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(54) **Title:**
**POLISHING PAD**

(57) **Abstract:**
14 POLISHING PAD ABSTRACT The invention provides a polishing pad comprising a polishing layer having a polishing surface comprising plurality of grooves disposed into the polishing layer a measurable depth from the polishing surface, and a barrier region free of grooves, and a transparent window disposed in and surrounded by the barrier region. Figure 1

# POLISHING PAD

## ABSTRACT

The invention provides a polishing pad comprising a polishing layer having a polishing surface comprising plurality of grooves disposed into the polishing layer a measurable depth from the polishing surface, and a barrier region free of grooves, and a transparent window disposed in and surrounded by the barrier region.

Figure 1

POLISHING PAD

## BACKGROUND OF THE INVENTION

[0001] Chemical-mechanical polishing ("CMP") processes are used in the manufacturing of microelectronic devices to form flat surfaces on semiconductor wafers, field emission displays, and many other microelectronic substrates. For example, the manufacture of semiconductor devices generally involves the formation of various process layers, selective removal or patterning of portions of those layers, and deposition of yet additional process layers above the surface of a semiconducting substrate to form a semiconductor wafer. The process layers can include, by way of example, insulation layers, gate oxide layers, conductive layers, layers of metal or glass, etc. It is generally desirable in certain steps of the wafer process that the uppermost surface of the process layers be planar, i.e., flat, for the deposition of subsequent layers. CMP is used to planarize process layers wherein a deposited material, such as a conductive or insulating material, is polished to planarize the wafer for subsequent process steps.

[0002] In a typical CMP process, a wafer is mounted upside down on a carrier in a CMP tool. A force pushes the carrier and the wafer downward toward a polishing pad. The carrier and the wafer are rotated above the rotating polishing pad on the CMP tool's polishing table. A polishing composition (also referred to as a polishing slurry) generally is introduced between the rotating wafer and the rotating polishing pad during the polishing process. The polishing composition typically contains a chemical that interacts with or dissolves portions of the uppermost wafer layer(s) and an abrasive material that physically removes portions of the layer(s). The wafer and the polishing pad can be rotated in the same direction or in opposite directions, whichever is desirable for the particular polishing process being carried out. The carrier also can oscillate across the polishing pad on the polishing table.

[0003] In polishing the surface of a wafer, it is often advantageous to monitor the polishing process *in situ*. One method of monitoring the polishing process *in situ* involves the use of a polishing pad having an aperture or window. The aperture or window provides a portal through which light can pass to allow the inspection of the wafer surface during the polishing process. Polishing pads having apertures and windows are known and have been used to polish substrates, such as the surface of semiconductor devices. For example, U.S.

Patent 5,605,760 provides a pad having a transparent window formed from a solid, uniform polymer, which has no intrinsic ability to absorb or transport slurry. U.S. Patent 5,433,651 discloses a polishing pad wherein a portion of the pad has been removed to provide an aperture through which light can pass. U.S. Patents 5,893,796 and 5,964,643 disclose removing a portion of a polishing pad to provide an aperture and placing a transparent polyurethane or quartz plug in the aperture to provide a transparent window, or removing a portion of the backing of a polishing pad to provide a translucency in the pad. U.S. Patents 6,171,181 and 6,387,312 disclose a polishing pad having a transparent region that is formed by solidifying a flowable material (e.g., polyurethane) at a rapid rate of cooling.

[0004] A problem often encountered during chemical-mechanical polishing is the tendency for the polishing composition and the resulting polishing debris to accumulate at the polishing pad window. The accumulated polishing composition and polishing debris can obstruct transmission of light through the window thereby reducing the sensitivity of the optical endpoint detection method.

[0005] Although several of the above-described polishing pads are suitable for their intended purpose, a need remains for other polishing pads that provide effective planarization coupled with effective optical endpoint detection, particularly in the chemical-mechanical polishing of a substrate. In addition, there is a need for polishing pads having satisfactory features such as polishing efficiency, slurry flow across and within the polishing pad, resistance to corrosive etchants, and/or polishing uniformity. Finally, there is a need for polishing pads that can be produced using relatively low cost methods and which require little or no conditioning prior to use.

## BRIEF SUMMARY OF THE INVENTION

[0006] The invention provides a polishing pad comprising (a) a polishing layer having a polishing surface comprising (1) a plurality of grooves disposed into the polishing layer a measurable depth from the polishing surface, and (2) a barrier region free of grooves, and (b) a transparent window disposed in and surrounded by the barrier region. The invention further provides a method of polishing a substrate comprising (i) providing a workpiece to be polished, (ii) contacting the workpiece with the polishing pad of the invention, and (iii) abrading at least a portion of the surface of the workpiece with the polishing system to polish the workpiece.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

**[0007]** Figure 1 is a schematic top view illustrating a polishing pad of the invention having a polishing layer (10) comprising a polishing surface (12) with continuous grooves (40) and discontinuous grooves (50) and a substantially transparent window (15) disposed in a barrier region (20) substantially free of grooves.

**[0008]** Figure 2 is a fragmentary, partially cross-sectional perspective view depicting a polishing pad of the invention having a polishing layer (10) comprising a polishing surface (12) with continuous grooves (40) and discontinuous grooves (50) disposed into the polishing layer (10) a measurable depth from the polishing surface and a substantially transparent window (15) disposed in a barrier region (20) substantially free of grooves.

**[0009]** Figure 3 is a fragmentary, partially cross-sectional perspective view depicting a polishing pad of the invention having a polishing layer (10) comprising a polishing surface (12) with continuous grooves (40) and discontinuous grooves (50) disposed into the polishing layer a measurable depth from the polishing surface and a substantially transparent window (15) disposed in a barrier region (20) free of grooves, wherein the depth of the discontinuous grooves transition from a maximum value to zero proximate to the barrier region (20).

**[0010]** Figure 4 is a fragmentary, partially cross-sectional perspective view depicting a polishing pad of the invention having a polishing layer (10) and a sub-layer (30), wherein the sub-layer has an aperture (35) substantially aligned with the transparent window (15).

## DETAILED DESCRIPTION OF THE INVENTION

**[0011]** The invention is directed to a chemical-mechanical polishing pad comprising a polishing layer and a transparent window. The polishing layer has a polishing surface comprising (a) a plurality of grooves disposed into the polishing layer and (b) a barrier region free of grooves. The transparent window is disposed in and surrounded by the barrier region. While not wishing to be bound to any particular theory, it is believed that the presence of a barrier region substantially free of grooves surrounding the transparent window will reduce the amount of polishing composition that remains on or within the transparent window.

[0012] The polishing pad can have any suitable dimensions. Typically, the polishing pad will be circular in shape (as is used in rotary polishing tools) or will be produced as a looped linear belt (as is used in linear polishing tools). Preferably, the polishing pad is circular.

[0013] Figure 1 depicts a circular polishing pad of the invention comprising a polishing layer (10) comprising a polishing surface (12), continuous grooves (40) and discontinuous grooves (50), and a transparent window (15) disposed in a barrier region (20) substantially free of grooves.

[0014] The grooves disposed in the polishing layer facilitate the lateral transport of polishing compositions across the surface of the polishing pad. The grooves can be in any suitable pattern. For example, grooves can be in the form of slanted grooves, circular grooves, concentric grooves, spiral grooves, radial grooves, or XY crosshatch pattern. The polishing pad can have two or more different groove patterns. For example, the polishing pad can have a combination of concentric grooves and radial grooves or a combination of concentric grooves and XY crosshatch grooves. Preferably, the grooves are concentric.

[0015] The grooves can be continuous in connectivity across the surface of the polishing pad. Alternatively, the grooves can be discontinuous across the surface of the pad wherein each discontinuous groove has a first end and a second end. In one embodiment, as depicted in Figure 1, a portion of the grooves, i.e., one or more grooves, are continuous (40), and a portion of the grooves, i.e., one or more grooves, are discontinuous (50).

[0016] As depicted in Figure 2, each groove has a measurable depth from the polishing surface. The depth can be any suitable depth. For example, the depth can be 1 mm or less, 0.8 mm or less, 0.6 mm or less, 0.5 mm or less, 0.4 mm or less, 0.3 mm or less, 0.2 mm or less, or 0.1 mm or less. The depth of each continuous and/or discontinuous groove can be constant or can vary along the length or the circumference of the grooves. In one embodiment, as shown in Figure 3, the depth of a discontinuous groove (50) transitions from a maximum depth to zero, i.e., the groove tapers to the polishing surface (12) at at least one end of the discontinuous groove. Preferably, the depth transition occurs gradually, i.e., over a length of about 0.5 mm or more, 1 mm or more, about 2 mm or more, about 3 mm or more, about 4 mm or more, or about 5 mm or more. In one embodiment, the depth transition from a maximum depth to zero occurs proximate to the barrier region.

[0017] The polishing pad further comprises a barrier region which is substantially free of grooves or desirably merely free of grooves. In one embodiment, as shown in Figure 1, the barrier region (20) is disposed between the first and second ends of concentric, discontinuous grooves (50).

[0018] The barrier region can have any suitable dimensions and any suitable shape. The perimeter of the barrier region, defined by adjacent continuous and/or discontinuous grooves, can be any suitable shape (e.g., round, oval, square, rectangular, triangular, and so on). When the barrier region is oval or rectangular in shape, the barrier region typically has a long diameter axis or length of about 2 cm or more (e.g., about 3 cm or more, about 4 cm or more about 5 cm or more, about 6 cm or more, about 7 cm or more, about 8 cm or more, about 9 cm or more, about 10 cm or more, about 11 cm or more, or about 12 cm or more) and a short diameter axis or width of about 1 cm or more (e.g., about 2 cm or more, about 3 cm or more, about 4 cm or more, about 5 cm or more, about 6 cm or more, about 7 cm or more, or about 8 cm or more). When the barrier region is circular or square in shape, the perimeter of the barrier region typically has a diameter or width of about 2 cm or more (e.g., about 3 cm or more, about 4 cm or more, about 5 cm or more, about 6 cm or more, about 7 cm or more, about 8 cm or more, about 9 cm or more, or about 10 cm or more)]

[0019] As depicted in Figure 1, the transparent window (15) is disposed in and surrounded by the barrier region (20). The transparent window can be disposed symmetrically or asymmetrically in the barrier region.

[0020] The transparent window will have a perimeter that defines the transparent window in the barrier region. Each point on the perimeter of the transparent window will have a shortest distance L to a continuous and/or discontinuous groove, thereby providing a series of shortest distances or spacings from the perimeter of the transparent window to the grooves (i.e., $L_1$, $L_2$, $L_3$, ...). The smallest value ($L_{min}$) and the largest value ($L_{max}$)of the series of shortest distances can be any suitable length. For example, $L_{min}$ can be about 0.5 cm or more (e.g., about 1 cm or more, about 1.5 cm or more, about 2 cm or more, about 3 cm or more, or about 4 cm or more). In addition, or alternatively, $L_{min}$ can be 10 cm or less (e.g., about 8 cm or less, about 7 cm or less, about 6 cm or less, about 5 cm or less, or about 4 cm or less). $L_{max}$ can be independently about 0.5 cm or more (e.g., about 1 cm or more, about 1.5 cm or more, about 2 cm or more, about 3 cm or more, or about 4 cm or more). In addition, or alternatively, the $L_{max}$ can be independently 10 cm or less (e.g., about 8 cm or less, about 7 cm or less, about 6 cm or less, about 5 cm or less, or about 4 cm or less). $L_{min}$ and $L_{max}$ can be the same or different with respect to, independently, continuous grooves and discontinuous grooves. Moreover, the series of shortest distances $L_1$, $L_2$, $L_3$, etc. need not be the same such that there is uniform spacing between the transparent window and the grooves.

[0021] The transparent window can have any suitable dimensions (e.g., length, width, diameter, and thickness) and any suitable shape (e.g., round, oval, square, rectangular, triangular, and so on). When the transparent window is oval or rectangular in shape, the transparent window typically has a long diameter axis or length of about 1 cm or more (e.g., about 2 cm or more, about 3 cm or more, about 4 cm or more, about 5 cm, about 6 cm or more, about 7 cm or more, or about 8 cm or more) and a short diameter axis or width of about 0.5 or more (e.g., about 1 cm or more, about 1.5 cm or more, about 2 cm or more, about 3 cm or more, or about 4 cm or more). When the transparent window is circular or square in shape, the transparent window typically has a diameter or width of about 1 cm or more, (e.g., about 2 cm or more, about 3 cm or more, about 4 cm or more, or about 5 cm or more).

[0022] The transparent window (15) comprises an optically transmissive material. The presence of the transparent window enables the polishing pad to be used in conjunction with an *in situ* CMP process monitoring technique. Typically, the optically transmissive material has a light transmission of at least about 10% or more (e.g., about 20% or more, about 30% or more, or about 40% or more) at one or more wavelengths of from about 190 nm to about 10,000 nm (e.g.; about 190 nm to about 3500 nm, about 200 nm to about 1000 nm, or about 200 nm to about 780 nm). The optically transmissive material can be any suitable material, many of which are known in the art. The optically transmissive material can be the same or different than the material in the remainder of the polishing pad. For example, the optically transmissive material can consist of a glass or polymer-based plug that is inserted in an aperture of the polishing pad or can comprise the same polymeric material used in the remainder of the polishing pad.

[0023] The transparent window can be affixed to the polishing pad by any suitable means. For example, the transparent window can be affixed to the polishing pad through the use of an adhesive. Desirably, the transparent window is affixed to the polishing layer without the use of an adhesive, for example by welding. Similarly, the transparent window can have any suitable structure (e.g., crystallinity), density, and porosity. For example, the transparent window can be solid or porous (e.g., microporous or nanoporous having an average pore size of less than 1 micron). Preferably, the transparent window is solid or is nearly solid (e.g., has a void volume of about 3% or less).

[0024] As depicted in Figure 2, the transparent window (15) can be flush with the polishing surface (12) of the polishing layer, i.e., the upper most window surface is substantially co-planar with the polishing surface. Alternatively, the transparent window can be recessed from the polishing surface of the polishing layer.

[0025] The polishing layer can be used alone or optionally as one layer of a multi-layer stacked polishing pad. For example, as shown in Figure 4, the polishing layer (10) comprising a polishing surface (12), a barrier region substantially free of grooves (20), continuous grooves (40) and discontinuous grooves (50), and a transparent window (15) can be used in combination with a sub-layer (30) that is substantially coextensive with the polishing layer. In some embodiments, the sub-layer (30) comprises an aperture (35) that is substantially aligned with the transparent window (15) of the polishing layer.

[0026] The polishing layer, the barrier region, the transparent window, and the sub-layer of the polishing pad can comprise any suitable material, which can be the same or different. Desirably, the polishing layer, the barrier region, the transparent window, and the sub-layer of the polishing pad each independently comprise a polymer resin. The polymer resin can be any suitable polymer resin. Typically, the polymer resin is selected from the group consisting of thermoplastic elastomers, thermoset polymers, polyurethanes (e.g., thermoplastic polyurethanes), polyolefins (e.g., thermoplastic polyolefins), polycarbonates, polyvinylalcohols, nylons, elastomeric rubbers, elastomeric polyethylenes, polytetrafluoroethylenes, polyethyleneterephthalates, polyimides, polyaramides, polyarylenes, polyacrylates, polystyrenes, polymethylmethacrylates, copolymers thereof, and mixtures thereof. Preferably, the polymer resin is polyurethane, more preferably thermoplastic polyurethane. The polishing layer, the barrier region, the transparent window, and the sub-layer can comprise a different polymer resin. For example, the polishing layer can comprise porous thermoset polyurethane, the sub-layer can comprise closed-cell porous polyurethane foam, and the transparent window can comprise solid thermoplastic polyurethane.

[0027] The polishing layer and the sub-layer typically will have different chemical (e.g., polymer composition) and/or physical properties (e.g., porosity, compressibility, transparency, and hardness). For example, the polishing layer and the sub-layer independently can be closed cell (e.g., a porous foam), open cell (e.g., a sintered material), or solid (e.g., cut from a solid polymer sheet). Preferably the polishing layer is less compressible than the sub-layer. The polishing layer and the sub-layer can be formed by any suitable method, many of which are known in the art. Suitable methods include casting, cutting, reaction injection molding, injection blow molding, compression molding, sintering, thermoforming, and pressing the porous polymer into the desired polishing pad shape. Other polishing pad elements also can be added to the porous polymer before, during, or after shaping the porous polymer, as desired. For example, backing materials can be applied, holes can be drilled, or surface textures can be provided (e.g., grooves, channels), by various methods generally known in the art.

[0028] The polishing layer optionally further comprise organic or inorganic particles. For example, the organic or inorganic particles can be selected from the group consisting of metal oxide particles (e.g., silica particles, alumina particles, ceria particles), diamond particles, glass fibers, carbon fibers, glass beads, aluminosilicates, phyllosilicates (e.g., mica particles), cross-linked polymer particles (e.g., polystyrene particles), water-soluble particles, water-absorbent particles, hollow particles, combinations thereof, and the like. The particles can have any suitable size. For example, the particles can have an average particle diameter of about 1 nm to about 10 microns (e.g., about 20 nm to about 5 microns). The amount of the particles in the body of the polishing pad can be any suitable amount, for example, from about 1 wt.% to about 95 wt.% based on the total weight of the polishing pad body.

[0029] The polishing pad of the invention is particularly suited for use in conjunction with a chemical-mechanical polishing (CMP) apparatus. Typically, the apparatus comprises a platen, which, when in use, is in motion and has a velocity that results from orbital, linear, or circular motion, a polishing pad of the invention in contact with the platen and moving with the platen when in motion, and a carrier that holds a workpiece to be polished by contacting and moving relative to the surface of the polishing pad. The polishing of the workpiece takes place by the workpiece being placed in contact with the polishing pad and then the polishing pad moving relative to the workpiece, typically with a polishing composition therebetween, so as to abrade at least a portion of the workpiece to polish the workpiece. The polishing composition can be any suitable polishing composition. A polishing composition typically comprises a liquid carrier (e.g., an aqueous carrier), a pH adjustor, and an abrasive. Depending on the type of workpiece being polished, the polishing composition optionally further comprises oxidizing agents, organic acids, complexing agents, pH buffers, surfactants, corrosion inhibitors, anti-foaming agents, and the like. The CMP apparatus can be any suitable CMP apparatus, many of which are known in the art. The polishing pad of the invention also can be used with linear polishing tools.

[0030] Desirably, the CMP apparatus further comprises an *in situ* polishing endpoint detection system, many of which are known in the art. Techniques for inspecting and monitoring the polishing process by analyzing light or other radiation reflected from a surface of the workpiece are known in the art. Such methods are described, for example, in U.S. Patent 5,196,353, U.S. Patent 5,433,651, U.S. Patent 5,609,511, U.S. Patent 5,643,046, U.S. Patent 5,658,183, U.S. Patent 5,730,642, U.S. Patent 5,838,447, U.S. Patent 5,872,633, U.S. Patent 5,893,796, U.S. Patent 5,949,927, and U.S. Patent 5,964,643. Desirably, the inspection or monitoring of the progress of the polishing process with respect to a workpiece being polished enables the determination of the polishing end-point, i.e., the determination of when to terminate the polishing process with respect to a particular workpiece.

[0031] The polishing pad of the invention is suitable for use in a method of polishing many types of workpieces (e.g., substrates or wafers) and workpiece materials. For example, the polishing pad can be used to polish workpieces including memory storage devices, glass substrates, memory or rigid disks, metals (e.g., noble metals), magnetic heads, inter-layer dielectric (ILD) layers, polymeric films, low and high dielectric constant films, ferroelectrics, micro-electro-mechanical systems (MEMS), semiconductor wafers, field emission displays, and other microelectronic substrates, especially microelectronic substrates comprising insulating layers (e.g., metal oxide, silicon nitride, or low dielectric materials) and/or metal-containing layers (e.g., copper, tantalum, tungsten, aluminum, nickel, titanium, platinum, ruthenium, rhodium, iridium, alloys thereof, and mixtures thereof). The term "memory or rigid disk" refers to any magnetic disk, hard disk, rigid disk, or memory disk for retaining information in electromagnetic form. Memory or rigid disks typically have a surface that comprises nickel-phosphorus, but the surface can comprise any other suitable material. Suitable metal oxide insulating layers include, for example, alumina, silica, titania, ceria, zirconia, germania, magnesia, and combinations thereof. In addition, the workpiece can comprise, consist essentially of, or consist of any suitable metal composite. Suitable metal composites include, for example, metal nitrides (e.g., tantalum nitride, titanium nitride, and tungsten nitride), metal carbides (e.g., silicon carbide and tungsten carbide), nickel-phosphorus, alumino-borosilicate, borosilicate glass, phosphosilicate glass (PSG), borophosphosilicate glass (BPSG), silicon/germanium alloys, and silicon/germanium/ carbon alloys. The workpiece also can comprise, consist essentially of, or consist of any suitable semiconductor base material. Suitable semiconductor base materials include single-crystal silicon, poly-crystalline silicon, amorphous silicon, silicon-on-insulator, and gallium arsenide.

[0032] All references, including publications, patent applications, and patents, cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0033] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0034] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

CLAIM(S):

1. A polishing pad comprising:
   (a) a polishing layer having a polishing surface, wherein the polishing surface comprises:
      (1) a plurality of grooves disposed into the polishing layer a measurable depth from the polishing surface, and
      (2) a barrier region free of grooves, and
   (c) a transparent window disposed in and surrounded by the barrier region.

2. The polishing pad of claim 1, wherein the depth transitions from a maximum value to zero proximate to the barrier region.

3. The polishing pad of claim 2, wherein the depth transition is gradual.

4. The polishing pad of claim 3, wherein the polishing pad is circular and the grooves are concentric.

5. The polishing pad of claim 4, wherein one or more of the concentric grooves are discontinuous and have a first end and a second end, and wherein the barrier region is disposed between the first and second ends.

6. The polishing pad of claim 1, wherein any one or more of the following applies,
   (a) the transparent window has an upper most window surface substantially co-planar with the polishing surface;
   (b) the polishing layer comprises polyurethane;
   (c) the transparent window comprises thermoplastic polyurethane;
   (d) the polishing pad further comprises a sub-layer.

7. A method of polishing a substrate comprising
   (i) providing a workpiece to be polished,
   (ii) contacting the workpiece with the polishing pad of claim 1, and
   (iii) abrading at least a portion of the surface of the workpiece with the polishing pad to polish the workpiece.

8. The method of claim 7, wherein the method further comprises detecting *in situ* a polishing endpoint.

9. The method of claim 7, wherein the workpiece is contacted with a chemical-mechanical polishing composition located between the workpiece and the polishing pad.

10. The method of claim 7, wherein the depth transitions from a maximum value to zero proximate to the barrier region.

11. The method of claim 10, wherein the depth transition is gradual.

12. The method of claim 11, wherein the polishing pad is circular and the grooves are concentric.

13. The method of claim 12, wherein one or more of the concentric grooves are discontinuous and have a first end and a second end, and wherein the barrier region is disposed between the first and second ends.

14. The method of claim 7, wherein any one or more of the following applies,

(a) the transparent window has an upper most window surface substantially co-planar with the polishing surface;

(b) the polishing layer comprises polyurethane;

(c) the transparent window comprises thermoplastic polyurethane;

(d) the polishing pad further comprises a sublayer.

FIG. 1

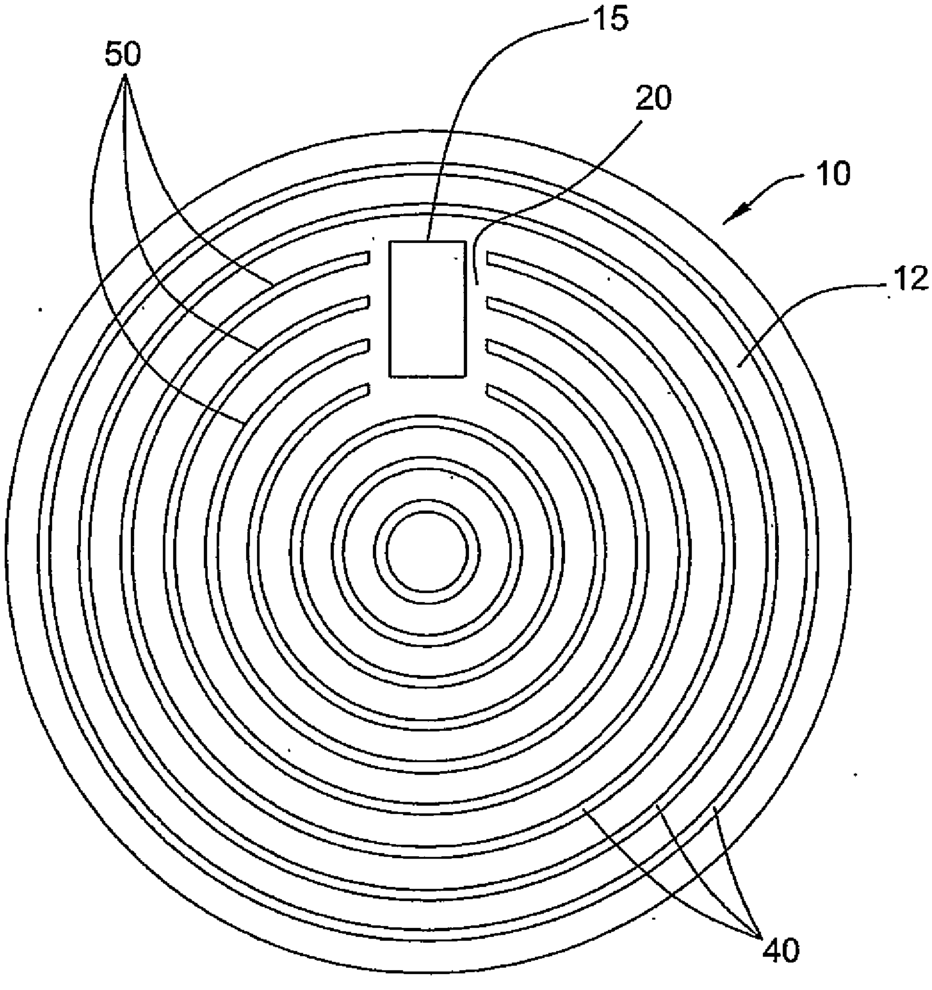

FIG. 2

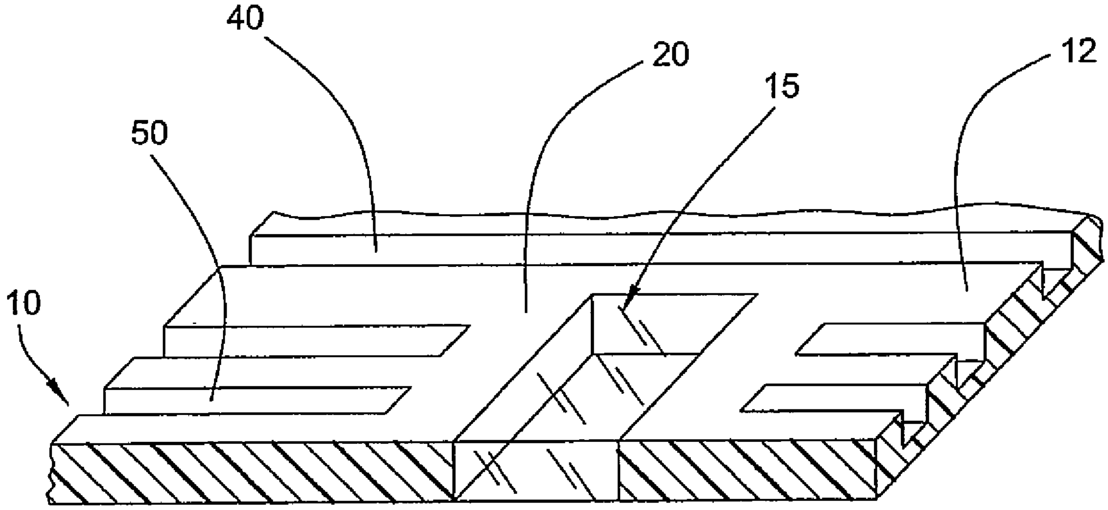

FIG. 3

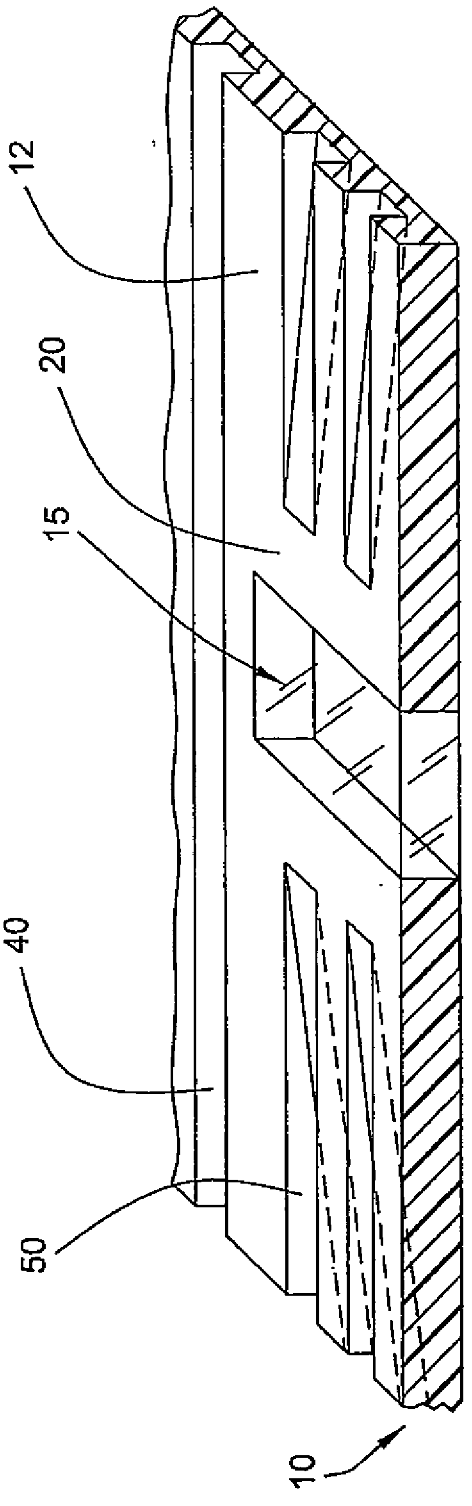

FIG. 4