concept of the present invention can apply to substrates with recessed features. For example, recess vias after CMP can form a pattern on the wafer and a most suitable design of channels can be used to achieve best contaminant removal efficiency.

[00115] A substrate, as an example used herein, denotes without limitation, semiconductor wafers, hard drive disks, optical discs, glass substrates, and flat panel display surfaces, liquid crystal display surfaces, etc., which may become contaminated during manufacturing or handling operations. Depending on the actual substrate, a surface may become contaminated in different ways, and the acceptable level of contamination is defined in the particular industry in which the substrate is handled.

[00116] Although a few embodiments of the present invention have been described in detail herein, it should be understood, by those of ordinary skill, that the present invention may be embodied in many other specific forms without departing from the spirit or scope of the invention. Therefore, the present examples and embodiments are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details provided therein, but may be modified and practiced within the scope of the appended claims.

Claims

1. A method of removing particles from a surface of a substrate, comprising:

dispensing a layer of a cleaning material on the surface of the substrate, wherein the substrate is rotated by a substrate support, and wherein the cleaning material is a viscoelastic solution which includes a polymeric compound**,** the polymeric compound being soluble in a cleaning solution to form the cleaning material, the cleaning material captures and entraps at least some of the particles from the surface of the substrate; and

dispensing a rinsing liquid on the layer of the cleaning material on the surface of the substrate to remove the layer of cleaning material, wherein an energy is applied on the cleaning material during or prior to dispensing the rinsing liquid on the layer of the cleaning material, wherein the energy applied increases a solid-like response of the cleaning material to facilitate removal of the cleaning material from the substrate surface, and wherein the energy is continuously introduced for a time period shorter than a characteristic time as a response time for the viscoelastic solution to respond to a change in an force applied to the viscoelastic solution, wherein the at least some of the particles that are entrapped by the cleaning material are removed along with the cleaning material.

2. The method of claim 1, wherein the energy is introduced by a force applied on the layer of the cleaning material during the dispensing of the rinsing liquid, wherein dispensed rinsing liquid removes the layer of the cleaning material.

3. The method of claim 1, wherein the substrate and the cleaning material are cooled to a temperature between about 0^{o}C to about 30^{o}C prior to and during dispensing the rinsing liquid, and wherein cooling of the cleaning material increases the solid-like response of the cleaning material to make the cleaning material and the entrapped particles easier to remove by the dispensed rinsing liquid.

4. The method of claim 1, wherein the energy introduced is applied by a suction force on the layer of the cleaning material, and wherein the suction force pulls the layer of the cleaning

material away from the surface of the substrate to remove the cleaning material and the entrapped particles.

5. The method of claim 1, wherein a surface pre-treatment liquid is applied on the surface of the substrate prior to the layer of the cleaning material is dispensed on the surface of the substrate.

6. The method of claim 1, wherein the energy introduced in a low frequency acoustic energy whose frequency is greater than a reciprocal of the characteristic, and wherein the frequency is between about 10 Hz to about 500 Hz.

7. The method of claim 1, wherein the rinsing liquid is dispensed on the layer of the cleaning material by a spray jet, and wherein the spray jet introduces the energy applied on the cleaning material by the force of the spray jet.

8. The method of claim 1, wherein the energy is introduced in a megasonic or ultrasonic acoustic energy whose frequency is greater than a reciprocal of the characteristic time.

9. The method of claim 1, wherein the energy is introducing by oscillating the substrate around an axis of the substrate during or after the layer of the cleaning material is dispensed on the surface of the substrate.

10. The method of claim 1, wherein the rinsing liquid is de-ionized water.

11. The method of claim 3, wherein the substrate and the cleaning material are cooled by spraying cold water on the backside of the substrate or substrate support.

12. The method of claim 5, wherein the pre-treatment liquid is selected from a group consisting of de-ionized water (DIW), APM (ammonium peroxide mixture), DSP (diluted sulfuric-acid peroxide mixture), SPM (sulfuric-acid peroxide mixture), DI-O3 (de-ionized water mixed with ozone), HF (hydrogen fluoride), and BOE (buffered oxide etch) solution.

13. The method of claim 7, wherein the rinsing liquid is mixed with a carrier gas in the spray jet, and wherein the carrier gas is a gas or a combination of two or more gases selected from a group consisting of N_2, air, O_2, Ar, He.

14. The method of claim 8, wherein the frequency of the megasonic or ultrasonic acoustic energy is selected from a group consisting of about 28 kHz, about 44 kHz, about 112 kHz, about 800 kHz, about 1.4 MHz, and about 2 MHz.

15. The method of claim 9, wherein the oscillatory frequency is greater than a reciprocal of the characteristic time.

16. The method of claim 1, further comprising:

applying a drying-assisting liquid on the surface of the substrate after the layer of the cleaning material has been removed; and

drying the surface of the substrate after the dry-assisting liquid has been applied by rotating the substrate.

17. The method of claim 16, wherein the drying-assisting liquid is isopropyl alcohol (IPA), a mixture of IPA and water, a vapor phase IPA, or a mixture of vapor phase IPA and an inert gas.

18. A method of removing particles from a surface of a substrate, comprising:

dispensing a layer of a viscoelastic cleaning material on the surface of the substrate, wherein the substrate is rotated by a substrate support, and wherein the viscoelastic cleaning material captures and entraps at least some of the particles from the surface of the substrate; and

dispensing a rinsing liquid on the layer of the viscoelastic cleaning material on the surface of the substrate to remove the layer of viscoelastic cleaning material, wherein an energy is applied on the viscoelastic cleaning material during or prior to dispensing the rinsing liquid on the layer of the viscoelastic cleaning material, wherein the energy is continuously introduced for a time period shorter than a characteristic time as a response time for the viscoelastic cleaning material to respond to a change in an force applied to the viscoelastic cleaning material, wherein

the energy applied increases a solid-like response of the viscoelastic cleaning material to facilitate removal of the viscoelastic cleaning material from the substrate surface, and wherein the at least some of the particles that are entrapped by the viscoelastic cleaning material are removed along with the viscoelastic cleaning material.

19. A method of removing particles from a surface of a substrate in an apparatus having a number of processing slots, comprising:

moving the substrate to a first processing slot of the apparatus by a substrate support, wherein the first processing slot of the apparatus is separated from the processing slots below the first processing slot by the substrate support;

dispensing a layer of a viscoelastic cleaning material on the surface of the substrate, wherein the substrate is rotated by a substrate support, and wherein the viscoelastic cleaning material captures and entraps at least some of the particles from the surface of the substrate;

moving the substrate to a second processing slot of the apparatus by the substrate support, wherein the second processing slot of the apparatus is separated from processing slots below the second processing slot by the substrate support; and

dispensing a rinsing liquid on the layer of the viscoelastic cleaning material on the surface of the substrate to remove the layer of the viscoelastic cleaning material, wherein an energy is applied on the viscoelastic cleaning material during or prior to dispensing the rinsing liquid on the layer of the viscoelastic cleaning material, wherein the energy is continuously introduced for a time period shorter than a characteristic time as a response time for the viscoelastic cleaning material to respond to a change in an force applied to the viscoelastic cleaning material, wherein the energy applied increases a solid-like response of the viscoelastic cleaning material to facilitate removal of the viscoelastic cleaning material from the substrate surface, and wherein the at least some of the particles that are entrapped by the viscoelastic cleaning material are removed along with the cleaning material.

20. The method of claim 19, further comprising:

moving the substrate to a third processing slot of the apparatus by the substrate support, wherein the third processing slot of the apparatus is separated from the processing slots below the

second processing slot by the substrate support or the backside of the substrate support becomes an exterior of the apparatus;

applying a drying-assisting liquid on the surface of the substrate that has been removed of the layer of the viscoelastic cleaning material, wherein the substrate spins when the drying-assisting liquid is being applied; and

drying the substrate by spinning the substrate after the drying-assisting liquid has been applied.

21. The method of claim 19, wherein the backside of the substrate support is sprayed with a cold liquid to lower the temperature of the substrate and the layer of viscoelastic cleaning material before and during the rinsing liquid is applied on the layer of the viscoelastic cleaning material, and wherein lowering the temperature of the layer of the viscoelastic cleaning material increases the elastic nature of the viscoelastic cleaning material.

22. The method of claim 19, wherein the energy is applied by a vacuum suction on the layer of the viscoelastic cleaning material prior to dispensing the rinsing liquid when the substrate is in the first or the second processing slot.

23. The method of claim 19, wherein the rinsing liquid is dispensed by a spray jet, and the energy is applied on the layer of the viscoelastic cleaning material by the spray jet.

24. The method of claim 19, wherein the energy is an acoustic energy with a frequency greater than a reciprocal of the characteristic time.