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(54) CHEMICAL MECHANICAL PLANARIZATION SLURRY AND METHOD FOR FORMING SAME

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Description

FIELD OF THE DISCLOSURE

[0001] The following is directed to a CMP slurry, and more particularly, a CMP slurry including a particulate material and an oxidizer.

DESCRIPTION OF THE RELATED ART

[0002] Gallium nitride based structures are recognized as a promising material for short wavelength optoelectronic devices and high-power, high-frequency electronic devices. However, the potential of this material has been limited by the lack of a suitable lattice matched substrate for epitaxially grown device layers. This has led to the development of bulk GaN substrates. With the development of these substrates, surface preparation techniques must also be investigated to provide atomically smooth, damage-free surfaces, such as chemical mechanical planarization (CMP). Additionally, alternative processes that may further expand GaN technologies, including wafer bonding, and layer transfer techniques, often require planarization steps creating a need for a well-controlled GaN CMP process.

[0003] CMP uses a combination of chemical and mechanical reactions to remove material leaving a planarized, damage-free surface. Ideally, material removal is achieved by chemically altering the surface to a mechanically weaker form. This material is then abraded from the surface leaving the bulk undisturbed. Planarization occurs due to the acceleration of both mechanical grinding and chemical transformation at the high points. While CMP slurries have been developed, a need exists for improved CMP slurries.

[0004] EP 2 818 526 A1 describes chemical mechanical polishing (CMP) slurry compositions for polishing copper substrates and a method of using the CMP compositions. The CMP slurry compositions comprise from 0.0 wt% to 25 wt% abrasive; from 0.01 wt% to 22 wt% chelating agent; from 0.001 wt% to 1 wt% corrosion inhibitor; from 0.0001 wt% to 0.50 wt% choline salt; from 0.0001 wt% to 0.20 wt% organic amine; from 0.01 wt% to 10 wt% oxidizer; and from 0.00001 wt% to 0.05 wt% biocide, wherein the CMP slurry composition has a pH in the range of 5.0 to 8.0.

[0005] From US 2010/0258528 A1 a slurry composition and chemically activated CMP methods for polishing a substrate having a silicon carbide surface using such slurries. In such methods, the silicon carbide surface is contacted with a CMP slurry composition that comprise i) a liquid carrier and ii) a plurality of particles having at least a soft surface portion, whereas the soft surface portion includes a transition metal compound that provides a Mohs hardness $\leq$ 6, and optionally iii) an oxidizing agent. The oxidizing agent can include a transition metal. The slurry is moved relative to the silicon carbide comprising surface, wherein at least a portion of the silicon carbide surface is removed.

[0006] WO 2009/017734 A1 discloses a chemical mechanical polishing slurry containing multiple oxidizers and nano abrasive particles (including engineered nano diamond particles) suitable for polishing multilayer substrate with tungsten and Ti/TiN barrier layers. The slurry contains no metallic catalyst and has low total abrasive particle content. The absence of metal ions can be advantageous for certain applications as certain metal ions may present contamination issues. A low total abrasive content may also lower the total defect counts, reduce the slurry waste treatment burden, and simplify the post CMP clean process.

[0007] WO 2016/032820 A1 deals with chemical mechanical polishing (CMP) including providing a slurry including composite particles dispersed in a water based carrier that comprises a plurality of hard particles on an outer surface of a soft-core particle. The hard particles have a Mohs hardness of at least 1 greater than a Mohs hardness of the soft shell core particle and/or a Vickers hardness of at least 500 kg/mm^2 greater than the soft-core particle. A substrate having a substrate surface with a hardness greater than a Mohs number of 6 or a Vickers hardness greater than 1,000 kg/mm^2 is placed into a CMP apparatus having a rotating polishing pad, and a CMP is performed with the rotating polishing pad and the slurry to polish the substrate surface.

[0008] US 2012/0252213 A1 describes a method of chemically mechanically polishing a substrate having a Group III-nitride surface, the method including providing a chemical-mechanical polishing slurry composition. The slurry composition includes a slurry solution comprising a liquid carrier and an oxidizer including a transition metal or a per-based compound. The slurry solution includes at least one component that reacts with the Group III-nitride surface to form a softened Group III-nitride surface. The Group III-nitride comprising surface is contacted with the slurry composition by a pad to form the softened Group III-nitride surface. The pad is moved relative to the softened Group III-nitride surface, wherein at least a portion of the softened Group III-nitride surface is removed.

[0009] From US 2016/122590 A1 slurries and associated methods for the chemical mechanical planarization (CMP) of tungsten-containing films on semiconductor wafers are known. The slurries comprise abrasive particles, activator-containing particles, peroxygen oxidizer, pH adjustor, and the remaining being water. The slurries have a pH in the range of 4 to 10.

[0010] US 9 343 321 B2 discloses a method for chemical mechanical polishing of a substrate including polishing the substrate at a stock removal rate of greater than about 2.5 Å/min to achieve a Ra of not greater than about 5 Å. The substrate can be a III-V substrate or a SiC substrate. The polishing utilizes a chemical mechanical polishing slurry comprising ultradispersed diamonds and at least 80 wt% water.

SUMMARY

[0011] The present invention refers to a CMP slurry including a carrier; a particulate material within the carrier comprising an alumina containing material wherein the alumina containing material comprises a majority content of alpha alumina and a transition phase alumina at a content of at least 0.5 wt.% and not greater than 20 wt.% for a total weight of the particulate material; an oxidizer comprising at least one material selected from the group of peroxides, persulfates, permanganates, periodates, perchlorates, hypochlorites, iodates, peroxymonosulfates, cerric ammonium nitrate, periodic acid, ferricyanides, or any combination thereof; and a material removal rate index (MRR) of at least 500 nm/hr and an average roughness index (Ra) of not greater than 0.5 nm (5 Angstroms) according to the Standardized Polishing Test conducted on a 10.16 cm (4") diameter GaN wafer (Ga-face) as further specified in the description.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] The following is directed to a CMP slurry for using in chemical mechanical planarization of wafers. Some suitable wafer materials that can be finished with the CMP slurry can include semiconductor materials, such as Group III-V compounds. Group III-V compounds can include those compounds including at least one Group III and Group V element from the Periodic Table of elements. Some suitable examples of Group III-V compounds can include nitride compounds, such as gallium nitride (GaN) materials. Notably, the CMP slurry can be used on a wafer to obtain a damage-free surface, which is epi-ready (i.e. ready for growing by homo-epitaxy).

[0013] The CMP slurry includes a carrier, a particulate material within the carrier, and an oxidizer. According to one embodiment, the carrier can be a liquid material configured to contain the particulate material, oxidizer and any other components within the slurry. The carrier can be a polar or non-polar material. In at least one embodiment, the carrier can include water. In particular instances, the carrier can consist essentially of water, such as deionized water.

[0014] The CMP slurry may be formed to include a particular content of the carrier. For example, the slurry can include a content of the carrier within a range of at least 50 wt% and not greater than 99.5 wt% for total weight of the slurry. Notably, the carrier may represent the majority component within the slurry, such that the content (wt%) of the carrier in the slurry is greater than all other components (e.g., particulate material, oxidizer, etc.) within the slurry.

[0015] The CMP slurry includes a particulate material that is contained within the carrier. The particulate material is an abrasive material that is configured to conduct material removal operations during use of the CMP slurry. In at least one embodiment, the slurry can include a certain content of the particulate material, such as not greater 30 wt% for the total weight of the slurry. In still other instances, the content of the particulate material within the slurry can be not greater than 25 wt%, such as not greater than 20 wt% or not greater than 15 wt% or not greater than 10 wt% or not greater than 8 wt% or not greater than 6 wt% or not greater than 5 wt% or not greater than 4 wt% or not greater than 3 wt% or not greater than 2 wt% or not greater than 1 wt%. Still, in at least one non-limiting embodiment, the particulate material can be present in an amount of at least 0.5 wt% of the total weight of the slurry, such as at least 0.8 wt% or at least 1 wt% or at least 1.3 wt% at least 1.5 wt% or at least 1.7 wt% or at least 2 wt% or at least 2.5 wt% or at least 3 wt% or at least 3.5 wt% or at least 4 wt% or at least 5 wt%. It will be appreciated that the particulate material can be present in an amount within a range including any of the minimum and maximum percentages noted above, including for example, within a range of at least 0.5 wt% and not greater than 30 wt%, such as within a range of at least 0.5 wt% and not greater than 20 wt%, or even within a range including at least 3 wt% and not greater than 10 wt%.

[0016] The particulate material within the carrier comprises an alumina containing material wherein the alumina containing material comprises a majority content of alpha alumina and a transition phase alumina at a content of at least 0.5 wt.% and not greater than 20 wt.% for a total weight of the particulate material.

[0017] The abrasive particles may have a particular hardness facilitating certain performance of the CMP slurry. For example, the abrasive particles may have a Mohs hardness of at least 7, such as at least 8 or even at least 9.

[0018] The alumina-containing material includes a majority content of alpha alumina. For example, the particulate material can include at least 60 wt% alpha alumina for the total weight of the particulate material, such as at least 70 wt% or at least 80 wt% or at least 90 wt% or even at least 95 wt%.

[0019] The particulate material includes at least one other polymorphic form alumina besides the alpha-phase alumina, namely a transition phase of alumina like chi-phase alumina, eta-phase alumina, rho-phase alumina, gamma-phase alumina, theta-phase alumina, kappa-phase alumina, delta-phase alumina or any combination thereof. In at least one instance, the transition phase alumina consists essentially of theta phase alumina. More particularly, the entirety of the transition phase alumina present within the particulate material can be theta phase alumina.

[0020] The particulate material includes at least 0.5 wt% of the transition phase alumina for the total weight of the particulate material. In other instances, the content of the transition phase alumina in the particulate material can be or at least 0.8 wt% or at least 1 wt% or at least 1.5 wt% at least 2 wt% or at least 2.5 wt% or at least 3 wt% or at least 3.5 wt% or at least 4 wt% or at least 4.5

wt% or even at least 5 wt% for the total weight of the particulate material. The particulate material includes not greater than 20 wt% of the transition phase alumina for the total weight of the particulate material, such as not greater than 19 wt% or not greater than 18 wt% or not greater than 17 wt% or not greater than 16 wt% or not greater than 15% or not greater than 14 wt% or not greater than 13 wt% or not greater than 12 wt% or not greater than 11 wt% or not greater than 10 wt% or not greater than 9 wt% or not greater than 8 wt% or not greater than 7 wt% or not greater than 6 wt% or not greater than 5 wt% or not greater than 4 wt% or not greater than 3 wt% or not greater than 2 wt% or not greater than 1.5 wt% or not greater than 1 wt% or not greater than 0.5 wt% of the transition phase alumina for the total weight of the particulate material. The content of the transition phase alumina in the particulate material can be within a range including any of the minimum and maximum percentages noted above, including for example, within a range of at least 0.5 wt% and not greater than 20 wt% or within a range of at least 1 wt% and not greater than 10 wt% or within a range including at least 2 wt% and not greater than 10 wt%.

[0021] The particulate material may include a combination of alpha alumina, a transition phase alumina, and aluminum hydroxide. In such embodiments, the content of the alpha alumina is greater than the content of aluminum hydroxide. Moreover, in such embodiments, the content of aluminum hydroxide may be greater than the content of the transition phase alumina within the particulate material.

[0022] While certain embodiments herein have noted that the particulate material includes a majority content of alpha alumina and 0.5 wt% to 20 wt% transition phase alumina, the particulate material can be essentially free or free of certain species. For example, the particulate material can be essentially free of titanium oxide, silicon dioxide, zirconium oxide, cesium oxide, borides, nitrides, carbides, diamond, or any combination thereof. Reference herein to a composition that is essentially free of a reference material is reference to a composition that includes none of the reference material or trace amounts of the reference material. In such instances where the reference material is present in trace amounts, such amounts are not sufficient to affect the properties of the composition.

[0023] The CMP slurry includes an oxidizer. The oxidizers are selected from peroxides, persulfates, permanganates, periodates, perchlorates, hypocholorites, iodates, peroxymonosulfates, cerric ammonium nitrate, periodic acid, ferricyanides, or any combination thereof. In at least one embodiment, the oxidizer includes potassium permanganate ($KMnO_4$). In more particular instances, the oxidizer may consist essentially of potassium permanganate ($KMnO_4$).

[0024] The oxidizer may be present in the slurry in a particular amount, which may facilitate improved performance of the slurry. For example, the slurry may include a content of the oxidizer in an amount within a range of at least 1 g/L (grams/liter) and not greater than 20 g/L. All reference to content of oxidizer in g/L is reference to liters of slurry. In at least one embodiment, the oxidizer can be present in an amount of at least 2 g/L, such as at least 3 g/L or at least 4 g/L or at least 5 g/L. Still, in one non-limiting embodiment, the slurry may include a content of the oxidizer of not greater than 18 g/L, such as not greater than 16 g/L or not greater than 14 g/L or not greater than 12 g/L or not greater than 10 g/L or not greater than 8 g/L or not greater than 6 g/L or not greater than 4 g/L. It will be appreciated that the content of the oxidizer within the slurry can be within a range including any of the minimum and maximum values noted above, including for example, within a range including at least 2 g/L and not greater than 18 g/L, such as within a range of at least 3 g/L and not greater than 16 g/L or even within a range of at least 4 g/L and not greater than 10 g/L.

[0025] According to one aspect, the CMP slurry may optionally include a co-particle. The co-particle can be a particle that is distinct and separate from the particulate material. The co-particle may have, but need not necessarily have, abrasive capabilities. In at least one embodiment, the co-particle can have a hardness that is less than the hardness of the particulate material. For example, the co-particle may have a Mohs hardness that is not greater than 8, such as not greater than 7 or not greater than 6.

[0026] In at least one embodiment, the co-particle can include a material such as an oxide, carbide, nitride, boride, or any combination thereof. In certain instances, the co-particle can include an element selected from the group of aluminum, calcium, sodium, silicon, titanium, cerium, magnesium, or any combination thereof. In certain instances, the co-particle may be an oxide, such as a silicate, and more particularly, an aluminosilicate or borosilicate material. In at least one embodiment, the co-particle can consist essentially of an aluminosilicate. In another embodiment, the co-particle can consist essentially of an aluminosilicate.

[0027] The CMP slurry can contain a certain content of the co-particle that may facilitate improved performance of the CMP slurry. For example, the slurry can include not greater 20 wt% of the co-particle for the total weight of the slurry. In still other instances, the content of the co-particle within the slurry can be not greater than 18 wt%, such as not 15 wt% or not greater than 12 wt% or not greater than 10 wt% or not greater than 8 wt% or not greater than 6 wt% or not greater than 5 wt% or not greater than 4 wt% or not greater than 3 wt% or not greater than 2 wt% or not greater than 1 wt%. Still, in at least one non-limiting embodiment, the co-particle can be present in an amount of at least 0.1 wt% of the total weight of the slurry, such as at least 0.2 wt% or at least 0.3 wt% or at least 0. 5 wt% or at least 0.8 wt% or at least 1 wt% or at least 1.3 wt% at least 1.5 wt% or at least 1.7 wt% or at least 2 wt% or at least 2.5 wt% or at least 3 wt% or at least 3.5 wt% or at least 4 wt% or at least 5 wt%. It will

be appreciated that the co-particle can be present in an amount within a range including any of the minimum and maximum percentages noted above, including for example, within a range of at least 0.1 wt% and not greater than 20 wt%, such as within a range of at least 0.1 wt% and not greater than 10 wt%, or even within a range including at least 0.2 wt% and not greater than 5 wt%.

[0028] Furthermore, the CMP slurry may be formed to create a particular relationship between the content (wt%) of the particulate material (PM) relative to the content (wt%) of the co-particle (CP), such that a particulate ratio value CP/PM is defined. In one embodiment, the content of the particulate material can be equal to or greater than the content of the co-particle within the CMP slurry. For example, the particulate ratio value (CP/PM) can be not greater than 1, such as not greater than 0.95 or not greater than 0.9 or not greater than 0.8 or not greater than 0.7 or not greater than 0.6 or not greater than 0.5 or not greater than 0.4 or not greater than 0.3 or not greater than 0.2 or not greater than 0.1. Still, in at least one non-limiting embodiment, the particulate ratio value (CP/PM) can be at least 0.01 or at least 0.05 or at least 0.1 or at least 0.15 or at least 0.2 or at least 0.25 or at least 0.3 or at least 0.35 or at least 0.4 or at least 0.45 or at least 0.5 or at least 0.55 or at least 0.6 or at least 0.65 or at least 0.7 or at least 0.75 or at least 0.8 or at least 0.85 or at least 0.9. It will be appreciated that the particulate ratio value can be within a range including any of the minimum and maximum values noted above, including for example, within a range of at least 0.05 and not greater than 0.95, such as within a range of at least 0.05 and not greater than 0.7 or even within a range including at least 0.1 and not greater than 0.5.

[0029] The co-particle may have a particular synergy with one or more components within the CMP slurry, including for example, the particulate material, oxidizer, or other additives. Moreover, it will be understood that the CMP slurry may include a blend of co-particles, wherein the blend includes at least two different types of co-particles. Different types of co-particles can differ from each other based on hardness, composition, average particle size, average crystallite size, particle shape, content or any combination thereof.

[0030] According to one embodiment, the CMP slurry may optionally include one or more additives. Some suitable examples of such additives can include surfactants, dispersants, chelating agents, buffers, pH modifiers, or any combination thereof.

[0031] The content of one or more additives within the CMP slurry may be less than the content of other components, including for example, the carrier, particulate material, oxidizer, and/or co-particle. In one particular embodiment, the additive may be present in the slurry in an amount within a range of at least 1 g/L (grams/liter) and not greater than 20 g/L. It will be appreciated that this content may refer to the content of one additive or the total content of all additives. Reference herein to grams/liter of additive will be understood to refer to grams of material (i.e., additive) per liter of slurry. In at least one embodiment, the one or more additives can be present in an amount of at least 2 g/L, such as at least 3 g/L or at least 4 g/L or at least 5 g/L. Still, in one non-limiting embodiment, the slurry may include a content of the one or more additives of not greater than 18 g/L, such as not greater than 16 g/L or not greater than 14 g/L or not greater than 12 g/L or not greater than 10 g/L or not greater than 8 g/L or not greater than 6 g/L or not greater than 4 g/L. It will be appreciated that the content of the one or more additives within the slurry can be within a range including any of the minimum and maximum values noted above, including for example, within a range including at least 2 g/L and not greater than 18 g/L, such as within a range of at least 2 g/L and not greater than 12 g/L or even within a range of at least 2 g/L and not greater than 8 g/L.

[0032] In at least one embodiment, the CMP slurry can include a pH modifier, which may include an acid, a base, or a combination thereof. In one particular embodiment, the CMP slurry can include an acid and have an acidic pH. For example, the slurry can have a pH of not greater than 6, such as not greater than 5 or not greater than 4 or not greater than 3 or not greater than 2 or not greater than 1.5 or not greater than 1. Still, in one non-limiting embodiment, the CMP slurry can have a pH of at least 0.5, such as at least 0.8 or at least 1 or at least 1.3 or at least 1.5 or at least 1.7 or at least 2 or at least 2.5 or at least 3 or at least 3.5 or at least 4. It will be appreciated that the pH of the CMP slurry can be within a range including any of the minimum and maximum values noted above, including for example, within a range of at least 0.5 and not greater than 6, such as within a range of including at least 1 and not greater than 4 or within a range including at least 1 and not greater than 3.

[0033] In at least another embodiment, the CMP slurry of embodiments herein can be used in polishing a substrate that may include a particular material. In particular, according to one embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may include a Group III-N semiconductor material, such as, a GaN semiconductor material or an AlN semiconductor material or an InN semiconductor material or an InAlN semiconductor material or a BN semiconductor material or a TlN semiconductor material. According to still another embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may include a Group III-V semiconductor material, such as, a GaAs semiconductor material or an InGaAs semiconductor material or a GaP semiconductor material or an InSb semiconductor material or a InAs semiconductor material or a BAs semiconductor material or an AlAs semiconductor material or an AlSb semiconductor material. According to yet another embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may include a Group IV semiconductor material, such as, a Si semiconductor material or a Ge semiconductor material or a SiGe semiconductor material or a SiSn semiconductor material or a Diamond semiconduc-

tor material or a graphene semiconductor material or a SiC semiconductor material or a GeSn semiconductor material.

[0034] In at least another embodiment, the CMP slurry of embodiments herein can be used in polishing a substrate that may consist of a particular material. In particular, according to one embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may consist of a Group III-N semiconductor material, such as, a GaN semiconductor material or an AlN semiconductor material or an InN semiconductor material or an InAlN semiconductor material or a BN semiconductor material or a TIN semiconductor material. According to still another embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may consist of a Group III-V semiconductor material, such as, a GaAs semiconductor material or an InGaAS semiconductor material or a GaP semiconductor material or an InSb semiconductor material or a InAs semiconductor material or a BAs semiconductor material or an AlAs semiconductor material or an AlSb semiconductor material. According to yet another embodiment, the CMP slurry of embodiments herein can be used to polish a substrate that may consist of a Group IV semiconductor material, such as, a Si semiconductor material or a Ge semiconductor material or a SiGe semiconductor material or a SiSn semiconductor material or a Diamond semiconductor material or a graphene semiconductor material or a SiC semiconductor material or a GeSn semiconductor material.

[0035] The CMP slurry of the embodiments herein has demonstrated remarkable performance compared to other CMP slurries. In particular, the CMP slurry is capable of a combination of material removal rate and average roughness index that is remarkable when compared to conventional CMP slurries. The CMP slurry has a material removal rate index (MRR) of at least 500 nm/hr and an average roughness index (Ra) of not greater than 0.5 nm (5 Angstroms) according to the Standardized Polishing Test defined below.

[0036] The Standardized Polishing Test is conducted on a 4" diameter GaN wafer (Ga-face). Three GaN wafers having a starting average surface roughness 1.0-1.2 nm (10-12Å) are wax mounted on alumina discs 10.92 cm ((4.3 inches) in diameter and a thickness of 0.41 cm (0.16 inches)) and placed into templates on a 91.44 cm (36") Speedfam GPAW polisher. Polishing is conducted on the wafers using an Eminess IC 1000 spiral grooved polishing pad. The wafers are processed at 50 RPM platen rotation speed with a downward polishing pressure of 441.3 kPa (6.4 psi). The slurry flow rate is set at 20 ml/minute and added to the center of the polishing pad for 1 minute before beginning the polishing process. The wafers are processed in three, 60-minute intervals for a total of 180 minutes of processing time. The pad temperature during the polishing process is maintained between 31-32°C. After processing, the wafers are cleaned using a PVA sponge and DI water. The wafers are placed in a ultrasonic bath at 30°C for 10 minutes. The surfaces of the wafers are dried using a PVA sponge. The wafers are finally cleaned with an isopropanol pre-soaked clean room wipe. It will be appreciated that the Standardized Polishing Test is to be conducted on 10.16 cm (4 inch) diameter GaN wafers, but the CMP polishing slurry is applicable to any range of wafers, including for example, wafers having a diameter of at least 5.08 cm (2 inches) or at least 10.16 cm (4 inches) or at least 15.24 cm (6 inches) and larger.

[0037] Material removal rate is determined by the change in mass of the wafer before and after polishing. The change in mass of the wafer before and after is divided by the time spent polishing to calculate the material removal rate. The mass of the wafers are measured using a benchtop scale. The surface roughness of the wafers is determined using a Bruker Dimension Icon atomic force microscope. The instrument maps a 10x10 um region of the wafer using ScanAsyst Tapping mode. The results for all three wafers are measured and averaged to calculate the average surface roughness index value of the CMP slurry.

[0038] As noted herein, the CMP slurry has an average material removal rate index (MRR) of at least 500 nm/hr according to the standardized polishing test. In another embodiment, the average material removal rate index (MRR) can be greater, such as at least 510 nm/hr or at least 520 nm/hr or at least 530 nm/hr or at least 540 nm/hr or at least 550 nm/hr or at least 560 nm/hr or at least 570 nm/hr or at least 580 nm/hr or at least 590 nm/hr or at least 600 nm/hr or at least 610 nm/hr or at least 620 nm/hr or at least 630 nm/hr or at least 640 nm/hr or at least 650 nm/hr or at least 660 nm/hr or at least 670 nm/hr or at least 680 nm/hr or at least 690 nm/hr or at least 700 nm/hr or at least 710 nm/hr or at least 720 nm/hr or at least 730 nm/hr or at least 740 nm/hr or at least 750 nm/hr or at least 760 nm/hr or at least 770 nm/hr or at least 780 nm/hr or at least 790 nm/hr or at least 800. Still, in at least one non-limiting embodiment, the average material removal rate index (MRR) can be not greater than 2000 nm/hr or not greater than 1900 nm/hr or not greater than 1800 nm/hr or not greater than 1700 nm/hr or not greater than 1600 nm/hr or not greater than 1500 nm/hr or not greater than 1400 nm/hr or not greater than 1300 nm/hr or not greater than 1200 nm/hr or not greater than 1100 nm/hr or not greater than 1000 nm/hr or not greater than 900 nm/hr or not greater than 800 nm/hr. It will be appreciated that the average material removal rate index (MRR) can be within a range including any of the minimum and maximum values noted above, including for example, within a range including at least 500 nm/hr and not greater than 2000 nm/hr, such as within a range including at least 500 nm/hr and not greater than 1800 nm/hr or within a range including at least 700 nm/hr and not greater than 1800 nm/hr.

[0039] In another aspect and noted herein, the CMP slurry has a particular average roughness index according to the standardized polishing test. The average

roughness index (Ra) is not greater than 0.5 nm (5 Angstroms), such as not greater than 0.45 nm (4.5 Angstroms) or not greater than 0.42 nm (4.2 Angstroms) or not greater than 0.40 nm (4.0 Angstroms) or not greater than 0.38 nm (3.8 Angstroms) or not greater than 0.35 nm (3.5 Angstroms) or not greater than 0.32 nm (3.2 Angstroms) or not greater than 0.30 nm (3.0 Angstroms) or not greater than 0.28 nm (2.8 Angstroms) or not greater than 0.25 nm (2.5 Angstroms) or not greater than 0.22 nm (2.2 Angstroms) or not greater than 0.20 nm (2.0 Angstroms) or not greater than 0.18 nm (1.8 Angstroms) or not greater than 0.15 nm (1.5 Angstroms) or not greater than 0.12 nm (1.2 Angstroms) or not greater than 0.10 nm (1.0 Angstroms). The average roughness index can be at least 0.01 nm (0.1 Angstroms), such as at least 0.05 nm (0.5 Angstroms) or at least 0.08 nm (0.8 Angstroms) or at least 0.10 nm (1 Angstrom) or at least 0.12 nm (1.2 Angstroms) or at least 0.15 nm (1.5 Angstroms). It will be appreciated that the CMP slurries of the embodiments can have an average roughness index within a range including any of the minimum and maximum values noted above, including for example, within a range including at least 0.01 nm (0.1 Angstroms) and not greater than 0.5 nm (5 Angstroms), such as within a range including at least 0.01 nm (0.1 Angstroms) and not greater than 0.3 nm (3 Angstroms) or even within a range including at least 0.01 nm (0.1 Angstroms) and not greater than 0.2 nm (2 Angstroms). Moreover, it will be appreciated that the foregoing average roughness index values of the CMP slurry can be combined with any of the foregoing average material removal rate index values noted above.

[0040] The CMP slurries of the foregoing embodiments can be formed by selecting a suitable carrier material and adding the desired components to the slurry, such as the particulate material, oxidizer, co-particle, and any other additives. The carrier and components can be mixed together in a suitable manner to ensure homogenous dispersion of the components within the carrier and formation of the CMP slurry. The slurry may then be used in chemical mechanical planarization processes as understood by those of skill in the art.

[0041] Many different aspects and embodiments are possible. Some of those aspects and embodiments are described herein.

Examples:

Example 1

[0042] A CMP slurry representative of one of the embodiments was formed as Sample 1. Sample 1 included approximately 95-97 wt% deionized water, approximately 2-3 wt% of an alumina material which included approximately 93-96 wt% alpha alumina, 3-5 wt% gibbsite, and 0.5-2 wt% theta alumina (sum totaling 100%), 0.55 wt% oxidizer, 0.54 wt% of a co-particle of an aluminosilicate dispersant. Sample 1 had a pH of approximately 1.5.

[0043] Sample 1 was tested according to the Standardized Polishing test and demonstrated a material removal rate index of approximately 800 nm/hr and an average roughness index (Ra) of approximately 0.02 nm (0.2 Angstroms).

Example 2

[0044] A CMP slurry representative of one of the embodiments was formed as Sample 2. Sample 2 included 96.95 wt% deionized water, 2 wt% of an alumina material (which included approximately 93-96 wt% alpha alumina, 3-5 wt% gibbsite, and 0.5-2 wt% theta alumina (sum totaling 100%), 0.55 wt% potassium permanganate (i.e., oxidizer), and 0.5 wt% of a co-particle of an aluminosilicate dispersant. Sample 2 had a pH of approximately 1.5.

[0045] Sample 2 was tested according to the Standardized Polishing test and demonstrated a material removal rate index of 800 nm/hr and an average roughness index (Ra) of 0.131 nm (1.31 Angstroms). A visual inspection of the polished workpiece after the Standardized Polishing Test revealed no scratches on the surface of the workpiece.

Example 3

[0046] A comparative CMP slurry was formed as Sample 3. Sample 3 included 97.38 wt% deionized water, 2 wt% of an alumina material (which included approximately 93-96 wt% alpha alumina, 3-5 wt% gibbsite, and 0.5-2 wt% theta alumina (sum totaling 100%)), 0.12 wt% hydrogen peroxide (i.e., oxidizer), and 0.5 wt% of a co-particle of an aluminosilicate dispersant. Sample 3 had a pH of approximately 1.5.

[0047] Sample 3 was tested according to the Standardized Polishing test and demonstrated a material removal rate index of 478 nm/hr and an average roughness index (Ra) of 0.778 nm (7.78 Angstroms). A visual inspection of the polished workpiece after the Standardized Polishing revealed a high number of scratches and pits on the surface of the workpiece.

Example 4

[0048] A comparative CMP slurry was formed as Sample 4. Sample 4 included 96.7 wt% deionized water, 2 wt% of an alumina material (which included approximately 93-96 wt% alpha alumina, 3-5 wt% gibbsite, and 0.5-2 wt% theta alumina (sum totaling 100%)), 0.8 wt% potassium periodate (i.e., oxidizer), and 0.5 wt% of a co-particle of an aluminosilicate dispersant. Sample 4 had a pH of approximately 1.5.

[0049] Sample 4 was tested according to the Standardized Polishing test and demonstrated a material removal rate index of 456 nm/hr and an average roughness index (Ra) of 0.56 nm (5.60 Angstroms). A visual inspection of the polished workpiece after the Standardized Polishing revealed a high number of scratches and pits on the surface of the workpiece.

Claims

1. A CMP slurry comprising:

   a carrier;
   a particulate material within the carrier comprising an alumina containing material wherein the alumina containing material comprises a majority content of alpha alumina and a transition phase alumina at a content of at least 0.5 wt.% and not greater than 20 wt.% for a total weight of the particulate material;
   an oxidizer comprising at least one material selected from the group of peroxides, persulfates, permanganates, periodates, perchlorates, hypochlorites, iodates, peroxymonosulfates, cerric ammonium nitrate, periodic acid, ferricyanides, or any combination thereof; and
   a material removal rate index (MRR) of at least 500 nm/hr and an average roughness index (Ra) of not greater than 0.5 nm (5 Angstroms) according to the Standardized Polishing Test conducted on a 10.16 cm (4") diameter GaN wafer (Ga-face) as further specified in the description.

2. The CMP slurry of claim 1, further comprising an acidic pH.

3. The CMP slurry of claim 2, wherein the pH is not greater than 6 and at least 0.5.

4. The CMP slurry of claim 1, wherein the material removal rate index (MRR) is at least 510 nm/hr and not greater than 2000 nm/hr.

5. The CMP slurry of claim 1, wherein the average roughness index is not greater than 0.45 nm (4.5 Angstroms) and at least 0.01 nm (0.1 Angstroms).

6. The CMP slurry of claim 1, wherein the carrier includes water.

7. The CMP slurry of claim 1, wherein the particulate material is present in an amount of at least 0.5 wt% and not greater than 30 wt% for the total weight of the composition.

8. The CMP slurry of claim 1, further comprising one or more additives selected from the group consisting of surfactants, dispersants, chelating agents, buffers, and pH modifiers.

9. The CMP slurry of claim 8, wherein a total content of the additives is within a range including at least 1 g per liter of the CMP slurry and not greater than 20 g per liter of the CMP slurry.

10. The CMP slurry of claim 1, wherein the oxidizer comprises potassium permanganate ($KMnO_4$).

11. The CMP slurry of claim 1, wherein the oxidizer is present within a range including at least 1 g/L and not greater than 20 g/L.

12. The CMP slurry of claim 1, further comprising a co-particle including at least one of an oxide, a carbide, a nitride, a boride, diamond, or any combination thereof.

13. The CMP slurry of claim 12, wherein the co-particle includes at least one element selected from the group of aluminum, calcium, sodium, silicon, titanium, cerium, magnesium, iron, or any combination thereof.

14. The CMP slurry of claim 1, wherein the CMP slurry is used to polish a substrate comprising a Group III-N semiconductor material or a Group III-V semiconductor material or a Group IV semiconductor material.

Patentansprüche

1. CMP-Schlamm, der umfasst:

   ein Trägermaterial;
   ein partikelförmiges Material innerhalb des Trägermaterials, das ein aluminiumoxidhaltiges Material umfasst, wobei das aluminiumoxidhaltige Material bezogen auf ein Gesamtgewicht des Partikelmaterials einen Mehrheitsgehalt von Alpha-Aluminiumoxid und ein Übergangsphasen-Aluminiumoxid mit einem Gehalt von mindestens 0,5 Gew.-% und nicht mehr als 20 Gew.-% umfasst;
   ein Oxidationsmittel, das mindestens ein Material umfasst, das aus der Gruppe aus Peroxiden, Persulfaten, Permanganaten, Periodaten, Perchloraten, Hypochloriten, Jodaten, Peroxymonosulfaten, Cerammoniumnitrat, Periodsäure, Ferricyaniden oder einer beliebigen Kombination davon ausgewählt ist; und
   gemäß dem standardisierten Poliertest, der an einem GaN-Wafer (Ga-Fläche) mit 10,16 cm (4 Zoll) Durchmesser durchgeführt wurde, wie in der Beschreibung weiter angegeben, einen Materialabtragsratenindex (MRR-Index) (MRR = material removal rate) von mindestens 500 nm/h und einen durchschnittlichen Rauhigkeitsindex (Ra) von nicht mehr als 0,5 nm (5 Angström).

2. CMP-Schlamm nach Anspruch 1, der ferner einen sauren pH-Wert umfasst.

3. CMP-Schlamm nach Anspruch 2, wobei der pH-

Wert nicht größer als 6 und mindestens 0,5 ist.

4. CMP-Schlamm nach Anspruch 1, wobei der Materialabtragsratenindex (MRR) mindestens 510 nm/h und nicht mehr als 2000 nm/h beträgt.

5. CMP-Schlamm nach Anspruch 1, wobei der durchschnittliche Rauheitsindex nicht mehr als 0,45 nm (4,5 Angström) und mindestens 0,01 nm (0,1 Angström) beträgt.

6. CMP-Schlamm nach Anspruch 1, wobei das Trägermaterial Wasser enthält.

7. CMP-Schlamm nach Anspruch 1, wobei das Partikelmaterial bezogen auf das Gesamtgewicht der Zusammensetzung in einer Menge von mindestens 0,5 Gew.-% und nicht mehr als 30 Gew.-% vorliegt.

8. CMP-Schlamm nach Anspruch 1, der ferner ein oder mehrere Additive umfasst, die ausgewählt sind aus der Gruppe, bestehend aus Tensiden, Dispergiermitteln, Chelatbildnern, Puffern und pH-Modifizierern.

9. CMP-Schlamm nach Anspruch 8, wobei ein Gesamtgehalt der Additive innerhalb eines Bereichs liegt, der mindestens 1 g pro Liter des CMP-Schlamms und nicht mehr als 20 g pro Liter des CMP-Schlamms einschließt.

10. CMP-Schlamm nach Anspruch 1, wobei das Oxidationsmittel Kaliumpermanganat ($KMnO_4$) umfasst.

11. CMP-Schlamm nach Anspruch 1, wobei das Oxidationsmittel in einem Bereich vorliegt, der mindestens 1 g/l und nicht mehr als 20 g/l einschließt.

12. CMP-Schlamm nach Anspruch 1, der ferner ein Co-Partikel umfasst, das mindestens eines aus einem Oxid, einem Carbid, einem Nitrid, einem Borid, Diamant oder einer beliebigen Kombination davon einschließt.

13. CMP-Schlamm nach Anspruch 12, wobei das Co-Partikel mindestens ein Element einschließt, das aus der Gruppe aus Aluminium, Calcium, Natrium, Silicium, Titan, Cer, Magnesium, Eisen oder einer beliebigen Kombination davon ausgewählt ist.

14. CMP-Schlamm nach Anspruch 1, wobei der CMP-Schlamm verwendet wird, um ein Substrat zu polieren, das ein Halbleitermaterial der Gruppe III-N oder ein Halbleitermaterial der Gruppe III-V oder ein Halbleitermaterial der Gruppe IV umfasst.

Revendications

1. Boue de CMP comprenant :

   un support ;
   un matériau particulaire à l'intérieur du support comprenant un matériau contenant de l'alumine, dans laquelle le matériau contenant de l'alumine comprend une teneur majoritaire en alumine alpha et une alumine en phase de transition à une teneur d'au moins 0,5 % en poids et non supérieure à 20 % en poids pour un poids total du matériau particulaire ;
   un oxydant comprenant au moins un matériau choisi dans le groupe des peroxydes, persulfates, permanganates, periodates, perchlorates, hypochlorites, iodates, peroxymonosulfates, nitrate d'ammonium cerrique, acide périodique, ferricyanures ou toute combinaison de ceux-ci ; et
   un indice de taux d'enlèvement de matière (MRR) d'au moins 500 nm/h et un indice de rugosité moyen (Ra) ne dépassant pas 0,5 nm (5 angströms) selon le test de polissage standardisé réalisé sur une tranche GaN de 10,16 cm (4") de diamètre (face Ga) comme spécifié plus en détail dans la description.

2. Boue de CMP selon la revendication 1, comprenant en outre un pH acide.

3. Boue de CMP selon la revendication 2, dans laquelle le pH n'est pas supérieur à 6 et au moins de 0,5.

4. Boue de CMP selon la revendication 1, dans laquelle l'indice de taux d'enlèvement de matière (MRR) est d'au moins 510 nm/h et non supérieur à 2000 nm/h.

5. Boue de CMP selon la revendication 1, dans laquelle l'indice de rugosité moyen n'est pas supérieur à 0,45 nm (4,5 angströms) et au moins 0,01 nm (0,1 angström).

6. Boue de CMP selon la revendication 1, dans laquelle le support comprend de l'eau.

7. Boue de CMP selon la revendication 1, dans laquelle la matière particulaire est présente en une quantité d'au moins 0,5 % en poids et non supérieure à 30 % en poids pour le poids total de la composition.

8. Boue de CMP selon la revendication 1, comprenant en outre un ou plusieurs additifs choisis dans le groupe constitué de tensioactifs, dispersants, agents chélatants, tampons et modificateurs de pH.

9. Boue de CMP selon la revendication 8, dans laquelle une teneur totale des additifs se situe dans une plage

comprenant au moins 1 g par litre de boue de CMP et pas plus de 20 g par litre de boue de CMP.

10. Boue de CMP selon la revendication 1, dans laquelle l'oxydant comprend du permanganate de potassium ($KMnO_4$).

11. Boue de CMP selon la revendication 1, dans laquelle l'oxydant est présent dans une plage comprenant au moins 1 g/L et pas plus de 20 g/L.

12. Boue de CMP selon la revendication 1, comprenant en outre une co-particule comprenant au moins l'un d'un oxyde, d'un carbure, d'un nitrure, d'un borure, d'un diamant ou de toute combinaison de ceux-ci.

13. Boue de CMP selon la revendication 12, dans laquelle la co-particule comprend au moins un élément choisi dans le groupe constitué par l'aluminium, le calcium, le sodium, le silicium, le titane, le cérium, le magnésium, le fer ou toute combinaison de ceux-ci.

14. Boue de CMP selon la revendication 1, dans laquelle la boue de CMP est utilisée pour polir un substrat comprenant un matériau semi-conducteur du groupe III-N ou un matériau semi-conducteur du groupe III-V ou un matériau semi-conducteur du groupe IV.

REFERENCES CITED IN THE DESCRIPTION

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