 < \theta < 45^\circ)$ tilted from Y axis, leads each point on the substrate passing through the strips, and the lateral component movement along X' direction, an angle $\theta (0 < \theta < 45^\circ)$ tilted from X axis, leads each point on the substrate passing through node and antinode of the ultra/mega sonic wave in each oscillation cycle. Meanwhile, the reflection plate is oscillated along X' direction with the amplitude of integer times of half wavelength, so as to ensure the overall power intensity in the space between the ultra/mega sonic device and the reflection plate in each oscillation cycle the same. Herein the oscillation speed of the reflection plate is faster than the oscillation speed of the substrate. This is a solution for the difficulty in the parallelism adjustment of the reflection plate to meet the best standing wave formation condition. It also makes the acoustic wave field in the plating bath stable between each oscillating period, if the condition of the plating bath is unstable by time. The application of above motion controlling mechanism is critical in the plating bath. In FIGS. 5A and 5B, numeral "502" indicates the ultra/mega sonic device, numeral "504" indicates the reflection plate, numeral "506" indicates the substrate.

[0036] FIG. 6 is a top view showing an apparatus for uniform metallization on substrate according to another exemplary embodiment of the present invention. The apparatus includes an immersion bath 6021, at least one set of electrode, an electricity conducting substrate holder 6003, an ultra/mega sonic device 6004, a reflection plate 6005, a rotating actuator 6030 and a horizontal actuator 6013. The immersion bath

6021 contains at least one metal salt electrolyte. The at least one set of electrode connects to an independent power supply. The electricity conducting substrate holder 6003 holds at least one substrate and electrically connects with a conductive side of the substrate. The conductive side of the substrate is exposed to face the electrode. The ultra/mega sonic device 6004 and the reflection plate 6005 are disposed parallel for generating ultra/mega sonic standing wave in the immersion bath 6021. The rotating actuator 6030 rotates the substrate holder 6003 along its axis in the standing wave field, so as to result in a uniform overall power intensity distribution across the substrate in an accumulated time. The rotation speed of the rotating actuator 6030 is in the range of 10 to 100rpm. At least one layer of permeable membrane is set between the substrate and the electrode. Each set of electrode includes one piece of electrode or more pieces of electrodes with independent power control. The horizontal actuator 6013 oscillates the substrate holder 6003 in the plane of the substrate holder 6003. The horizontal actuator 6013 is a linear type or a swing type. The ultra/mega sonic device 6004 and the reflection plate 6005 which is parallel to the ultra/mega sonic device 6004 are mounted on opposite sidewalls of the immersion bath 6021 with a small tilted angle θ ($0 < \theta < 45^\circ$), resulting in the angle θ formed between the substrate holder 6003 horizontal oscillation direction and normal direction of propagation direction of the ultra/mega sonic standing wave. The substrate holder 6003 is set parallel to the horizontal plane. The surfaces of the ultra/mega sonic device 6004 and the reflection plate 6005 are immersed in the metal salt electrolyte, and the standing wave is formed in the space between the parallel surfaces of the ultra/mega sonic device 6004 and the reflection plate 6005. The propagation direction of the standing wave is parallel to the surface of the substrate. The standing wave tilts the angle θ from X axis perpendicular to the substrate holder 6003 oscillation direction. When the lateral component $\Delta X'$, along the propagation direction of the ultra/mega sonic standing wave, of oscillating distance of substrate is integer times of a quarter wavelength of the ultra/mega sonic standing wave, each point of the substrate surface passes through nodes and antinodes of the standing wave during oscillating, obtaining

the same overall power intensity of ultra/mega sonic wave in each cycle of oscillation. In this case, the oscillation amplitude ΔY should equal to:

[0037]
$$\Delta Y = \frac{N \cdot \frac{\lambda}{4}}{\sin \theta}, N=1, 2, 3 \dots$$

[0038] where λ is the wavelength of the ultra/mega sonic wave and N is an integer. The reflection plate 6005 is made of one layer or multiple layers and a space may be provided between layers of the reflection plate 6005 for minimizing the acoustic energy lost. In order to keep the surface of the reflection plate 6005 parallel to the surface of the ultra/mega sonic device 6004, an adjusting mechanism is used to set the reflection plate 6005 position. An oscillating actuator 6006 is mounted to the backside of the reflection plate 6005 with a bellow component 6007 for flexible sealing. The oscillating actuator 6006 oscillates the reflection plate 6005 back and forth along X' direction which is the standing wave propagation direction, so as to change the distance of the space between the ultra/mega sonic device 6004 and the reflection plate 6005. The oscillating actuator 6006 has a frequency operated from 1 to 10Hz and amplitude equaling to N times of half wavelength of ultra/mega sonic wave, N is an integer from 1 to 10. The oscillating actuator 6006 works while the horizontal actuator 6013 horizontally oscillates the substrate and the rotating actuator 6030 rotates the substrate in the acoustic wave field. The oscillation speed of the oscillating actuator 6006 is faster than the oscillation speed of the horizontal actuator 6013. A vertical actuator moves the substrate holder 6003 up and down to load or unload the substrate into or out of the immersion bath 6021.

[0039] FIG. 7 is a sectional view showing an apparatus for uniform metallization on substrate according to further another exemplary embodiment of the present invention. The apparatus includes an immersion bath 7021, at least one set of electrode 7002, an electricity conducting substrate holder 7003, at least one ultra/mega sonic device 7004, a reflection plate 7005, a rotating actuator 7030 and a vertical actuator 7012. The immersion bath 7021 contains at least one metal salt electrolyte.

The at least one set of electrode 7002 connects to an independent power supply. The electricity conducting substrate holder 7003 holds at least one substrate 7001 and electrically connects with a conductive side of the substrate 7001. The conductive side of the substrate 7001 is exposed to face the electrode 7002. The at least one ultra/mega sonic device 7004 and the reflection plate 7005 are disposed parallel for generating ultra/mega sonic standing wave in the immersion bath 7021. The rotating actuator 7030 rotates the substrate holder 7003 along its axis in the standing wave field, so as to result in a uniform overall power intensity distribution across the substrate 7001 in an accumulated time. The rotation speed of the rotating actuator 7030 is in the range of 10 to 100rpm. At least one piece of permeable membrane 7011 with one layer or multi layers is set between the electrode 7002 and the substrate 7001. Each set of electrode 7002 includes one piece of electrode or more pieces of electrodes with independent power control. The ultra/mega sonic device 7004 and the reflection plate 7005 parallel to the ultra/mega sonic device 7004 are mounted on opposite sidewalls of the immersion bath 7021 with a small angle $\theta (0 < \theta < 45)$ relative to Z axis that is the substrate oscillation direction, and the substrate 7001 is set parallel to the horizontal plane. The ultra/mega sonic device 7004 and the reflection plate 7005 are immersed in the metal salt electrolyte, and the standing wave is formed between the parallel surfaces of the ultra/mega sonic device 7004 and the reflection plate 7005. The substrate holder 7003 is connected to the vertical actuator 7012, and the substrate holder 7003 is oscillated by the vertical actuator 7012 along the direction perpendicular to the horizontal plane with an amplitude from 1 to 300mm and a frequency from 0.001 to 0.5Hz. The vertical actuator 7012 oscillates the substrate holder 7003 holding the substrate 7001 up and down periodically along Z axis that is tilted an angle $\theta (0 < \theta < 45)$ relative to the normal direction of the standing wave propagation direction. When the lateral component $\Delta X''$, along the standing wave propagation direction, of oscillating distance of the substrate 7001 is integer times of a quarter wavelength of the standing wave, each point of the substrate 7001 surface passes through nodes and antinodes of the standing wave during oscillating, obtaining

the same overall power intensity of the ultra/mega sonic wave in each cycle of oscillation. In this case, the oscillation amplitude ΔZ should equal to:

[0040]
$$\Delta Z = \frac{N \cdot \frac{\lambda}{4}}{\sin \theta}, N=1, 2, 3 \dots$$

[0041] where λ is the wavelength of the ultra/mega sonic standing wave and N is an integer. Meanwhile, the lateral component ΔZ of oscillation along Z axis ensures each point on the substrate 7001 in the acoustic wave field can obtain the same overall power intensity of the ultra/mega sonic wave in each cycle of oscillation. In this case, the power intensity on each point of the substrate 7001 is uniform over the course of process. The vertical actuator 7012 moves the substrate holder 7003 up and down to load or unload the substrate 7001 into or out of the immersion bath 7021.

[0042] FIG. 8 is a sectional view showing an apparatus for uniform metallization on substrate according to further another exemplary embodiment of the present invention. The apparatus includes an immersion bath 8021, at least one set of electrode 8002, an electricity conducting substrate holder 8003, at least one ultra/mega sonic device 8004, a reflection plate 8005, rotating actuator 8030, and a vertical actuator 8012. The immersion bath 8021 contains at least one metal salt electrolyte. The at least one set of electrode 8002 connects to an independent power supply. The electricity conducting substrate holder 8003 holds at least one substrate 8001 and electrically connects with a conductive side of the substrate 8001. The conductive side of the substrate 8001 is exposed to face the electrode 8002. The at least one ultra/mega sonic device 8004 and the reflection plate 8005 are disposed parallel for generating ultra/mega sonic standing wave in the immersion bath 8021. The rotating actuator 8030 rotates the substrate holder 8003 along its axis in the standing wave field so as to result in a uniform overall power intensity distribution across the substrate 8001 in an accumulated time. The rotation speed of the rotating actuator 8030 is in the range of 10 to 100rpm. At least one piece of permeable membrane 8011 with one layer or multi layers is set between the electrode 8002 and the substrate 8001. Each set of electrode

8002 includes one piece of electrode or more pieces of electrodes with independent power control. The ultra/mega sonic device 8004 and the reflection plate 8005 parallel to the ultra/mega sonic device 8004 are mounted on opposite sidewalls of the immersion bath 8021 and perpendicular to the horizontal plane. The electrode 8002 which is seated on a sloping bath base 8022, and the substrate holder 8003 have a small tilted angle θ ($0 < \theta < 45$) relative to the horizontal plane. The ultra/mega sonic device 8004 and the reflection plate 8005 are immersed in the metal salt electrolyte, and the standing wave is formed between the ultra/mega sonic device 8004 and the reflection plate 8005. The substrate holder 8003 is connected to the vertical actuator 8012, and the substrate holder 8003 is oscillated by the vertical actuator 8012 along a direction tilted the angle θ ($0 < \theta < 45$) relative to the normal direction of the horizontal plane with an amplitude from 1 to 300mm and a frequency from 0.001 to 0.5Hz. The vertical actuator 8012 oscillates the substrate holder 8003 holding the substrate 8001 up and down periodically along its axis along Z' direction tilted a small angle θ ($0 < \theta < 45$) from Z axis that is perpendicular to the standing wave propagation direction. When the lateral component ΔX , along the standing wave propagation direction, of oscillating distance of the substrate 8001 is integer times of a quarter wavelength of the ultra/mega sonic standing wave, each point of the substrate 8001 surface passes through nodes and antinodes of the standing wave during oscillating, obtaining the same overall power intensity of the ultra/mega sonic wave in each cycle of oscillation. In this case, the oscillation amplitude $\Delta Z'$ should equal to:

[0043]
$$\Delta Z' = \frac{N \cdot \frac{\lambda}{4}}{\sin \theta}, N=1, 2, 3 \dots$$

[0044] where λ is the wavelength of the ultra/mega sonic wave and N is an integer. Meanwhile, the lateral component $\Delta Z'$ of oscillation along Z' direction ensures each point on the substrate 8001 in the acoustic wave field can obtain the same overall power intensity. In this case, the power intensity on each point of the substrate 8001 is uniform over the course of process. The vertical actuator 8012

moves the substrate holder 8003 up and down to load or unload the substrate 8001 into or out of the immersion bath 8021.

[0045] It can be seen from FIG. 7 and FIG. 8 that the vertical actuator oscillates the substrate holder along a direction that an angle θ ($0 < \theta < 45^\circ$) is formed between the substrate holder oscillation direction and normal direction of propagation direction of the ultra/mega sonic standing wave. The amplitude of the substrate

oscillation equals to $\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$, $N=1, 2, 3, \dots$ where λ is the wavelength of the ultra/mega sonic standing wave and N is an integer, θ is the angle between the substrate oscillation direction and the normal direction of propagation direction of the ultra/mega sonic standing wave.

[0046] FIG. 9 is a sectional view showing an apparatus for uniform metallization on substrate according to another exemplary embodiment of the present invention. The apparatus includes an immersion bath 9021, at least one set of electrode 9002, an electricity conducting substrate holder 9003, at least one ultra/mega sonic device 9004, a rotating actuator 9030, a vertical actuator 9012 and an acoustic reflector 9005. The immersion bath 9021 contains at least one metal salt electrolyte. The at least one set of electrode 9002 connects to an independent power supply. The electricity conducting substrate holder 9003 holds at least one substrate 9001 and electrically connects with a conductive side of the substrate 9001. The conductive side of the substrate 9001 is exposed to face the electrode 9002. The at least one ultra/mega sonic device 9004 generates ultra/mega sonic wave in the immersion bath 9021. The rotating actuator 9030 rotates the substrate holder 9003 along its axis in the acoustic wave field so as to result in a uniform overall power intensity distribution across the substrate 9001 in an accumulated time. The substrate holder 9003 is connected to the vertical actuator 9012, and the substrate holder 9003 is oscillated by the vertical actuator 9012 along normal direction of propagation direction of the ultra/mega sonic wave with an amplitude from 1 to 300mm and a frequency from 0.001 to 0.5Hz. The

acoustic reflector 9005 is placed opposite to the ultra/mega sonic device 9004 and with a tilted angle relative to the ultra/mega sonic device 9004, avoiding forming standing wave across the surface of the substrate 9001. The acoustic reflector 9005 is tilted at its width direction to form the angle α ($0 < \alpha < 45$) relative to the ultra/mega sonic device 9004, reflecting the primary acoustic wave upwards and out of the immersion bath 9021, so as to avoid the standing wave formation. In addition, the ultra/mega sonic device 9004 and the tilted acoustic reflector 9005 set the path where the acoustic stream which is formed by the acoustic wave, flows horizontally and then out of the immersion bath 9021. At least one piece of permeable membrane 9011 with one layer or multi layers is set between the electrode 9002 and the substrate 9001.

[0047] A method for uniform metallization on substrate according to an embodiment of the present invention includes the following steps.

[0048] Process Sequence

[0049] Step 1: supplying at least one metal salt electrolyte into an immersion bath, wherein the metal is selected from a group of metals including Cu, Au, Ag, Pt, Ni, Sn, Co, Pd, Zn;

[0050] Step 2: transferring a substrate to a substrate holder that is electrically connected with a conductive side of the substrate and the conductive side of the substrate exposed to face an electrode connecting to an independent power supply;

[0051] Step 3: applying a first bias voltage to the substrate, wherein the first bias voltage is in the range of 0.1V to 10V;

[0052] Step 4: rotating the substrate with a rotation speed in the range of 10 rpm to 100rpm;

[0053] Step 5: immersing the substrate into the immersion bath;

[0054] Step 6: applying an electrical current to the substrate, wherein the electrical current is in the range of 0.1A to 100A;

[0055] Step 7: turning on an ultra/mega sonic device, wherein the power intensity of the ultra/mega sonic device is in the range of 0.01 to 3 W/cm² and the operating frequency of the ultra/mega sonic device is set between 20KHz to 10MHz;

[0056] Step 8: oscillating the substrate holder in the acoustic wave field, the oscillation amplitude is from 1mm to 300mm and the frequency is from 0.001 to 0.5Hz; meanwhile, periodically changing the distance of space between the ultra/mega sonic device and a reflection plate, changing length of the distance of space between

the ultra/mega sonic device and the reflection plate equals to $N \cdot \frac{\lambda}{2}$, where λ is the wavelength of the ultra/mega sonic wave and N is an integer number from 1 to 10, and changing frequency is in range of 1 to 10 HZ;

[0057] Step 9: turning off the ultra/mega sonic device and stopping oscillation of the substrate holder and stopping periodically changing the distance of space between the ultra/mega sonic device and the reflection plate;

[0058] Step 10: applying a second bias voltage to the substrate, wherein the second bias voltage is in range of 0.1V to 5V;

[0059] Step 11: bringing the substrate out of the metal salt electrolyte;

[0060] Step 12: stopping rotating the substrate.

[0061] In the step 8, the amplitude of the substrate oscillation equals to $\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$, N=1, 2, 3...where λ is the wavelength of the ultra/mega sonic wave and N is an integer, θ is the angle between substrate oscillation direction and the normal direction of propagation direction of the ultra/mega sonic wave. The θ is in range of 0 to 45 degree. The frequency of the space distance changing periodically is larger than the frequency of substrate oscillation. Alternatively, the amplitude of the substrate oscillation in the acoustic wave field is controlled as integer times of quarter wavelength of the ultra/mega sonic wave. Alternatively, the substrate oscillates with

an angle θ in range of 0 to 45 degree, tilted to the normal direction of propagation direction of the ultra/mega sonic wave, and the amplitude of the substrate oscillation

equals to $\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$, $N=1, 2, 3 \dots$ where λ is wavelength of the ultra/mega sonic wave and N is an integer.

[0062] Although the present invention has been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention.

CLAIMS

1. An apparatus for uniform metallization on substrate comprising:
an immersion bath containing at least one metal salt electrolyte;
at least one set of electrode connecting to an independent power supply;
a substrate holder holding at least one substrate and electrically connecting with a conductive side of the substrate, the conductive side of the substrate exposed to face the electrode;
at least one ultra/mega sonic device and a reflection plate disposed parallel for generating ultra/mega sonic standing wave in the immersion bath; and
a rotating actuator rotating the substrate holder along its axis in the standing wave field, so as to result in a uniform overall power intensity distribution across the substrate in an accumulated time.
2. The apparatus of claim 1, further comprising a horizontal actuator oscillating the substrate holder along propagation direction of the ultra/mega sonic standing wave.
3. The apparatus of claim 2, wherein the amplitude of the substrate oscillation equals to $N \cdot \frac{\lambda}{4}$, $N=1, 2, 3 \dots$ where λ is the wavelength of the ultra/mega sonic standing wave and N is an integer.
4. The apparatus of claim 1, further comprising a horizontal actuator oscillating the substrate holder along a direction tilted an angle θ relative to normal direction of propagation direction of the ultra/mega sonic standing wave.
5. The apparatus of claim 4, wherein the amplitude of the substrate oscillation equals to $\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$, $N=1, 2, 3 \dots$ where λ is the wavelength of the ultra/mega sonic

standing wave and N is an integer, θ is the angle between the substrate oscillation direction and the normal direction of propagation direction of the ultra/mega sonic standing wave.

6. The apparatus of claim 4, wherein the θ is 0-45 degrees.

7. The apparatus of claim 1, further comprising a vertical actuator moving the substrate holder up and down to load or unload the substrate into or out of the immersion bath.

8. The apparatus of claim 1, further comprising a vertical actuator oscillating the substrate holder along a direction that an angle θ is formed between the substrate holder oscillation direction and normal direction of propagation direction of the ultra/mega sonic standing wave.

9. The apparatus of claim 8, wherein the amplitude of the substrate oscillation

$$\frac{N \bullet \frac{\lambda}{4}}{\sin \theta}$$
 equals to $\frac{N \bullet \frac{\lambda}{4}}{\sin \theta}$, N=1, 2, 3...where λ is the wavelength of the ultra/mega sonic standing wave and N is an integer, θ is the angle between the substrate oscillation direction and the normal direction of propagation direction of the ultra/mega sonic standing wave.

10. The apparatus of claim 8, wherein the vertical actuator moves the substrate holder up and down to load or unload the substrate into or out of the immersion bath.

11. The apparatus of claim 8, wherein the vertical actuator oscillates the substrate holder along the direction perpendicular to the horizontal plane.

12. The apparatus of claim 8, wherein the vertical actuator oscillates the substrate holder along the direction tilted an angle relative to the normal direction of the horizontal plane.

13. The apparatus of claim 12, wherein the substrate and the electrode are set with a tilted angle relative to the horizontal plane.

14. The apparatus of claim 1, wherein each set of electrode includes one piece of electrode or more pieces of electrodes with independent power control.

15. The apparatus of claim 1, further comprising at least one layer of permeable membrane being set between the substrate and the electrode.

16. The apparatus of claim 1, wherein the rotation speed of the rotating actuator is in the range of 10 to 100rpm.

17. The apparatus of claim 1, wherein the ultra/mega sonic device and the reflection plate are mounted on opposite sidewalls of the immersion bath and tilt an angle θ relative to the substrate oscillation direction, and the substrate is set parallel to the horizontal plane, the substrate oscillation direction is perpendicular to the horizontal plane.

18. The apparatus of claim 1, wherein the ultra/mega sonic device and the reflection plate are mounted on opposite sidewalls of the immersion bath and perpendicular to the horizontal plane, the substrate and the electrode are set with a tilted angle relative to the horizontal plane, the substrate is oscillated along a direction tilted the angle relative to the normal direction of the horizontal plane.

19. The apparatus of claim 1, further comprising an adjusting mechanism for adjusting the surface of the reflection plate to be parallel to the surface of the ultra/mega sonic device.

20. The apparatus of claim 19, wherein the adjusting mechanism includes an oscillating actuator for oscillating the reflection plate along propagation direction of the ultra/mega sonic standing wave, the oscillation amplitude is equal to N times of half wavelength of the ultra/mega sonic standing wave, N is an integer number from 1 to 10.

21. The apparatus of claim 20, wherein the frequency of the oscillating actuator is 1 to 10 HZ.

22. An apparatus for uniform metallization on substrate comprising:
an immersion bath containing at least one metal salt electrolyte;
at least one set of electrode connecting to an independent power supply;
a substrate holder holding at least one substrate and electrically connecting with a conductive side of the substrate, the conductive side of the substrate exposed to face the electrode;
at least one ultra/mega sonic device for generating ultra/mega sonic wave in the immersion bath; and
a rotating actuator rotating the substrate holder along its axis in the acoustic wave field, so as to result in a uniform overall power intensity distribution across the substrate in an accumulated time.

23. The apparatus of claim 22, further comprising a vertical actuator oscillating the substrate holder along normal direction of propagation direction of the ultra/mega sonic wave.

24. The apparatus of claim 22, further comprising an acoustic reflector placed with a tilted angle relative to the ultra/mega sonic device, avoiding forming standing wave across the surface of the substrate.

25. The apparatus of claim 24, wherein the acoustic reflector is tilted at its width direction to form the tilted angle relative to the ultra/mega sonic device, so as to reflect the acoustic wave upwards and out of the immersion bath.

26. The apparatus of claim 25, wherein the ultra/mega sonic device and the tilted acoustic reflector set the path where the acoustic stream flows horizontally and then out of the immersion bath.

27. A method for uniform metallization on substrate comprising:
supplying at least one metal salt electrolyte into an immersion bath;
transferring a substrate to a substrate holder that is electrically connected with a conductive side of the substrate and the conductive side of the substrate exposed to face an electrode connecting to an independent power supply;
applying a first bias voltage to the substrate;
rotating the substrate;
immersing the substrate into the immersion bath;
applying an electrical current to the substrate;
turning on an ultra/mega sonic device;
oscillating the substrate holder in the acoustic wave field, and meanwhile periodically changing the distance of space between the ultra/mega sonic device and a reflection plate;
turning off the ultra/mega sonic device and stopping oscillation of the substrate holder and stopping periodically changing the distance of space between the ultra/mega sonic device and the reflection plate;
applying a second bias voltage to the substrate;

bringing the substrate out of the metal salt electrolyte; and
stopping rotating the substrate.

28. The method of claim 27, wherein
the first bias voltage is 0.1V to 10V;
the electrical current is 0.1A to 100A;
the ultra/mega sonic device has an operating frequency of 20KHz to 10MHz
and a power intensity of 0.01 to 3W/cm²;
the substrate oscillates with an amplitude of 1mm to 300mm and a frequency of
0.001 to 0.5Hz;
the second bias voltage is 0.1V to 5V.

29. The method of claim 27, wherein the substrate rotates with a rotation speed
in range of 10rpm to 100rpm.

30. The method of claim 27, wherein the amplitude of the substrate oscillation
$$\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$$

equals to $\frac{N \cdot \frac{\lambda}{4}}{\sin \theta}$, N=1, 2, 3...where λ is the wavelength of the ultra/mega sonic wave
and N is an integer, θ is the angle between substrate oscillation direction and the
normal direction of propagation direction of the ultra/mega sonic wave.

31. The method of claim 27, wherein the frequency of the space distance
changing periodically is larger than the frequency of substrate oscillation.

32. The method of claim 27, wherein the amplitude of the substrate oscillation
in the acoustic wave field is controlled as integer times of quarter wavelength of the
ultra/mega sonic wave.

33. The method of claim 27, wherein the substrate oscillates with an angle θ in range of 0 to 45 degree, tilted to the normal direction of propagation direction of the

ultra/mega sonic wave, and the amplitude of the substrate oscillation equals to $\frac{N \bullet \frac{\lambda}{4}}{\sin \theta}$,
 $N=1, 2, 3 \dots$ where λ is the wavelength of the ultra/mega sonic wave and N is an integer.