

inertness compared to many other materials that comprise an integrated circuit. This greater hardness and chemical inertness makes the removal of silicon carbide using CMP techniques difficult. Removing silicon carbide with conventional CMP compositions and methods frequently results in the unwanted removal of other materials such as silicon dioxide.

[0009] Although many of the known CMP slurry compositions are suitable for limited purposes, the conventional compositions tend to exhibit unacceptable polishing rates and corresponding selectivity levels to insulator materials used in wafer manufacture. Known polishing slurries tend to produce poor film removal traits for the underlying films, or produce deleterious film-corrosion, which leads to poor manufacturing yields.

[0010] In addition, known polishing compositions and methods do not provide the ability to selectively remove silicon carbide from a semiconductor wafer without removing materials such as silicon dioxide from the same wafer at unacceptably high levels. As the technology for integrated circuit devices advances, traditional materials are being used in new and different ways to achieve the level of performance needed for advanced integrated circuits. In particular, silicon nitride, silicon carbide, and silicon dioxide are being used in various combinations to achieved new and ever more complex device configurations. In general, the structural complexity and performance characteristics vary across different applications.

[0011] There is an ongoing need to develop new polishing methods and compositions that provide relatively high rates of removal of silicon carbide and to selectively remove silicon carbide in preference to other materials present on the surface of the semiconductor wafer. The present invention provides such improved polishing methods and compositions. These and other advantages of the invention, as well as additional inventive features, will be apparent from the description of the invention provided herein.

BRIEF SUMMARY OF THE INVENTION

[0012] The present ~~disclosure~~invention provides methods for polishing silicon carbide from the surface of a substrate in preference to silicon dioxide, as well as polishing compositions useful

in such methods. The method of the present ~~disclosure~~invention comprises abrading the surface of the substrate with an aqueous polishing composition comprising a particulate silica abrasive and at least one acidic buffering agent providing a pH in the range of about 2 to about 7. The methods

of the present ~~disclosure~~^{invention} selectively remove silicon carbide (as well as silicon nitride) from the surface of the substrate in preference to silicon dioxide. In particular, the methods and compositions of the present ~~disclosure~~^{invention} provide a greater removal rate for silicon carbide when polishing a semiconductor wafer than the corresponding silicon dioxide removal rate.

[0013] In a preferred embodiment, the present ~~disclosure~~^{invention} provides a method for selectively removing silicon carbide from the surface of a substrate in preference to silicon dioxide (particularly PETEOS silicon dioxide). The silicon carbide may or may not contain at least some nitrogen. As used herein, the term "silicon carbide" refers to substantially pure silicon carbide and to a silicon carbide materials that include some nitrogen in the film matrix. For convenience, nitrogen-containing silicon carbide is represented herein as "SiCN" when specific reference is being made to such materials. Silicon carbide that is substantially free of nitrogen is referred to as substantially pure silicon carbide, or for convenience, "SiC". The polishing composition is capable of abrading silicon carbide present on the surface of the substrate at a removal rate higher than the removal rate for concurrent abrading of silicon dioxide present on the surface of the substrate. Preferably, in the silicon carbide films containing nitrogen, the portion of the substrate has a nitrogen content of at least about 1 weight percent nitrogen, and not more than about 25 weight percent nitrogen (e.g., about 1 to about 20 weight percent).

[0013a] In an aspect, there is provided a chemical-mechanical polishing (CMP) method for selectively removing silicon carbide from the surface of substrate in preference to silicon dioxide, the method comprising the steps of: (a) contacting a surface of the substrate with a polishing pad and an aqueous CMP composition; and (b) causing relative motion between the substrate and the polishing pad while maintaining a portion of the aqueous CMP composition in contact with the surface between the pad and the substrate to abrade at least a portion of the silicon carbide present in the substrate from the surface; wherein the CMP composition contains a particulate alumina-doped colloidal silica abrasive present at a concentration in the range of 0.1 to 5 percent by weight, and an acidic buffering agent providing a pH in the range of 2 to 7, the aqueous CMP composition being capable of abrading silicon carbide present on the surface of the substrate at a higher removal rate than the concurrent abrading of silicon dioxide present on the surface of the substrate.

[0013b] In another aspect, there is provided a chemical-mechanical polishing (CMP) method for selectively removing silicon carbide from the surface of a substrate in preference to silicon dioxide, the method comprising the steps of: (a) contacting a surface of the substrate with a polishing pad and an aqueous CMP composition; and (b) causing relative motion between the substrate and the polishing pad while maintaining a portion of the aqueous CMP composition in contact with the surface between the pad and the substrate for a period of time sufficient to abrade at least a portion of the silicon carbide present in the substrate from the surface; wherein the CMP composition contains 0.1 to 1 percent by weight of alumina-doped colloidal silica having a mean particle size in the range of 40 to 150 nanometers, and a buffering agent comprising an organic acid, the buffering agent providing a pH in the range of 2 to 5; the CMP composition being capable of abrading silicon carbide present on the surface of the substrate at a higher removal rate than the concurrent abrading of silicon dioxide present on the surface of the substrate.

[0014] The acidic buffering agent is selected to provide a predetermined composition pH in the range of about 2 to 7 (e.g., about 2 to about 5, more preferably about 3.3 to about 4.5), and preferably a predetermined pH buffering capacity. Preferably, the buffering agent comprises an organic acid (preferably less than about 0.5 percent by weight) such as a carboxylic acid, a phosphonic acid, or a combination of the two. More preferably, the acidic buffering agent comprises acetic acid, 1-hydroxyethylidene-1,1-diphosphonic acid, and/or glycine. In other embodiments, the acidic buffering agent can comprise an inorganic acid such as phosphoric acid.

[0015] The degree of removal rate selectivity for silicon carbide and silicon nitride versus silicon dioxide (SiO_2) varies depending upon the acidic buffering agent and pH of the composition, as well as the concentration of the abrasive. The highest silicon carbide and silicon nitride removal rates obtained with the methods and compositions of the present ~~disclosure~~^{invention} generally occur within the pH range in which the chosen acidic buffering agent

exhibits its optimum buffering capacity. For example, the optimum pH for silicon carbide removal obtained with a phosphonic acid is generally lower than the optimum pH for silicon carbide removal obtained with a composition containing a carboxylic acid. For example, the optimum pH for silicon carbide removal (particularly for SiCN removal) for a phosphonic acid-containing composition is typically in the range of pH 3 to pH 4; whereas the optimum pH for a carboxylic acid-containing composition may be closer to pH 4 to pH 4.5. For silicon carbide removal selectivity relative to silicon dioxide materials that are generally more easily abraded and removed than PETEOS silicon dioxide, it is preferred that the pH be in the range of about 3 to about 7, preferably above 3.5.

[0016] The particulate abrasive used in the compositions and methods of the present disclosure~~invention~~ comprises a silica material such as colloidal silica, fumed silica, or alumina-doped silica, preferably having a mean particle size in the range of about 20 nanometers to about 150 nanometers. In some preferred embodiments, the composition comprises about 0.1 to about 5 percent by weight of particulate abrasive and about 50 ppm to about 150 ppm (about 0.005 to about 0.015 percent by weight) of at least one acidic buffering agent. A particularly preferred silica material is an alumina-doped colloidal silica, preferably having a mean particle size in the range of about 40 to about 150 nm (e.g., about 40 to about 50 nm).

[0017] The CMP compositions and methods described herein provide an unexpectedly high selectivity for silicon carbide removal compared to silicon dioxide (e.g., PETEOS silicon dioxide) removal. Typically, the silicon carbide removal rate obtained during polishing of a semiconductor wafer according to the methodology of the present disclosure~~invention~~ exceeds the PETEOS silicon dioxide removal rate by a factor of about 3 or more, more typically by a factor of about 20 or more.

[0018] In another ~~embodiment~~aspect, the present ~~disclosure~~invention provides a chemical-mechanical polishing method for modulating the silicon carbide-to-silicon dioxide removal rate ratio when polishing a suitable substrate. In another aspect, there is provided a chemical-mechanical polishing (CMP) method of modulating the selectivity for removal of silicon carbide versus silicon dioxide from a substrate surface in a CMP process, the method comprising the steps of: (a) polishing a silicon carbide substrate and a silicon dioxide substrate under predetermined polishing conditions with a CMP composition comprising a particulate alumina-doped colloidal silica abrasive and an acidic buffering agent; (b) determining a silicon carbide-to-silicon dioxide removal rate ratio for the substrates polished in step (a); (c) altering a polishing parameter to increase or decrease the silicon carbide-to-silicon dioxide removal rate ratio as desired; the polishing parameter to be altered being selected from the group consisting of the pH of the composition, the concentration of the buffering agent in the composition, the concentration of silica in the composition, or a combination of two or more of the foregoing. In general, silicon dioxide removal rates described herein refer to removal of any type of silicon dioxide, preferably PETEOS-type silicon dioxide (i.e., silicon dioxide formed by plasma-enhanced tetraethylorthosilicate decomposition, sometimes also abbreviated as TEOS). For example, the modulating method includes polishing a silicon carbide substrate and a silicon dioxide substrate under predetermined polishing conditions with a CMP