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POLISHING PAD WITH FLOATING ELEMENTS
AND METHOD OF MAKING AND USING THE SAME

CROSS REFERENCE TO RELATED APPLICATION

- 5 This application claims the benefit of U.S. Provisional Patent Application No. 61/081,891, filed July 18, 2008, the disclosure of which is incorporated by reference herein in its entirety.

TECHNICAL FIELD

- 10 The present disclosure relates to polishing pads with floating polishing elements, and to methods of making and using such polishing pads in a polishing process, for example, in a chemical mechanical planarization process.

BACKGROUND

- 15 During the manufacture of semiconductor devices and integrated circuits, silicon wafers are iteratively processed through a series of deposition and etching steps to form overlying material layers and device structures. A polishing technique known as chemical mechanical planarization (CMP) may be used to remove surface irregularities (such as bumps, areas of unequal elevation, troughs, and trenches) remaining after the deposition
20 and etching steps, with the objective of obtaining a smooth wafer surface without scratches or depressions (known as dishing), with high uniformity across the wafer surface.

- In a typical CMP polishing process, a substrate such as a wafer is pressed against and relatively moved with respect to a polishing pad in the presence of a working liquid
25 that is typically a slurry of abrasive particles in water and/or an etching chemistry. Various CMP polishing pads for use with abrasive slurries have been disclosed, for example, U.S. Pat. Nos. 5,257,478; 5,921,855; 6,126,532; 6,899,598 B2; and 7,267,610. Fixed abrasive polishing pads are also known, as exemplified by U.S. Pat. No. 6,908,366 B2, in which the abrasive particles are generally fixed to the surface of the pad, often in the form of
30 precisely shaped abrasive composites extending from the pad surface. Recently, a polishing pad having a multiplicity of polishing elements extending from a compressible underlayer and affixed to the underlayer by a guide plate was described in WO/2006057714. Although a wide variety of polishing pads are known and used, the art

continues to seek new and improved polishing pads for CMP, particularly in CMP processes where larger die diameters are being used, or where higher levels of wafer surface flatness and polishing uniformity are required.

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SUMMARY

In one exemplary embodiment, the present disclosure describes a polishing pad comprising a plurality of polishing elements, each of the polishing elements bonded to a support layer so as to restrict lateral movement of the polishing elements with respect to one or more of the other polishing elements, but remaining moveable in an axis normal to a polishing surface of the polishing elements. In certain exemplary embodiments, the polishing elements are thermally bonded to the support layer. In some exemplary
10 embodiments, at least a portion of the polishing elements comprise porous polishing elements, and in additional embodiments, at least a surface of each porous polishing element comprises a plurality of pores.

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In some particular embodiments of porous polishing elements, the pores may be distributed throughout substantially the entire porous polishing element. In other particular embodiments of porous polishing elements, the pores may be distributed substantially at the polishing surface of the element. In certain exemplary embodiments, the pores distributed substantially at the polishing surface of the element comprise a
20 plurality of channels having a cross-sectional shape selected from the group consisting of cylindrical, triangular, rectangular, trapezoidal, hemispherical, and combinations thereof.

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In another exemplary embodiment, the present disclosure describes a polishing pad comprising a support layer having a first major side and a second major side opposite the first major side, and a plurality of polishing elements affixed to the first major side of the support layer, wherein the polishing elements extend from the first major side of the
25 support layer along a first direction substantially normal to the first major side. In certain exemplary embodiments, the polishing elements are thermally bonded to the support layer. In some exemplary embodiments, at least a portion of the polishing elements comprise porous polishing elements, and in additional embodiments, at least a surface of each
30 porous polishing element comprises a plurality of pores.

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In some particular embodiments of porous polishing elements, the pores may be distributed throughout substantially the entire porous polishing element. In other

particular embodiments, the pores may be distributed substantially at the polishing surface of the elements. In some exemplary embodiments, the pores distributed substantially at the polishing surface of the element comprise a plurality of channels having a cross-sectional shape selected from the group consisting of cylindrical, triangular, rectangular, trapezoidal, hemispherical, and combinations thereof.

5 In a further exemplary embodiment, a method of making a polishing pad is provided, the method comprising forming a plurality of polishing elements, and bonding the polishing elements to a support layer. In some exemplary embodiments, bonding the polishing elements to the support layer comprises thermal bonding, actinic radiation
10 bonding, adhesive bonding, and combinations thereof.

In some exemplary embodiments, the method further comprises arranging the plurality of polishing elements in a pattern before bonding the polishing elements to the support layer. In certain exemplary embodiments, arranging the plurality of polishing elements in a pattern comprises arranging the polishing elements in a template, arranging
15 the polishing elements on the support layer, and combinations thereof. In certain embodiments, at least a portion of the polishing elements comprise porous polishing elements. In some additional embodiments, at least a portion of the polishing elements comprise substantially non-porous polishing elements.

In some particular exemplary embodiments, the method includes forming porous
20 polishing elements by injection molding of a gas saturated polymer melt, injection molding of a reactive mixture that evolves a gas upon reaction to form a polymer, injection molding of a mixture comprising a polymer dissolved in a supercritical gas, injection molding of a mixture of incompatible polymers in a solvent, injection molding of porous thermoset particulates dispersed in a thermoplastic polymer, and combinations
25 thereof.

In an additional exemplary embodiment, the present disclosure is directed to a method of using a polishing pad as described above in a polishing process, the method comprising contacting a surface of a substrate with a polishing surface of a polishing pad comprising a plurality of polishing elements thermally bonded to a support layer, and
30 relatively moving the polishing pad with respect to the substrate to abrade the surface of the substrate. In some exemplary embodiments, at least a portion of the polishing elements comprise porous polishing elements, and in certain embodiments, at least a

surface of each porous polishing element comprises a plurality of pores. In other exemplary embodiments, a working liquid may be provided to an interface between the polishing pad surface and the substrate surface.

Exemplary embodiments of polishing pads having porous polishing elements according to the present disclosure have various features and characteristics that enable their use in a variety of polishing applications. In some presently preferred embodiments, polishing pads of the present disclosure may be particularly well suited for chemical mechanical planarization (CMP) of wafers used in manufacturing integrated circuits and semiconductor devices. In certain exemplary embodiments, the polishing pad described in this disclosure may provide some or all of the following advantages.

For example, in some exemplary embodiments, a polishing pad according to the present disclosure may act to better retain a working liquid used in the CMP process at the interface between the polishing surface of the pad and the substrate surface being polished, thereby improving the effectiveness of the working liquid in augmenting polishing. In other exemplary embodiments, a polishing pad according to the present disclosure may reduce or eliminate dishing and/or edge erosion of the wafer surface during polishing.

In further exemplary embodiments, use of a polishing pad with porous elements according to the present disclosure may permit processing of larger diameter wafers while maintaining the required degree of surface uniformity to obtain high chip yield, processing of more wafers before conditioning of the pad surface is needed in order to maintain polishing uniformity of the wafer surfaces, or reducing process time and wear on the pad conditioner. In certain embodiments, CMP pads with porous polishing elements may also offer the benefits and advantages of conventional CMP pads having surface textures such as grooves, but may be manufactured more reproducibly at a lower cost. In additional embodiments, bonding of the polishing elements to the support layer may eliminate the need to use a guide plate to affix the elements to the support layer.

Various aspects and advantages of exemplary embodiments of the disclosure have been summarized. The above Summary is not intended to describe each illustrated embodiment or every implementation of the present certain exemplary embodiments of the present invention. The Drawings and the Detailed Description that follow more particularly exemplify certain preferred embodiments using the principles disclosed herein.

BRIEF DESCRIPTION OF DRAWINGS

Exemplary embodiments of the present disclosure are further described with reference to the appended figures, wherein:

FIG. 1 is a side view of a polishing pad having floating polishing elements bonded to a support layer according to one exemplary embodiment of the disclosure.

FIG. 2 is a side view of a polishing pad having floating polishing elements bonded to a support layer and including a guide plate according to another exemplary embodiment of the disclosure.

FIG. 3A is a perspective view of a template with polishing elements arranged in a pattern useful in fabricating a polishing pad according to one exemplary embodiment of the disclosure.

FIG. 3B is a top view of a template with polishing elements arranged in a pattern useful in fabricating a polishing pad according to one exemplary embodiment of the disclosure.

FIG. 4 is a perspective view of a porous polishing element having a porous polishing surface according to another exemplary embodiment of the disclosure.

FIG. 5 is a side view of an exemplary bonding apparatus useful in a method for bonding a multiplicity of polishing elements to a support layer according to an exemplary embodiment of the disclosure.

FIG. 6 is an image showing a template useful in arranging a multiplicity of polishing elements into a pattern before bonding the polishing elements to a support layer, and the resulting support layer having a multiplicity of bonded polishing elements arranged in the pattern, according to an additional exemplary embodiment of the disclosure.

FIG. 7 is an image of the resulting support layer having a multiplicity of bonded polishing elements arranged in the pattern, according to the embodiment of FIG. 6.

FIG. 8 is an image of a polishing pad according to yet another exemplary embodiment of the disclosure, the polishing pad comprising the multiplicity of floating polishing elements bonded to the support layer according to the embodiment of FIG. 7, the support layer being affixed to a compliant underlayer.

Like reference numerals in the drawings indicate like elements. The drawings herein are not drawn to scale, and in the drawings the components of the polishing pads are sized to emphasize selected features.

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DETAILED DESCRIPTION

In a typical CMP slurry process for wafer polishing, a wafer possessing a characteristic topography is put in contact with a polishing pad and a polishing solution containing an abrasive and a polishing chemistry. If the polishing pad is compliant, the phenomenon of dishing and erosion may occur due to the soft pad polishing the low areas on the wafer at the same rate as the raised areas. If the polishing pad is rigid, dishing and erosion may be greatly reduced; however, although rigid polishing pads may advantageously yield good within die planarization uniformity, they may also disadvantageously yield poor within wafer uniformity, due to a rebound effect which occurs on the wafer perimeter. This rebound effect results in poor edge yield and a narrow CMP polishing process window. In addition, it may be difficult to develop a stable polishing process with a rigid polishing pad, because such pads are sensitive to different wafer topographies, and are completely dependent upon use of a pad conditioner to create an optimal polishing texture which holds the polishing solution and interfaces with the wafer.

The present disclosure is directed to improved polishing pads with a multiplicity of floating polishing elements bonded to a support layer, which in various embodiments combine some of the advantageous characteristics of both compliant and rigid polishing pads, while eliminating or reducing some of the disadvantageous characteristics of the respective pads. By describing the polishing elements as "floating" polishing elements bonded to a support layer, Applicant means that each of the polishing elements is bonded to a support layer so as to restrict lateral movement of the polishing elements with respect to one or more of the other polishing elements, but remaining moveable in an axis generally normal to a polishing surface of the polishing elements.

Various exemplary embodiments of the disclosure will now be described with particular reference to the Drawings. Exemplary embodiments of the present disclosure may take on various modifications and alterations without departing from the spirit and scope of the disclosure. Accordingly, it is to be understood that the embodiments of the

present invention are not to be limited to the following described exemplary embodiments, but are to be controlled by the limitations set forth in the claims and any equivalents thereof.

Referring to FIG. 1, an exemplary embodiment of a polishing pad 2 is shown, comprising a plurality of polishing elements 4-4', each of the polishing elements 4-4' being bonded to a support layer 10 so as to restrict lateral movement of the polishing elements 4-4' with respect to one or more of the other polishing elements 4-4', but remaining moveable in an axis normal to a polishing surface 14 of each polishing element 4-4'. In the particular embodiment illustrated by FIG. 1, the polishing elements 4-4' are shown affixed to a first major side of the support layer 10, for example, by direct thermal bonding to the support layer 10, or by using an adhesive.

In the particular exemplary embodiment illustrated by FIG. 1, support layer 10 is affixed to a compliant layer 16 positioned on a side opposite the plurality of polishing elements 4-4'. Furthermore, an optional adhesive layer 12 is shown at an interface between compliant layer 16 and the support layer 10. Optional adhesive layer 12 may be used to affix the second major side of the support layer 10 to the compliant layer 16. Additionally, an optional pressure sensitive adhesive layer 18, affixed to the compliant layer 16 opposite the plurality of polishing elements 4-4', may be used to temporarily (e.g., removably) secure the polishing pad 2 to a polishing platen (not shown in FIG. 1) of a CMP polishing apparatus (not shown in FIG. 1).

An optional polishing composition distribution layer 8, which may also serve as a guide plate for the polishing elements 4-4', is additionally shown in FIG. 1. During a polishing process, the optional polishing composition distribution layer 8 aids distribution of the working liquid and/or polishing slurry to the individual polishing elements 4-4'. When used as a guide plate, the polishing composition distribution layer 8 (guide plate) may be positioned on the first major side of the support layer 10 to facilitate arrangement of the plurality of polishing elements 4-4', such that a first major surface of the polishing composition distribution layer 8 (guide plate) is distal from the support layer 10, and a second major surface of the polishing composition distribution layer 8 (guide plate) is opposite the first major surface of the polishing composition distribution layer 8 (guide plate).

The polishing elements 4-4' extend from the first major surface of the polishing composition distribution layer 8 (guide plate) along a first direction substantially normal to the first major side of the support layer 10. If polishing composition distribution layer 8 is also used as a guide plate, then preferably, a plurality of apertures 6 are provided
5 extending through the polishing composition distribution layer 8 (guide plate). A portion of each polishing element 4 extends into a corresponding aperture 6. Thus, the plurality of apertures 6 may serve to guide the arrangement of polishing elements 4 on the support layer 10.

In one exemplary embodiment illustrated by FIG. 1, at least a portion of the
10 polishing elements 4-4' are porous polishing elements 4, and some polishing elements 4-4' are substantially nonporous polishing elements 4'. It will be understood, however, that in other exemplary embodiments not shown in FIG. 1, all of the polishing elements 4-4' may be selected to be porous polishing elements 4, or all of the polishing elements 4-4' may be selected to be substantially nonporous polishing elements 4'.

In the particular embodiment illustrated by FIG. 1, two porous polishing elements
15 4 are shown along with one substantially nonporous polishing element 4'. Furthermore, the porous polishing elements 4 are shown as including both a porous polishing surface 14 and pores 15 distributed substantially throughout the entire polishing element 4. However, it will be understood that any number of polishing elements 4-4' may be used, and that any
20 number of polishing elements 4-4' may be selected to be porous polishing elements 4 or substantially nonporous polishing elements 4'.

In addition, in some exemplary embodiments not illustrated by FIG. 1, the multiplicity of polishing elements 4-4' may be arranged in a pattern, for example, on a major surface of the support layer 10, or in a template or jig used to arrange the polishing
25 elements before bonding to the support layer. For example, FIGs. 3A-3B illustrate one exemplary arrangement of a plurality of polishing elements 4-4' arranged in a generally circular two-dimensional array pattern 32 in a template 30. After arranging the plurality of polishing elements 4-4' in the pattern 32 in template 30, a first major side of the support layer 10 may be contacted with and bonded to the plurality of polishing elements 4-4', for
30 example, by direct thermal bonding to the support layer 10, or by using an adhesive, or other bonding material.

Furthermore, it will be understood that the polishing pad 2 need not comprise only substantially identical polishing elements 4. Thus, for example, any combination or arrangement of porous polishing elements and non-porous polishing elements may make up the plurality of porous polishing elements 4. It will also be understood that any number, combination or arrangement of porous polishing elements 4 and substantially nonporous polishing elements 4' may be used advantageously in certain embodiments to form a polishing pad having floating polishing elements 4-4' bonded to a support layer 10.

In some additional exemplary embodiments illustrated by FIG. 1, at least a surface of a porous polishing element 4, in this case at least polishing surface 14, comprises a plurality of pores (not shown in FIG. 1, but illustrated in FIG. 4). In other exemplary embodiments, each of the porous polishing elements 4 is also shown as having a plurality of pores 15 distributed substantially throughout the entire polishing element 4. In other exemplary embodiments (not shown in FIG. 1, but illustrated by FIG. 4), the pores are distributed substantially at or near only the polishing surface 14 of the porous polishing elements 4. However, it is to be understood that polishing pads 2 having combinations or arrangements of polishing elements 4 with pores distributed substantially throughout the entire polishing element 4, polishing elements 4 with pores distributed substantially at or near only the polishing surface 14 of the polishing element 4, and polishing elements 4 with substantially no pores, are contemplated within the scope of the present disclosure, and may also be advantageously fabricated.

Referring to FIG. 2, another exemplary embodiment of a polishing pad 2' is shown, the polishing pad 2' comprising a support layer 10 having a first major side and a second major side opposite the first major side; a plurality of polishing elements 4-4' bonded to the first major side of the support layer 10; and an optional guide plate 28 having a first major surface and a second major surface opposite the first major surface, the guide plate 28 positioned to arrange the plurality of polishing elements 4-4' on the first major side of support layer 10 with the first major surface of optional guide plate 28 distal from the support layer 10. In the particular embodiment illustrated by FIG. 1, the polishing elements 4-4' are shown affixed to a first major side of the support layer 10, for example, by direct thermal bonding to the support layer 10, or by using an adhesive.

In the particular exemplary embodiment illustrated by FIG. 2, support layer 10 is affixed to a compliant layer 16 positioned on the second major side of the support layer 10

opposite the plurality of polishing elements 4-4' affixed to the first major side of the support layer 10. Furthermore, an optional adhesive layer 12 is shown at an interface between compliant layer 16 and the support layer 10. Optional adhesive layer 12 may be used to affix the second major side of the support layer 10 to the compliant layer 16.

5 Additionally, an optional pressure sensitive adhesive layer 18, affixed to the compliant layer 16 opposite the plurality of polishing elements 4-4', may be used to temporarily (e.g., removably) secure the polishing pad 2' to a polishing platen (not shown in FIG. 2) of a CMP polishing apparatus (not shown in FIG. 2).

An optional guide plate 28 is also shown in the exemplary embodiment of FIG. 2.
10 The optional guide plate 28, which may also serve as an alignment template for arranging the plurality of polishing elements 4-4' on the first major side of support layer 10, is not generally required in order to produce polishing pads 2' according to the present disclosure. In certain exemplary embodiments, the optional guide plate 28 may be entirely eliminated from the polishing pad, as illustrated by polishing pad 2 of FIG. 1. Such
15 embodiments may advantageously be easier and less expensive to fabricate than other known polishing pads comprising a multiplicity of polishing elements.

An optional polishing composition distribution layer 8', which may also serve as a guide plate for the polishing elements 4-4', is additionally shown in FIG. 2. During a polishing process, the optional polishing composition distribution layer 8' aids distribution
20 of the working liquid and/or polishing slurry to the individual polishing elements 4-4'. When used as a guide plate, the polishing composition distribution layer 8 may be positioned on the first major side of the support layer 10 to facilitate arrangement of the plurality of polishing elements 4-4', such that a first major surface of the polishing composition distribution layer 8' is distal from the support layer 10, and a second major
25 surface of the polishing composition distribution layer 8' is opposite the first major surface of the polishing composition distribution layer 8'. A plurality of apertures 6 may also be provided extending through at least the optional guide plate 28 (if present) and/or the optional polishing composition distribution layer 8' (if present), as shown in FIG. 2

As illustrated by FIG. 2, each polishing element 4-4' extends from the first major
30 surface of the optional guide plate 28 along a first direction substantially normal to the first major side of support layer 10. In some embodiments shown in FIG. 2, each polishing element 4-4' has a mounting flange, and each polishing element 4-4' is bonded

to the first major side of the support layer 10 by engagement of the corresponding flange to the first major side of the support layer 10, and optionally, the second major surface of optional polishing composition distribution layer 8'. Consequently, during a polishing process, the polishing elements 4-4' are free to independently undergo displacement in a direction substantially normal to the first major side of support layer 10, while still remaining bonded to the support layer 10, and optionally additionally affixed to the support layer 10 by the optional polishing composition distribution layer 8'.

In such embodiments, at least a portion of each polishing element 4-4' extends into a corresponding aperture 6, and each polishing element 4-4' also passes through the corresponding aperture 6 and extends outwardly from the first major surface of the optional guide plate 28. Thus, the plurality of apertures 6 of optional guide plate 28 and/or optional polishing composition distribution layer 8', may also serve as a template to guide the lateral arrangement of polishing elements 4-4' on the first major side of support layer 10. In other words, optional guide plate 28 and/or optional polishing composition distribution layer 8' may be used as a template or guide to arrange the plurality of polishing elements 4-4' on the first major side of support layer 10 during the polishing pad fabrication process.

In the particular embodiment illustrated by FIG. 2, the optional guide plate 28 may comprise an adhesive (not shown) positioned at the interface between the support layer 10 and the polishing composition distribution layer 8'. The optional guide plate 28 may thus be used to affix the optional polishing composition distribution layer 8' to the support layer 10, thereby securely affixing the plurality of polishing elements 4-4' to the first major side of support layer 10. However, other bonding methods may be used, including direct bonding of the polishing elements 4-4' to the support layer 10 using, for example, heat and pressure.

In a related exemplary embodiment illustrated in FIG. 2, the plurality of apertures may be arranged as an array of apertures, wherein at least a portion of the apertures 6 comprise a main bore formed by optional polishing composition distribution layer 8', and an undercut region formed by optional guide plate 28, and the undercut region forms a shoulder that engages with the corresponding polishing element flange, thereby securely affixing polishing elements 4-4' to support layer 10 without requiring direct bonding of the polishing elements 4-4' to support layer 10. In addition, in some exemplary

embodiments not illustrated by FIG. 2, the multiplicity of polishing elements 4-4' may be arranged in a pattern, for example, as a two-dimensional array of elements arranged on a major surface of the support layer 10, or in a template or jig used to arrange the polishing elements before bonding to the support layer.

5 In further exemplary embodiments illustrated by FIG. 2, at least a surface of a porous polishing element 4, in this case at least polishing surface 14 comprises a plurality of pores (not shown in FIG. 2, but illustrated in FIG. 4). In other exemplary embodiments, each of the porous polishing elements 4 is also shown as having a plurality of pores 15 distributed substantially throughout the entire polishing element 4. In other exemplary
10 embodiments (not shown in FIG. 2, but illustrated by FIG. 4), the pores are distributed substantially at or near only the polishing surface 14 of the porous polishing elements 4. However, it is to be understood that polishing pads 2' having combinations or arrangements of polishing elements 4 with pores distributed substantially throughout the entire polishing element 4, polishing elements 4 with pores distributed substantially at or
15 near only the polishing surface 14 of the polishing element 4, and polishing elements 4 with substantially no pores, are contemplated within the scope of the present disclosure, and may also be advantageously fabricated.

With reference now to FIG. 4, a porous polishing element 4 having a porous polishing surface 14 comprising a plurality of pores 15 may be used in a polishing pad
20 according to another exemplary embodiment of the disclosure. The porous polishing element 4 of FIG. 4 is also shown with a flange 25, which may be used to facilitate bonding to a support layer (not shown in FIG. 4), for example, as illustrated in FIG. 2. The porous polishing element shown in FIG. 4 comprises a plurality of pores 15 positioned substantially at the polishing surface 14. However, it will be understood that in
25 other embodiments, for example, the embodiments shown in FIGs. 1-2, the plurality of pores 15 may be distributed both throughout the entire porous polishing element 4 and at the polishing surface 14. It will be further understood that in other embodiments, the plurality of pores 15 may be distributed throughout the porous polishing element 4, but not at the polishing surface 14.

30 FIG. 4 illustrates one particular shape of a porous polishing element 4. It will be understood that the same shape may be used to produce a substantially nonporous polishing element 4'. It will be further understood that the polishing elements 4-4' may be

formed in virtually any shape, and that a plurality of polishing elements 4-4' having two or more different shapes may be advantageously used and optionally arranged in a pattern before bonding to a support layer (not shown in FIG. 4) used to form a polishing pad (not shown in FIG. 4).

5 In some exemplary embodiments, the polishing elements 4-4' may be characterized by a height (H) and a width (W), as illustrated by FIG. 4. In addition, the cross-sectional shape of the polishing elements 4-4', taken through a polishing element 4-4' in a direction generally parallel to the polishing surface 14, may vary widely depending on the intended application. Although FIG. 4 shows a generally cylindrical polishing
10 element 4 having a generally circular cross section, other cross-sectional shapes are possible and may be desirable in certain embodiments. For example, circular, elliptical, triangular, square, rectangular, and trapezoidal cross-sectional shapes may be useful.

 For generally cylindrical polishing elements 4 having a circular cross section as shown in FIG. 4, the cross-sectional diameter of the polishing element 4 in a direction
15 generally parallel to the polishing surface 14 is, in some embodiments, at least about 50 micrometers (μm), more preferably at least about 1 mm, still more preferably at least about 5 mm. In certain embodiments, the cross-sectional diameter of the polishing element 4 in a direction generally parallel to the polishing surface 14 is at most about 20 mm, more preferably at most about 15 mm, still more preferably at most about 12 mm.
20 In some embodiments, the diameter of the polishing element, taken at the polishing surface 14 and corresponding to width (W) as shown in FIG. 4, may be from about 50 μm to about 20 mm, in certain embodiments the diameter is from about 1 mm to about 15 mm, and in other embodiments the cross-sectional diameter is from about 5 mm to about 12 mm.

25 For non-cylindrical polishing elements having a non-circular cross section, a characteristic dimension may be used to characterize the polishing element size in terms of a height, width, and/or length. In certain exemplary embodiments, the characteristic dimension may be selected to be at least about 50 μm , more preferably at least about 1 mm, still more preferably at least about 5 mm. In certain embodiments, the
30 cross-sectional diameter of the polishing element 4 in a direction generally parallel to the polishing surface 14 is at most about 20 mm, more preferably at most about 15 mm, still more preferably at most about 12 mm.

In other exemplary embodiments, the cross-sectional area of each polishing element 4 in a direction generally parallel to the polishing surface 14, may be at least about 1 mm², in other embodiments at least about 10 mm², and in still other embodiments at least about or 20 mm². In other exemplary embodiments, the cross-sectional area of each polishing element 4 in a direction generally parallel to the polishing surface 14, may be at most about 1,000 mm², in other embodiments at most about 500 mm², and in still other embodiments at most about 250 mm².

The polishing elements (4-4' in FIGs. 1-2) may be distributed on a major side of the support layer (10 in FIG. 1-2) in a wide variety of patterns, depending on the intended application, and the patterns may be regular or irregular. The polishing elements may reside on substantially the entire surface of the support layer, or there may be regions of the support layer that include no polishing elements. In some embodiments, the polishing elements have an average surface coverage of the support layer of at least 30%, at least 40%, or at least 50%. In further embodiments, the polishing elements have an average surface coverage of the support layer of at most about 80%, at most about 70%, or at most about 60% of the total area of the major surface of the support layer, as determined by the number of polishing elements, the cross-sectional area of each polishing element, and the cross-sectional area of the polishing pad.

The cross-sectional area of the polishing pad in a direction generally parallel to a major surface of the polishing pad may, in some exemplary embodiments, range from about 100 cm² to about 300,000 cm², in other embodiments from about 1,000 cm² to about 100,000 cm², and in yet other embodiments, from about 2,000 cm² to about 50,000 cm².

Prior to the first use of the polishing pad (2 in FIG. 1, 2' in FIG. 2) in a polishing operation, in some exemplary embodiments, each polishing element (4-4' in FIGs. 1-2) extends along the first direction substantially normal to the first major side of the support layer (10 in FIGs. 1-2). In certain exemplary embodiments, the polishing elements extend along the first direction at least about 0 mm, 0.25 mm, at least about 0.3 mm, or at least about 0.5 mm above a plane including the optional polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2) and/or optional guide plate (28 in FIG. 2).

In other exemplary embodiments, the polishing surfaces of the polishing elements may be made flush with the exposed major surface of the optional polishing composition distribution layer. In other exemplary embodiments, the polishing surfaces of the

polishing elements may be made recessed below the exposed major surface of the optional polishing composition distribution layer, and subsequently made flush with, or made to extend beyond, the exposed major surface of the optional polishing composition distribution layer, for example, by removal of a portion of the optional polishing composition distribution layer. Such embodiments may be advantageously used with polishing composition distribution layers that are selected to be abraded or eroded during the polishing process or in optional conditioning processes applied to the polishing pad before, during, or after contact with a workpiece.

In further exemplary embodiments, each polishing element 4-4' extends along the first direction at least about 0.25 mm, at least about 0.3 mm, or at least about 0.5 mm above a plane including the support layer (10 in FIGs. 1-2). In additional exemplary embodiments, the height of the polishing surface (14 in FIGs. 1-2) above the base or bottom of the polishing element, that is, the height (H) of the polishing element as shown in FIG. 4, may be 0.25 mm, 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 5.0 mm, 10 mm or more, depending on the polishing composition used and the material selected for the polishing elements.

Referring again to FIGs. 1-2, the depth and spacing of the apertures (6 in FIG. 1-2) throughout the optional polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2) and/or optional guide plate 28 may be varied as necessary for a specific CMP process. In some embodiments, the polishing elements (4-4' in FIGs. 1-2) are each maintained substantially in planar orientation with respect to one other and the polishing composition distribution layer (8 in FIG. 1, 28 in FIG. 2) and guide plate 31, and project above the surface of the optional polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2) and/or optional guide plate 28.

In some exemplary embodiments, the void volume created by the extension of the polishing elements 4-4' above any optional guide plate (28 in FIG. 2) and any optional polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2) may provide room for distribution of a polishing composition on the surface of the optional polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2). The polishing elements 4-4' protrude above the polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2) by an amount that depends at least in part on the material characteristics of the polishing elements and the desired flow of polishing composition (working liquid and or abrasive

slurry) over the surface of the polishing composition distribution layer (8 in FIG. 1, 8' in FIG. 2).

As illustrated by FIGs. 1-2, in some exemplary embodiments, at least a portion of the polishing elements 4-4' are porous polishing elements 4, which in certain
5 embodiments at least have a porous polishing surface (14 in FIGs. 1-2), which may make sliding or rotational contact with a substrate (not shown in FIG. 1) to be polished. In other
embodiments, the porous polishing elements may not have a porous polishing surface 14, but may have pores 15 distributed throughout substantially the entire porous polishing
element 4. Such porous polishing elements may be useful as compliant polishing elements
10 exhibiting some of the advantageous characteristics of a compliant polishing pad. Suitable porous polishing elements are disclosed in co-pending U.S. Provisional Patent Application
No. 61/075970, filed June 26, 2008, titled "POLISHING PAD WITH POROUS
ELEMENTS AND METHOD OF MAKING AND USING THE SAME".

In some particular exemplary embodiments, one or more of the porous polishing
15 elements 4 may comprise a plurality of pores 15 distributed throughout substantially the entire polishing element 4 in the form of a porous foam. The foam may be a closed cell
foam, or an open cell foam. Closed cell foams may be preferred in some embodiments. Preferably, the plurality of pores 15 in the foam exhibits a unimodal distribution of pore
size, for example, pore diameter. In certain exemplary embodiments, the plurality of pores
20 exhibits a mean pore size of at least about 1 nanometer (nm), at least about 100 nm, at least about 500 nm, or at least about 1 μ m. In other exemplary embodiments, the plurality
of pores exhibits a mean pore size of at most about 100 μ m, at most about 50 μ m, at most
about 10 μ m, or at most about 1 μ m. In certain presently preferred embodiments, the
plurality of pores exhibits a mean pore size from about 1 μ m to about 50 μ m.

Referring now to FIGs. 1-2 and 4, the polishing surface 14 of polishing elements
25 4-4' may be a substantially flat surface, or may be textured. In certain presently preferred
embodiments, at least the polishing surface of each porous polishing element is made
porous, for example with microscopic surface openings or pores 15, which may take the
form of orifices, passageways, grooves, channels, and the like. Such pores 15 at the
30 polishing surface may act to facilitate distributing and maintaining a polishing
composition (e.g., a working liquid and/or abrasive polishing slurry not shown in the

figures) at the interface between a substrate (not shown) and the corresponding porous polishing elements.

In certain exemplary embodiments illustrated by FIG. 4, the polishing surface 14 comprises pores 15 that are generally cylindrical capillaries. The pores 15 may extend
5 from the polishing surface 14 into the polishing element 4. In a related embodiment, the polishing surface comprises pores 15 that are generally cylindrical capillaries extending from the polishing surface 14 into the porous polishing element 4. The pores need not be cylindrical, and other pore geometries are possible, for example, conical, rectangular, pyramidal, and the like. The characteristic dimensions of the pores can, in general, be
10 specified as a depth, along with a width (or diameter), and a length. The characteristic pore dimensions may range from about 25 μm to about 6,500 μm in depth, from about 5 μm to about 1000 μm in width (or diameter), and from about 10 μm to about 2,000 μm in length.

In other exemplary embodiments (not illustrated), the polishing surface comprises
15 pores in the form of a plurality of channels, wherein each channel extends across at least a portion of the polishing surface of a corresponding polishing element, preferably in a direction generally parallel to the polishing surface. Preferably, each channel extends across the entire polishing surface of a corresponding polishing element in a direction generally parallel to the polishing surface. In other exemplary embodiments (not
20 illustrated), the pores may take the form of a two-dimensional array of channels in which each channel extends across only a portion of the polishing surface.

In further exemplary embodiments (not illustrated), the channels may have virtually any shape, for example, cylindrical, triangular, rectangular, trapezoidal, hemispherical, and combinations thereof. In some exemplary embodiments, the depth of
25 each channel in a direction substantially normal to the polishing surface of the polishing elements is selected to be in the range of at least about 100 μm to about 7500 μm . In other exemplary embodiments, the cross-sectional area of each channel in a direction substantially parallel to the polishing surface of the polishing elements is selected to be in the range from about 75 square micrometers (μm^2) to about $3 \times 10^6 \mu\text{m}^2$.

30 In further exemplary embodiments, the support layer may be substantially incompressible, such as a rigid film or other hard substrate, but is preferably compressible to provide a positive pressure directed toward the polishing surface. In some exemplary

embodiments, the support layer may comprise a flexible and compliant material, such as a compliant rubber or polymer. In other exemplary embodiments, the support layer is preferably made of a compressible polymeric material, foamed polymeric materials being preferred. In certain embodiments, closed cell foams may be preferred, although in other
5 embodiments, and open cell foam may be used. In additional exemplary embodiments, the polishing elements may be formed with the support layer as a unitary sheet of polishing elements affixed to the support layer, which may be a compressible or compliant support layer.

 The support layer is preferably liquid impermeable, to prevent penetration or
10 permeation of a working liquid into or through the support layer. However, in some embodiments, the support layer may comprise liquid permeable materials, alone or in combination with an optional barrier that acts to prevent or inhibit liquid penetration or permeation through the support layer. Furthermore, in other embodiments, a porous support layer may be used advantageously, for example, to retain a working liquid (e.g., a
15 polishing slurry) at the interface between the polishing pad and a workpiece during polishing.

 In certain exemplary embodiments, the support layer may comprise a polymeric material selected from silicone, natural rubber, styrene-butadiene rubber, neoprene, polyurethane, polyester, polyethylene, and combinations thereof. The support layer may
20 further comprise a wide variety of additional materials, such as fillers, particulates, fibers, reinforcing agents, and the like.

 Polyurethanes have been found to be particularly useful support layer materials, with thermoplastic polyurethanes (TPUs) being particularly preferred. In some presently preferred embodiments, the support layer is a film comprising one or more TPU, for
25 example, an ESTANE TPU (available from Lubrizol Advanced Materials, Inc., Cleveland, OH), a TEXIN or DESMOPAN TPU (available from Bayer Material Science, Pittsburgh, PA), a PELLETHANE TPU (available from Dow Chemical Company, Midland, MI), and the like.

 The polishing elements may comprise a wide variety of materials, with polymeric
30 materials being preferred. Suitable polymeric materials include, for example, polyurethanes, polyacrylates, polyvinyl alcohol polyesters, polycarbonates, and acetals available under the trade designation DELRIN (available from E.I. DuPont de Nemours,

Inc., Wilmington, DE). In some exemplary embodiments, at least some of the polishing elements comprise a thermoplastic polyurethane, a polyacrylate, polyvinyl alcohol, or combinations thereof.

5 The polishing elements may also comprise a reinforced polymer or other composite material, including, for example, metal particulates, ceramic particulates, polymeric particulates, fibers, combinations thereof, and the like. In certain embodiments, polishing elements may be made electrically and/or thermally conductive by including therein fillers such as, carbon, graphite, metals or combinations thereof. In other
10 embodiments, electrically conductive polymers such as, for example, polyanilines (PANI) sold under the trade designation ORMECOM (available from Ormecon Chemie, Ammersbek, Germany) may be used, with or without the electrically or thermally conductive fillers referenced above.

In some exemplary embodiments, the polishing pad further comprises a compliant layer affixed to the support layer opposite the polishing elements. The compliant layer
15 may be affixed to the support layer by any means of bonding surfaces, but preferably, an adhesive layer positioned at an interface between the compliant layer and the support layer is used to affix the support layer to the compliant layer opposite the polishing elements.

In certain embodiments, the compliant layer is preferably compressible to provide a positive pressure directing the polishing surfaces of the polishing elements toward a
20 workpiece during polishing. In some exemplary embodiments, the support layer may comprise a flexible and compliant material, such as a compliant rubber or polymer. In other exemplary embodiments, the support layer is preferably made of a compressible polymeric material, foamed polymeric materials being preferred. In certain embodiments, closed cell foams may be preferred, although in other embodiments, and open cell foam
25 may be used.

In some particular embodiments, the compliant layer may comprise a polymeric material selected from silicone, natural rubber, styrene-butadiene rubber, neoprene, polyurethane, polyethylene, and combinations thereof. The compliant layer may further
30 comprise a wide variety of additional materials, such as fillers, particulates, fibers, reinforcing agents, and the like. The compliant layer is preferably liquid impermeable (although permeable materials may be used in combination with an optional barrier to prevent or inhibit liquid penetration into the compliant layer).

Preferred polymeric materials for use in the compliant layer are polyurethanes, with TPUs being particularly preferred. Suitable polyurethanes include, for example, those available under the trade designation PORON from Rogers Corp., Rogers, CT, as well as those available under the trade designation PELLETHANE from Dow Chemical, Midland, MI, particularly PELLETHANE 2102-65D. Other suitable materials include polyethylene terephthalates (PET), such as, for example biaxially oriented PET widely available under the trade designation MYLAR, as well as bonded rubber sheets (e.g., rubber sheets available from Rubberite Cypress Sponge Rubber Products, Inc., Santa Ana, CA, under the trade designation BONDTEX).

In some exemplary embodiments, polishing pads according to the present disclosure may have certain advantages when used in a CMP process, for example, improved within wafer polishing uniformity, a flatter polished wafer surface, an increase in edge die yield from the wafer, and improved CMP process operating latitude and consistency. While not wishing to be bound by any particular theory, these advantages may result from decoupling of the polishing surfaces of the polishing elements from the compliant layer underlying the support layer, thereby allowing the polishing elements to "float" in a direction substantially normal to the polishing surface of the elements when contacting the polishing pad to a workpiece during a polishing process.

In some embodiments, decoupling of the polishing surfaces of the polishing elements from the compliant underlayer may be augmented by incorporating into the polishing article an optional guide plate including a plurality of apertures extending through the guide plate from a first major surface to a second major surface, wherein at least a portion of each polishing element extends into a corresponding aperture, and wherein each polishing element extends outwardly from the second major surface of the guide plate. The optional guide plate, which preferably comprises a stiff or non-compliant material, may be used to maintain the spatial orientation of polishing surface, as well as to maintain lateral movement of the elements on the polishing pad. In other embodiments, however, the optional guide plate is not required, because the spatial orientation of the polishing elements is maintained and lateral movement is prevented by bonding the elements to the support layer, preferably by thermally bonding the polishing elements directly to the support layer.

The optional guide plate can be made of a wide variety of materials, such as polymers, copolymers, polymer blends, polymer composites, or combinations thereof. A rigid, non-compliant, non-conducting and liquid impermeable polymeric material is generally preferred, and polycarbonates have been found to be particularly useful.

5 In further embodiments, polishing pads of the present disclosure may further comprise an optional polishing composition distribution layer covering at least a portion of a first major side of the support layer, as well as the first major surface of the optional guide plate (if present). The optional polishing composition distribution layer may be made of a wide variety of polymeric materials. The optional polishing composition
10 distribution layer may, in some embodiments, comprise at least one hydrophilic polymer. Preferred hydrophilic polymers include polyurethanes, polyacrylates, polyvinyl alcohols, polyoxymethylenes, and combinations thereof. In one particular embodiment, the polishing composition layer may comprise a hydrogel material, such as, for example a hydrophilic polyurethane or polyacrylate, that can absorb water, preferably in a range of
15 about 5 to about 60 percent by weight, to provide a lubricious surface during polishing operations.

In additional exemplary embodiments, the optional polishing composition distribution layer comprises a compliant material, for example, a porous polymer or foam, to provide a positive pressure directed toward to substrate during polishing operations
20 when the polishing composition distribution layer is compressed. In certain exemplary embodiments, the compliance of the polishing composition distribution layer is selected to be less than the compliance of the optional compliant layer. Porous or foamed materials with open or closed cells may be preferred compliant materials for use in an optional polishing composition distribution layer in certain embodiments. In some particular
25 embodiments, the optional polishing composition distribution layer has between about 10 and about 90 percent porosity.

In certain exemplary embodiments, the polishing surfaces of the polishing elements may be made flush with or recessed below the exposed major surface of the optional polishing composition distribution layer. Such embodiments may be
30 advantageously employed to maintain a working liquid, for example a polishing slurry, at the interface between the exposed polishing surfaces of the polishing elements and a workpiece. In such embodiments, the polishing composition distribution may be

advantageously selected to comprise a material that is abraded or eroded during the polishing process or in optional conditioning processes applied to the polishing surface of the polishing pad before, during, or after contact with a workpiece.

In further exemplary embodiments, the polishing composition distribution layer
5 may act to substantially uniformly distribute a polishing composition across the surface of the substrate undergoing polishing, which may provide more uniform polishing. The polishing composition distribution layer may optionally include flow resistant elements such as baffles, grooves (not shown in the figures), pores, and the like, to regulate the flow rate of the polishing composition during polishing. In further exemplary embodiments,
10 the polishing composition distribution layer can include various layers of different materials to achieve desired polishing composition flow rates at varying depths from the polishing surface.

In some exemplary embodiments, one or more of the polishing elements may include an open core region or cavity defined within the polishing element, although such
15 an arrangement is not required. In some embodiments, as described in WO/2006/055720, the core of the polishing element can include sensors to detect pressure, conductivity, capacitance, eddy currents, and the like. In yet another embodiment, the polishing pad may include a window extending through the pad in the direction normal to the polishing surface, or may use transparent layers and/or transparent polishing elements, to allow for
20 optical end-pointing of a polishing process, as described in the co-pending U.S. Provisional Patent Application No. 61/053,429, filed May 15, 2008, titled "POLISHING PAD WITH ENDPOINT WINDOW AND SYSTEMS AND METHOD OF USING THE SAME."

The term "transparent layer" as used above is intended to include a layer that
25 comprises a transparent region, which may be made of a material that is the same or different from the remainder of the layer. In some exemplary embodiments, the element, layer or region may be transparent, or may be made transparent by applying heat and/or pressure to the material, or a transparent material may be cast in place in an aperture suitably positioned in a layer to create a transparent region. In an alternative embodiment,
30 the entire support layer may be made of a material that is or may be made transparent to energy in the range of wavelength(s) of interest utilized by an endpoint detection

apparatus. Preferred transparent materials for a transparent element, layer or region include, for example, transparent polyurethanes.

Furthermore, as used above, the term "transparent" is intended to include an element, layer, and or region that is substantially transparent to energy in the range of wavelength(s) of interest utilized by an endpoint detection apparatus. In certain exemplary
5 embodiments, the endpoint detection apparatus uses one or more source of electromagnetic energy to emit radiation in the form of ultraviolet light, visible light, infrared light, microwaves, radio waves, combinations thereof, and the like. In certain
10 embodiments, the term "transparent" means that at least about 25% (e.g., at least about 35%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, at
15 least about 90%, at least about 95%) of energy at a wavelength of interest that impinges upon the transparent element, layer or region is transmitted therethrough.

In some exemplary embodiments, the support layer is transparent. In certain exemplary embodiments, at least one polishing element is transparent. In additional
15 exemplary embodiments, at least one polishing element is transparent, and the adhesive layer and the support layer are also transparent. In further exemplary embodiments, the support layer, the guide plate, the polishing composition distribution layer, at least one
20 polishing element, or a combination thereof is transparent.

The present disclosure is further directed to a method of using a polishing pad as described above in a polishing process, the method including contacting a surface of a
20 substrate with a polishing surface of a polishing pad comprising a plurality of polishing elements, at least some of which are porous, and relatively moving the polishing pad with respect to the substrate to abrade the surface of the substrate. In certain exemplary
25 embodiments, a working liquid may be provided to an interface between the polishing pad surface and the substrate surface. Suitable working liquids are known in the art, and may be found, for example, in U.S. Patent Nos. 6,238,592 B1; 6,491,843 B1; and
WO/200233736.

The polishing pads described herein may, in some embodiments, be relatively easy and inexpensive to manufacture. A brief discussion of some exemplary methods for
30 making polishing pads according to the present disclosure is described below, which discussion is not intended to be exhaustive or otherwise limiting. Thus, in further exemplary embodiments, a method of making a polishing pad is provided, the method

comprising forming a plurality of polishing elements, and bonding the polishing elements to a support layer to form a polishing pad. Bonding of the polishing elements to the support layer may, in some embodiments, comprise thermal bonding, or use of a bonding material to effect adhesive bonding, actinic radiation bonding, or combinations thereof.

5 In certain embodiments, the polishing elements are thermally bonded to the support layer. Thermal bonding may be achieved, for example, by contacting a major surface of the support layer with a surface of each polishing element to form a bonding interface, and heating the polishing elements and the support layer to a temperature at which the polishing elements and support layer soften, melt, or flow together to form a
10 bond at the bonding interface. Ultrasonic welding may also be used to effect thermal bonding of the polishing elements to the support layer. In some presently preferred embodiments, pressure is applied to the bonding interface while heating the polishing elements and the support layer. In further presently preferred embodiments, the support layer is heated to a temperature greater than the temperature to which the polishing
15 elements are heated.

 In other exemplary embodiments, bonding the polishing elements to the support layer involves using a bonding material that forms a physical and/or chemical union at an interface between the polishing elements and a major surface of the support layer. Such a physical and/or chemical union may, in certain embodiments, be formed using an adhesive
20 positioned at the bonding interface between each polishing element and the major surface of the support layer. In other embodiments, the bonding material may be a material that forms a bond by curing, for example, by thermally curing, radiation curing (e.g., curing using actinic radiation such as ultraviolet light, visible light, infrared light, electron beams or other radiation sources), and the like.

25 In certain embodiments, at least some of the polishing elements are substantially non-porous polishing elements. In certain presently preferred embodiments, at least a portion of the polishing elements may be porous polishing elements. Thus, in certain exemplary embodiments, the method includes forming the porous polishing elements by injection molding of a gas saturated polymer melt, injection molding of a reactive mixture
30 that evolves a gas upon reaction to form a polymer, injection molding of a mixture comprising a polymer dissolved in a supercritical gas, injection molding of a mixture of

incompatible polymers in a solvent, injection molding of porous thermoset particulates dispersed in a thermoplastic polymer, and combinations thereof.

In some exemplary embodiments, the porous polishing elements have pores distributed substantially throughout the entire polishing element. In other embodiments, the pores may be distributed substantially at the polishing surface of the porous polishing elements. In some additional embodiments, the porosity imparted to the polishing surface of a porous polishing element may be imparted, for example, by injection molding, calendaring, mechanical drilling, laser drilling, needle punching, gas dispersion foaming, chemical processing, and combinations thereof.

It will be understood that the polishing pad need not comprise only substantially identical polishing elements. Thus, for example, any combination or arrangement of porous polishing elements and non-porous polishing elements may make up the plurality of porous polishing elements. It will also be understood that any number, combination or arrangement of porous polishing elements and substantially nonporous polishing elements may be used advantageously in certain embodiments to form a polishing pad having floating polishing elements bonded to a support layer.

In further exemplary embodiments, the polishing elements may be arranged to form a pattern. Any pattern may be advantageously employed. For example, the polishing elements may be arranged to form a two-dimensional array, for example, a rectangular, triangular, or circular array of polishing elements. In additional exemplary embodiments, the polishing elements may include both porous polishing elements and substantially nonporous polishing elements arranged in a pattern on the support layer. In certain exemplary embodiments, the porous polishing elements may be advantageously arranged with respect to any substantially nonporous polishing elements to form an arrangement of porous polishing elements and nonporous polishing elements on the major surface of the support layer. In such embodiments, the number and arrangement of porous polishing elements relative to substantially nonporous polishing elements may be selected advantageously to obtain desirable polishing performance.

For example, in some exemplary embodiments, the porous polishing elements may be arranged substantially near the center of a major surface of the polishing pad, and substantially nonporous polishing elements may be arranged substantially near the peripheral edge of the major surface of the polishing pad. Such exemplary embodiments

may desirably more effectively retain a working liquid, for example an abrasive polishing slurry, in the contact zone between the polishing pad and the wafer surface, thereby improving wafer surface polishing uniformity (e.g., reduced dishing at the wafer surface) as well as reducing the quantity of waste slurry generated by the CMP process. Such
5 exemplary embodiments may also desirably provide more aggressive polishing at the edges of the die, thereby reducing or eliminating the formation of an edge ridge, and improving yield and die polish uniformity.

In other exemplary embodiments, the porous polishing elements may be arranged substantially near the edge of a major surface of the polishing pad, and substantially
10 nonporous polishing elements may be arranged substantially near the center of the major surface of the polishing pad. Other arrangements and/or patterns of polishing elements are contemplated as falling within the scope of the present disclosure.

In certain embodiments, the polishing elements may be arranged in a pattern by placement on a major surface of the support layer. In other exemplary embodiments, the
15 polishing elements may be arranged in a pattern using a template of the desired pattern, and the support layer may be positioned over or under the polishing elements and the template prior to bonding, with a major surface of the support layer contacting each polishing element at a bonding interface.

Exemplary embodiments of polishing pads having polishing elements according to
20 the present disclosure may have various features and characteristics that enable their use in a variety of polishing applications. In some presently preferred embodiments, polishing pads of the present disclosure may be particularly well suited for chemical mechanical planarization (CMP) of wafers used in manufacturing integrated circuits and semiconductor devices. In certain exemplary embodiments, the polishing pad described in
25 this disclosure may provide advantages over polishing pads that are known in the art.

For example, in some exemplary embodiments, a polishing pad according to the present disclosure may act to better retain a working liquid used in the CMP process at the interface between the polishing surface of the pad and the substrate surface being polished, thereby improving the effectiveness of the working liquid in augmenting polishing. In
30 other exemplary embodiments, a polishing pad according to the present disclosure may reduce or eliminate dishing and/or edge erosion of the wafer surface during polishing. In some exemplary embodiments, use of a polishing pad according to the present disclosure

in a CMP process may result in improved within wafer polishing uniformity, a flatter polished wafer surface, an increase in edge die yield from the wafer, and improved CMP process operating latitude and consistency.

5 In further exemplary embodiments, use of a polishing pad with porous elements according to the present disclosure may permit processing of larger diameter wafers while maintaining the required degree of surface uniformity to obtain high chip yield, processing of more wafers before conditioning of the pad surface is required in order to maintain polishing uniformity of the wafer surface, or reducing process time and wear on the pad conditioner.

10 Exemplary polishing pads according to the present disclosure will now be illustrated with reference to the following non-limiting examples.

EXAMPLES

15 The following non-limiting examples illustrate various methods for preparing both porous and non-porous polishing elements which may be used to prepare polishing pads comprising a plurality of polishing elements bonded to a support layer.

Example 1

20 This example illustrates the preparation of both nonporous polishing elements (Example 1A) and porous polishing elements (Example 1B) in which pores are distributed substantially throughout the entire polishing element. The porous polishing elements were prepared by injection molding of a mixture comprising a polymer dissolved in a supercritical gas.

25 A thermoplastic polyurethane (ESTANE ETE 60DT3 NAT 022P, Lubrizol Advanced Materials, Inc., Cleveland, OH) having a melt index of 5 at 210°C and 3800 g of force was selected. Pellets of the thermoplastic polyurethane were fed into an 80 ton MT Arburg injection molding press (Arburg GmbH, Lossburg, Germany) equipped with a 30 mm diameter single screw (L/D = 24:1) at elevated temperature and pressure to produce a polymer melt.

30 In Example 1A, the polymer melt was injection molded into a 32-cavity, cold runner mold (solid shot weight of 9.2 grams) to form substantially nonporous polishing elements having a hollow internal cylindrical cavity and weighing 0.15 grams/element.

In Example 1B, nitrogen gas was injected under elevated temperature and pressure into the polymer melt using a Trexel SII-TR10 outfitted with a Mass Pulse Dosing delivery system (available from Trexel, Inc., Woburn, MA), resulting in formation of a 0.6% w/w blend of supercritical nitrogen in the polymer melt. The supercritical nitrogen and polymer melt blend was injection molded into the 32-cavity, cold runner mold (solid shot weight of 9.2 grams) to form porous polishing elements having a hollow internal cylindrical cavity and weighing 0.135 g, and in which pores are distributed substantially throughout the entire polishing element.

The temperatures for each zone of the extruder, mold temperature, screw, injection, pack pressures, molding times and clamp tonnages are summarized in Table 1 for comparative Example 1A and 1B.

Table 1

Extrusion Parameter	Example 1A (Nonporous)	Example 1B (Porous)
Zone 1 Temperature (Feed) (°C)	182.2	182.2
Zone 2 Temperature (°C)	187.8	187.8
Zone 3 Temperature (°C)	204.4	204.4
Zone 4 Temperature (°C)	215.6	215.6
Zone 6 Temperature (Nozzle) (°C)	215.6	215.6
Zone 7 Temperature (Nozzle) (°C)	215.6	215.6
Screw Speed (% of maximum)	2	2.5
Mold Temperature (°C)	32.2	100
Screw Pressure (kg/cm ²)	105.5	175.8
Nitrogen Concentration (%)	0	0.6
Nitrogen Injection Time (seconds)	0	1.5
Injection Time (seconds)	0.29	0.2
Peak Injection Pressure (kg/cm ²)	1863.1	1687.4
Pack Time (seconds)	2.5	1
Pack Pressure (kg/cm ²)	703.1	246.1
Cool Time (seconds)	12	14
Clamp Tonnage (kg)	79832.3	36287.4

Example 2

This example illustrates the preparation of a porous polishing element in which pores are distributed substantially only at the polishing surface of the element.

Nonporous polishing elements were first prepared by injection molding a thermoplastic polyurethane (ESTANE ETE 60DT3 NAT 022P, Lubrizol Advanced Materials, Inc., Cleveland, OH) having a melt index of 5 at 210°C and 3800 g of force to form generally cylindrical polishing elements measuring about 15 mm in diameter, as described generally above in Example 1A.

The polishing surface of an injection molded polishing element was then laser drilled to form a porous polishing element using an AVIA 355 nm ultraviolet laser (Coherent, Inc., Santa Clara, CA) operating with a nanosecond pulse rate, repetition rate of 15kHz, power setting of 60-80% (0.8 – 1.1 watts) and a scan rate between 100 mm/sec to 300 mm/sec (run time total of 29.8 seconds and 13.2 seconds).

Example 3

This example illustrates the preparation of both nonporous polishing elements (Example 3A) and porous polishing elements (Example 3B) in which pores are distributed substantially only at the polishing surface of the element in the form of a plurality of channels formed on the polishing surface.

Porous polishing elements were prepared by injection molding a thermoplastic polyurethane (ESTANE ETE 60DT3 NAT 022P, available from Lubrizol Advanced Materials, Inc., Cleveland, OH) having a melt index of 5 at 210°C and 3800 g of force. Pellets of the thermoplastic polyurethane were fed into an Engel 100 ton injection molding press (Engel Machinery, Inc., York, PA) equipped with a 25 mm diameter single screw (L/D = 24.6:1) at elevated temperature and pressure to produce a polymer melt.

The thermoplastic polyurethane melt was injection molded into a 2-cavity, cold runner mold (shot weight of 34.01 grams) equipped with a ribbed mold insert in one cavity and a blank mold insert in the other cavity. The injection molding conditions are summarized in Table 2.

Table 2

Extrusion Parameter	Value
Zone 1 Temperature (Feed) (°C)	49
Zone 2 Temperature (°C)	193.3
Zone 3 Temperature (°C)	204.4
Zone 4 Temperature (°C)	204.4
Screw Speed (rpm)	300
Mold Temperature (°C)	12.8
Injection Time (seconds)	1.25
Peak Injection Pressure (kg/cm ²)	2109.2
Pack Time (seconds)	9
Pack Pressure (kg/cm ²)	421.8
Cool Time (seconds)	50
Clamp Tonnage (kg)	36287.4

Figure 5 illustrates one exemplary apparatus useful in the method for thermal bonding of polishing elements to a support layer. A multiplicity of nonporous polishing elements 4' may be arranged in a two-dimensional array pattern in template 30 (see FIG. 3A) positioned on release layer 34. Support layer 10 may be laid over the exposed surfaces of the polishing elements 4'. Release layer 34' may be placed over the exposed surface of the support layer 10, and the entire assembly may be placed between the upper platen 36 and lower platen 38 of a heated press.

It will be understood that the relative order and arrangement of elements in the exemplary apparatus may be varied without deviating from the scope of the disclosure. Thus, for example, the support layer 10 may be placed on release layer 34 and overlaid with the template 30 before arranging the nonporous polishing elements 4 in a two-dimensional array pattern in the template, and overlaying the arranged elements with release layer 34'. Furthermore, porous polishing elements 4 may be substituted for nonporous polishing elements 4' in any number, arrangement or combination.

Example 4

Example 4 illustrates a method of thermally bonding injection molded thermoplastic polyurethane polishing elements prepared according to Example 1 to a support layer film comprising a thermoplastic polyurethane.

Polishing elements (15 mm diameter) were formed by injection molding a thermoplastic polyurethane (TPU), ESTANE 58144 (available from Lubrizol Advanced Materials, Inc., Cleveland, OH) according to Example 1. The polishing elements were arranged in a generally circular two-dimensional array pattern using a polycarbonate
5 template as shown in FIG. 6, and bonded to a 26 μ m thick support layer formed by extrusion of a thermoplastic polyurethane (TPU), ESTANE 58887-NAT02 (available from Lubrizol Advanced Materials, Inc., Cleveland, OH) into film form at 182°C.

Thermal bonding was carried out in a heated platen press (Pasadena Hydraulics Press Company, El Monte, CA) substantially as shown in FIG. 5. The upper platen was
10 maintained at approximately 143.3°C, and the lower platen was maintained at approximately 26.7°C. Sufficient pressure was applied to make contact between the TPU polishing elements and the TPU support layer, which were positioned between paper release liners as shown in FIG. 5. Bonding was substantially complete and uniform after 30 seconds. After thermally bonding the TPU support layer to the TPU polishing
15 elements, the paper liners were removed to yield a clear integral sheet of TPU support layer with thermally bonded TPU polishing elements, as shown in FIG. 7.

Example 5

Example 5 illustrates the method of thermally bonding injection molded
20 thermoplastic polyurethane polishing elements prepared according to Example 1 to a support layer film comprising a different thermoplastic polyurethane.

Polishing elements (6 mm diameter) were formed by injection molding a TPU (ESTANE 58212 (available from Lubrizol Advanced Materials, Inc., Cleveland, OH) according to Example 1. The polishing elements were arranged in a generally circular
25 two-dimensional array pattern using a polycarbonate template (FIG. 6), and thermally bonded to a 122 μ m thick TPU film support layer (Stevens Urethane ST-1522CL, Easthampton, MA).

Thermal bonding was carried out in a heated platen press (HIX N-800 single platen press, Pittsburgh, KS) substantially as shown in FIG. 5. The upper platen was maintained
30 at approximately 149°C, and the lower platen was maintained at approximately 26.7°C. A pressure of 40 psi (about 275,790 Pa) was applied to the TPU polishing elements and the TPU support layer, which were positioned between paper release liners as shown in

FIG. 5. Bonding was substantially complete and uniform after 15 seconds. After thermally bonding the TPU support layer to the TPU polishing elements, the paper liners were removed to yield a clear integral sheet of TPU support layer with thermally bonded TPU polishing elements.

5

Example 6

Example 6 illustrates an alternate method of thermally bonding injection molded thermoplastic polyurethane polishing elements prepared according to Example 1 to a support layer film comprising polyester.

10

Polishing elements (15 mm diameter) were formed by injection molding a TPU (ESTANE 58144, available from Lubrizol Advanced Materials, Inc., Cleveland, OH) according to Example 1. The polishing elements were arranged directly on a major surface of the support layer, a 102 μm thick polyester film (3M Thermo-Bond 615 Film, 3M Company, St. Paul, MN), and thermally bonded to the support layer.

15

Thermal bonding was carried out in a heated platen press (Pasadena Hydraulics Press, El Monte, CA). The upper platen was maintained at approximately 121°C, and the lower platen was maintained at approximately 26.7°C. Sufficient pressure was applied to make contact between the TPU polishing elements and the support layer, which were positioned between paper release liners. Bonding was substantially complete and uniform after 20 seconds. After thermally bonding the support layer to the TPU polishing elements, the paper liners were removed to yield a clear integral sheet of support layer with thermally bonded TPU polishing elements.

20

Example 7

25

Example 7 illustrates the method of thermally bonding injection molded thermoplastic polyurethane polishing elements prepared according to Example 1 to a support layer comprising a different polyester film.

30

Polishing elements (15 mm diameter) were formed by injection molding a TPU (ESTANE 58144, available from Lubrizol Advanced Materials, Inc., Cleveland, OH) according to Example 1. The polishing elements were arranged directly on a major surface the support layer, a 102 μm thick polyester film (3M Thermo-Bond 668 Film, 3M Company, St. Paul, MN), and thermally bonded to the support layer.

Thermal bonding was carried out in a heated platen press (HIX N-800 single platen press, Pittsburgh, KS). The upper platen was maintained at approximately 149°C, and the lower platen was maintained at approximately 26.7°C. A pressure of 40 psi (about 275,790 Pa) was applied to the TPU polishing elements and the support layer, which were positioned between paper release liners. Bonding was substantially complete and uniform after 15 seconds.

Example 8

Example 8 illustrates a method of thermally bonding an integral film comprising polishing elements bonded to a support layer to a compliant layer to form a polishing pad having floating elements.

After thermally bonding the TPU support layer to the TPU polishing elements as described in Example 4, the major surface of the support layer opposite the polishing elements was affixed to a 1.59 mm thick polyurethane foam compliant layer (Rogers PORON urethane foam, Part#4701-50-20062-04, obtained from American Flexible, Chaska, MN) by hand lamination to a 127 µm thick adhesive layer (3M 9672 Transfer Adhesive, 3M Company, St. Paul, MN). The polishing pad was completed by hand laminating a pressure sensitive adhesive (3M 442DL Transfer Tape, 3M Company, St. Paul, MN) to the polyurethane foam compliant layer on a surface opposite the polishing elements.

FIG. 8 is a photograph of a polishing pad comprising floating polishing elements bonded to a support layer, wherein the support layer is affixed to a compliant sub-layer with an adhesive, and wherein a pressure sensitive adhesive is adhered to the compliant sub-layer on a major surface opposite the polishing elements, according to yet another exemplary embodiment of the disclosure.

Example 9

The polishing pad of Example 8 was mounted to an aluminum polishing platen using the Transfer Tape pressure sensitive adhesive on the bottom surface of the compliant foam sub-layer. The polishing platen with polishing pad was then mounted in a CETR Polisher (CP-4, Center for Tribology, Inc, Campbell, CA), placed into contact with a diamond pad dresser (3M Sintered Abrasive Conditioner A3800) and stressed under various conditions (see Table 1) in deionized water for 5 minutes.

After each test condition, the pad was inspected for element debonding and none was detected. To determine if the pad could withstand continual conditioning or wear, the pad was ran until the tops were wore off at 8 lbf (about 3,632 gr), 60 rpm table and platen speed and 10 mm oscillation (4 cycles/min). Throughout the test, the pad was periodically checked for polishing element de-bonding, and none was detected. The test conditions are summarized in Table 3.

Table 3

CONDITION	Applied Force (lbf)	Table/Platen Speed (RPM)	Water Flowrate (ml/min)
1	2	60/60	25
2	4	60/60	50
3	6	60/60	50
4	8	60/60	50
5	8	100/100	50
6	10	60/60	50

Using the teachings provided in the Detailed Description and Examples hereinabove, individual porous and optionally, nonporous polishing elements may be affixed to a support layer to provide polishing pads according to various additional embodiments of the present invention. It will be understood that polishing pads according to exemplary embodiments the present invention need not comprise only substantially identical polishing elements. Thus, for example, any combination or arrangement of porous polishing elements and non-porous polishing elements may make up the plurality of porous polishing elements. It will also be understood that any number, combination or arrangement of porous polishing elements and substantially nonporous polishing elements may be used advantageously in certain embodiments to form a polishing pad having floating polishing elements bonded to a support layer.

In one particularly advantageous embodiment illustrating a unitary polishing pad, a multi-cavity mold may be provided with a back-fill chamber, wherein each cavity corresponds to a polishing element. A plurality of polishing elements, which may include porous polishing elements and nonporous polishing element as described herein, may be formed by injection molding a suitable polymer melt into the multi-cavity mold, and back-filling the back-fill chamber with the same polymer melt or another polymer melt to form a support layer. The polishing elements remain affixed to the support layer upon

cooling of the mold, thereby forming a plurality of polishing elements as a unitary sheet of polishing elements with the support layer.

Reference throughout this specification to “one embodiment”, “certain embodiments”, “one or more embodiments” or “an embodiment”, whether or not
5 including the term “exemplary” preceding the term “embodiment”, means that a particular feature, structure, material, or characteristic described in connection with the embodiment is included in at least one embodiment of the certain exemplary embodiments of the present invention. Thus, the appearances of the phrases such as “in one or more
10 embodiments”, “in certain embodiments”, “in one embodiment” or “in an embodiment” in various places throughout this specification are not necessarily referring to the same embodiment of the certain exemplary embodiments of the present invention. Furthermore, the particular features, structures, materials, or characteristics may be combined in any suitable manner in one or more embodiments.

While the specification has described in detail certain exemplary embodiments, it
15 will be appreciated that those skilled in the art, upon attaining an understanding of the foregoing, may readily conceive of alterations to, variations of, and equivalents to these embodiments. Accordingly, it should be understood that this disclosure is not to be unduly limited to the illustrative embodiments set forth hereinabove. In particular, as used
20 herein, the recitation of numerical ranges by endpoints is intended to include all numbers subsumed within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5). In addition, all numbers used herein are assumed to be modified by the term ‘about’.

Furthermore, all publications and patents referenced herein are incorporated by reference in their entirety to the same extent as if each individual publication or patent was specifically and individually indicated to be incorporated by reference.

25 Various exemplary embodiments have been described. These and other embodiments are within the scope of the following claims.

CLAIMS:

1. A polishing pad comprising a plurality of thermally bonded polishing elements, each of the polishing elements thermally bonded without an adhesive to a major side of a support layer wherein lateral movement of the polishing elements with respect to one or more of the other polishing elements is restricted, but the polishing elements remain moveable in an axis normal to a polishing surface of the polishing elements, and wherein the polishing pad further comprises a support layer having a first major side and a second major side opposite the first major side, wherein each polishing element has an exposed polishing surface, and wherein the polishing elements extend from the first major side of the support layer along a first direction normal to the first major side.
2. The polishing pad according to claim 1, further comprising a polishing composition distribution layer covering a portion or entirety of the major side of the support layer.
3. The polishing pad according to claim 1, further comprising a compliant layer affixed to the support layer on a side opposite the major side of the support layer and the polishing elements.
4. The polishing pad according to claim 1, wherein each polishing element extends along the first direction 0.25 mm or greater above a plane including the support layer.
5. The polishing pad according to claim 1, wherein one or more of the polishing elements comprises a porous polishing element, wherein each porous polishing element comprises a plurality of pores.
6. The polishing pad according to claim 1, wherein some or all of the polishing elements are selected to have a cross-section, taken in the first direction, selected from circular, elliptical, triangular, square, rectangular, and trapezoidal.

7. The polishing pad according to claim 1, wherein the plurality of polishing elements are formed as a unitary sheet of polishing elements with the support layer.
8. The polishing pad according to claim 1, wherein a portion or entirety of the polishing elements comprise a thermoplastic polyurethane, a polyacrylate, polyvinyl alcohol, or combinations thereof.
9. The polishing pad according to claim 1, wherein the polishing elements have one or more dimension from 0.1 mm to 30 mm.
10. The polishing pad according to claim 1, wherein the support layer comprises a thermoplastic polyurethane.
11. The polishing pad according to claim 1, wherein a portion or entirety of the polishing elements comprise abrasive particulates.
12. The polishing pad according to claim 1, wherein the polishing elements are arranged in a two-dimensional array pattern on the major side of the support layer.
13. The polishing pad according to claim 1, wherein one or more polishing element is transparent.
14. The polishing pad according to claim 1, wherein the support layer is transparent.
15. A method of using a polishing pad comprising:
 - contacting a surface of a substrate with a polishing surface of a polishing pad according to claim 1;
 - relatively moving the polishing pad with respect to the substrate to abrade the surface of the substrate.

16. A method of making a polishing pad, comprising:
forming a plurality of polishing elements; and
thermally bonding the polishing elements to a support layer to form a
polishing pad according to claim 1.
17. The method according to claim 16, further comprising arranging the plurality
of polishing elements in a pattern before thermally bonding the polishing elements to
the support layer.