Method for polishing a substrate composed of semiconductor material

The invention relates to a method for polishing a substrate composed of semiconductor material, which method comprises at least two different method steps. At least one step of the method is a polishing step by means of which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad.

WO 99/55491 A1 describes a two-stage polishing method, comprising a first polishing step, in which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad. A polishing step in which such a polishing pad - also called "fixed-abrasive pad" - is used is referred to hereinafter as FAP step for short. The subsequent second polishing step of the two-stage polishing method is a chemical mechanical polishing of the substrate on a polishing pad containing no bonded abrasive material. Abrasive material is introduced here in the form of a slurry between the substrate and the polishing pad. Such a polishing step is referred to hereinafter as CMP step for short. It is used in the two-stage polishing method in accordance with WO 99/55491 A1 in particular in order to eliminate scratches left by the FAP step on the polished surface of the substrate.

EP 1 717 001 A1 is one example of the fact that FAP steps are also used when polishing semiconductor wafers which have not yet had any component structures form upon their surface. During the polishing of such semiconductor wafers, it is primarily important to produce at least one lateral surface which is particularly planar and which has a minimal microroughness and nanotopography.

Example embodiments can provide an improved polishing method for substrates composed of semiconductor material, which method opens up particularly low values in particular with regard to the microroughness.

In an aspect of the invention, there is provided a method for polishing a substrate composed of semiconductor material, comprising at least one polishing step of type A, by means of which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad, wherein a polishing agent solution is introduced between the substrate and the polishing pad during the polishing step; and at least one polishing step of type B, by means of which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad, wherein a polishing agent slurry containing abrasive material is introduced between the substrate and the polishing pad during the polishing step.

In example embodiments, the polishing steps of type A and type B are in each case an FAP step. They differ in that in the polishing step of type B a polishing agent slurry containing unbonded abrasive material as solid is introduced between the substrate and the polishing pad, while in the polishing step of type A, the polishing agent slurry is replaced by a polishing agent solution which, as the expression already describes, is free of solids. The expression polishing agent is used hereafter as a generic term for polishing agent slurries and polishing agent solutions.

The proportion of abrasive material in the polishing agent slurry is preferably 0.25 to 20% by weight. The size distribution of the abrasive material particles is preferably monomodal in nature. The average particle size is 5 to 300 nm, particularly preferably 5 to 50

nm. The abrasive material comprises a material that mechanically removes the substrate material, preferably one or more of the oxides of the elements aluminum, cerium or silicon. A polishing agent slurry containing colloidally disperse silicic acid is particularly preferred. The pH of the polishing agent slurry preferably lies within a range of 9 to 11.5 and is preferably set by additives such as sodium carbonate (Na_2CO_3) potassium carbonate (K_2CO_3), sodium hydroxide (NaOH), potassium hydroxide (KOH), ammonium hydroxide (NH_4OH), tetramethylammonium hydroxide (TMAH) or any desired mixtures of these compounds. The polishing agent slurry can furthermore contain one or more further additives, for example surface-active additives such as wetting agents and surfactants, stabilizers acting as protective colloids, preservatives, biocides, alcohols and complexing agents.

The polishing agent solution is water in the simplest case, preferably deionized water (DIW) having the customary purity for use in the semiconductor industry. However, the polishing agent solution can also contain compounds such as sodium carbonate (Na_2CO_3) potassium carbonate (K_2CO_3), sodium hydroxide (NaOH), potassium hydroxide (KOH), ammonium hydroxide (NH_4OH), tetramethylammonium hydroxide (TMAH) or any desired mixtures thereof. In this case, the pH of the polishing agent solution preferably lies within a range of 10 to 12, and the proportion of the compounds mentioned in the polishing agent solution is preferably 0.01 to 10% by weight. The polishing agent solution can furthermore contain one or more further additives, for example surface-active additives such as wetting agents and surfactants, stabilizers acting as protective colloids, preservatives, biocides, alcohols and complexing agents.

Suitable substrates which are polished include, in particular, semiconductor wafers composed of materials such as silicon, galliumarsenide, Si_xGe_{1-x}, sapphire and siliconcarbide. Particularly suitable substrates are semiconductor wafers composed of silicon and substrates derived therefrom. The surface to be polished of the semiconductor wafer composed of silicon can be present in a state such as arises after the separation of the semiconductor wafer from a crystal, after lapping of the semiconductor wafer, after grinding of the semiconductor wafer, after etching of the semiconductor wafer or after a semiconductor wafer polishing that has already been effected. A substrate derived from a semiconductor wafer composed of silicon should be understood to mean, in particular, substrates having a layer structure, for example semiconductor wafers having a layer deposited by means of epitaxy, SOI substrates ("silicon on insulator") and sSOI substrates (strained silicon on insulator) and intermediate products thereof. The intermediate products also include donor semiconductor wafers from which layers have been transferred to other substrates, in particular in the course of producing SOI substrates. In order to be able to be reused, the surface of the donor semiconductor wafer that is uncovered by the layer transfer, said surface being comparatively rough and having a characteristic step in the edge region, has to be smoothed. The surfaces to be polished of the substrates need not or not only consist of silicon. By way of example, layers composing III-V compound semiconductor such as galliumarsenide or an alloy composed of silicon and germanium (Si_xGe_{1-x}) may be involved. Further examples are layers composed of indium phosphide, galliumnitride and aluminum galliumarsenide. The surface of Si_xGe_{1-x} layers is often characterized by a pattern caused by dislocations and known as "cross hatch", and must generally be smoothed

before one or more further layers can be deposited thereon.

If substrates with layers of germanium or Si_xGe_{1-x} are to be polished, the polishing agent slurry or the polishing agent solution or both can contain an oxidizing agent as further additive. Suitable oxidizing agents are hydrogen peroxide (H_2O_2) and ozone (O_3). The additive converts germanium into a water-soluble compound. Without the additive, germanium-containing particles can arise in the course of polishing and can scratch the polished surface.

The method can be carried out in the form of a double-side polishing in principle. In this case, both sides of a semiconductor wafer are polished simultaneously. A particularly suitable area of application is single-side polishing, however. In this case, substrates having a large diameter, for example semiconductor wafers composed of silicon having a diameter of 300 mm, are usually polished singly. With the aid of a polishing head, they are pressed by the lateral surface to be polished against the polishing pad lying on a polishing plate. A polishing head also includes a retainer ring that laterally encloses the substrate and prevents it from sliding from the polishing head during polishing. In the case of modern polishing heads, the lateral surface of the semiconductor wafer which is remote from the polishing pad bears on an elastic membrane that transmits the polishing pressure exerted. The membrane is part of a possibly subdivided chamber system that forms a gas or liquid cushion. However, polishing heads are also in use in which an elastic support ("backing pad") is used instead of a membrane. The substrate is polished with the feeding of a polishing agent between the substrate and the polishing pad and with rotation

of the polishing head and of the polishing plate. In this case, the polishing head can initially also be moved translationally over the polishing pad, whereby more comprehensive use of the polishing pad area is obtained.

Furthermore, the method can equally be carried out on single-plate and multi-plate polishing machines. The use of multi-plate polishing machines having preferably two or three polishing plates and polishing heads is preferred, such that a corresponding number of substrates can be polished simultaneously. Different polishing pads and different polishing agents can also be used in this case.

The method uses at least one polishing pad containing an abrasive material bonded in the polishing pad. Suitable abrasive materials comprise for example particles of oxides of the elements cerium, aluminum, silicon, zirconium and particles of hard materials such as siliconcarbide, boronnitride and diamond. Particularly suitable polishing pads have a surface topography shaped by replicated microstructures. These microstructures ("posts") have for example the form of columns having a cylindrical or polygonal cross section or the form of pyramids or truncated pyramids. Polishing pads of this type are commercially available and offered for example by 3M Corp., USA. More detailed descriptions of such polishing pads are contained for example in WO 92/13680 A1 and US 2005/227590 A1.

The method comprises in each case at least one polishing step of type A and of type B. An FAP pad is used in both polishing steps. This may involve the same polishing pad or it is possible to use different polishing pads. In accordance with a particularly preferred embodiment of the method, the

polishing is temporally subdivided into at least three substeps 1, 2 and 3, wherein process parameters that control the mean material removal (MR), such as polishing agent, polishing agent flow rate and polishing step duration, for example, are controlled in such a way that a mean material removal results which in substep 1 is greater than that in substep 2, and in substep 2 it is greater than or equal to that in substep 3. Of substeps 1, 2 and 3, at least one substep is configured as polishing step of type A and at least one substep is configured as polishing step of type B. Substep 1 is preferably embodied as polishing step of type A, substep 2 preferably as polishing step of type B, and substep 3 either as polishing step of type A or as polishing step of type B.

The method can comprise
further polishing steps, for example a CMP step, which is referred to here as polishing step of type C. Such a polishing step is preferably carried out after a polishing step of type A or type B. Furthermore, the substrate can be etched or cleaned, for example using an alkaline etchant and/or using an etchant having an acidic pH, after a polishing step of type A or type B.

The efforts to reduce the microroughness can be supported by accompanying measures. One preferred measure consists in reducing the polishing pressure by at least 10% in an end phase of the polishing, preferably 5 to 300 s before the substrate is raised from the polishing plate, and continuing to polish the substrate at this reduced polishing pressure until lift-off from the polishing plate. A further preferred measure consists in cleaning the polishing pad using a cleaning agent, by distributing the cleaning agent on the polishing pad with the aid of an open-pored foam body. This is preferably done in situ, that is to say during the polishing of the substrate. The pad cleaning

differs from a pad conditioning by virtue of the fact that the foam body does not contain any abrasive materials bonded thereto. In principle, any elastic plastic foam having an open cell structure is suitable, for example polyurethane foams, polyvinyl alcohol foams, polystyrene foams, silicone foams, epoxy foams, urea-formaldehyde foams, polyimide foams, polybenzimidazole foams, foams based on phenolic resins, polyethylene foams, polypropylene foams, polyacrylic foams, polyester foams and viscose foams. The polishing agent used in the respective polishing step is suitable, in particular, as cleaning agent.

The example embodiments are explained in more detail below using the example of preferred exemplary embodiments and its advantageous effect with regard to the reduction of microroughness is set out by means of comparative experiments.

The substrates were semiconductor wafers composed of silicon having a diameter of 300 mm and having an upper layer composed of a relaxed silicon-germanium alloy having the composition $Si_{0.8}Ge_{0.2}$. They were polished on a single-side polishing machine from Strasbaugh, Inc. of type nHance 6EG and were subsequently cleaned, dried and passed to a stage for examining the polished surface. The individual-wafer polishing machine configured in particular for development work is equipped with one polishing head and with one polishing plate. The polishing head is mounted cardanically and comprises a fixed baseplate coated with a backing pad, and a movable retainer ring. Through holes in the baseplate, cushions can be established in two concentric pressure zones, an inner and an outer zone, the substrate floating on said air cushions during polishing. Pressure can be applied to the movable retainer ring by means of compressed air bellows in order thus to pretension the polishing pad upon contact

with the substrate and to keep it plane. For the comparative examples and exemplary embodiments, an FAP pad from 3M Corp., USA, was used, having abrasive particles of cerium oxide (CeO_2) bonded therein and having an average grain size of 0.55 µm.

In a first series of experiments, both the semiconductor wafers of the first comparative example and the semiconductor wafers of the first exemplary embodiment was subjected to a three-stage polishing method, polishing steps 1, 2 and 3. In the case of the comparative examples, polishing steps 1, 2 and 3 were without exception polishing steps of type A. In contrast thereto, the semiconductor wafers of the exemplary embodiments were subjected to a corresponding polishing in which polishing steps 2 and 3 were polishing steps of type B.

Further experiment parameters are summarized in the following table.

Table 1

Polishing step 1	**Exemplary embodiment**	**Comparative example**
Type	A	A
Polishing agent	K_2CO_3 solution (0.2% by weight K_2CO_3 proportion)	K_2CO_3 solution (0.2% by weight K_2CO_3 proportion)
Polishing agent flow rate	3000 ml/min	3000 ml/min
Duration	60 to 300 s	60 to 300 s
Polishing pressure	7 psi (48.26 kPa)	7 psi (48.26 kPa)
Polishing step 2		
Type	B	A
Polishing agent	Glanzox 3900 *) (1% by weight SiO_2 proportion)	DIW
Polishing agent flow rate	350 ml/min	350 ml/min
Duration	120 s	120 s
Polishing pressure	7 psi (48.26 kPa)	7 psi (48.26 kPa)
Polishing step 3		
Type	B	A
Polishing agent	Glanzox 3900*) (1% by weight SiO_2 proportion)	DIW
Polishing agent flow rate	350 ml/min	350 ml/min
Duration	10 s	10 s
Polishing pressure	3.5 psi (24.13 kPa)	3.5 psi (24.13 kPa)

*) Glanzox 3900 is the product name for a polishing agent slurry offered by Fujimi Incorporated, Japan, as

a concentrate. The concentrate having a pH of 10.5 contains approximately 9% by weight of colloidal SiO_2 having an average particle size of 30 to 40 nm. The SiO_2 proportion indicated in the table is based on the polishing agent.

After polishing, the semiconductor wafers were cleaned, dried and examined with regard to the residual microroughness. Three different measuring methods were employed in this case. The RMS roughness ("root mean square, RMS") was determined using a phase contrast profilometer of the MP2000 type from Chapman Instruments, USA, taking account of various lateral correlation lengths (filter lengths, "spatial wavelengths") that influence the roughness value. Furthermore, dark field scattered light ("haze") was measured using a Surfscan SP-1 from KLA-Tencor, USA, for various detector arrangements (channel mode: D="dark field"; N="narrow", W="wide"; O="oblique", N="normal"). The third measurement was an AFM measurement ("atomic force microscopy", AFM) on a square measurement area of 10 µm x 10 µm in the centre and 1mm from the edge of the semiconductor wafers, which is likewise used for determining the RMS roughness.

The results of the measurements are summarized in tables 2, 3 and 4.

Table 2

Chapman	**Polishing step 1 Duration(s)**	**RMS roughness [Angström]**				**MR [nm]**
Filter length [µm]		250	80	30	10	
Exemplary embodiment 1	60	1.17	0.81	0.51	0.19	210
Exemplary embodiment 1	150	1.13	0.79	0.49	0.18	280
Exemplary embodiment 1	270	0.92	0.61	0.38	0.15	450
Exemplary embodiment 2	270	0.72	0.45	0.27	0.11	420
Comparative example 1	60	11.59	8.92	5.47	1.78	190
Comparative example 1	160	7.69	5.62	3.28	1.07	270
Comparative example 1	300	5.79	4.24	2.47	0.80	460
Comparative example 2	300	3.97	3.05	1.92	0.66	520

Table 3

SP-1	**Polishing step 1 Duration [s]**	**"Haze" [ppm]**			
Channel mode		DWN	DNN	DWO	DNO
Exemplary embodiment 1	60	0.588	0.836	0.369	0.047
Exemplary embodiment 1	150	0.508	0.704	0.329	0.039
Exemplary Embodiment 1	270	0.384	0.487	0.275	0.032
Exemplary embodiment 2	270	0.326	0.264	0.225	0.020
Comparative example 1	60	1.497	4.712	1.405	0.134
Comparative example 1	160	1.346	4.391	1.061	0.117
Comparative example 1	300	1.127	3.947	0.800	0.099
Comparative example 2	300	1.005	3.582	0.706	0.094

Table 4

AFM	**Polishing step 1 Duration(s)**	**RMS roughness [Angström]**	
Position		Center	Edge-1mm
Exemplary embodiment 1	60	1.25	1.11
Exemplary embodiment 1	150	1.24	1.08
Exemplary embodiment 1	270	1.05	0.93
Exemplary embodiment 2	270	0.98	0.77
Comparative example 1	60	3.72	2.23
Comparative example 1	160	2.06	1.69
Comparative example 1	300	2.22	1.50
Comparative example 2	300	1.81	1.35

The tables show that significantly lower "haze" and RMS roughness values can be expected if polishing is effected according to the invention.

The above experiments in the first series of experiments (exemplary embodiment 1 and comparative example 1) were carried out without in-situ cleaning of the polishing pad. In a second series of experiments (exemplary embodiment 2 and comparative example 2), further semiconductor wafers of the same type were polished in the same way, except that in-situ cleaning of the polishing pad was additionally carried out using an open-pored sponge composed of polyester that was impregnated with the polishing agent as cleaning agent.

The rows in tables 2, 3 and 4 that indicate these experiments make it clear that the microroughness was able to be reduced further by means of this additional measure.

Patent claims

1. A method for polishing a substrate composed of semiconductor material, comprising at least one polishing step of type A, by means of which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad, wherein a polishing agent solution is introduced between the substrate and the polishing pad during the polishing step; and at least one polishing step of type B, by means of which the substrate is polished on a polishing pad containing an abrasive material bonded in the polishing pad, wherein a polishing agent slurry containing abrasive material is introduced between the substrate and the polishing pad during the polishing step.

2. A method as claimed in claim 1, wherein the polishing step of type B is performed before or after the polishing step of type A.

3. The method as claimed in claim 1 or claim 2, wherein the polishing step of type A and the polishing step of type B are performed on the same polishing plate.

4. The method as claimed in claim 1 or claim 2, wherein the polishing step of type A and the polishing step of type B are performed on different polishing plates.

5. The method as claimed in claim 1, comprising at least one polishing step of type C, by means of which the substrate is polished by means of a polishing pad in which no abrasive material is bonded, wherein a polishing agent slurry containing abrasive material is introduced between the substrate and the polishing pad during the polishing step.

6. The method as claimed in claim 1 or claim 5, wherein the polishing agent slurry contains one or more oxides of the elements aluminum, cerium or silicon as abrasive material.

7. The method as claimed in claim 6, wherein the polishing agent slurry has a solids proportion of 0.25 to 20% by weight.

8. The method as claimed in claim 6, wherein the polishing agent slurry contains an oxidizing agent and the substrate comprises germanium or contains germanium.

9. The method as claimed in claim 1, wherein the polishing agent solution contains an oxidizing agent and the substrate comprises germanium or contains germanium.

10. The method as claimed in claim 1 or claim 2, wherein the polishing pad is cleaned during a polishing step by a cleaning agent being distributed on the polishing pad with the aid of an open-pored foam body.

11. The method as claimed in claim 1 or claim 2, wherein the substrate is etched or cleaned after a polishing step of type A or of type B or after both polishing steps.