COMPOSITION AND METHOD FOR POLISHING POLYSILICON

BACKGROUND OF THE INVENTION

[0001] Silicon wafers used in electronic devices are typically prepared from a single crystal silicon ingot that is first sliced into thin wafers using a diamond saw, lapped to improve flatness, and etched to remove subsurface damage caused by lapping. The silicon wafers are then typically polished in a two-step process to remove nanotopography caused by etching and to achieve the desired thickness before the wafers are acceptable for use in electronic devices.

[0002] In the first polishing step, a high removal rate is required, and ideally the nanotopography would not be worsened during this step. Nanotopography is a parameter that measures the front-surface topology of an area and is defined as the deviation of a surface within a spatial wavelength of 0.2 to 20 mm. Nanotopography differs from surface flatness in that, for nanotopography, the flatness of the wafer surface is measured relative to the wafer surface itself, while for surface flatness, the flatness of the wafer surface is measured relative to a flat chuck used to hold the wafer. Thus, a wafer may have perfect flatness, yet still have nanotopography. If a wafer has surface irregularities on the front and back sides of the wafer, but the front and back surfaces are parallel, the wafer has perfect flatness. However, the same wafer will exhibit nanotopography. Nanotopography bridges the gap between roughness and flatness in the topology map of wafer surface irregularities in spatial frequency.

[0003] Conventional polishing compositions for silicon wafers exhibit high removal rates for silicon, but produce increased nanotopography of the silicon wafers. The increased nanotopography puts increased demands on the second, final polishing step to produce silicon wafers suitable for further processing into semiconductor substrates.

[0004] In addition, the edges of the silicon wafers can come into contact with processing apparatus and transporting cases, which can result in cracking or chipping at the edge surfaces of the wafers. Fine particles can be generated by the cracking or chipping, which can interfere with further processing. Contamination of the silicon wafers with very fine particles can also occur at the coarsened surface of the edge, which particles can be released during processing and result in contamination of the wafer surfaces. Thus, the outermost periphery edge of the wafer is typically chamfered and then mirror polished at an early stage of the wafer processing. Further, in some processes, the silicon wafers are oxidized on one side to form a protective layer of silicon oxide, and so part of the wafer edge comprises silicon oxide. While silicon polishing compositions can be used for edge polishing, typically,

a higher removal rate is needed for edge polishing of silicon wafers than for surface polishing. A suitable edge polishing composition desirably exhibits a useful removal rate on silicon oxide as well as on silicon.

[0005] Substrates in the electronics industry typically possess a high degree of integration, wherein the substrates comprise multilayer interconnected structures. The layers and structures on the substrate typically comprise a wide variety of materials, such as, e.g., single crystal silicon, polycrystalline silicon (polysilicon), silicon dioxide, silicon nitride, copper, and/or tantalum. Because these substrates require various processing steps, including chemical-mechanical planarization, to form the final multilayer interconnected structures, it is often highly-desirable to utilize polishing compositions and methods that are selective for specific materials, depending on the intended application. For example, when a substrate comprises tetraethylorthosilicate (TEOS), polysilicon, and silicon nitride, it can be highly-desirable to selectively polish polysilicon over TEOS and silicon nitride, such that the removal rate of polysilicon is higher compared with the removal rates of TEOS and silicon nitride. While the polishing selectivity for one material over others is beneficial, undesirable thinning and dishing of the materials can occur with increased polishing rates.

[0006] Thus, there remains a need in the art for improved polishing compositions for silicon wafers.

BRIEF SUMMARY OF THE INVENTION

[0007] The invention provides a polishing composition comprising (a) silica, (b) a compound or compounds that increases the removal rate of silicon, (c) a tetraalkylammonium salt, and (d) water, wherein the polishing composition has a pH of 7 to 11.

[0008] A first embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 5 wt.% of one or more organic carboxylic acids, (c) 0.0005 wt.% to 2 wt.% of one or more aminophosphonic acids, (d) 0.01 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) optionally one or more bicarbonate salts, (f) optionally potassium hydroxide, and (g) water, wherein the polishing composition has a pH of 7 to 11.

[0009] A second embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of one or more polyaminocarboxylic acids, (c) 0.05 wt.% to 5 wt.% of one or more amines, (d) 0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) 0.001 wt.% to 1 wt.% of one or more diol

compounds, (f) optionally one or more bicarbonate salts, and (g) water, wherein the polishing composition has a pH of 7 to 11.

[0010] A third embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of one or more polyaminocarboxylic acids, (c) 0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (d) 0.01 wt.% to 5 wt.% of one or more organic carboxylic acids, (e) optionally 0.1 wt.% to 5 wt.% of one or more amines, (f) optionally one or more bicarbonate salts, and (g) water, wherein the polishing composition has a pH of 7 to 11.

[0011] A fourth embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.02 wt.% to 5 wt.% of one or more nitrogen-containing heterocyclic compounds, (c) 0.05 wt.% to 2 wt.% of one or more aminophosphonic acids, (d) 0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) optionally one or more bicarbonate salts, and (f) water, wherein the polishing composition has a pH of 7 to 11.

[0012] A fifth embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.005 wt.% to 2 wt.% of one or more aminophosphonic acids, (c) 0.001 wt.% to 0.1 wt.% of one or more polysaccharides, (d) 0.05 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) 0.01 wt.% to 2 wt.% of a bicarbonate salt, (f) 0.005 wt.% to 2 wt.% of one or more compounds comprising an azole ring, (g) optionally potassium hydroxide, and (h) water, wherein the polishing composition has a pH of 7 to 11.

[0013] The invention also provides a method for chemically-mechanically polishing a substrate with the inventive chemical-mechanical polishing composition.

[0014] A first embodiment of the inventive method for chemically-mechanically polishing a substrate comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.02 wt.% to 5 wt.% of one or more organic carboxylic acids, (c) 0.02 wt.% to 2 wt.% of one or more aminophosphonic acids, (d)0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) optionally one or more bicarbonate salts, (f) optionally potassium hydroxide, and (g) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing

composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0015] A second embodiment of the inventive method for chemically-mechanically polishing a substrate comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of one or more polyaminocarboxylic acids, (c) 0.05 wt.% to 5 wt.% of one or more amines, (d) 0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) 0.001 wt.% to 1 wt.% of one or more diol compounds, (f) optionally one or more bicarbonate salts, and (g) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0016] A third embodiment of the inventive method for chemically-mechanically polishing a substrate comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of one or more polyaminocarboxylic acids, (c) 0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (d) 0.01 wt.% to 5 wt.% of one or more organic carboxylic acids, (e) optionally 0.1 wt.% to 5 wt.% of one or more amines, (f) optionally one or more bicarbonate salts, and (g) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0017] A fourth embodiment of the inventive method for chemically-mechanically polishing a substrate comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.02 wt.% to 5 wt.% of one or more nitrogen-containing heterocyclic compounds, (c) 0.05 wt.% to 2 wt.% of one or more aminophosphonic acids, (d)0.1 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) optionally one or more bicarbonate salts, and (f) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0018] A fifth embodiment of the inventive method for chemically-mechanically polishing a substrate comprises (i) contacting the substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of (a) 0.5 wt.% to 20 wt.%

of silica, (b) 0.005 wt.% to 2 wt.% of one or more aminophosphonic acids, (c) 0.001 wt.% to 0.1 wt.% of one or more polysaccharides, (d) 0.05 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) 0.01 wt.% to 2 wt.% of a bicarbonate salt, (f) 0.005 wt.% to 2 wt.% of one or more compounds comprising an azole ring, (g) optionally potassium hydroxide, and (h) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0019] The invention further provides a method for polishing an edge of a silicon wafer, wherein the edge consists essentially of silicon, which method comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of (a) 0.5 wt.% to 20 wt.% of wet process silica, (b) 0.01 wt.% to 5 wt.% of an organic carboxylic acid, (c) 0.0005 wt.% to 2 wt.% of an aminophosphonic acid, (d) 0.01 wt.% to 5 wt.% of a tetraalkylammonium salt, (e) potassium hydroxide, (f) optionally, a bicarbonate salt, and (g) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the edge of the silicon wafer with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the edge to polish the edge of the silicon wafer.

[0020] The invention additionally provides a method for polishing an edge of a wafer, wherein the edge has a surface consisting essentially of silicon and silicon oxide, which method comprises (i) contacting a substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 5 wt.% of an organic carboxylic acid, (c) 0.0005 wt.% to 1 wt.% of an aminophosphonic acid, (d) 0.01 wt.% to 5 wt.% of a tetraalkylammonium salt, (e) optionally, a bicarbonate salt, (f) optionally, potassium hydroxide, and (g) water, wherein the polishing composition has a pH of 7 to 11, (ii) moving the polishing pad relative to the edge of the wafer with the chemical-mechanical polishing composition therebetween, and (iii) abrading at least a portion of the edge to polish the edge of the wafer.

BRIEF DESCRIPTION OF THE DRAWING(S)

[0021] FIG. 1 is a schematic drawing that illustrates the surface parameter R_{max}.

[0022] FIGS. 2 and 3 are graphical representations of the data of Example 9 illustrating the removal rates of blanket layers of polysilicon, silicon nitride, and silicon oxide with various polishing compositions at 6.89 kPa (1 psi) and 20.68 kPa (3 psi), respectively.

DETAILED DESCRIPTION OF THE INVENTION

[0023] The invention provides a polishing composition comprising (a) silica, (b) a compound or compounds that increases the removal rate of silicon, (c) a tetraalkylammonium salt, and (d) water, wherein the polishing composition has a pH of 7 to 11.

[0024] The silica can be any suitable form of silica such as wet-process type silica, fumed silica, or combinations thereof. For example, the silica can comprise wet-process type silica particles (e.g., condensation-polymerized or precipitated silica particles). Condensation-polymerized silica particles typically are prepared by condensing $Si(OH)_4$ to form colloidal particles, where colloidal particles are defined as having an average particle size between 1 nm and 1000 nm. Such abrasive particles can be prepared in accordance with U.S. Patent 5,230,833 or can be obtained as any of various commercially available products, such as the Akzo-Nobel Bindzil 50/80 product, the Nalco DVSTS006 product, and the Fuso PL-2 product, as well as other similar products available from DuPont, Bayer, Applied Research, Nissan Chemical, and Clariant.

[0025] The silica can comprise fumed silica particles. Fumed silica particles can be produced from volatile precursors (e.g., silicon halides) in a pyrogenic process by hydrolysis and/or oxidation of the precursors in a high temperature flame (H_2/air or H_2/CH_4/air) to produce the fumed silica. The solution containing the precursor can be sprayed into a high temperature flame using a droplet generator, and the metal oxide can then be collected. Typical droplet generators include bi-fluid atomizers, high-pressure spray nozzles, and ultrasonic atomizers. Suitable fumed silica products are commercially available from producers such as Cabot, Tokuyama, and Degussa.

[0026] The silica can have any suitable average particle size (i.e., average particle diameter). The silica can have an average particle size of 4 nm or more, e.g., 10 nm or more, 15 nm or more, 20 nm or more, or 25 nm or more. Alternatively, or in addition, the silica can have an average particle size of 180 nm or less, e.g., 120 nm or less, 110 nm or less, 100 nm or less, 90 nm or less, 80 nm or less, 70 nm or less, 60 nm or less, 50 nm or less, or 40 nm or less. Thus, the silica can have an average particle size bounded by any two of the above endpoints. For example, the silica can have an average particle size of 10 nm to 100 nm, 20 nm to 100 nm, 20 nm to 80 nm, 20 nm to 60 nm, or 20 nm to 40 nm. For a non-spherical silica particle, the size of the particle is the diameter of the smallest sphere that encompasses the particle.

[0027] The polishing composition can comprise any suitable amount of silica. Typically, the polishing composition can contain 0.5 wt.% or more, e.g., 1 wt.% or more, 2 wt.% or

more, or 5 wt.% or more of silica. Alternatively, or in addition, the polishing composition can contain 20 wt.% or less, e.g., 15 wt.% or less, 10 wt.% or less, 8 wt.% or less, 6 wt.% or less, or 5 wt.% or less of silica. Thus, the polishing composition can comprise silica in an amount bounded by any two of the above endpoints recited for silica. For example the polishing composition can comprise 0.5 wt.% to 20 wt.%, 1 wt.% to 15 wt.%, 5 wt.% to 15 wt.%, or 0.5 wt.% to 5 wt.% of silica.

[0028] The silica particles preferably are colloidally stable. The term colloid refers to the suspension of silica particles in the liquid carrier. Colloidal stability refers to the maintenance of that suspension through time. In the context of this invention, an abrasive is considered colloidally stable if, when the abrasive is placed into a 100 ml graduated cylinder and allowed to stand unagitated for a time of 2 hours, the difference between the concentration of particles in the bottom 50 ml of the graduated cylinder ([B] in terms of g/ml) and the concentration of particles in the top 50 ml of the graduated cylinder ([T] in terms of g/ml) divided by the initial concentration of particles in the abrasive composition ([C] in terms of g/ml) is less than or equal to 0.5 (i.e., $\{[B] - [T]\}/[C] \leq 0.5$). More preferably, the value of [B]-[T]/[C] is less than or equal to 0.3, and most preferably is less than or equal to 0.1.

[0029] The polishing composition comprises water. The water is used to facilitate the application of the abrasive particles, compound(s) that increase the removal rate of silicon, and any other additives to the surface of a suitable substrate to be polished or planarized. Preferably, the water is deionized water.

[0030] The polishing composition has a pH of 11 or less (e.g., 10 or less). Preferably, the polishing composition has a pH of 7 or more (e.g., 8 or more). Even more preferably, the polishing composition has a pH of 7 to 11 (e.g., 8 to 10). The polishing composition optionally contains pH adjusting agents, for example, potassium hydroxide, ammonium hydroxide, and/or nitric acid. The polishing composition also optionally comprises pH buffering systems. Many such pH buffering systems are well known in the art. The pH buffering agent can be any suitable buffering agent, for example, bicarbonate-carbonate buffer systems, aminoalkylsulfonic acids, and the like. The polishing composition can comprise any suitable amount of a pH adjustor and/or a pH buffering agent, provided that a suitable amount is used to achieve and/or maintain the pH of the polishing composition within a suitable range.

[0031] The polishing composition optionally further contains one or more bicarbonate salts. The bicarbonate salt can be any suitable bicarbonate salt and can be, for example, potassium bicarbonate, sodium bicarbonate, ammonium bicarbonate, or combinations thereof.

[0032] The polishing composition can contain any suitable amount of the bicarbonate salt(s). Typically, the polishing composition can contain 0.01 wt.% or more, e.g., 0.03 wt.% or more, 0.05 wt.% or more, 0.08 wt.% or more, 0.1 wt.% or more, 0.2 wt.% or more, 0.3 wt.% or more, 0.5 wt.% or more, 0.7 wt.% or more, 0.9 wt.% or more, 1 wt.% or more, 1.2 wt.% or more, 1.5 wt.% or more, 1.7 wt.% or more, or 1.9 wt.% or more of the azole ring-containing compound(s). Alternatively, or in addition, the polishing composition can contain 2.0 wt.% or less, e.g., 1.8 wt.% or less, 1.6 wt.% or less, 1.4 wt.% or less, 1.2 wt.% or less, 1.0 wt.% or less, 0.8 wt.% or less, 0.6 wt.% or less, 0.4 wt.% or less, 0.2 wt.% or less, 0.1 wt.% or less, 0.08 wt.% or less, 0.06 wt.% or less, 0.04 wt.% or less, 0.02 wt.% or less, or 0.015 wt.% or less of the azole ring-containing compound(s). Thus, the polishing composition can comprise the bicarbonate salt(s) in an amount bounded by any two of the above endpoints recited for the bicarbonate salt(s). For example the polishing composition can comprise 0.01 wt.% to 2 wt.%, 0.1 wt.% to 1.8 wt.%, 0.2 wt.% to 1.2 wt.%, or 0.7 wt.% to 1.6 wt.% of the bicarbonate salt(s).

[0033] The polishing composition optionally further contains potassium hydroxide. The polishing composition can contain any suitable amount of potassium hydroxide. Typically, the polishing composition can contain 0.05 wt.% or more, e.g., 0.1 wt.% or more, or 0.25 wt.% or more of potassium hydroxide. Alternatively, or in addition, the polishing composition can contain 2 wt.% or less, e.g., 1.5 wt.% or less, 1 wt.% or less, 0.8 wt.% or less, or 0.6 wt.% or less of potassium hydroxide. Thus, the polishing composition can comprise potassium hydroxide in an amount bounded by any two of the above endpoints recited for potassium hydroxide. For example the polishing composition can comprise 0.05 wt.% to 1 wt.%, 0.1 wt.% to 2 wt.%, 0.1 wt.% to 1 wt.%, or 0.25 wt.% to 0.8 wt.% of potassium hydroxide.

[0034] The polishing composition optionally further comprises one or more other additives. Such additives include any suitable dispersing agent, such as, for example, homopolymers or random, block, or gradient acrylate copolymers comprising one or more acrylic monomers (e.g., polyacrylates, polymethacrylates, vinyl acrylates and styrene acrylates), combinations thereof, and salts thereof. Other suitable additives include biocides. The biocide can be any suitable biocide, for example, an isothiazolinone biocide.

[0035] A first embodiment of the inventive chemical-mechanical polishing composition provides a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 5 wt.% of an organic carboxylic acid, (c) 0.0005 wt.% to 2 wt.% of an aminophosphonic acid, (d) 0.01 wt.% to 5 wt.% of a tetraalkylammonium salt, (e) optionally a bicarbonate salt, (f) optionally potassium hydroxide, and (g) water, wherein the polishing composition has a pH of 7 to 11.

[0036] The polishing composition of the first embodiment contains one or more suitable organic carboxylic acids or salts thereof. The organic carboxylic acid can be an alkyl carboxylic acid or aryl carboxylic acid and can be optionally substituted with groups selected from the group consisting of C_1-C_{12} alkyl, amino, substituted amino (e.g., methylamino, dimethylamino, and the like), hydroxyl, halogen, and combinations thereof. Preferably, the organic carboxylic acid is a hydroxycarboxylic acid (e.g., an aliphatic hydroxycarboxylic acid or a hydroxybenzoic acid), an amino acid, an amino hydroxybenzoic acid, or a pyridine carboxylic acid. Non-limiting examples of suitable hydroxycarboxylic acids include malonic acid, lactic acid, malic acid, tartaric acid, acetohydroxamic acid, glycolic acid, 2-hydroxybutyric acid, benzilic acid, salicylic acid, and 2,6-dihydroxybenzoic acid. Non-limiting examples of suitable amino acids include glycine, alanine, proline, lysine, cysteine, leucine, aspartic acid, glutamic acid, and 2-amino-4-thiazolacetic acid. Non-limiting examples of an amino hydroxybenzoic acid include 3-aminosalicylic acid and 3-amino-4-hydroxybenzoic acid. Non-limiting examples of pyridine carboxylic acids include picolinic acid and nicotinic acid.

[0037] The polishing composition of the first embodiment can contain any suitable amount of the organic carboxylic acid(s). The polishing composition can contain 0.01 wt.% or more, e.g., 0.02 wt.% or more, e.g., 0.05 wt.% or more, 0.1 wt.% or more, or 0.5 wt.% or more of the organic carboxylic acid(s). Alternatively, or in addition, the polishing composition can contain 5 wt.% or less, e.g., 4 wt.% or less, 3 wt.% or less, 2 wt.% or less, or 1 wt.% or less of the organic carboxylic acid(s). Thus, the polishing composition can comprise the organic carboxylic acid(s) in an amount bounded by any two of the above endpoints recited for the organic carboxylic acid(s). For example the polishing composition can comprise 0.01 wt.% to 5 wt.%, 0.02 wt.% to 5 wt.%, 0.05 wt.% to 4 wt.%, or 0.1 wt.% to 3 wt.% of the organic carboxylic acid(s).

[0038] The polishing composition of the first embodiment contains one or more suitable aminophosphonic acids. Preferably, the aminophosphonic acid is selected from the group consisting of ethylenediaminetetra(methylene phosphonic acid), amino tri(methylene

phosphonic acid), diethylenetriaminepenta(methylene phosphonic acid), salts thereof, and combinations thereof. More preferably, the aminophosphonic acid is amino tri(methylene phosphonic acid).

[0039] The polishing composition of the first embodiment can contain any suitable amount of the aminophosphonic acid(s). Typically, the polishing composition can contain 0.0005 wt.% or more, e.g., 0.001 wt.% or more, 0.01 wt.% or more, 0.02 wt.% or more, 0.05 wt.% or more, 0.1 wt.% or more, 0.2 wt.% or more, or 0.5 wt.% or more of the aminophosphonic acid(s). Alternatively, or in addition, the polishing composition can contain 2 wt.% or less, e.g., 1.5 wt.% or less, or 1 wt.% or less of the aminophosphonic acid(s). Thus, the polishing composition can comprise the aminophosphonic acid(s) in an amount bounded by any two of the above endpoints recited for the aminophosphonic acid(s). For example the polishing composition can comprise 0.0005 wt.% to 2 wt.%, 0.02 wt.% to 2 wt.%, 0.05 wt.% to 2 wt.%, 0.1 wt.% to 1.5 wt.%, or 0.5 wt.% to 1 wt.% of the aminophosphonic acid(s).

[0040] The polishing composition of the first embodiment comprises one or more suitable tetraalkylammonium salt(s). The tetraalkylammonium salt preferably comprises a cation selected from the group consisting of tetramethylammonium, tetraethylammonium, tetrapropylammonium, and tetrabutylammonium. The tetraalkylammonium salt can have any suitable cation including but not limited to hydroxide, chloride, bromide, sulfate, or hydrogensulfate. In an embodiment, the tetraalkylammonium salt is a tetraalkylammonium hydroxide (e.g., tetramethylammonium hydroxide).

[0041] The polishing composition of the first embodiment can comprise any suitable amount of the tetraalkylammonium salt(s). Typically, the polishing composition can contain 0.01 wt.% or more, e.g., 0.1 wt.% or more, 0.2 wt.% or more, or 0.5 wt.% or more of the tetraalkylammonium salt(s). Alternatively, or in addition, the polishing composition can contain 5 wt.% or less, e.g., 4 wt.% or less, 3 wt.% or less, 2 wt.% or less, or 1 wt.% or less of the tetraalkylammonium salt(s). Thus, the polishing composition can comprise the tetraalkylammonium salt(s) in an amount bounded by any two of the above endpoints recited for the tetraalkylammonium salt(s). For example the polishing composition can comprise 0.01 wt.% to 5 wt.%, 0.1 wt.% to 5 wt.%, 0.2 wt.% to 4 wt.%, or 0.5 wt.% to 3 wt.% of the tetraalkylammonium salt(s).

[0042] In an embodiment, the polishing composition consists essentially of (a) 0.5 wt.% to 20 wt.% of wet process silica, (b) 0.01 wt.% to 5 wt.% of an organic carboxylic acid selected from the group consisting of lactic acid, oxalic acid, 2-hydroxybutyric acid, benzilic

acid, and combinations thereof, (c) 0.0005 wt.% to 2 wt.% of an aminophosphonic acid selected from the group consisting of ethylenediaminetetra(methylene phosphonic acid), amino tri(methylene phosphonic acid), diethylenetriaminepenta(methylene phosphonic acid), and combinations thereof, (d) 0.01 wt.% to 5 wt.% of a tetraalkylammonium hydroxide, (e) 0.05 wt.% to 2 wt.% of potassium hydroxide, (f) 0.05 wt.% to 5 wt.% of potassium bicarbonate, and (g) water.

[0043] A second embodiment of the inventive chemical-mechanical polishing composition provides a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of a polyaminocarboxylic acid, (c) 0.1 wt.% to 5 wt.% of an amine, (d) 0.1 wt.% to 5 wt.% of a tetraalkylammonium salt, (e) 0.001 wt.% to 1 wt.% of a diol compound, (f) optionally a bicarbonate salt, and (g) water, wherein the polishing composition has a pH of 7 to 11.

[0044] The polishing composition of the second embodiment comprises one or more suitable polyaminocarboxylic acids. The term polyaminocarboxylic acid as used herein refers to a compound having two or more amino groups and two or more carboxylic acid groups. Preferably, the polyaminocarboxylic acid is selected from the group consisting of ethylenediaminetetraacetic acid, diethylenetriaminepentaacetic acid, N-(hydroxyethyl)ethylenediaminetriacetic acid, nitrilotriacetic acid, methylglycinediacetic acid, salts thereof, and combinations thereof. More preferably, the polyaminocarboxylic acid is selected from the group consisting of ethylenediaminetetraacetic acid or a salt thereof (e.g., a mono-, di-, tri-, or tetrasodium salt thereof).

[0045] The polishing composition of the second embodiment can comprise any suitable amount of the polyaminocarboxylic acid(s). Typically, the polishing composition can contain 0.01 wt.% or more, e.g., 0.1 wt.% or more, 0.2 wt.% or more, or 0.5 wt.% or more of the polyaminocarboxylic acid(s). Alternatively, or in addition, the polishing composition can contain 2 wt.% or less, e.g., 1.5 wt.% or less, or 1.0 wt.% or less of the polyaminocarboxylic acid(s). Thus, the polishing composition can comprise the polyaminocarboxylic acid(s) in an amount bounded by any two of the above endpoints recited for the polyaminocarboxylic acid(s). For example the polishing composition can comprise 0.01 wt.% to 2 wt.%, 0.1 wt.% to 1.5 wt.%, or 0.5 wt.% to 1 wt.% of the polyaminocarboxylic acid(s).

[0046] The polishing composition of the second embodiment comprises one or more suitable amines. Non-limiting examples of suitable amines include piperazine, aminoethylpiperazine, 2-methyl-2-aminoethanol, (2-aminoethyl)-2-aminoethanol, ethanolamine, diethanolamine, triethanolamine, ethylenediamine, diethylenetriamine,

tetraethylenepentamine, hydrazine, 2-hydroxyethylhydrazine, semicarbazide, hydroxylamine, N-methylhydroxylamine, O-methylhydroxylamine, and O-carboxymethylhydroxylamine. More preferably, the amine is piperazine or aminoethylpiperazine.

[0047] The polishing composition of the second embodiment can comprise any suitable amount of the amine(s). Typically, the polishing composition can contain 0.05 wt.% or more, e.g., 0.1 wt.% or more, 0.2 wt.% or more, or 0.5 wt.% or more of the amine(s). Alternatively, or in addition, the polishing composition can contain 5 wt.% or less, e.g., 4 wt.% or less, 3 wt.% or less, 2 wt.% or less, or 1 wt.% or less of the amine(s). Thus, the polishing composition can comprise the amine(s) in an amount bounded by any two of the above endpoints recited for the amine(s). For example the polishing composition can comprise 0.05 wt.% to 5 wt.%, 0.2 wt.% to 4 wt.%, or 0.5 wt.% to 3 wt.% of the amine(s).

[0048] The polishing composition of the second embodiment comprises one or more suitable tetraalkylammonium salts. The tetraalkylammonium salt and amount thereof can be as recited for the first embodiment of the polishing composition.

[0049] The polishing composition of the second embodiment comprises one or more suitable diol compounds. The diol compound can be any suitable diol compound and typically is a 1,2-diol compound or a 1,3-diol compound. Typically, the diol compound is a linear or branched-chain C_2-C_{10} diol compound. Non-limiting examples of suitable 1,2-diol compounds include 1,2-propane diol, 1,2-butane diol, 1,2-pentane diol, 2,3-pentane diol, and combinations thereof. Non-limiting examples of suitable 1,3-diol compounds include 1,3-propane diol, 1,3-butane diol, 1,3-pentane diol, 2,4-pentane diol, and combinations thereof.

[0050] The polishing composition of the second embodiment can comprise any suitable amount of the diol compound(s). Typically, the polishing composition can contain 0.001 wt.% or more, e.g., 0.005 wt.% or more, 0.01 wt.% or more, or 0.05 wt.% or more of the diol compound(s). Alternatively, or in addition, the polishing composition can contain 1 wt.% or less, e.g., 0.75 wt.% or less, 0.5 wt.% or less, 0.25 wt.% or less, or 0.1 wt.% or less of the diol compound(s). Thus, the polishing composition can comprise the diol compound(s) in an amount bounded by any two of the above endpoints recited for the diol compound(s). For example the polishing composition can comprise 0.001 wt.% to 1 wt.%, 0.005 wt.% to 0.75 wt.%, or 0.01 wt.% to 0.5 wt.% of the diol compound(s).

[0051] A third embodiment of the inventive chemical-mechanical polishing composition comprises a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.01 wt.% to 2 wt.% of a

polyaminocarboxylic acid, (c) 0.1 wt.% to 5 wt.% of a tetraalkylammonium salt, (d) 0.1 wt.% to 5 wt.% of an organic carboxylic acid, (e) optionally 0.1 wt.% to 5 wt.% of an amine, (f) optionally a bicarbonate salt, and (g) water, wherein the polishing composition has a pH of 7 to 11. The polyaminocarboxylic acid, tetraalkylammonium salt, organic carboxylic acid, amine, and amounts thereof contained in the third embodiment of the inventive chemical-mechanical polishing composition can be as recited herein for the first and second embodiments of the inventive polishing composition.

[0052] A fourth embodiment of the inventive chemical-mechanical polishing composition provides a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.02 wt.% to 5 wt.% of a nitrogen-containing heterocyclic compound, (c) 0.05 wt.% to 2 wt.% of an aminophosphonic acid, (d) 0.1 wt.% to 5 wt.% of a tetraalkylammonium salt, (e) optionally a bicarbonate salt, and (f) water, wherein the polishing composition has a pH of 7 to 11. The aminophosphonic acid, tetraalkylammonium salt, and amounts thereof contained in the fourth embodiment of the inventive chemical-mechanical polishing composition can be as recited herein for the first embodiment of the inventive polishing composition.

[0053] The polishing composition of the fourth embodiment comprises one or more suitable nitrogen-containing heterocyclic compounds. The term nitrogen-containing heterocyclic compound as used herein refers to a 5-, 6-, or 7-membered ring compound having one or more nitrogen atoms contained as part of the ring system. In an embodiment, the nitrogen-containing heterocyclic compound is a triazole. In a preferred embodiment, the nitrogen-containing heterocyclic compound is an aminotriazole. Non-limiting examples of suitable aminotriazoles include 3-amino-1,2,4-triazole, 3-amino-1,2,4-triazole-5-carboxylic acid, 3-amino-5-mercapto-1,2,4-triazole, and 4-amino-5-hydrazino-1,2,4-triazole-3-thiol. In another embodiment, the nitrogen-containing heterocyclic compound is a thiazole. Non-limiting examples of suitable thiazoles include 2-amino-5-methylthiazole, 2-amino-4-thoazoleacetic acid, and thiazole. In another embodiment, the nitrogen-containing heterocyclic compound is a heterocyclic N-oxide. Non-limiting examples of suitable heterocyclic N-oxides include 2-hydroxypyridine-N-oxide, 4-methylmorpholine-N-oxide, and picolinic acid N-oxide.

[0054] The polishing composition of the fourth embodiment can comprise any suitable amount of the nitrogen-containing heterocyclic compound. The polishing composition can contain 0.02 wt.% or more, e.g., 0.05 wt.% or more, 0.1 wt.% or more, or 0.5 wt.% or more of the nitrogen-containing heterocyclic compound(s). Alternatively, or in addition, the

polishing composition can contain 5 wt.% or less, e.g., 4 wt.% or less, 3 wt.% or less, 2 wt.% or less, or 1 wt.% or less of the nitrogen-containing heterocyclic compound(s). Thus, the polishing composition can comprise the nitrogen-containing heterocyclic compound(s) in an amount bounded by any two of the above endpoints recited for the nitrogen-containing heterocyclic compound(s). For example the polishing composition can comprise 0.02 wt.% to 5 wt.%, 0.05 wt.% to 4 wt.%, or 0.1 wt.% to 3 wt.% of the nitrogen-containing heterocyclic compound(s).

[0055] A fifth embodiment of the inventive chemical-mechanical polishing composition provides a chemical-mechanical polishing composition consisting essentially of or consisting of (a) 0.5 wt.% to 20 wt.% of silica, (b) 0.005 wt.% to 2 wt.% of one or more aminophosphonic acids, (c) 0.001 wt.% to 0.1 wt.% of one or more polysaccharides, (d) 0.05 wt.% to 5 wt.% of one or more tetraalkylammonium salts, (e) 0.01 wt.% to 2 wt.% of a bicarbonate salt, (f) 0.005 wt.% to 2 wt.% of one or more compounds comprising an azole ring, (g) optionally potassium hydroxide, and (h) water, wherein the polishing composition has a pH of 7 to 11. The aminophosphonic acid, tetraalkylammonium salt, and amounts thereof contained in the fifth embodiment of the inventive chemical-mechanical polishing composition can be as recited herein for the first embodiment of the inventive polishing composition.

[0056] The polishing composition of the fifth embodiment comprises one or more suitable polysaccharides. The polysaccharide can be hydroxyethylcellulose. Additional non-limiting examples of suitable polysaccharides are dextran, carboxymethyl dextran, dextran-sulfonate salt, chitosan, xanthan gum, carboxymethylcellulose, and carrageenan.

[0057] The polishing composition of the fifth embodiment can comprise any suitable amount of the polysaccharide(s). Typically, the polishing composition can contain 0.001 wt.% or more, e.g., 0.002 wt.% or more, 0.003 wt.% or more, 0.004 wt.% or more, 0.005 wt.% or more, 0.007 wt.% or more, 0.01 wt.% or more, 0.02 wt.% or more, 0.03 wt.% or more, 0.04 wt.% or more, 0.05 wt.% or more, 0.06 wt.% or more, 0.07 wt.% or more, 0.08 wt.% or more, or 0.09 wt.% or more of the polysaccharide(s). Alternatively, or in addition, the polishing composition can contain 0.1 wt.% or less, e.g., 0.09 wt.% or less, 0.08 wt.% or less, 0.07 wt.% or less, 0.06 wt % or less, 0.05 wt.% or less, 0.04 wt.% or less, 0.03 wt.% or less, 0.02 wt.% or less, or 0.01 wt.% or less of the polysaccharide(s). Thus, the polishing composition can comprise the polysaccharide(s) in an amount bounded by any two of the above endpoints recited for the polysaccharide(s). For example, the polishing composition

can comprise 0.001 wt.% to 0.1 wt.%, 0.005 wt.% to 0.09 wt.%, or 0.01 wt.% to 0.08 wt.% of the polysaccharide(s).

[0058] The polysaccharide(s) can have any suitable molecular weight. Typically, the polysaccharide(s) can have a molecular weight of 9,000 daltons to 100,000 daltons. When the polysaccharide is hydroxyethylcellulose, the preferred molecular weight range is 25,000 daltons to 100,000 daltons. When the polysaccharide is dextran, or any suitable dextran derivative, the preferred molecular weight range is 9,000 daltons to 40,000 daltons. Thus, the polysaccharide(s) can have a molecular weight of 9,000 daltons or more, e.g., 10,000 daltons or more, 15,000 daltons or more, 20,000 daltons or more, 25,000 daltons or more, 30,000 daltons or more, 35,000 daltons or more, 40,000 daltons or more, 45,000 daltons or more, 50,000 daltons or more, 55,000 daltons or more, or 60,000 daltons or more. Alternatively, or in addition, the polysaccharide(s) can have a molecular weight of 100,000 daltons or less, e.g., 95,000 daltons or less, 90,000 daltons or less, 85,000 daltons or less, 80,000 or less, 75,000 daltons or less, 70,000 daltons or less, 65,000 daltons or less, 60,000 daltons or less, 55,000 daltons or less, 50,000 daltons or less, 45,000 daltons or less, 40,000 daltons or less, 35,000 daltons or less, 30,000 daltons or less, 25,000 daltons or less, 20,000 daltons or less, 15,000 daltons or less, or 10,000 daltons or less. Thus, the polysaccharide(s) can have a molecular weight bounded by any two of the above endpoints recited for the polysaccharide(s). For example, the polysaccharide(s) can have a molecular weight of 9,000 daltons to 100,000 daltons, 10,000 daltons to 95,000 daltons, 25,000 daltons to 90,000 daltons, 30,000 daltons to 80,000 daltons, 9,000 daltons to 40,000 daltons, 10,000 daltons to 35,000 daltons, 15,000 daltons to 30,000 daltons, 15,000 daltons to 40,000 daltons, or 10,000 daltons to 25,000 daltons.

[0059] The polishing composition of the fifth embodiment comprises one or more suitable azole ring-containing compound(s). Typically, suitable triazole compounds can be substituted with one or more substituents at the 3-, 4-, and 5-position, or any combination thereof. Non-limiting examples of suitable triazole compounds are 3-amino-1,2,4-triazole, 3-amino-1,2,4-triazole-5-carboxylic acid, 3,5-diamino-1,2,4-triazole, 4-amino-5-hydrazino-1,2,4-triazole-3-thiol, and 4-amino-1,2,4-triazole. In a preferred embodiment, the azole ring-containing compound is a triazole.

[0060] The polishing composition of the fifth embodiment can comprise any suitable amount of the azole ring-containing compound(s). Typically, the polishing composition can contain 0.005 wt.% or more, e.g., 0.007 wt.% or more, 0.01 wt.% or more, 0.03 wt.% or more, 0.05 wt.% or more, 0.08 wt.% or more, 0.1 wt.% or more, 0.3 wt.% or more, 0.5 wt.%

or more, 0.7 wt.% or more, 0.9 wt.% or more, 1 wt.% or more, 1.2 wt.% or more, 1.5 wt.% or more, 1.7 wt.% or more, or 1.9 wt.% or more of the azole ring-containing compound(s). Alternatively, or in addition, the polishing composition can contain 2.0 wt.% or less, e.g., 1.8 wt.% or less, 1.6 wt.% or less, 1.4 wt.% or less, 1.2 wt.% or less, 1.0 wt.% or less, 0.8 wt.% or less, 0.6 wt.% or less, 0.4 wt.% or less, 0.2 wt.% or less, 0.1 wt.% or less, 0.08 wt.% or less, 0.06 wt.% or less, 0.04 wt.% or less, 0.02 wt.% or less, 0.01 wt.% or less, or 0.008 wt.% or less of the azole ring-containing compound(s). Thus, the polishing composition can comprise the azole ring-containing compound(s) in an amount bounded by any two of the above endpoints recited for the azole ring-containing compound(s). For example, the polishing composition can comprise 0.005 wt.% to 2.0 wt.%, 0.01 wt.% to 1.9 wt.%, or 0.05 wt.% to 1.7 wt.% of the azole ring-containing compound(s).

[0061] The polishing composition of the invention can be prepared by any suitable technique, many of which are known to those skilled in the art. The polishing composition can be prepared in a batch or continuous process. Generally, the polishing composition can be prepared by combining the components thereof in any order. The term "component" as used herein includes individual ingredients (e.g., silica, compound(s) that increases the removal rate of silicon, tetraalkylammonium salt, etc.) as well as any combination of ingredients (e.g., silica, compound(s) that increases the removal rate of silicon, tetraalkylammonium salt, buffers, etc.).

[0062] For example, in one embodiment, the silica can be dispersed in water. The organic carboxylic acid, aminophosphonic acid, and tetraalkylammonium salt can then be added, and mixed by any method that is capable of incorporating the components into the polishing composition. Other compounds that increase the removal rate of silicon similarly can be utilized in the preparation of the polishing composition. The polishing composition can be prepared prior to use, with one or more components, such as a pH adjusting component, added to the polishing composition just before use (e.g., within 7 days before use, or within 1 hour before use, or within 1 minute before use). The polishing composition also can be prepared by mixing the components at the surface of the substrate during the polishing operation.

[0063] The polishing composition also can be provided as a concentrate which is intended to be diluted with an appropriate amount of water prior to use. In such an embodiment, the polishing composition concentrate can comprise, for example, silica, a compound or compounds that increases the removal rate of silicon, a tetraalkylammonium salt, and water in amounts such that, upon dilution of the concentrate with an appropriate

amount of water, each component of the polishing composition will be present in the polishing composition in an amount within the appropriate range recited above for each component. For example, the abrasive, compound or compounds that increases the removal rate of silicon, and tetraalkylammonium salt can each be present in the concentrate in an amount that is 2 times (e.g., 3 times, 4 times, 5 times, 10 times, or 15 times) greater than the concentration recited above for each component so that, when the concentrate is diluted with an equal volume of water (e.g., 2 equal volumes water, 3 equal volumes of water, 4 equal volumes of water, 9 equal volumes of water, or 14 equal volumes of water, respectively), each component will be present in the polishing composition in an amount within the ranges set forth above for each component. Furthermore, as will be understood by those of ordinary skill in the art, the concentrate can contain an appropriate fraction of the water present in the final polishing composition in order to ensure that the compound or compounds that increase the removal rate of silicon, and other suitable additives are at least partially or fully dissolved in the concentrate.

[0064] The invention further provides a method of chemically-mechanically polishing a substrate comprising (i) contacting a substrate with a polishing pad and the polishing composition described herein, (ii) moving the polishing pad relative to the substrate with the polishing composition therebetween, and (iii) abrading at least a portion of the substrate to polish the substrate.

[0065] Although the polishing composition of the invention can be used to polish any substrate, the polishing composition is particularly useful in the polishing of a substrate comprising, consisting essentially of, or consisting of silicon, for example, silicon wafers used in the electronics industry. In this regard, the silicon can be undoped silicon, or it can be doped silicon, such as p-type silicon doped with boron or aluminum. In addition, the silicon can be polysilicon. The inventive polishing composition and method of use thereof is suitable for the pre-polishing or the final polishing of silicon wafers as produced from silicon single crystals by diamond sawing and rough grinding, as well as for edge polishing of silicon wafers and for use in the reclamation of silicon wafers by polishing.

[0066] In an embodiment, the inventive method provides improved removal rates for polysilicon over the removal rates for other materials, such as silicon oxide and silicon nitride. For example, in an embodiment, the inventive method provides improved selectivity for polishing polysilicon over silicon oxide and silicon nitride. Additionally, the inventive method advantageously minimizes the dishing of substrate materials such as polysilicon, such

that the inventive method is suitable for chemical-mechanical polishing applications in the electronics industry, among others.

[0067] Advantageously, the inventive polishing method exhibits improved nanotopography when used to polish silicon wafers after lapping and etching of diamond sawed silicon wafers. One way to measure change in nanotopography during chemical-mechanical polishing is to determine the value of the parameter: ΔR_z / d wherein R_z is the average maximum height of the profile, ΔR_z is the change in R_z from one time point to another time point, e.g., before and after chemical-mechanical polishing, and d is the amount of material removed in microns over that same time span, with the result expressed in nanometers. Referring to the FIG., R_{max} represents the largest peak to valley height in a given sampling length L, and R_z represents the average of 5 R_{max} values in 5 contiguous sampling lengths. Sampling length L is approximately 5 mm. Suitable techniques for measuring R_{max} (to enable the calculation of R_z) include stylus profilometry, optical profilometry, and atomic force microscopy. Suitable instruments for stylus profilometry and optical profilometry are available from, e.g., Veeco Instruments (Plainview, NY). Desirably, the inventive polishing method results in a ΔR_z / d that is zero or less, that is, substrate nanotopography is either unchanged or improved after use of the inventive polishing method.

[0068] The polishing method of the invention is particularly suited for use in conjunction with a chemical-mechanical polishing apparatus. Typically, the apparatus comprises a platen, which, when in use, is in motion and has a velocity that results from orbital, linear, or circular motion, a polishing pad in contact with the platen and moving with the platen when in motion, and a carrier that holds a substrate to be polished by contacting and moving the substrate relative to the surface of the polishing pad. The polishing of the substrate takes place by the substrate being placed in contact with the polishing pad and the polishing composition of the invention and then the polishing pad moving relative to the substrate, so as to abrade at least a portion of the substrate to polish the substrate.

[0069] A substrate can be polished with the chemical-mechanical polishing composition with any suitable polishing pad (e.g., polishing surface). Suitable polishing pads include, for example, woven and non-woven polishing pads. Moreover, suitable polishing pads can comprise any suitable polymer of varying density, hardness, thickness, compressibility, ability to rebound upon compression, and compression modulus. Suitable polymers include, for example, polyvinylchloride, polyvinylfluoride, nylon, fluorocarbon, polycarbonate, polyester, polyacrylate, polyether, polyethylene, polyamide, polyurethane, polystyrene,

polypropylene, coformed products thereof, and mixtures thereof. Hard polyurethane polishing pads are particularly useful in conjunction with the inventive polishing method.

[0070] Desirably, the chemical-mechanical polishing apparatus further comprises an in situ polishing endpoint detection system, many of which are known in the art. Techniques for inspecting and monitoring the polishing process by analyzing light or other radiation reflected from a surface of the substrate being polished are known in the art. Such methods are described, for example, in U.S. Patent 5,196,353, U.S. Patent 5,433,651, U.S. Patent 5,609,511, U.S. Patent 5,643,046, U.S. Patent 5,658,183, U.S. Patent 5,730,642, U.S. Patent 5,838,447, U.S. Patent 5,872,633, U.S. Patent 5,893,796, U.S. Patent 5,949,927, and U.S. Patent 5,964,643. Desirably, the inspection or monitoring of the progress of the polishing process with respect to a substrate being polished enables the determination of the polishing end-point, i.e., the determination of when to terminate the polishing process with respect to a particular substrate.

[0071] In an embodiment, the inventive method provides a method for polishing an edge of a silicon wafer, wherein the edge consists essentially of silicon. In another embodiment, the inventive method provides a method for polishing an edge of a wafer, wherein the edge has a surface consisting essentially of silicon and silicon oxide. The edge polishing can be carried out using techniques that are well known in the art. For example, edge polishing can be performed using edge polishers supplied by SpeedFam Co., Ltd., Kanagawa, Japan.

[0072] Advantageously, the inventive polishing method exhibits improved chucking mark performance when used to polish the edges of silicon wafers, wherein the edges of the silicon wafers consist essentially of silicon or consist essentially of silicon and silicon oxide. In edge polishing, the silicon wafers are typically held in place using a vacuum chuck attached to the back side of the wafer. The vacuum often draws polishing compositions onto the back of the wafer during polishing, where it can dry. The dried residue is referred to as a chucking mark. If the residue resulting from drying of the polishing compositions is not easily removed, the wafers then require additional cleaning steps after polishing, thereby adding to the cost of manufacture. Desirably, the inventive method results in chucking marks which are dry white residues and easily removed during further processing of the wafers.

[0073] Advantageously, the inventive method further provides improved removal rates when used to polish wafers edges consisting essentially of silicon, thereby improving production throughput of the wafers. In addition, when used to polish wafers consisting essentially of silicon and silicon oxide, the inventive method exhibits improved removal rates for silicon oxide relative to silicon, thereby resulting in even polishing of the wafer edges.

[0074] In another embodiment, the inventive method provides improved removal rates of polysilicon over other materials, such as TEOS and silicon nitride, when the inventive method is used to polish wafers consisting essentially or exclusively of polysilicon, TEOS, and silicon nitride.

[0075] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

EXAMPLE 1

[0076] This example demonstrates the effect of an organic carboxylic acid, an aminophosphonic acid, and a tetraalkylammonium salt on the removal rate and surface roughness observed for silicon substrates achievable by the polishing composition of the invention.

[0077] Seven similar substrates, which substrates comprised 102 cm (4 inch) diameter circular silicon wafers, were polished with seven different polishing compositions (Polishing Compositions 1A-1G). All of the polishing compositions contained 1 wt.% silica, wet-process silica (Polishing Compositions 1A, 1B, 1D, and 1F) or fumed silica (Polishing Compositions 1C, 1E, and 1G), 0.27 wt.% tetramethylammonium hydroxide, and 0.05 wt.% potassium bicarbonate in water at a pH of 10.5. Polishing Composition 1A (comparative) further contained 0.017 wt.% ethylenediaminetetraacetic acid and 0.067 wt.% piperazine. Polishing Compositions 1B-1G further contained 0.033 wt.% diethylenetriaminepenta(methylene phosphonic acid) and an organic carboxylic acid, which was either 0.08 wt.% malonic acid (Polishing Compositions 1B and 1C), 0.067 wt.% lactic acid (Polishing Compositions 1D and 1E), or 0.107 wt.% malic acid (Polishing Compositions 1F and 1G).

[0078] Following polishing, the removal rates for silicon and the magnitude of the change in nanotopography, $\Delta R_z/d$, were determined for each of the polishing compositions. The results are summarized in Table 1.

Table 1

Polishing Composition	Silicon Removal Rate (Å/min)	$\Delta R_z/d$ (nm)
1A (comparative)	6500	6
1B (invention)	5700	0
1C (invention)	5200	0.1
1D (invention)	5150	0.4
1E (invention)	5650	0.4
1F (invention)	5700	-0.2
1G (invention)	5400	0

[0079] As is apparent from the results set forth in Table 1, the inventive polishing compositions exhibited silicon removal rates that were approximately 79% to 88% of the removal rate exhibited by the comparative polishing composition, yet the inventive polishing compositions exhibited a change in surface roughness caused by polishing that ranged from a decrease in surface roughness of approximately 0.2 nm (Polishing Composition 1F) to an increase in surface roughness of approximately 0.4 nm (Polishing Compositions 1D and 1E), while the comparative polishing composition exhibited an increase in surface roughness of approximately 6 nm.

EXAMPLE 2

[0080] This example demonstrates the effect of an organic carboxylic acid, a polyaminocarboxylic acid, and a tetraalkylammonium salt on the removal rate and surface roughness observed for silicon substrates achievable by the polishing composition of the invention.

[0081] Three similar substrates, which substrates comprised 102 cm (4 inch) diameter circular silicon wafers, were polished with three different polishing compositions (Polishing Compositions 2A-2C). Polishing Composition 2A (comparative) contained 1 wt.% wet-process silica, 0.0167 wt.% ethylenediaminetetraacetic acid, 0.067 wt.% piperazine, 0.27 wt.% tetramethylammonium hydroxide, and 0.05 wt.% potassium bicarbonate. Polishing Composition 2B (invention) contained 0.85 wt.% wet-process silica, 0.02 wt.% ethylenediaminetetraacetic acid, 0.083 wt.% oxalic acid, 0.2 wt.% tetramethylammonium hydroxide, and 0.1 wt.% potassium bicarbonate. Polishing Composition 2C (invention) contained 0.53 wt.% wet-process silica, 0.0167 wt.% ethylenediaminetetraacetic acid, 0.007 wt.% oxalic acid, 0.067 wt.% tetramethylammonium hydroxide, and 0.05 wt.% potassium bicarbonate.

[0082] Following polishing, the removal rates for silicon and the magnitude of the change in nanotopography, $\Delta R_z/d$, were determined for each of the polishing compositions. The results are summarized in Table 2.

Table 2

Polishing Composition	Silicon Removal Rate (Å/min)	$\Delta R_z/d$ (nm)
2A (comparative)	6700	4
2B (invention)	5900	-4
2C (invention)	5500	-7

[0083] As is apparent from the results set forth in Table 2, the inventive polishing compositions exhibited silicon removal rates that were approximately 82% to 88% of the removal rate exhibited by the comparative polishing composition, yet the inventive polishing compositions exhibited a decrease in surface roughness caused by polishing of approximately 4 nm and 7 nm, as compared to an increase in surface roughness caused by polishing with the comparative polishing composition of approximately 4 nm.

EXAMPLE 3

[0084] This example demonstrates the effect of an organic carboxylic acid, a polyaminocarboxylic acid, an amine, and a tetraalkylammonium salt on the removal rate and surface roughness observed for silicon substrates achievable by the polishing composition of the invention.

[0085] Two similar substrates, which substrates comprised 102 cm (4 inch) diameter circular silicon wafers, were polished with two different polishing compositions (Polishing Compositions 3A and 3B). Polishing Compositions 3A and 3B contained 1 wt.% wet-process silica, 0.0167 wt.% ethylenediaminetetraacetic acid, 0.067 wt.% piperazine, 0.27 wt.% tetramethylammonium hydroxide, and 0.05 wt.% potassium bicarbonate. Polishing Composition 3B (invention) further contained 0.033 wt.% benzilic acid.

[0086] Following polishing, the removal rates for silicon and the magnitude of the change in nanotopography, $\Delta R_z/d$, were determined for each of the polishing compositions. The results are summarized in Table 2.

Table 3

Polishing Composition	Silicon Removal Rate (Å/min)	$\Delta R_z/d$ (nm)
3A (comparative)	6250	6
3B (invention)	2550	-6

[0087] As is apparent from the results set forth in Table 3, the inventive polishing composition exhibited a silicon removal rate that was approximately 42% of the removal rate exhibited by the comparative polishing composition, yet the inventive polishing composition exhibited a decrease in surface roughness caused by polishing of approximately 6 nm as compared to an increase in surface roughness caused by polishing with the comparative polishing composition of approximately 6 nm.

EXAMPLE 4

[0088] This example demonstrates the effect of a diol compound, a polyaminocarboxylic acid, an amine, and a tetraalkylammonium salt on the removal rate and surface roughness observed for silicon substrates achievable by the polishing composition of the invention.

[0089] Two similar substrates, which substrates comprised 102 cm (4 inch) diameter circular silicon wafers, were polished with two different polishing compositions (Polishing Compositions 4A and 4B). Polishing Compositions 4A and 4B contained 1 wt.% wet-process silica, 0.0167 wt.% ethylenediaminetetraacetic acid, 0.067 wt.% piperazine, 0.27 wt.% tetramethylammonium hydroxide, and 0.05 wt.% potassium bicarbonate. Polishing Composition 3B (invention) further contained 0.033 wt.% 2,4-pentanediol (i.e., a diol compound).

[0090] Following polishing, the removal rates for silicon and the magnitude of the change in nanotopography, $\Delta R_z/d$, were determined for each of the polishing compositions. The results are summarized in Table 4.

Table 4

Polishing Composition	Silicon Removal Rate (Å/min)	$\Delta R_z/d$ (nm)
4A (comparative)	5350	-0.5
4B (invention)	4375	-5

[0091] As is apparent from the results set forth in Table 4, the inventive polishing composition exhibited a silicon removal rate that was approximately 82% of the removal rate exhibited by the comparative polishing composition, yet the inventive polishing composition exhibited a decrease in surface roughness caused by polishing of approximately 5 nm as compared to a decrease in surface roughness caused by polishing with the comparative polishing composition of approximately -0.5 nm.

EXAMPLE 5

[0092] This example demonstrates the chucking mark performance of an embodiment of the invention.

[0093] Two separate substrates, which substrates comprised sheets of polyvinyl chloride ("PVC") were misted with two different polishing compositions (Polishing Compositions 5A and 5B). Polishing Composition 5A (comparative) contained 0.04 wt.% of an aminophosphonic acid, 0.2 wt.% of tetramethylammonium hydroxide, 0.1 wt.% of potassium bicarbonate, 0.044 wt.% of oxalic acid, and 0.85 wt.% of a wet-process silica. Polishing Composition 5B (invention) contained 0.02 wt.% of an aminophosphonic acid, 0.13 wt.% of tetramethylammonium hydroxide, 0..7 wt.% of potassium bicarbonate, 0.04 wt.% of potassium hydroxide, 0.022 wt.% of lactic acid, and 0.67 wt.% of a wet-process silica.

[0094] After misting, the compositions were allowed to dry. Polishing Composition 5A left a gelled residue. Polishing Composition 5B left a dry, white residue.

EXAMPLE 6

[0095] This example demonstrates silicon removal rates achievable by the inventive polishing composition.

[0096] Two separate silicon substrates were polished with two different polishing compositions (Polishing Compositions 6A and 6B). Polishing Compositions 6A and 6B contained 0.02 wt.% of an aminophosphonic acid, 0.13 wt.% of tetramethylammonium hydroxide, 0.7 wt.% of potassium bicarbonate, 0.04 wt.% of potassium hydroxide, and 0.022 wt.% of lactic acid. Polishing Composition 6A further contained 10.0 wt.% of a wet-process silica, namely, Nalco DVSTS006. Polishing Composition 6B further contained 10.0 wt.% of a different wet-process silica, namely, Nalco TX11005.

[0097] Following polishing, the removal rates for silicon were determined in mg of silicon removed per minute of polishing. Polishing Composition 6A exhibited a silicon removal rate of 13.5 mg Si/min. Polishing Composition 6B exhibited a silicon removal rate of 14.2 mg Si/min.

EXAMPLE 7

[0098] This example demonstrates silicon removal rates achievable by the inventive polishing composition.

[0099] Two separate silicon substrates were polished with two different polishing compositions (Polishing Compositions 7A and 7B). Polishing Composition 7A contained 0.004 wt.% of an aminophosphonic acid, 0.027 wt.% tetramethylammonium hydroxide, 0.007 wt.% potassium bicarbonate, 0.08 wt.% potassium hydroxide, 0.013 wt.% lactic acid, and 1.2 wt.% fumed silica. Polishing Composition 7B contained 0.004 wt.% of an aminophosphonic acid, 0.053 wt.% tetramethylammonium hydroxide, 0.013 wt.% potassium

bicarbonate, 0.08 wt.% potassium hydroxide, 0.027 wt.% lactic acid, and 1.2 wt.% fumed silica.

[00100] Following polishing, the removal rates for silicon were determined in mg of silicon removed per minute of polishing. Polishing Composition 7A exhibited a silicon removal rate of 11.2 mg Si/min. Polishing Composition 7B exhibited a silicon removal rate of 11.8 mg Si/min.

EXAMPLE 8

[00101] This example demonstrates silicon oxide removal rates achievable by the inventive polishing composition.

[0100] Two separate silicon oxide substrates were polished with two different polishing compositions (Polishing Compositions 8A and 8B). The silicon oxide was derived from tetraethylorthosilicate. Polishing Composition 8A contained 0.015 wt.% of an aminophosphonic acid, 0.1 wt.% tetramethylammonium hydroxide, 0.025 wt.% potassium bicarbonate, 0.3 wt.% potassium hydroxide, 0.05 wt.% lactic acid, and 4.4 wt.% fumed silica. Polishing Composition 8B contained 0.015 wt.% of an aminophosphonic acid, 0.2 wt.% tetramethylammonium hydroxide, 0.05 wt.% potassium bicarbonate, 0.3 wt.% potassium hydroxide, 0.1 wt.% lactic acid, and 4.3 wt.% fumed silica.

[0101] Following polishing, the removal rates for silicon oxide were determined in mg of silicon removed per minute of polishing. Polishing Composition 8A exhibited a silicon oxide removal rate of 2.7 mg SiO/min. Polishing Composition 8B exhibited a silicon oxide removal rate of 4.9 mg SiO/min.

EXAMPLE 9

[0102] This example demonstrates the polishing selectivity for polysilicon over dielectric materials comprising silicon nitride or silicon oxide achievable by employing the inventive polishing composition.

[0103] Similar substrates containing blanket layers of polysilicon, silicon nitride, or silicon oxide (TEOS) were each polished in separate experiments with 11 different polishing compositions (Polishing Compositions 9A-9K). The amount (wt.%) of each component is relative to the total weight of the polishing composition. Polishing Composition 9A (invention) was initially prepared in concentrate form and contained 0.44 wt.% of an aminophosphonic acid (DEQUEST™ 2000EG), 4.0 wt.% tetramethylammonium hydroxide, 0.80 wt.% potassium hydroxide, 1.3 wt.% potassium bicarbonate, 0.17 wt.% 1,2,4-triazole, 13 wt.% potassium-stabilized colloidal silica (NALCO™ DVSTS006), 0.066 wt.% of a polysaccharide (hydroxyethylcellulose, molecular weight = 80,000 g/mol), and water. Prior

to use, Polishing Composition 9A was diluted with water to an abrasives concentration of 0.83 wt.%. Polishing Composition 9B (comparative) was initially prepared in concentrate form and contained 0.44 wt.% of an aminophosphonic acid (DEQUEST™ 2000EG), 2.6 wt.% tetramethylammonium hydroxide, 0.80 wt.% potassium hydroxide, 1.3 wt.% potassium bicarbonate, 0.33 wt.% 1,2,4-triazole, 13 wt.% potassium-stabilized colloidal silica (NALCO™ DVSTS006), and water. Prior to use, Polishing Composition 9B was diluted with water to an abrasives concentration of 0.83 wt.%. Polishing Composition 9C (comparative) was initially prepared in concentrate form and contained 25 wt.% fumed silica (100 nm particle size) and water, and the pH was adjusted to a pH of 10 with a small amount of potassium hydroxide. Prior to use, Polishing Composition 9C was diluted with water to an abrasives concentration of 12 wt.%. Polishing Composition 9D (comparative) was initially prepared in concentrate form and contained 0.060 wt.% of a polysaccharide (hydroxyethylcellulose, molecular weight = 80,000), 0.75 wt.% potassium hydroxide, 0.55 wt.% malonic acid, 4.0 wt.% condensation-polymerized high-purity colloidal silica (FUSO® PL-2), and water. Prior to use, Polishing Composition 9D was diluted with water to an abrasives concentration of 0.20 wt.%. Polishing Composition 9E (comparative) was initially prepared in concentrate form and contained 1.0 wt.% piperazine, 0.25 wt.% ethylenediaminetetraacetic acid (EDTA), 0.75 wt.% potassium bicarbonate, 4.0 wt.% tetramethylammonium hydroxide, 15 wt.% fumed colloidal silica (55 nm particle size), and water. Prior to use, Polishing Composition 9E was diluted with water to an abrasives concentration of 0.94 wt.%. Polishing Compositions 9F (comparative) and 9G (comparative) were initially prepared in concentrate form at a pH of 4-5 and contained 4.0 wt.% ion-exchanged colloidal silica (NALCO® 1034A) 0.40 wt.% tetrabutylphosphonium hydroxide, and water. Prior to use, Polishing Composition 9F was diluted with water to an abrasives concentration of 1.0 wt.%, and Composition 9G was used in concentrate form. Polishing Composition 9H (comparative) was prepared at a pH of 8.5 and contained 1.0 wt.% potassium-stabilized colloidal silica (NALCO® DVSTS006), 0.020 wt.% of an aminophosphonic acid (DEQUEST™ 2000EG), 0.020 wt.% of a polyoxypropylenediamine (JEFFAMINE™ D400; molecular weight = 400), 0.0050 wt.% ammonium hydroxide, and water, and Composition 9H was used as prepared. Polishing Composition 9I (comparative) contained 5.0 wt.% fumed silica (100 nm particle size), 0.060 wt.% DMAMP-80™ (80 % 2-dimethylamino-2-methyl-1-propanol, 20% water), 0.024 wt.% oxalic acid, 0.0010 KATHON™ (biocide), and water, and Composition 9I was used as prepared. Polishing Compositions 9J (comparative) and 9K (comparative) were initially prepared in concentrate

form and contained 0.15 wt.% acetic acid, 6.0 wt.% aluminum-doped colloidal silica (NALCO® TX13157), 10 ppm KATHON™ (biocide), and water. Prior to use, Polishing Compositions 9J and 9K were diluted with water to abrasives concentrations of 1 wt.% and 2 wt.%, respectively.

[0104] Substrates consisting of blanket layers of polysilicon (PolySi), silicon nitride (Si_3N_4), and silicon oxide (TEOS) were polished with each of the Polishing Compositions 9A-9K at both 6.89 kPa (1 psi) and 20.68 kPa (3 psi) downforce pressure of the substrate onto a polishing pad. Following polishing, the removal rates for polysilicon, silicon nitride, and silicon oxide were determined for each of the polishing compositions. The polysilicon polishing selectivities were calculated by dividing the polysilicon removal rate by the silicon nitride (PolySi/Si_3N_4) or TEOS (PolySi/TEOS) removal rate. The results are summarized in Table 5 and plotted in Figures 2 and 3.

Table 5

Polishing Composition	Substrate Removal Rate (Å/min)						Selectivity PolySi/Si_3N_4		Selectivity PolySi/TEOS	
	PolySi		Si_3N_4		TEOS					
	6.89 kPa	20.68 kPa	6.89 kPa	20.68 kPa	6.89 kPa	20.68 kPa	6.89 kPa	20.68 kPa	6.89 kPa	20.68 kPa
9A (invention)	322	4001	172	208	15	51	1.9	19	21	78
9B (comparative)	964	4453	174	210	15	61	5.5	21	64	73
9C (comparative)	1124	4230	295	937	702	2128	3.8	4.5	1.6	2.0
9D (comparative)	262	839	172	205	8	29	1.5	4.1	33	29
9E (comparative)	583	1250	163	165	1	1	3.6	7.6	580	1250
9F (comparative)	445	662	254	262	329	637	1.8	2.5	1.4	1.0
9G (comparative)	354	785	211	523	423	1131	1.7	1.5	0.84	0.69
9H (comparative)	704	1127	517	554	---	---	1.4	2.0	0.38	0.61
9I (comparative)	729	1811	278	495	13	23	2.6	3.7	56	79
9J (comparative)	242	333	436	739	6	29	0.56	0.45	40	11
9K (comparative)	277	368	485	898	12	59	0.57	0.41	23	6.2

[0105] As is apparent from the results set forth in Table 5 and graphically depicted in Figures 2 and 3, at 6.89 kPa (1 psi), Polishing Composition 9A (invention) and Polishing

Composition 9B (comparative) result in high polysilicon removal rates with good selectivity for polysilicon over TEOS; however, the polishing selectivity for polysilicon over silicon nitride is relatively low. When the polishing pressure is increased from 6.89 kPa (1 psi) to 20.68 kPa (3 psi), higher removal rates of polysilicon are observed for most polishing compositions, especially Polishing Compositions 9A and 9B. Significantly, when employing Inventive Polishing Composition 9A, the polishing selectivity for polysilicon over silicon nitride increases 10-fold when the polishing pressure is increased from 6.89 kPa (1 psi) to 20.68 kPa (3 psi). None of the Comparative Polishing Compositions 9B-9K exhibits such a large increase in the polishing selectivity for polysilicon over silicon nitride as compared to Inventive Polishing Composition 9A when the polishing pressure is increased from 6.89 kPa (1 psi) to 20.68 kPa (3 psi).

EXAMPLE 10

[0106] This example demonstrates favorable polysilicon dishing performance achievable with the inventive polishing composition.

[0107] Polishing Compositions 9A (invention) and 9B (comparative) of Example 9 were utilized to polish patterned wafers comprising polysilicon-filled TEOS trenches.

[0108] Polishing was performed at both 6.89 kPa (1 psi) and 20.68 kPa (3 psi) downforce pressure of the substrate onto a polishing pad for 30, 60, and/or 120 seconds. Following polishing, the amount of polysilicon dishing in a polysilicon-filled TEOS trench was determined. The results are summarized in Table 6.

Table 6

Polishing Composition	Polysilicon Dishing (Å)			
	6.89 kPa (1 psi)		20.68 kPa (3 psi)	
	60 s	120 s	30 s	60 s
9A (invention)	994	411	713	1076
9B (comparative)	1056	1507	1180	1840

[0109] The results in Table 6 demonstrate that the dishing performance for Polishing Composition 9A (invention) under a variety of process conditions (polishing pressure and polishing time) is lower and thus more favorable than the dishing performance of Polishing Composition 9B (comparative).

CLAIMS

1. A chemical-mechanical polishing composition consisting essentially of:

(a) 0.5 wt.% to 20 wt.% of silica,

(b) 0.005 wt.% to 2 wt.% of one or more aminophosphonic acids,

(c) 0.001 wt.% to 0.1 wt.% of one or more polysaccharides,

(d) 0.05 wt.% to 5 wt.% of one or more tetraalkylammonium salts,

(e) 0.01 wt.% to 2 wt.% of a bicarbonate salt,

(f) 0.005 wt.% to 2 wt.% of one or more compounds comprising an azole ring,

(g) optionally potassium hydroxide, and

(h) water,

wherein the polishing composition has a pH of 7 to 11.

2. The polishing composition of claim 1, wherein the silica is wet-process silica.

3. The polishing composition of claim 1, wherein the polishing composition contains 0.1 wt.% to 1 wt.% of one or more aminophosphonic acids

4. The polishing composition of claim 3, wherein the aminophosphonic acid is selected from the group consisting of ethylenediaminetetra(methylene phosphonic acid), amino tri(methylene phosphonic acid), diethylenetriaminepenta(methylene phosphonic acid), and combinations thereof.

5. The polishing composition of claim 4, wherein the aminophosphonic acid is amino tri(methylene phosphonic acid).

6. The polishing composition of claim 1, wherein the polysaccharide is hydroxyethylcellulose.

7. The polishing composition of claim 6, wherein the hydroxyethylcellulose has a molecular weight of 25,000 daltons to 100,000 daltons.

8. The polishing composition of claim 1, wherein the compound comprising an azole ring is a triazole compound.

9. The polishing composition of claim 1, wherein potassium hydroxide is present in the polishing composition.

10. A method for polishing a substrate comprising polysilicon, which method comprises:

(i) contacting the substrate with a polishing pad and a chemical-mechanical polishing composition consisting essentially of:

(a) 0.5 wt.% to 20 wt.% of silica,

(b) 0.005 wt.% to 2 wt.% of one or more aminophosphonic acids,

(c) 0.001 wt.% to 0.1 wt.% of one or more alkylated cellulose compounds,

(d) 0.05 wt.% to 5 wt.% of one or more tetraalkylammonium salts,

(e) 0.01 wt.% to 2 wt.% of a bicarbonate salt,

(f) 0.005 wt.% to 2 wt.% of one or more compounds comprising an azole ring,

(g) optionally potassium hydroxide, and

(h) water,

wherein the polishing composition has a pH of 7 to 11,

(ii) moving the polishing pad relative to the substrate with the chemical-mechanical polishing composition therebetween, and

(iii) abrading at least a portion of the substrate to polish the substrate.

11. The method of claim 10, wherein the silica is wet-process silica.

12. The method of claim 10, wherein the polishing composition contains 0.1 wt.% to 1 wt.% of one or more aminophosphonic acids

13. The method of claim 12, wherein the aminophosphonic acid is selected from the group consisting of ethylenediaminetetra(methylene phosphonic acid), amino tri(methylene phosphonic acid), diethylenetriaminepenta(methylene phosphonic acid), and combinations thereof.

14. The method of claim 13, wherein the aminophosphonic acid is amino tri(methylene phosphonic acid).

15. The method of claim 10, wherein the polysaccharide is hydroxyethylcellulose.

16. The method of claim 15, wherein the hydroxyethylcellulose has a molecular weight of 25,000 daltons to 100,000 daltons.

17. The method of claim 10, wherein the compound comprising an azole ring is a triazole compound.

18. The method of claim 10, wherein potassium hydroxide is present in the polishing composition.

19. The method of claim 10, wherein the substrate further comprises silicon oxide, silicon nitride, or a combination thereof.

20. The method of claim 19, wherein the silicon oxide or silicon nitride forms an interlayer dielectric layer.