(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
05 December 2019 (05.12.2019)

WIPO | PCT

(10) International Publication Number
WO 2019/229610 A1

(51) International Patent Classification:
B24D 9/00 (2006.01) *B24D 13/02* (2006.01) *B24D 7/00* (2006.01) *B24D 13/14* (2006.01) *B24D 9/08* (2006.01)

(21) International Application Number: PCT/IB2019/054339

(22) International Filing Date: 24 May 2019 (24.05.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/678,115 30 May 2018 (30.05.2018) US

(71) Applicant: **3M INNOVATIVE PROPERTIES COMPANY** [US/US]; 3M Center, Post Office Box 33427, Saint Paul, MN 55133-3427 (US).

(72) Inventors: **SVENTEK, Bruce A.**; 3M Center, Post Office Box 33427, Saint Paul, MN 55133-3427 (US). **LOPER, Stephen C.**; 3M Center, Post Office Box 33427, Saint Paul, MN 55133-3427 (US). **BAIRD, David G.**; 3M Center, Post Office Box 33427, Saint Paul, MN 55133-3427 (US). **NILSSON, Charles A.**; 4405 Douglas Drive North, Crystal, MN 55422 (US).

(74) Agent: **BRAMWELL, Adam M.** et al.; 3M Center, Office of Intellectual Property Counsel, Post Office Box 33427, Saint Paul, MN 55133-3427 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: ABRASIVE ROTARY TOOL

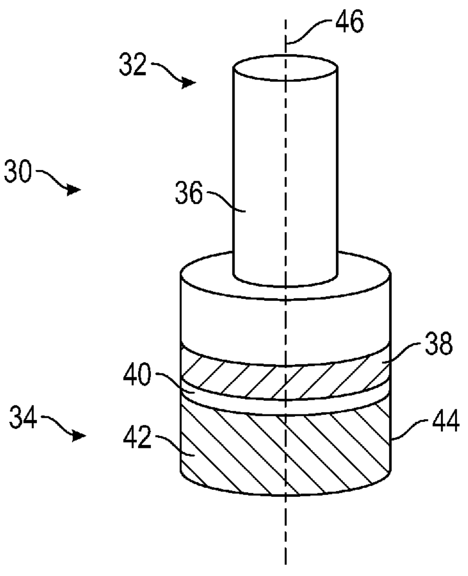

FIG. 1B

(57) Abstract: The disclosure provides abrasive rotary tools with replaceability and improved contact pressure. Exemplary abrasive rotary tools include an abrasive assembly holder, an abrasive assembly, and an elastic layer. The abrasive assembly includes an abrasive layer having a contact surface to abrade a surface of a substrate and a rigid support layer to provide support to the abrasive layer during abrasion against the surface of the substrate to maintain the contact surface substantially planar. The elastic layer is disposed between a shank and the abrasive layer and is configured to compress during abrasion of the substrate to increase contact time of the contact surface with the substrate. Exemplary abrasive rotary tools also include a coupling layer configured to attach the abrasive assembly to the abrasive assembly holder. After a sufficient amount of wear, the abrasive assembly is removed from the abrasive assembly holder and replaced with another abrasive assembly.

WO 2019/229610 A1

[Continued on next page]

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

— *with international search report (Art. 21(3))*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

ABRASIVE ROTARY TOOL

TECHNICAL FIELD

[0001] The invention relates to abrasive rotary tools.

BACKGROUND

[0002] Handheld electronics, such as touchscreen smartphones and tablets, often include a cover glass to provide durability and optical clarity for the devices. Production of cover glasses may use computer numerical control (CNC) machining for consistency of features in each cover glass and high-volume production. The edge finishing of the perimeter of a cover glass is important for strength and cosmetic appearance. Typically, diamond abrasive tools, such as metal bonded diamond tools, are used to machine the cover glasses. These tools may last a relatively long time and may be effective at high cutting rates. However, the tools may leave microcracks in the cover glass that become stress concentration points, which may significantly reduce the strength of the glass. To improve the strength or appearance of the cover glasses, the edges may be polished. For example, a polishing slurry, such as cerium oxide, is typically used to polish the glass covers. However, slurry-based polishing may be slow and require multiple polishing steps. Additionally, slurry polishing equipment may be large, expensive, and unique to particular features being polished. Overall, the slurry polishing systems themselves may produce low yields, create rounded corners of the substrate being abraded and increase labor requirements.

SUMMARY

[0003] The disclosure is generally directed to abrasive rotary tools with improved contact pressure on a substrate. Exemplary abrasive rotary tools include an abrasive assembly holder, an abrasive assembly, and an elastic layer. The abrasive assembly includes a rigid support layer and an abrasive layer. The abrasive layer has a contact surface configured to abrade a surface of a substrate. The rigid support layer is configured to provide support to the abrasive layer during abrasion against the surface of the substrate, such that the contact surface remains substantially planar. The elastic layer is disposed between a shank of the abrasive assembly holder and the abrasive layer, such as between the shaft and the rigid

support layer. The elastic layer is configured to compress during abrasion of the substrate, such that the contact surface may have increased contact time with the substrate. The abrasive rotary tool may exert more directionally-uniform contact force against the substrate with increased planarity, improved removal rate consistency, and/or improved lifetime compared to abrasive rotary tools that do not use a rigid support layer proximal to the abrasive layer and an elastic layer distal to the abrasive layer. Exemplary abrasive rotary tools also include a coupling layer configured to attach the abrasive assembly to an abrasive assembly holder of the rotary tool. After a sufficient amount of wear, the abrasive assembly is removed and replaced with another abrasive assembly.

[0004] In one embodiment, an abrasive rotary tool includes an abrasive assembly holder, an abrasive assembly, and an elastic layer. The abrasive assembly holder includes a shank defining an axis of rotation for the rotary tool. The abrasive assembly includes a rigid support layer and an abrasive layer. The rigid support layer has a Shore A hardness greater than about 90. The abrasive layer has a contact surface. The elastic layer is disposed between the shank and the abrasive layer. The elastic layer has a Shore A hardness less than about 70.

[0005] In another embodiment, an abrasive rotary tool includes an abrasive assembly holder, an abrasive assembly, and an elastic layer. The abrasive assembly holder includes a shank defining an axis of rotation for the rotary tool. The abrasive assembly includes a rigid support layer and an abrasive layer. The rigid support layer has a compression modulus of greater than about 1 GPa. The abrasive layer has a contact surface. The elastic layer is disposed between the shank and the abrasive layer. The elastic layer has an elastic modulus of less than about 0.1 GPa.

[0006] In another embodiment, a polishing system includes an abrasive rotary tool that includes an abrasive assembly holder, a first abrasive assembly, and a coupling layer. The abrasive assembly holder includes a shank defining an axis of rotation for the rotary tool. The first abrasive assembly coupled to the abrasive assembly holder and includes a first rigid support layer and a first abrasive layer having a first contact surface. The coupling layer is disposed between the shank and the abrasive layer. The polishing system further includes a second abrasive assembly that includes a second rigid support layer and a second abrasive layer having a second contact surface. The polishing system further includes a rotary tool replacement apparatus configured to remove the first abrasive assembly from the rotary tool and attach the second abrasive assembly to the abrasive assembly holder.

[0007] In another example, an assembly includes a computer-controlled machining system that includes a computer controlled rotary tool holder and a substrate platform, a substrate secured to the substrate platform, and an abrasive rotary tool as described above.

[0008] In another embodiment, a method for polishing a substrate includes providing a computer-controlled machining system that includes a computer controlled rotary tool holder and a substrate platform. The method further includes securing an abrasive rotary tool to the rotary tool holder of the computer-controlled machining system. The abrasive rotary tool includes an abrasive assembly holder, a first abrasive assembly, and a coupling layer. The abrasive assembly holder includes a shank defining an axis of rotation for the rotary tool. The first abrasive assembly is coupled to the abrasive assembly holder and includes a first rigid support layer and a first abrasive layer having a first contact surface. The coupling layer is disposed between the shank and the abrasive layer. The method further includes operating the computer-controlled machining system to abrade a contact surface of a substrate using the first abrasive assembly of the abrasive rotary tool. The method further includes removing the first abrasive assembly from the abrasive assembly holder of the abrasive rotary tool and attaching a second abrasive assembly to the abrasive assembly holder of the abrasive rotary tool. The second abrasive assembly includes a second rigid support layer and a second abrasive layer having a second contact surface.

[0009] The details of one or more embodiments of the disclosure are set forth in the accompanying drawings and the description below. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

[0010] Like symbols in the drawings indicate like elements. Dotted lines indicate optional or functional components, while dashed lines indicate components out of view.

[0011] FIG. 1A illustrates an assembly for abrading a substrate.

[0012] FIG. 1B illustrates a plan view diagram of a cylindrical rotary tool for abrading a substrate.

[0013] FIG. 1C illustrates a plan view diagram of a conical rotary tool for abrading a substrate.

[0014] FIG. 1D illustrates a side view cross-sectional diagram of a cylindrical abrasive rotary tool abrading a substrate along an x-axis.

[0015] FIG. 1E illustrates a side view cross-sectional diagram of a conical abrasive rotary tool abrading a substrate along a z-axis.

[0016] FIG. 2A illustrates a cover glass for an electronic component.

[0017] FIG. 2B illustrates a side view cross-sectional diagram of a portion of a substrate having two chamfered corners.

[0018] FIG. 2C illustrates a side view cross-sectional diagram of a portion of a substrate having one chamfered corner and three 90-degree corners.

[0019] FIG. 3A illustrates a side view cross-sectional diagram of an abrasive rotary tool with a replaceable abrasive assembly for abrading a substrate.

[0020] FIG. 3B illustrates a side view cross-sectional diagram of an abrasive rotary tool with a replaceable abrasive assembly for abrading a substrate.

[0021] FIG. 3C illustrates a side view cross-sectional diagram of an abrasive rotary tool with a replaceable abrasive assembly for abrading a substrate.

[0022] FIG. 4A illustrates a plan view diagram of an abrasive rotary tool having a magnetic coupling mechanism.

[0023] FIG. 4B illustrates a plan view diagram of an abrasive rotary tool having a threaded coupling mechanism.

[0024] FIG. 5A illustrates a side view diagram of a polishing system removing a first abrasive assembly from an abrasive assembly holder.

[0025] FIG. 5B illustrates a side view diagram of a polishing system attaching a second abrasive assembly from an abrasive assembly holder.

[0026] FIG. 6 is a flowchart illustrating example techniques for abrading a substrate using a rotary tool and replacing an abrasive assembly of the rotary tool.

[0027] FIG. 7 is a schematic diagram of an experimental system for determining detachment force measurements for a coupling layer of an abrasive rotary tool.

[0028] FIG. 8 is a diagram of an abrasive rotary tool having a detachable, flat abrasive assembly coupled to an abrasive assembly holder using a hook coupling mechanism.

[0029] FIG. 9A is a diagram of an abrasive rotary tool having a detachable, cylindrical abrasive assembly coupled to an abrasive assembly holder using a magnetic coupling mechanism

[0030] FIG. 9B is a diagram of abrasive rotary tool of FIG. 9A with a detachable abrasive assembly detached from an abrasive assembly holder.

DETAILED DESCRIPTION

[0031] The present disclosure describes abrasive articles that produce improved substrate geometry.

[0032] Often, an abrasive rotary tool may be used to abrade a particular surface of a component. A rigid abrasive rotary tool may exhibit high variation in application of pressure from a contact surface of an abrasive layer of the rotary tool, which may cause inconsistent abrading of the surface of the component due to variations in the surface of the component. To improve contact of the contact layer with the surface of the component, the abrasive layer may have a compressible backing that allows the contact surface of the abrasive layer to conform to the surface to the component. While such conformability may be desirable for provided rounded edges, it may be undesirable for providing planar edges. For example, the contact surface may apply a greater pressure at the corners of the surface of the component than the surface of the component, resulting in a non-planar surface of the component.

[0033] As discussed herein, abrasive rotary tools of the present disclosure may provide a planar contact surface with improved contact during abrasion of a substrate for a more consistent planarity of a surface of a substrate with less wear of the contact surface of the rotary tool. In one embodiment, an abrasive rotary tool includes a shank, an abrasive assembly, and an elastic layer. The abrasive assembly includes an abrasive layer and a rigid support layer. The abrasive layer is configured to contact a substrate at a surface and remove material from the surface of the substrate. The rigid support layer is configured to provide support to the abrasive layer during abrasion against the surface of the substrate, such that the contact surface remains substantially planar. For example, the rigid support layer may include materials that have a high hardness and/or low elasticity. The elastic layer is configured to compress during abrasion of the substrate, such that the contact surface may have more consistent contact with the substrate. For example, the elastic layer may include materials that have a low hardness and/or high elasticity. The high rigidity of the rigid support layer and the high elasticity of the elastic layer may result in an abrasive rotary tool that has a contact surface with reduced hysteresis along an axis of an exerted force while maintaining planarity.

[0034] In another embodiment, an abrasive rotary tool, such as the abrasive rotary tool described above, includes a coupling layer disposed between the shank and the abrasive layer. The coupling layer may be configured to secure the abrasive assembly to the tool and allow detachment of the abrasive assembly for replacement with another abrasive assembly. For example, after a set number of uses, the abrasive assembly may be replaced with a fresh abrasive assembly. The replaceability of the abrasive assembly may allow an operator to operate the rotary tool in a manner that results in abraded substrates having a greater consistency.

[0035] FIG. 1A illustrates an assembly 10, which includes a computer-controlled machining system 12 and a machining system controller 14. Controller 14 is configured to send control signals to machining system 12 for causing machining system 12 to machine, grind, or abrade a substrate 16 with a rotary tool 18, which is mounted within a rotary tool holder 20 of machining system 12. In one embodiment, machining system 12 may represent a CNC machine, such as a three, four, or five axis CNC machine, capable of performing routing, turning, drilling, milling, grinding, abrading, and/or other machining operations, and controller 14 may include a CNC controller that issues instructions to rotary tool holder 20 for performing machining, grinding, and/or abrading of substrate 16 with one or more rotary tools 18. Controller 14 may include a general purpose computer running software, and such a computer may combine with a CNC controller to provide the functionality of controller 14.

[0036] Substrate 16 is mounted and secured to substrate platform 22 in a manner that facilitates precise machining of substrate 16 by machining system 12. Substrate holding fixture 24 secures substrate 16 to substrate platform 22 and precisely locates substrate 16 relative to machining system 12. Substrate holding fixture 24 may also provide a reference location for control programs of machining system 12. While the techniques disclosed herein may apply to workpieces of any materials, substrate 16 may be a component for an electronic device. In some embodiments, substrate 16 may be a display element, e.g., a transparent display element, of an electronic device, such as a cover glass for an electronic device or, more particularly, a cover glass of a smartphone touchscreen. For example, such cover glasses may include chamfered edges for which a high degree of planarity and angularity are desired.

[0037] In some embodiments, substrate 16 may include a first major surface 2 (e.g. a top of substrate 16), a second major surface 4 (e.g. a bottom of substrate 16), and one or more edge surfaces 6 (e.g. sides of substrate 16). The area of edge surface 6 of substrate 16 is typically less than the area of the first major surface and/or second major surface of substrate 16. In some embodiments, the ratio of edge surface 6 of substrate 16 to the area of first major surface 2 of substrate 16 and/or the ratio of edge surface 6 of substrate 16 to the area of second major surface 4 of substrate 16 may be greater than 0.00001, greater than 0.0001, greater than 0.0005, greater than 0.001, greater than 0.005 or even greater than 0.01; less than 0.1, less than 0.05 or even less than 0.02. In some embodiments, a thickness of edge surface 6 measured normal to first and/or second major surfaces 2, 4, is no greater than 5 mm, no greater than 4 mm, no greater than 3 mm, no greater than 2 mm or even no greater than 1 mm. Edge surface 6 intersects first major surface 2 to form a first corner 3 and intersects second major surface 4 to form the second corner 5. In some embodiments, edge surface 6 may be substantially perpendicular to each of major surfaces 2, 4, while in other examples, edge surface 6 may include more than one edge surface, wherein at least one of the more than one edge surface is not perpendicular (e.g., a chamfered edge). During abrading of substrate 16, the one or more edge surfaces 6 may be abraded such that first and second corners 3, 5 may remain sharp and well-defined as material is removed during abrading. Further embodiments of substrate 16 will be described in FIGS. 1D-E and FIGS. 2A-C below.

[0038] In the embodiment of FIG. 1A, rotary tool 18 may be utilized to improve the surface finish of machined features of substrate 16, such as holes and edge features in a cover glass. In some embodiments, different rotary tools 18 may be used in series to iteratively improve the surface finish of the machined features. For example, assembly 10 may be utilized to provide a coarser grinding step using a fist rotary tool 18, or a set of rotary tools 18, followed by a finer abrading step using a second rotary tool 18, or a set of rotary tools 18. In some embodiments, a single rotary tool 18 may include different levels of abrasion to facilitate an iterative grinding and/or abrading process using fewer rotary tools 18. Each of these embodiments may reduce the cycle time for finishing and polishing a substrate following the machining of the features of the substrate as compared to other embodiments in which only a single grinding step is used to improve surface finish following machining of features in a substrate. In some embodiments, the substrate may remain secured to substrate holding fixture 24 throughout the iterations of the different rotary tools 18.

[0039] In the embodiment of FIG. 1A, assembly 10 includes rotary tool replacement apparatus 26. Rotary tool replacement apparatus 26 and/or machining system 12 may be configured to remove a used abrasive assembly of rotary tool 18 and attach a new abrasive assembly of rotary tool 18. For example, portions of rotary tool 18, such as an abrasive assembly holder, may remain fixed to rotary tool holder 20 while other portions of rotary tool 18, such as abrasive assembly configured to abrade a surface of substrate 16, may be replaced. Further operation of rotary tool replacement apparatus 26 may be described in FIGS. 5A-B and FIG. 6 below.

[0040] In some embodiments, following grinding and/or abrading using assembly 10, a substrate may be polished, e.g., using a separate polishing system to further improve the surface finish. In general, the better the surface finish prior to polishing, the less time is required to provide a desired surface finish following the polishing. To abrade an edge of substrate 16 with assembly 10, controller 14 may issue instructions to rotary tool holder 20 to precisely apply an abrasive layer of a rotary tool 18 against one or more features of substrate 16 as rotary tool holder 20 rotates rotary tool 18. The instructions may include for example, instructions to precisely follow the contours of features of substrate 16 with a single abrasive rotary tool 18. Apparatus 26 houses replacement abrasive assemblies, having abrasive layers, for rotary tool 18, to automatically replenish the abrasive assembly/abrasive layer of rotary tool 18 or to change a shape of rotary tool 18 partially or completely.

[0041] In accordance with embodiments discussed herein, abrasive rotary tool 18 is configured to apply a consistent contact pressure against a surface of substrate 16 over a period of time. Abrasive rotary tool 18 includes an abrasive assembly holder and an abrasive assembly coupled to the abrasive assembly holder. The abrasive assembly holder includes a shank defining an axis of rotation for rotary tool 18. The abrasive assembly includes a rigid support layer and an abrasive layer having a contact surface configured to remove material from substrate 16. The rigid support layer is configured to support the abrasive layer and maintain the contact surface of the abrasive layer in a substantially planar orientation during transmission of a contact force at the contact surface. Rotary tool 18 further includes an elastic layer disposed between the shank of the abrasive assembly holder, which receives one or more applied forces from an abrading machine, and the abrasive layer of the abrasive assembly, which applies a contact pressure to a substrate through a contact surface. The elastic layer is configured to compress during transmission of the contact force at the contact surface. In this way, rotary tool 18 may present a contact surface that exhibits improved contact while maintaining planarity.

[0042] FIGS. 1B and 1C illustrate exemplary rotary tools, such as may be used as rotary tool 18 of FIG. 1A. FIG. 1B illustrates a cylindrical abrasive rotary tool 30 for exerting a force substantially perpendicular to an axis of rotation 46 of rotary tool 30, while FIG. 1C illustrates a conical abrasive rotary tool 50 for exerting a force substantially parallel to an axis of rotation 66 of rotary tool 50. While cylindrical and conical abrasive rotary tools are illustrated in FIGS. 1B and 1C, other forms of abrasive rotary tools may be used. For example, to exert a force from a flat contact surface, a cylindrical abrasive rotary tool having a contact surface normal to an axis of rotation may be used, such as shown in FIGS. 3A-3C, FIGS. 4A-4B, and FIGS. 5A-5B.

[0043] Referring to the embodiment of FIG. 1B, rotary tool 30 includes an abrasive assembly holder 32 and an abrasive assembly 34. Abrasive assembly holder 32 includes a shank 36 that defines axis of rotation 46 of rotary tool 30. Abrasive assembly 34 is coupled to abrasive assembly holder 32, such as through a permanent or non-permanent coupling mechanism (not shown). Abrasive assembly 34 includes a rigid support layer 40 and an abrasive layer 42. Abrasive layer 42 includes a contact surface 44 that is substantially parallel (e.g., within 5 degrees) to axis of rotation 46. In the embodiment of FIG. 1B, rotary tool 30 includes an elastic layer 38 disposed between shank 36 and abrasive layer 42. Elastic layer 38 may be a portion of abrasive assembly holder 32 or abrasive assembly 34.

[0044] Referring to the embodiment of FIG. 1C, rotary tool 50 includes an abrasive assembly holder 52 and an abrasive assembly 54. Abrasive assembly holder 52 includes a shank 56 that defines axis of rotation 66 of rotary tool 50. Abrasive assembly 54 is coupled to abrasive assembly holder 52, such as through a permanent or non-permanent coupling mechanism (not shown). Abrasive assembly 54 includes a rigid support layer 60 and an abrasive layer 62. Abrasive layer 62 includes a contact surface 64 that forms an included angle with axis of rotation 66. In some embodiments, the included angle between contact surface 64 and axis of rotation 62 may be between 5 degrees and 90 degrees, 5 degrees and 85 degrees, 5 degrees and 80 degrees or even 5 degrees and 70 degrees, such as shown in FIG. 1C. In the embodiment of FIG. 1C, rotary tool 50 includes an elastic layer 58 disposed between shank 56 and abrasive layer 52. Elastic layer 58 may be a portion of abrasive assembly holder 52 or abrasive assembly 54.

[0045] FIG. 1D illustrates a side view cross-sectional diagram of cylindrical abrasive rotary tool 30 abrading a substrate 70 along an x-axis, as indicated by arrow 78. Substrate 70 includes an edge surface 72 that intersects adjacent surfaces to form a first corner 74 and a second corner 76. Substrate 70 may be, for example, an outer edge of a coverglass. Rotary tool 30 rotates around axis of rotation 46, causing contact surface 44 to contact substrate 70 at edge surface 72. A rotary tool holder (not shown), such as rotary tool holder 20 of FIG. 1, may exert a force on shaft 36 that is perpendicular to axis of rotation 46, as indicated by arrow 78, such that rotary tool 30 exerts a contact pressure on edge surface 72 of substrate 70. As contact surface 44 contacts edge surface 72, elastic layer 38 may either allow movement of contact surface 44 in a direction (x-axis) substantially parallel (e.g., within 10 degrees) to the exerted force, while contact surface 44 maintains a substantially planar orientation against edge surface 72, or compress on one side and expand on the other side of elastic layer 38 if an angle is desired. As a result, contact surface 44 may remove material from edge surface 72 evenly, such that corners 74 and 76 maintain their angularity.

[0046] FIG. 1E illustrates a side view cross-sectional diagram of conical abrasive rotary tool 50 abrading a substrate 80 along a z-axis. Abrasive rotary tool 50 includes abrasive assembly holder 52, which includes shank 56 that defines axis of rotation 66 of rotary tool 50, and abrasive assembly 54, which includes rigid support layer 60 and abrasive layer 62. Substrate 80 includes chamfered surface 82 that intersects adjacent surfaces to form a first corner 84 and a second corner 86. Substrate 80 may be, for example, an inner edge of a coverglass, such as a hole. Rotary tool 50 rotates around axis of rotation 66, causing contact surface 64 to contact substrate 80 at chamfered surface 82. A rotary tool holder (not shown), such as rotary tool holder 20 of FIG. 1A, may exert a downward force, as indicated by arrow 88, on shank 56, such that rotary tool 50 exerts a contact pressure on chamfered surface 82 of substrate 80. As contact surface 64 contacts chamfered surface 82, elastic layer 58 compresses to allow movement of contact surface 64 in a direction (z-axis) substantially parallel to the exerted force, while contact surface 64 maintains a substantially planar orientation against chamfered surface 82. As a result, contact surface 64 may remove material from chamfered surface 82 evenly.

[0047] Abrasive assembly holders discussed herein, such as abrasive assembly holders 32 and 52, may be configured to couple to abrasive assemblies, such as abrasive assemblies 34 and 54. In some examples, an abrasive assembly holder may couple directly to (i.e. share a same interface with) an abrasive assembly, such as through a non-permanent coupling layer (e.g. a magnetic coupling layer, as will be further described in FIGS. 3-6). In some embodiments, an abrasive assembly holder may couple indirectly to an abrasive assembly, such as through a coupling layer (e.g. a thermoset, high strength adhesive), an elastic layer, or other layer. Abrasive assembly holders may also be configured to couple to a rotary tool holder, such as rotary tool holder 20 of FIG. 1A. For example, a shank of the abrasive assembly holder may have a shape, surface, or other feature configured to attach to the rotary tool holder.

[0048] Abrasive assembly holders discussed herein may be configured to receive an applied force from a rotary tool holder, such as a rotational force around the axis of rotation of the shank and a directional force along at least one of an x-, y-, or z-axis, and transmit at least a portion of the applied force to the abrasive assembly. In the embodiment of FIG. 1D, shank 36 of abrasive assembly holder 32 receives a rotational force around rotational axis 46 and a force along an x-axis and transmits the rotational and x-axis forces to abrasive assembly 34. In the embodiment of FIG. 1E, shank 56 of abrasive assembly holder 32 receives a rotational force around rotational axis 66 and a force along a z-axis and transmits the rotational and z-axis forces to abrasive assembly 54.

[0049] Abrasive assemblies discussed herein, such as abrasive assemblies 34 and 54, may be configured to couple to an abrasive assembly holder, such as abrasive assembly holders 32 and 52. In some embodiments, an abrasive assembly may couple directly to an abrasive assembly holder, such as through a non-permanent coupling layer, while in other embodiments, an abrasive assembly may couple indirectly to an abrasive assembly holder.

[0050] Abrasive assemblies discussed herein may be configured to receive an applied force from the abrasive assembly holder, such as a rotational force around the axis of rotation of the shank and a directional force along at least one of an x-, y-, or z-axis, and transmit at least a portion of the applied force to a contact surface of the abrasive assembly. In the embodiment of FIG. 1D, abrasive assembly 34 receives a rotational force around rotational axis 46 and a force along the x-axis through elastic layer 38 and transmits the rotational and x-axis forces to contact surface 44. In the embodiment of FIG. 1E, abrasive assembly 54 receives a rotational force around rotational axis 66 and a force along a z-axis through elastic layer 58 and transmits the rotational and z-axis forces to contact surface 64.

[0051] Rigid support layers discussed herein, such as rigid support layers 40 and 60, may be configured to support an abrasive layer, such as abrasive layers 42 and 62, in response to a contact pressure of the abrasive assembly against a substrate. A rigid support layer may support an abrasive layer by receiving a contact pressure from the abrasive layer, such as a pressure typically encountered during abrading of a substrate and resisting deformation to substantially maintain planarity at an interface between the rigid support layer and the abrasive layer. In contrast, elastic layers discussed herein, such as elastic layers 38 and 58, may be configured to deform in response to a contact pressure of the abrasive assembly against a substrate. An elastic layer may deform by receiving a contact pressure, such as from a rigid support layer, coupling layer, or other layer forming an interface with the elastic layer, and compressing in at least a portion of the elastic layer.

[0052] In some embodiments, the rigid support layer and the elastic layer may each be composed of a material selected according to softness. Softness of a material may be correlated with the conformability of the material; generally, a softer material may have a higher conformability at a given contact pressure. Softness may be represented by and selected based on a variety of properties of each material of the rigid support layer and the elastic layer. For example, a softer material may be a material with a lower hardness (as indicated using any appropriate hardness scale, such as Shore A or Shore OO), a material with a lower elastic modulus, a material with a higher compressibility (typically quantified via a material’s Poisson’s ratio or deflection), or a material with a modified structure, such as containing a plurality of gas inclusions such as a foam, etc.

[0053] In some embodiments, the rigid support layer and the elastic layer may each be composed of a material selected according to hardness. Hardness may represent a measure of each of the rigid support layer and the elastic layer to deform in response to a force. In some cases, the hardness may be most appropriately measured using different scales for the rigid support layer and the elastic layer (e.g., Shore A durometer for the elastic layer and Rockwell scale for the rigid support layer). In some embodiments, the rigid support layer has a sufficiently high hardness, such that rigid support layer does not substantially deform against a substrate under normal operating conditions. In some embodiments, the rigid support layer may have a hardness that is greater than about 90 Shore A, or greater than about 95 Shore A. In some embodiments, the elastic layer has a sufficiently low hardness, such that the elastic layer deforms against a substrate under normal operating conditions. In some embodiments, the elastic layer may have a hardness that is less than about 70 Shore A, or less than about 50 Shore A, or less than about 40 Shore A, or less than about 30 Shore A or less than about 20 Shore A, or less than about 10 Shore A.

[0054] In some embodiments, the rigid support layer and the elastic layer may each be composed of a material selected according to compressibility. Compressibility may represent a measure of the relative change of a material of each of the rigid support layer and the elastic layer in response to a pressure, while the terms “compressible” or “incompressible” may refer to a material property of compressibility. For example, the term “substantially incompressible” refers to a material having a Poisson’s ratio greater than about 0.45. Compressibility of a material may be expressed as a particular pressure required to compress the material to a reference deflection (e.g., 25% deflection). In some embodiments, the compressibility of the layer may be measured via Compression Force Deflection Testing per ASTM D3574 or a modified version thereof, when the layer is foam; and via Compression-Deflection Testing per ASTM D1056 when the layer is a flexible cellular material such as, for example, sponge or expandable rubber.

[0055] In some embodiments, the compressibility of the elastic layer may be relatively high for operating conditions encountered during abrading. In some embodiments, the elastic layer may have a compressibility at 25% deflection of less than about 1.5 MPa (220 psi), less than about 1.1 MPa (160 psi), less than about 0.31 MPa (45 psi) and/or a Poisson’s ratio less than about 0.5, less than about 0.4, less than 0.3 or preferably less than about 0.1.

[0056] In some embodiments, the rigid support layer may be substantially incompressible, e.g., the relative volume change of the material in response to a contact pressure is less than 5%, less than 2%, less than 1%, less than 0.5%, or less than 0.2%.

[0057] In some embodiments, the rigid support layer and the elastic layer may each be composed of a material selected according to elasticity. Elasticity (or stiffness) may represent a measure of the relative deformation (strain) of a material of each of the rigid support layer and the elastic layer in response to a pressure (stress), while the terms “elastic” or “inelastic” may refer to a material property of elasticity. For example, the term “substantially inelastic” refers to a material having a Poisson’s ratio greater than about 0.45. Elasticity of a material may be expressed as a tensile modulus, Young’s modulus, or elastic modulus. In some embodiments, the elasticity of the layer may be measured via Standard Test Method for Young’s Modulus, Tangent Modulus, and Chord Modulus per ASTM E111-17.

[0058] In some embodiments, the rigid support layer has a sufficiently low elasticity, such that the rigid support layer does not substantially deform against a substrate under normal operating conditions. In some embodiments, the rigid elastic layer may be substantially inelastic, e.g., the relative volume change of the material in response to a contact pressure is less than 5%, less than 2%, less than 1%, less than 0.5%, or less than 0.2%. In some embodiments, the rigid support layer is made of substantially incompressible material which has been patterned, 3D printed, embossed, or engraved to provide the desired conformability. In some embodiments, the rigid support layer includes at least one of: a metal, such as aluminum 6061, 2011, or 2024 or steel 4140, W1, or 01; a plastic, such as nylon, polycarbonate, or acrylic; a rubber; and the like.

[0059] In some embodiments, the elastic layer has a sufficiently high elasticity, such that the elastic layer compresses against the substrate under normal operating conditions. In some embodiments, the elastic layer may have a Young’s Modulus of less than about 1.5 MPa (220 psi), less than about 1.1 MPa (160 psi), less than about 0.31 MPa (45 psi) and/or a Poisson’s ratio less than about 0.5, less than about 0.4, less than 0.3 or preferably less than about 0.1. In some embodiments, the elastic layer comprises at least one of an elastomer, a fabric, a nonwoven material, or a spring.

[0060] In some embodiments, the elastic layer may be composed of a material selected according to elastic deformation. Elastic deformation may represent an ability of a material to recover to its original state after being deformed. The material may be elastically deformable, e.g., being capable of substantially 100% (e.g., 90% or more, 95% or more, 99% or more, 99.5% or more, or 99.9% or more) recovering to its original state after being deformed.

[0061] In some embodiments, the elastic layer may be composed of a material selected according to relaxation modulus, e.g. stress relaxation modulus. Relaxation modulus may represent a measure of a time-dependent viscoelastic property. In this disclosure, relaxation modulus is expressed in percentage and is determined from the relaxation modulus versus time curve provided from a stress relaxation test (e.g., as measured using ASTM D6048) using the following equation:

[0062] Relaxation modulus (%) = (instantaneous modulus - modulus after 2 minutes relaxation under a constant compressive strain) / instantaneous modulus X 100. In some embodiments, at least one of rigid support layer and the elastic layer has a relaxation modulus of less than 25%.

[0063] In some embodiments, the elastic layer may be configured for various thicknesses. For example, a thickness of the elastic layer may correlate with a force or distance of rebound of the elastic layer, such that the elastic layer may have a thickness that provides a particular range or distance of movement relative to the force produced or absorbed by the elastic layer. As an example, an elastic layer of an abrasive rotary tool intended for substrates with a relatively high degree of planarity may be thinner than an elastic layer of an abrasive rotary tool intended for substrates with a relatively low degree of planarity, as a higher degree of planarity may result in less compression or travel of the elastic layer. In some embodiments, the elastic layer thickness may be less than 3 mm, less than 2 mm, or less than 1 mm. In some embodiments, the elastic layer includes at least one of an elastomer, a fabric, or a nonwoven material. Suitable elastomers may include thermoset elastomers such as, for example, nitriles, fluoroelastomers, chloroprenes, epichlorohydrins, silicones, urethanes, polyacrylates, EPDM (ethylene propylene diene monomer) rubbers, SBR (styrenebutadiene rubber), butyl rubbers, nylon, polystyrene, polyethylene, polypropylene, polyester, polyurethane, etc. In some embodiment, the density of the elastic layer may be greater than 0.2 g/cm^3, greater than 0.4 g/cm^3, 0.6 greater than g/cm^3, greater than 0.8 g/cm^3, greater than 0.85 g/cm^3, greater than 0.9 g/cm^3, greater than 0.95 g/cm^3, greater than 1.0 g/cm^3, greater than 1.1 g/cm^3 or even greater than

1.2 g/cm^3; less than 2.0 g/cm^3, less than 1.8 g/cm^3, less than 1.6 g/cm^3, less than 1.4 g/cm^3 or even less than 1.2 g/cm^3.

[0064] The elastic layer may also be formed from a variety of materials having one or more properties discussed above. In some embodiments, when elastic layer includes one of a foam, an engraved, structured, 3D printed, or embossed elastomer, a fabric or nonwoven layer, or a soft rubber. A suitable foam may be open-celled or closed-celled, including, for example, synthetic or natural foams, thermoformed foams, polyurethanes, polyesters, polyethers, filled or grafted polyethers, viscoelastic foams, melamine foam, polyethylenes, cross-linked polyethylenes, polypropylenes, silicone, ionomeric foams, etc. The elastic layer may also include foamed elastomers, vulcanized rubbers, including, for example, isoprene, neoprene, polybutadiene, polyisoprene, polychloroprene, natural rubber, nitrile rubber, polyvinyl chloride and nitrile rubber, ethylene-propylene copolymers such as EPDM (ethylene propylene diene monomer), and butyl rubber (e.g., isobutylene-isoprene copolymer). In some embodiments, the elastic layer contains various compressible structures. For example, it may include any suitable compressible structures such as, for example, springs, nonwovens, fabrics, air bladders, etc. In some embodiments, the elastic layer may be 3D printed to provide desired Poisson's ratio, compressibility, and elastic response. In some embodiment, the density of the elastic layer may be greater than 0.2 g/cm^3, greater than 0.25 g/cm^3, greater than 0.3 g/cm^3, greater than 0.35 g/cm^3, greater than 0.4 g/cm^3, greater than 0.45 g/cm^3 or even greater than 0.50 g/cm^3; less than 1.2 g/cm^3, less than 1.0 g/cm^3, less than 0.95 g/cm^3, less than 0.90 g/cm^3, less than 0.85 g/cm^3, less than 0.80 g/cm^3, less than 0.75 g/cm^3, or even less than 0.70 g/cm^3.

[0065] Abrasive layers as discussed herein, such as abrasive layers 42 and 62, include a contact surface, such as contact surfaces 44 and 64. The contact surface is configured to contact and abrade one or more surfaces of a substrate. Abrading may include grinding, polishing, and any other action that removes material from the substrate. As will be appreciated by those skilled in the art, the contact surface can be formed according to a variety of methods including, e.g., molding, extruding, embossing, and combinations thereof.

[0066] The abrasive layer is not particularly limited and may include, but is not limited to, traditional coated abrasives and structured abrasives (e.g. 3M TRIZACT ABRASIVE, available from 3M Company, St. Paul, Minnesota). The abrasive layer may include a base layer, e.g. backing layer, and a contact layer. The base layer may be formed from a polymeric material. For example, the base layer may be formed from thermoplastics, such as polypropylene, polyethylene, polyethylene terephthalate and the like; thermosets, such as polyurethanes, epoxy resin, and the like; or any combinations thereof. The base layer may include any number of layers. The thickness of the base layer (i.e., the dimension of the base layer in a direction normal to the first and second major surfaces) may be less than 10 mm, less than 5 mm, less than 1 mm, less than 0.5 mm, less than 0.25 mm, less than 0.125 mm, or less than 0.05 mm.

[0067] In some embodiments, the contact surface of the abrasive layer includes a microstructured surface. The microstructured surface may include microstructures configured to increase a contact pressure of the contact surface on one or more surfaces of a substrate. In some embodiments, the microstructured surface may include a plurality of cavities interspaced between the outermost abrasive material of the abrasive layer. For example, the shape of the cavities may be selected from among a number of geometric shapes such as a cubic, cylindrical, prismatic, hemispherical, rectangular, pyramidal, truncated pyramidal, conical, truncated conical, cross, post-like with a bottom surface which is arcuate or flat, or combinations thereof. Alternatively, some or all of the cavities may have an irregular shape. In various embodiments, one or more of the side or inner walls that form the cavities may be perpendicular relative to the top major surface or, alternatively, may be tapered in either direction (i.e., tapered toward the bottom of the cavity or toward the top of the cavity— toward the major surface). The angle forming the taper can range from about 1 to 75 degrees, from about 2 to 50 degrees, from about 3 to 35 degrees, or from between about 5 to 15 degrees. The height, or depth, of the cavities can be at least 1 micron, at least 10 micron, or at least 500 micron, or at least 1000 micron; less than 10 mm, less than 5 mm, or less than 1 mm. The height of the cavities may be the same, or one or more of the cavities may have a height that is different than any number of other cavities. In some embodiments, the cavities can be provided in an arrangement in which the cavities are in aligned rows and columns. In some instances, one or more rows of cavities can be directly aligned with an adjacent row of cavities. Alternatively, one or more rows of cavities can be offset from an adjacent row of cavities. In further embodiments, the cavities can be arranged in a spiral, helix, corkscrew, or lattice fashion.

In still further embodiments, the composites can be deployed in a "random" array (i.e., not in an organized pattern).

[0068] In some embodiments, the microstructured surface of the contact surface includes a plurality of precisely shaped abrasive composites. "Precisely shaped abrasive composite" refers to an abrasive composite having a molded shape that is the inverse of the mold cavity which is retained after the composite has been removed from the mold; preferably, the composite is substantially free of abrasive particles protruding beyond the exposed surfaces of the shape before the abrasive layer has been used, as described in U.S. Pat. No. 5,152,917 (Pieper et al.), which is incorporate herein by reference in its entirety. The plurality of precisely shaped abrasive composites may include a combination of abrasive particles and resin/binder forming a fixed abrasive. In some embodiments, contact surface 70 may be formed as a two-dimensional abrasive material, such as an abrasive sheet with a layer of abrasive particles held to a backing by one or more resin or other binder layers. Alternatively, the contact surface may be formed as a three-dimensional abrasive material, such as a resin or other binder layer that contains abrasive particles dispersed therein and is formed into a three-dimensional structure (forming a microstructured surface) via a molding or embossing process, for example, followed by curing, crosslinking, and/or crystallizing of the resin to solidify and maintain the three-dimensional structure. The three-dimensional structure may include a plurality of precisely shaped abrasive composites. In either embodiment, the contact surface may include an abrasive composite which has appropriate height to allow for the abrasive composite to wear during use and/or dressing to expose a fresh layer of abrasive particles. The abrasive layer may comprise a three-dimensional, textured, flexible, fixed abrasive construction including a plurality of precisely shaped abrasive composites. The precisely shaped abrasive composites may be arranged in an array to form the three-dimensional, textured, flexible, fixed abrasive construction. The abrasive layer may comprise abrasive constructions that are patterned. Abrasive layers available under the trade designation TRIZACT patterned abrasive and TRIZACT diamond tile abrasives available from 3M Company, St. Paul, Minnesota, are exemplary patterned abrasives. Patterned abrasive layers include monolithic rows of abrasive composites precisely aligned and manufactured from a die, mold, or other techniques.

[0069] The shape of each precisely shaped abrasive composite may be selected for the particular application (e.g., workpiece material, working surface shape, contact surface shape, temperature, resin phase material). The shape of each precisely shaped abrasive composite may be any useful shape, e.g., cubic, cylindrical, prismatic, right parallelepiped, pyramidal, truncated pyramidal, conical, hemispherical, truncated conical, cross, or post-like sections with a distal end. Composite pyramids may, for instance, have three, four sides, five sides, or six sides. The cross-sectional shape of the abrasive composite at the base may differ from the cross-sectional shape at the distal end. The transition between these shapes may be smooth and continuous or may occur in discrete steps. The precisely shaped abrasive composites may also have a mixture of different shapes. The precisely shaped abrasive composites may be arranged in rows, spiral, helix, or lattice fashion, or may be randomly placed. The precisely shaped abrasive composites may be arranged in a design meant to guide fluid flow and/or facilitate swarf removal.

[0070] The precisely shaped abrasive composites may be set out in a predetermined pattern or at a predetermined location within the abrasive layer. For example, when the abrasive layer is made by providing an abrasive/resin slurry between a backing and mold, the predetermined pattern of the precisely shaped abrasive composites will correspond to the pattern of the mold. The pattern is thus reproducible from abrasive layer to abrasive layer. The predetermined patterns may be in an array or arrangement, by which is meant that the composites are in a designed array such as aligned rows and columns, or alternating offset rows and columns. In another embodiment, the abrasive composites may be set out in a "random" array or pattern. By this is meant that the composites are not in a regular array of rows and columns as described above. It is understood, however, that this "random" array is a predetermined pattern in that the location of the precisely shaped abrasive composites is predetermined and corresponds to the mold.

[0071] An abrasive material forming the contact surface of the abrasive layer may include a polymeric material, such as a resin. In some embodiments, the resin phase may include a cured or curable organic material. The method of curing is not critical, and may include, for instance, curing via energy such as UV light or heat. Examples of suitable resin phase materials include, for instance, amino resins, alkylated urea-formaldehyde resins, melamine-formaldehyde resins, alkylated benzoguanamine-formaldehyde resins, acrylate resins (including acrylates and methacrylates), phenolic resins, urethane resins, and epoxy resins.

[0072] Examples of suitable abrasive particles for the abrasive layer include cubic boron nitride, fused aluminum oxide, ceramic aluminum oxide, heat treated aluminum oxide, white fused aluminum oxide, black silicon carbide, green silicon carbide, titanium diboride, boron carbide, silicon nitride, tungsten carbide, titanium carbide, diamond, cubic boron nitride, hexagonal boron nitride, alumina zirconia, iron oxide, ceria, garnet, fused alumina zirconia, alumina-based sol gel derived abrasive particles and the like. The alumina abrasive particle may contain a metal oxide modifier. The diamond and cubic boron nitride abrasive particles may be mono crystalline or polycrystalline. Other examples of suitable inorganic abrasive particles include silica, iron oxide, chromia, ceria, zirconia, titania, tin oxide, gamma, alumina, and the like. The abrasive particles may be abrasive agglomerate particles. Abrasive agglomerate particles typically comprise a plurality of abrasive particles, a binder, and optional additives. The binder may be organic and/or inorganic. Abrasive agglomerates may be randomly shape or have a predetermined shape associated with them.

[0073] In some embodiments, the abrasive layer, including resin, abrasive particles, and any additional additives dispersed in the resin, may be a coating on the rigid support layer. In some particular embodiments, an abrasive layer may be formed from an abrasive composite layer deposited on a base layer, the base layer may include a primer layer between the abrasive composite layer and the base layer. The base layer itself may be positioned over a backing layer, such as the rigid support layer or elastic layer, with an adhesive securing the base layer to the backing layer.

[0074] In various embodiments, abrasive rotary tools as described herein may be suitable for edge or major surface grinding a cover glass. For example, a cover glass may include various surfaces for which a high degree of planarity of each surface (i.e., flatness of a surface) and a high degree of angularity between surfaces (i.e., sharpness of angles between surfaces) are desirable. FIG. 2A illustrates cover glass 100, which is a cover glass for an electronic device such as a cellular phone, personal music player, or other electronic device. In some embodiments, cover glass 100 may be a component of a touchscreen for the electronic device. Cover glass 100 may be an alumina-silicate based glass with a thickness of less than 1 mm, although other compositions are also possible, such as a thickness of less than 5 mm, less than 4 mm, less than 3 mm or even less than 2 mm.

[0075] Cover glass 100 includes a first major surface 102 opposing a second major surface 104. Generally, but not always, major surfaces 102, 104 are planar surfaces. Edge surface 106 follows the perimeter of major surfaces 102, 104, the perimeter including rounded corners 108. Edge surface 106 intersects first major surface 102 at a first corner and second major surface 104 at a second corner, the first and second corners, generally, extends around the entire perimeter of the substrate.

[0076] To provide an increased resistance to cracking and improved appearance, the surfaces of cover glass 100, including major surfaces 102, 104 and edge surface 106 should be smoothed to the extent practical during manufacturing of cover glass 100. In addition, as disclosed herein, abrasive rotary tools, such as those described with respect to FIGS. 1A-E, may be used to reduce edge surface roughness, such as edge surface 106 and corners of edge surface 106 formed at the intersection of major surfaces 102, 104, using a CNC machine prior to polishing via an abrasive layer having a polishing grade abrasive particle. The intermediate grinding step may reduce polishing time of the polishing step that provides the desired surface finish qualities of cover glass 80, which may not only reduce production time, but may also provide more precise dimensional control for the production of cover glass 100. The particle size of the fine grade abrasive particle may be greater than the particle size of the polishing grade abrasive particle.

[0077] FIG. 2B illustrates an exemplary edge section 110 of a cover glass, such as cover glass 100 of FIG. 2A. Edge section 110 includes a first major surface 114 opposing a second major surface 116. Edge surface 112 intersects first major surface 114 at a first corner surface 118 and second major surface 116 at a second corner surface 120. Abrasive rotary tools as discussed herein, such as abrasive rotary tools 30 and 50 of FIG. 1, may be configured to abrade at least one of edge surface 112, as with cylindrical abrasive rotary tool 30, one of first corner surface 118 and second corner surface 120, as with conical abrasive rotary tool 50, or one of first major surface 114 and second major surface 116, as with a cylindrical abrasive rotary tool having a bottom contact surface, to a high degree of planarity and/or angularity.

[0078] FIG. 2C illustrates an exemplary edge section 130 of a cover glass, such as cover glass 100 of FIG. 2A. Edge section 130 includes a first major surface 134 opposing a second major surface 136. Edge surface 132 intersects first major surface 134 at a first corner surface 138 and second major surface 116 at a second corner. Abrasive rotary tools as discussed herein, such as abrasive rotary tools 30 and 50 of FIG. 1, may be configured to abrade at least one of edge surface 132, as with cylindrical abrasive rotary tool 30, corner surface 120, as with conical abrasive rotary tool 50, or one of first major surface 134 and second major surface 136, as with a cylindrical abrasive rotary tool having a bottom contact surface, to a high degree of planarity and/or angularity.

[0079] In various embodiments, abrasive assemblies disclosed herein may be removable from an abrasive rotary tool holder. For example, as an abrasive rotary tool abrades surfaces of one or more substrates, a contact surface of the abrasive layer may wear down and have reduced effectiveness, which may lead to longer abrading times and/or inconsistent material removal from surfaces of the substrates. However, other components of the abrasive rotary tool, such as a shank, may have a lifetime significantly longer than a lifetime of the abrasive layer. Replaceable abrasive layers may be time-consuming to replace and may not be consistently applied to and/or removed from a surface of the rotary tool. For example, in addition to manually aligning and applying an abrasive layer, an attachment surface for attaching the abrasive layer may require cleaning.

[0080] To maintain a contact surface with a high and/or consistent material removal rate, abrasive rotary tools, as disclosed herein, may include removable abrasive assemblies that may be removed from and attached to an abrasive assembly holder of the abrasive rotary tool. The removable abrasive assemblies may be quickly replaced and have a more consistently applied abrasive layer as compared to abrasive rotary tools that utilize replaceable abrasive layers.

[0081] Abrasive rotary tools as disclosed herein may include a coupling layer disposed between a shank of the abrasive rotary tool and the abrasive layer of the abrasive rotary tool. The coupling layer may be disposed at a variety of locations between the shank and the abrasive layer of the abrasive rotary tool.

[0082] FIG. 3A illustrates a side view cross-sectional diagram of an abrasive rotary tool 200 with a replaceable flat abrasive assembly 204 for abrading a substrate through a contact surface 214. Abrasive assembly 204 includes an abrasive layer 212 and a rigid support layer 210 coupled to abrasive layer 212. Abrasive assembly 204 is coupled to abrasive assembly holder 202 through a coupling layer 216. In the embodiment of FIG.

3A, abrasive assembly holder 202 includes shank 206 and elastic layer 208. Rigid support layer 210 may provide a rigid support to abrasive layer 212, such that abrasive assembly 204 may have a substantially planar contact surface during abrading. Further, abrasive assembly 204 may include few components, allowing abrasive assembly 204 to be manufactured at low cost.

[0083] FIG. 3B illustrates a side view cross-sectional diagram of an abrasive rotary tool 220 with a replaceable flat abrasive assembly 224 for abrading a substrate through a contact surface 234. Abrasive assembly 224 includes an abrasive layer 232, an elastic layer 228, and a rigid support layer 230 coupled to abrasive layer 232 and elastic layer 228. Abrasive assembly 224 is coupled to abrasive assembly holder 222 through a coupling layer 236. In the embodiment of FIG. 3B, abrasive assembly holder 222 includes shank 226. As in FIG. 3A above, rigid support layer 230 may provide a rigid support for abrasive layer 232, such that abrasive assembly 224 may have a substantially planar contact surface 234 during abrading. Further, abrasive assembly 224 may include elastic layer 228, such that elastic layer 228 may be replaced with replacement of abrasive assembly 224.

[0084] FIG. 3C illustrates a side view cross-sectional diagram of an abrasive rotary tool 240 with a replaceable flat abrasive assembly 244 for abrading a substrate through a contact surface 254. Abrasive assembly 244 includes an abrasive layer 252 coupled to a rigid support layer 250. Abrasive assembly 244 is coupled to abrasive assembly holder 242 through a coupling layer 256. In the embodiment of FIG. 3C, abrasive assembly holder 242 includes shank 246 and at least a portion of coupling layer 256. Elastic layer 248, which is a component of abrasive assembly 244, may provide a compressive support for abrasive layer 252, such that abrasive assembly 244 may have a substantially conformable contact surface 254 during abrading. Further, as abrasive assembly 244 includes elastic layer 248, elastic layer 248 may be replaced with replacement of abrasive assembly 244.

[0085] The coupling layer may be configured to non-permanently couple the abrasive assembly to the abrasive assembly holder. A non-permanent coupling mechanism may be any coupling mechanism that utilizes an interlocking coupling mechanism (e.g., threading) or non-interlocking range of detachment pressures or forces (e.g. magnetic force). In some examples, a non-permanent coupling mechanism may enable the abrasive assembly to be removed from the abrasive assembly holder without damage to at least one of the abrasive assembly and the abrasive assembly holder. The coupling layer may use a variety of coupling mechanisms to couple the abrasive assembly to the abrasive assembly holder, such as adhesion mechanisms (e.g., adhesives), magnetic mechanisms (e.g., magnets), and mechanical mechanisms (e.g., threads). In some embodiments, the coupling layer comprises at least one of a magnetic coupling layer, an adhesive coupling layer, and a mechanical coupling layer, such as a hook and loop coupling layer, or a threaded coupling layer. The coupling layer may include more than one portion, such that each of an abrasive assembly and an abrasive assembly holder may include a portion of the coupling layer. For example, an abrasive rotary tool may include a magnetic coupling layer that comprises a magnet and the rigid support layer comprises a ferromagnetic material. In this embodiment, the ferromagnetic material may include at least one of ferromagnetic steel and ferromagnetic stainless steel.

[0086] In some embodiments, such as rotary tools that utilize a magnetic or adhesive coupling mechanism, a coupling layer may have an associated detachment pressure or force. The detachment pressure or force of the coupling layer may represent a predetermined pressure or force or a range of pressures or forces that may be applied to the rotary tool to detach an abrasive assembly from an abrasive assembly holder. In some embodiments, the detachment pressure or force may be calibrated to be above a maximum force experienced during abrading, such that regularly-experienced operating forces may not dislodge the abrasive assembly. In some embodiments, the detachment pressure or force may be calibrated to be below a maximum applied force capability of an abrading machine, such that an applied force below the maximum applied force will remove the abrasive assembly. In some embodiments, the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa. Further discussion of the detachment pressure may be found, for example, in FIG. 7 below.

[0087] In some embodiments, such as rotary tools that utilize a mechanical coupling mechanism, a coupling layer may have an associated coupling sequence. The coupling sequence may have an associated set of one or more steps to detach an abrasive assembly and/or attach an abrasive assembly. For example, a rotary tool utilizing a threaded coupling mechanism may have a coupling sequence that includes a counter-clockwise rotational force or torque to detach an abrasive assembly and a clockwise rotational force or torque to attach an abrasive assembly.

[0088] FIG. 4A illustrates a plan view diagram of an abrasive rotary tool 300 having a magnetic coupling mechanism. Abrasive rotary tool 300 includes an abrasive assembly holder 302 and an abrasive assembly 304. Abrasive assembly holder 302 includes a shank 306 defining an axis of rotation for the rotary tool and elastic layer 308. Abrasive assembly 304 includes a rigid support layer 310 and an abrasive layer 312 having a contact surface 314. Elastic layer 308 is disposed between shank 306 and a magnetic coupling layer 316.

[0089] In the embodiment of FIG. 4A, magnetic coupling layer 316 is configured to couple to rigid support layer 310. For example, magnetic coupling layer 316 may be a magnet, while rigid support layer 310 may be a ferromagnetic material. Rigid support layer 310 may include rotating stops 320 configured to fit into rotating stop gaps 318 of magnetic coupling layer 316, such that abrasive assembly 304 may remain fixed during a rotation force applied to abrasive assembly 304 without limiting a detachment force applied downward. In some embodiments, magnetic coupling layer 316 may be a permanent magnet, such that a detachment pressure of magnetic layer 316 may be relatively constant for a particular material of abrasive assembly 304. In some embodiments, magnetic coupling layer 316 may be a non-permanent magnet, such as an induced magnet, such that abrasive assembly 304 may be detached from abrasive assembly holder 302 through removal of an electrical current from magnetic coupling layer 316.

[0090] FIG. 4B illustrates a plan view diagram of an abrasive rotary tool 320 having a threaded coupling mechanism. Abrasive rotary tool 320 includes an abrasive assembly holder 322 and an abrasive assembly 324. Abrasive assembly holder 322 includes a shank 326 defining an axis of rotation for rotary tool 320, a threaded coupling layer 336, and an elastic layer disposed between shank 326 and threaded coupling layer 336. Threaded coupling layer 336 includes internal threads 338. Abrasive assembly 324 includes a rigid support layer 330 and an abrasive layer 332 having a contact surface 334. Rigid support layer 330 includes external threads 340.

[0091] In the embodiment of FIG. 4B, threaded coupling layer 336 is configured to couple to rigid support layer 330 of abrasive assembly 324. External threads 340 of rigid support layer 330 may engage the internal threads 338 of threaded coupling layer 336, thereby enabling the coupling of abrasive assembly 324 to abrasive assembly holder 322 via threaded coupling layer 336. For example, internal threads 338 and external threads 340 may be configured in a direction opposite an intended direction of rotation of rotary tool 320.

[0092] In some embodiments, a rotary tool replacement apparatus may be used to attach and remove abrasive assemblies discussed herein from abrasive assembly holders. The rotary tool replacement apparatus may be configured to according to the coupling mechanism of the abrasive rotary tool, such as a coupling sequence or a detachment pressure or range of pressures. As such, a variety of coupling mechanisms may be used by the rotary tool replacement apparatus to attach abrasive assemblies and remove abrasive assemblies, such as adhesive mechanisms (e.g., adhesives), magnetic mechanisms (e.g., magnets), and mechanical mechanisms (e.g., threads or mechanical “quick connects”). For example, for a rotary tool that utilizes a threaded coupling mechanism as in rotary tool 320 of FIG. 4B, a rotary tool replacement apparatus may be configured to remove a first abrasive assembly by unscrewing the first abrasive assembly and attach a second abrasive assembly by screwing in a second abrasive assembly. As another example, such as for a rotary tool that utilizes a magnetic coupling mechanism as in rotary tool 300 of FIG. 4A, a rotary tool replacement apparatus may be configured to remove an abrasive assembly by applying a force that is greater than a detachment magnetic force of the magnetic coupling layer.

[0093] FIGS. 5A and 5B illustrate a polishing system 416 that includes a rotary tool replacement apparatus 412. Rotary tool replacement apparatus 412 may be configured to replace abrasive assemblies from an abrasive assembly holder 402. In the embodiments of FIGS. 5A and 5B, rotary tool replacement apparatus 412 may be configured to receive a first rotary tool 400A, remove a first abrasive assembly 404A from abrasive assembly holder 402 of first rotary tool 400A, and attach a second abrasive assembly 404B to abrasive assembly holder 402 to form a second abrasive rotary tool 400B.

[0094] In the embodiments of FIGS. 5A and 5B, rotary tool replacement apparatus 412 includes a first securing device 414A and a second securing device 414B (referred to collectively as “securing devices 414”); however, in other embodiments, rotary tool replacement apparatus may include a greater or fewer number of securing devices 414.

First securing device 414A may be configured to secure first abrasive assembly 404A for removal of first abrasive assembly 404A from abrasive assembly holder 402, while second securing device 414B may be configured to secure second abrasive assembly 404B for attachment of second abrasive assembly 404B to abrasive assembly holder 402.

[0095] FIG. 5A illustrates a side view diagram of polishing system 416 removing first abrasive assembly 404A from an abrasive assembly holder 402. First abrasive assembly 404A is coupled to abrasive assembly holder 402 through coupling layer 410 to form first abrasive rotary tool 400A. First abrasive assembly 404A includes a first rigid support layer and a first contact surface. Abrasive assembly holder 402 includes a shank 406, coupling layer 410, and an elastic layer 408 disposed between shank 406 and coupling layer 410. Shank 406 may be attached to a rotary tool holder (not shown), such as rotary tool holder 20 of FIG. 1A. In the embodiment of FIG. 5A, first securing device 414A is shown securing first abrasive assembly 404A, such that abrasive assembly 404A may be removed from abrasive assembly holder 402. For example, the rotary tool holder securing shank 406 may pull abrasive assembly holder 402 from securing device 414A.

[0096] FIG. 5B illustrates a side view diagram of polishing system 416 attaching second abrasive assembly 404B to abrasive assembly holder 402. Second abrasive assembly 404B is coupled to abrasive assembly holder 402 through coupling layer 410 to form second rotary tool 400B. Second abrasive assembly 404B includes a second rigid support layer and a second contact surface. In the embodiment of FIG. 5B, second securing device 414B is shown releasing second abrasive assembly 404B for removal of second rotary tool 400B from rotary tool replacement apparatus 412. The rotary tool replacement apparatus may be configured to facilitate the replacement of any of the abrasive assembly embodiments of the present disclosure.

[0097] FIG. 6 is a flowchart illustrating exemplary techniques for abrading a substrate. While the techniques of FIG. 6 will be described with reference to an operator manipulating assembly 10 of FIG. 1A, other assemblies and agents of operation may be used. The operator provides computer-controlled machining system 12, which includes computer controlled rotary tool holder 20 and substrate platform 22 (500). The operator secures an abrasive rotary tool to rotary tool holder 20 of computer-controlled machining system 12 (510). As described herein, the abrasive rotary tool includes a first abrasive assembly coupled to an abrasive assembly holder through a non-permanent coupling layer.

[0098] The operator operates computer-controlled machining system 12, such as through controller 14, to abrade one or more surfaces of a substrate (520), such as substrate 16 of FIG. 1A, with the abrasive rotary tool. The operator may continue to operate computer-controlled machining system 12 to abrade other substrates until a threshold related to the abrasive assembly of the abrasive rotary tool is reached. The threshold may include a set number of substrates, a set amount of operating time of the abrasive assembly, a set removal rate, or any other measurable parameter that is related to wear of a contact surface of the abrasive assembly. In some embodiments, the threshold may be related to a type of abrading for the substrate. For example, once a coarse level of abrading is completed for a particular substrate, a finer level of abrading may be started, such that a different abrasive assembly corresponding to the finer level of abrading may be attached.

[0099] In response to reaching the threshold, the operator may remove the first abrasive assembly from the abrasive assembly holder of the abrasive rotary tool (530). For example, the operator may operate at least one of rotary tool holder 20 and/or a rotary tool replacement apparatus, such as rotary tool replacement apparatus 26, to secure the first abrasive assembly and apply a removal force or decoupling sequence to remove the first abrasive assembly from the abrasive assembly holder.

[0100] In response to removing the first abrasive assembly, the operator may attach a second abrasive assembly to the abrasive assembly holder of the abrasive assembly (540). For example, the operator may operate at least one of the rotary tool holder 20 and/or rotary tool replacement apparatus 26 to contact the abrasive assembly holder to the second abrasive assembly and apply an attachment force or coupling sequence to attach the second abrasive assembly from the abrasive assembly holder.

[0101] In another embodiment, the present disclosure provides a method of abrading a substrate which includes a multi-step process that includes two or more abrasive tools to abrade the substrate. The method utilizes a single, computer-controlled machining system and the abrasive tools may be used sequentially. The abrasive tools typically have different abrading characteristics, i.e. the abrasive layer of each abrasive tool has different abrading characteristics, resulting in a higher removal rate step followed by a lower removal rate step, the lower removal rate step may provide a substrate surface roughness that is lower than the substrate surface roughness after the high removal rate step. The abrading characteristic of the tool may be adjusted by, for example, replacing an abrasive assembly with a coarser contact surface or larger abrasive grain with an abrading assembly with a finer contact surface or smaller abrasive grain. The substrate being abraded may be maintained in the computer controlled machining system during the process, while changing the abrasive assembly and/or corresponding abrading parameters. Maintaining the substrate in the tool improves efficiency, as the substrate does not have to be removed from the machine, remounted and its position re-registered in a second machine that would then apply the second abrading step. Further, maintaining the abrasive assembly holder in the machine may improve efficiency and reduce waste, as components of the abrasive rotary tool that are not worn do not have to be replaced.

[0102] Select embodiments of the present disclosure include, but are not limited to, the following:

In a first embodiment, the present disclosure provides an abrasive rotary tool, comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

an abrasive assembly, comprising:

a rigid support layer, wherein the rigid support layer has a Shore A hardness greater than about 90; and

an abrasive layer having a contact surface; and

an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a Shore A hardness less than about 70.

In a second embodiment, the present disclosure provides an abrasive rotary tool according to the first embodiment, wherein the elastic layer has a Shore A hardness less than about 50.

In a third embodiment, the present disclosure provides an abrasive rotary tool according to the first or second embodiment, further comprising a coupling layer disposed between the shank and the abrasive layer.

In a fourth embodiment, the present disclosure provides an abrasive rotary tool according to the third embodiment, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

In a fifth embodiment, the present disclosure provides an abrasive rotary tool according to the third or fourth embodiments, wherein the elastic layer is disposed between the shank and the coupling layer.

In a sixth embodiment, the present disclosure provides an abrasive rotary tool according to the third or fourth embodiments, wherein the elastic layer is disposed between the coupling layer and the rigid support layer.

In a seventh embodiment, the present disclosure provides an abrasive rotary tool according to the third or fourth embodiments, wherein the elastic layer is disposed between the rigid support layer and the abrasive layer.

In an eighth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the third through seventh embodiments, wherein the coupling layer comprises at least one of a hook and loop coupling layer, a magnetic coupling layer, an adhesive coupling layer, and a mechanical coupling layer.

In a ninth embodiment, the present disclosure provides an abrasive rotary tool according to the eighth embodiment, wherein the magnetic coupling layer comprises a magnet and the rigid support layer comprises a ferromagnetic material.

In a tenth embodiment, the present disclosure provides an abrasive rotary tool according to the ninth embodiment, wherein the ferromagnetic material comprises at least one of ferromagnetic steel and ferromagnetic stainless steel.

In an eleventh embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through tenth embodiments, wherein the elastic layer comprises at least one of an elastomer, a fabric, a nonwoven material, or a spring.

In a twelfth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through eleventh embodiments, wherein the rigid support layer comprises at least one of a metal or a plastic.

In a thirteenth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through twelfth embodiments, wherein the contact surface of the abrasive layer includes a microstructured surface.

In a fourteenth embodiment, the present disclosure provides an abrasive rotary tool according to the thirteenth embodiment, wherein the contact surface comprises a plurality of precisely shaped abrasive composites.

In a fifteenth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through fourteenth embodiments, wherein the elastic layer has a relaxation modulus of less than 25%.

In a sixteenth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through fifteenth embodiments, wherein the contact surface of the abrasive layer is parallel to the axis of rotation of the rotary tool.

In a seventeenth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the first through fifteenth embodiments, wherein an included angle between contact surface of the abrasive layer and the axis of rotation is between 5 degrees and 90 degrees.

In an eighteenth embodiment, the present disclosure provides an abrasive rotary tool, comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

an abrasive assembly, comprising:

a rigid support layer, wherein the rigid support layer has a compression modulus of greater than about 1 GPa; and

an abrasive layer having a contact surface; and

an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has an elastic modulus of less than about 0.1 GPa.

In a nineteenth embodiment, the present disclosure provides an abrasive rotary tool according to the eighteenth embodiment, wherein the elastic layer has an elastic modulus of less than 0.01 GPa.

In a twentieth embodiment, the present disclosure provides an abrasive rotary tool according to the eighteenth or nineteenth embodiment, further comprising a coupling layer disposed between the shank and the abrasive layer.

In a twenty-first embodiment, the present disclosure provides an abrasive rotary tool according to the twentieth embodiment, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

In a twenty-second embodiment, the present disclosure provides an abrasive rotary tool according to the twentieth or twenty-first embodiments, wherein the elastic layer is disposed between the shank and the coupling layer.

In a twenty-third embodiment, the present disclosure provides an abrasive rotary tool according to the twentieth or twenty-first embodiments, wherein the elastic layer is disposed between the coupling layer and the rigid support layer.

In a twenty-fourth embodiment, the present disclosure provides an abrasive rotary tool according to the twentieth or twenty-first embodiments, wherein the elastic layer is disposed between the rigid support layer and the abrasive layer.

In a twenty-fifth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the twentieth through twenty-fifth embodiments, wherein the coupling layer comprises at least one of a hook and loop coupling layer, a magnetic coupling layer, an adhesive coupling layer, and a mechanical coupling layer.

In a twenty-sixth embodiment, the present disclosure provides an abrasive rotary tool according to the twenty-fifth embodiment, wherein the magnetic coupling layer comprises a magnet and the rigid support layer comprises a ferromagnetic material.

In a twenty-seventh embodiment, the present disclosure provides an abrasive rotary tool according to the twenty-sixth embodiment, wherein the ferromagnetic material comprises at least one of ferromagnetic steel and ferromagnetic stainless steel.

In a twenty-eighth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through twenty-seventh embodiments, wherein the elastic layer comprises at least one of an elastomer, a fabric, a nonwoven material, or a spring.

In a twenty-ninth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through twenty-eighth embodiments, wherein the rigid support layer comprises at least one of a metal or a plastic.

In a thirtieth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through twenty-ninth embodiments, wherein the contact surface of the abrasive layer includes a microstructured surface.

In a thirty-first embodiment, the present disclosure provides an abrasive rotary tool according to the thirtieth embodiment, wherein the contact surface comprises a plurality of precisely shaped abrasive composites.

In a thirty-second embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through thirty-first embodiments, wherein the elastic layer has a relaxation modulus of less than 25%.

In a thirty-third embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through thirty-second embodiments, wherein the contact surface of the abrasive layer is parallel to the axis of rotation of the rotary tool.

In a thirty-fourth embodiment, the present disclosure provides an abrasive rotary tool according to any one of the eighteenth through thirty-second embodiments, wherein an included angle between contact surface of the abrasive layer and the axis of rotation is between 5 degrees and 90 degrees.

In a thirty-fifth embodiment, the present disclosure provides a polishing system, comprising:

an abrasive rotary tool comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

a first abrasive assembly coupled to the abrasive assembly holder, comprising:

a first rigid support layer; and

a first abrasive layer having a first contact surface; and

a coupling layer disposed between the shank and the abrasive layer;

a second abrasive assembly, comprising:

a second rigid support layer; and

a second abrasive layer having a second contact surface; and

a rotary tool replacement apparatus configured to:

remove the first abrasive assembly from the rotary tool; and

attach the second abrasive assembly to the abrasive assembly holder.

In a thirty-sixth embodiment, the present disclosure provides a polishing system according to the thirty-fifth embodiment, wherein the abrasive assembly holder further comprises the coupling layer.

In a thirty-seventh embodiment, the present disclosure provides a polishing system according to the thirty-fifth or thirty-sixth embodiment, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

In a thirty-eighth embodiment, the present disclosure provides a polishing system according to any one of the thirty-fifth through thirty-seventh embodiments, wherein the abrasive rotary tool further comprises an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a Shore A hardness less than about 70, and

wherein the first and second rigid support layers have a Shore A hardness greater than about 90.

In a thirty-ninth embodiment, the present disclosure provides a polishing system according to any one of the thirty-fifth through thirty-eighth embodiments,

wherein the abrasive rotary tool further comprises an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a compressibility at 25% deflection of less than about 1.5 MPa, and

wherein the first and second rigid support layers have a compressibility at 25% deflection of greater than about 2 MPa.

In a fortieth embodiment, the present disclosure provides a polishing system according to any one of the thirty-fifth through thirty-ninth embodiments, wherein the rotary tool replacement apparatus includes a removal device configured to secure the first abrasive assembly.

In a forty-first embodiment, the present disclosure provides a polishing system according to any one of the thirty-fifth through fortieth embodiments, wherein the rotary tool replacement device is configured to remove the first abrasive assembly from the rotary tool using any one of a friction mechanism, a threading mechanism, and a magnetic mechanism.

In a forty-second embodiment, the present disclosure provides an assembly, comprising:

a computer-controlled machining system comprising a computer controlled rotary tool holder and a substrate platform;

a substrate secured to the substrate platform; and

an abrasive rotary tool of any of the first through thirty-fourth embodiments.

In a forty-third embodiment, the present disclosure provides an assembly according to the forty-second embodiment, wherein the substrate is a component for an electronic device.

In a forty-fourth embodiment, the present disclosure provides an assembly according to the forty-second or forty-third embodiment, wherein the component for an electronic device is a transparent, display element.

In a forty-fifth embodiment, the present disclosure provides an assembly according to any of the forty-second through forty-fourth embodiments, wherein an abrasive assembly of the abrasive rotary tool is a first abrasive assembly, and wherein the assembly further includes a rotary tool replacement apparatus configured to:

remove the first abrasive assembly from the abrasive assembly holder of the rotary tool; and

attach a second abrasive assembly to an abrasive assembly holder of the rotary tool.

In a forty-sixth embodiment, the present disclosure provides a method for polishing a substrate, comprising:

providing a computer-controlled machining system including a computer controlled rotary tool holder and a substrate platform;

securing an abrasive rotary tool to the rotary tool holder of the computer-controlled machining system, wherein the abrasive rotary tool comprises:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

a first abrasive assembly coupled to the abrasive assembly holder, comprising:

a first rigid support layer; and

a first abrasive layer having a first contact surface; and

a coupling layer disposed between the shank and the abrasive layer;

operating the computer-controlled machining system to abrade a contact surface of the substrate using the first abrasive assembly of the abrasive rotary tool;

removing the first abrasive assembly from the abrasive assembly holder of the abrasive rotary tool; and

attaching a second abrasive assembly to the abrasive assembly holder of the abrasive rotary tool, wherein the second abrasive assembly comprises:

a second rigid support layer; and

a second abrasive layer having a second contact surface.

In a forty-seventh embodiment, the present disclosure provides a method according to the forty-sixth embodiment, wherein the contact surface is a chamfered surface and the abrasive layer of the abrasive rotary tool abrades the chamfered surface.

[0103] EXAMPLES

[0104] The operation of the present disclosure will be further described with regard to the following detailed examples. These examples are offered to further illustrate the various specific and preferred embodiments and techniques. It should be understood, however, that many variations and modifications may be made while remaining within the scope of the present disclosure.

[0105] FIGS. 8 and 9A-9B are diagrams of example abrasive rotary tools as discussed herein. The abrasive rotary tools of FIGS. 8 and 9A-9B may be used, for example, as abrasive rotary tool 18 in assembly 10 of FIG. 1A. FIG. 8 illustrates Example 1 and FIGS. 9A and 9B illustrate Example 2.

[0106] Measurement of Detachment Pressure

[0107] FIG. 7 is a schematic diagram of an experimental system 600 for determining detachment force measurements for a coupling layer 620 of an abrasive rotary tool 614 as discussed herein. System 600 includes a CNC machine 602 and a CNC machine controller 604. Controller 604 is configured to send control signals to CNC machine 602 for causing CNC machine 602 to simulate operation of machining, grinding, or abrading a substrate with rotary tool 614, which is mounted within a rotary tool holder 606 of CNC machine 602. CNC machine 602 may be capable of performing routing, turning, drilling, milling, grinding, abrading, and/or other machining operations, and controller 604 may include a CNC controller that issues instructions to rotary tool holder 606 for performing machining, grinding, and/or abrading of the substrate with one or more rotary tools 614. Controller 604 may include a general purpose computer running software, and such a computer may combine with CNC controller 604 to provide the functionality of CNC controller 604. Rotary tool 614 may be any one of the abrasive rotary tools of the present disclosure.

[0108] Rotary tool 614 includes an abrasive assembly holder 616, an abrasive assembly 622, and a coupling layer 620. Abrasive assembly holder 616 includes a shank 617 and an elastic layer 618. Abrasive assembly 622 includes a rigid support layer and an abrasive layer having a contact surface.

[0109] Force gauge 610 may be coupled to a CNC machine base 608 communicatively coupled to CNC machine controller 604. Force gauge 610 may be communicatively coupled to a computer 612 configured to receive force measurements from force gauge 610. Rotary tool 614 is mounted to force gauge 610 by an attachment device (not shown) in a manner that facilitates measurement of the detachment force on rotary tool 614 by CNC machine 602, such as through clamping or other holding mechanism. Force gauge 610 is configured to measure the force received by coupling layer 620 of rotary tool 614 in one direction. Rotary tool holder 606 is moved away from CNC machine base 608, such as at a controlled displacement, strain, or force, to create a force. Force gauge 610 measures the force and records a peak force, which may represent the detachment force for coupling layer 620. Computer 612 may use the detachment force and an effective surface area of coupling layer 620 to determine a detachment pressure (e.g., expressed in psi or MPa) for coupling layer 620.

[0110] Measurement of Hardness

[0111] Shore A hardness for foams was measured using a Shore A durometer gauge, Model 1500, Type A, available from Rex Gauge Company, Buffalo Grove, Illinois, following the procedure of ASTM D2240, Revision 15. Rockwell A hardness for metals was determined from publicly available material property data. While not performed for this example, the Rockwell A hardness test to determine Rockwell A hardness may be carried out following the general procedures of, for example, ASTM E18-17e1.

[0112] Measurement of Elasticity

[0113] Elastic modulus for materials of the elastic layer was determined using publicly available material property data. While not performed for this example, the elasticity test to determine elastic modulus may be carried out following the general procedures of, for example, ASTM D1621-16.

[0114] Measurement of Compressibility

[0115] Compressibility at 25% deflection for materials of the elastic layer was determined using manufacturer data from McMaster Carr, P. O. Box 4355, Chicago, IL 60680-4355. While not performed for this example, the compressibility test to determine the compressibility at 25% deflection may be carried out using an MTS INSIGHT

Electromechanical Testing System available from MTS Systems Corp., 14000 Technology Drive, Eden Prairie, Minnesota, following the general procedures of ASTM D3574 (for foam materials) and ASTM D575 (for rubber materials).

[0116] The following table represents tested and estimated values for the various material properties in the example below, as described above.

Material	Hardness	Elastic Modulus	Compressibility	Detachment Pressure
6061 Aluminum	40 Rockwell A*	69 GPa *	N/A	N/A
Polyurethane	30 Shore A	140 MPa *	125 kPa *	N/A
DUAL LOCK	N/A	N/A	N/A	76 kPa
Magnet	N/A	N/A	N/A	395 kPa

*represents estimated values

[0117] Manufactured Examples

[0118] Example 1 is illustrated by FIG. 8. FIG. 8 is a diagram of an abrasive rotary tool 740 having a detachable, flat abrasive assembly 744 an abrasive assembly holder 742 using a DUAL LOCK coupling mechanism (part number SJ3550, available from 3M Company, St. Paul, MN 55144). Abrasive rotary tool 740 includes abrasive assembly 744 shown detached from abrasive assembly holder 742. Abrasive assembly holder 742 includes a shank 746 manufactured from 6061 type aluminum and an elastic layer 754. Elastic layer 754 is manufactured from wear resistant quick recovery foam (part number 86375K133, available from McMaster Carr, P. O. Box 4355, Chicago, IL 60680-4355). Adhesive transfer tape is applied to both surfaces of the elastic layer 754 (part number 9472LE from 3M Company, St. Paul, MN 55144). Abrasive assembly 744 includes a rigid support layer 748 and an abrasive layer 752 coupled to rigid support layer 748 and having a contact surface 752. Rigid support layer 748 is manufactured from 6061 aluminum. Abrasive layer 752 is part number 578XA-TP2 with PSA (available from 3M Company, St. Paul, MN 55144). Abrasive rotary tool 740 includes a coupling layer that includes a first coupling layer 750A coupled to shank 746 and a second coupling layer 750B coupled to rigid support layer 748 (collectively referred to as “coupling layer 750”). Coupling layer 750 uses a hook to hook coupling mechanism, with a portion of coupling layer 750 on each of abrasive assembly 744 and abrasive assembly holder 742.

[0119] Example 2 is illustrated by FIGS. 9A and 9B. FIG. 9A is a diagram of an abrasive rotary tool 760 having a detachable, cylindrical abrasive assembly 764 coupled to an abrasive assembly holder 762 using a magnetic coupling mechanism. Abrasive rotary tool 760 includes abrasive assembly 764 coupled to abrasive assembly holder 762. Abrasive assembly holder 762 includes a shank 766 manufactured with 6061 type aluminum. Abrasive assembly 764 includes a rigid support layer 768 and an abrasive layer 772, having a contact surface 774, coupled to rigid support layer 768. Rigid support layer 768 is manufactured from ferromagnetic steel. Abrasive layer 752 is manufactured from 578XA-TP2 with PSA (available from 3M Company, St. Paul, MN 55144). Abrasive assembly holder 762 includes an elastic layer 776 coupled to shank 766 and a coupling layer 770. Elastic layer 754 is manufactured from wear resistant quick recovery foam (part number 86375K133, available from McMaster Carr, P. O. Box 4355, Chicago, IL 60680-4355). Adhesive transfer tape (part number 9472LE from 3M Company, St. Paul, MN 55144) is applied to both surfaces of the elastic layer 754.Coupling layer 770 is disposed between elastic layer 776 and rigid support layer 768. Coupling layer 770 is manufactured from neodymium magnets (part number 5862K985K985, available from McMaster Carr, P.O. Box 4355, Chicago, IL 60680-4355), with a portion of coupling layer 770 on each of abrasive assembly 764 and abrasive assembly holder 762. The magnet is glued in place with CA4 from 3M Company, St. Paul, MN 55144)
Example 3 where the coupling layer can be an adhesive, e.g. such as a PSA. PSAs known in the art can be use, such as 91022 from 3M Company, St. Paul, MN 55144. Other adhesives can include, but not limited to, a releasable adhesive, transfer adhesive, hot melts adhesives, foam tape adhesives, instant adhesives, non-permanent adhesives like 4658F, 3798LM and permanent adhesives like CA5 cyanoacrylates from 3M Company, St. Paul, MN, 55144

[0120] FIG. 9B is a diagram of abrasive rotary tool 760 of FIG. 9A with detachable abrasive assembly 764 detached from abrasive assembly holder 762. As shown in FIG. 9B, abrasive assembly holder 762 includes a first coupling layer 770A coupled to elastic layer 776 and abrasive assembly 764 includes a second coupling layer 770B coupled to rigid support layer 768.

[0121] Detachment Pressure Examples

[0122] A detachment pressure was determined for each of the DUAL LOCK mechanism of FIG. 8 and the magnetic mechanism of FIGS. 9A-9B using the mechanism described in FIG. 7 above. The detachment force was measured using a Shimpo digital force gauge (model FGV-10, available from Shimpo, 3310 Kitty Hawk Road Suite 100, Wilmington, NC 28405). Separation force was measured while moving the tool shank in the positive Z direction. Peak force was recorded and separation pressure was calculated using area of contact for the coupling layer. The DUAL LOCK mechanism required a detachment pressure of 76 kPa. The neodymium mechanism required a separation of 395 kPa. In some examples, a larger area may result in higher force values, depending on factors like materials, surface quality, etc.

[0123] Various embodiments of the invention have been described. These and other embodiments are within the scope of the following claims.

CLAIMS:

1. An abrasive rotary tool, comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

an abrasive assembly, comprising:

a rigid support layer, wherein the rigid support layer has a Shore A hardness greater than about 90; and

an abrasive layer having a contact surface; and

an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a Shore A hardness less than about 70.

2. The abrasive rotary tool of claim 1, wherein the elastic layer has a Shore A hardness less than about 50.

3. The abrasive rotary tool of claim 1, further comprising a coupling layer disposed between the shank and the abrasive layer.

4. The abrasive rotary tool of claim 3, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

5. The abrasive rotary tool of claim 3, wherein the elastic layer is disposed between the shank and the coupling layer.

6. The abrasive rotary tool of claim 3, wherein the elastic layer is disposed between the coupling layer and the rigid support layer.

7. The abrasive rotary tool of claim 3, wherein the elastic layer is disposed between the rigid support layer and the abrasive layer.

8. The abrasive rotary tool of claim 3, wherein the coupling layer comprises at least one of a hook and loop coupling layer, a magnetic coupling layer, an adhesive coupling layer, and a mechanical coupling layer.

9. The abrasive rotary tool of claim 8, wherein the magnetic coupling layer comprises a magnet and the rigid support layer comprises a ferromagnetic material.

10. The abrasive rotary tool of claim 9, wherein the ferromagnetic material comprises at least one of ferromagnetic steel and ferromagnetic stainless steel.

11. The abrasive rotary tool of claim 1, wherein the elastic layer comprises at least one of an elastomer, a fabric, a nonwoven material, or a spring.

12. The abrasive rotary tool of claim 1, wherein the rigid support layer comprises at least one of a metal or a plastic.

13. The abrasive rotary tool of claim 1, wherein the contact surface of the abrasive layer includes a microstructured surface.

14. The abrasive rotary tool of claim 13, wherein the contact surface comprises a plurality of precisely shaped abrasive composites.

15. The abrasive rotary tool of claim 1, wherein the elastic layer has a relaxation modulus of less than 25%.

16. The abrasive rotary tool of claim 1, wherein the contact surface of the abrasive layer is parallel to the axis of rotation of the rotary tool.

17. The abrasive rotary tool of claim 1, wherein an included angle between contact surface of the abrasive layer and the axis of rotation is between 5 degrees and 90 degrees.

18. An abrasive rotary tool, comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

an abrasive assembly, comprising:

a rigid support layer, wherein the rigid support layer has a compression modulus of greater than about 1 GPa; and

an abrasive layer having a contact surface; and

an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has an elastic modulus of less than about 0.1 GPa.

19. The abrasive rotary tool of claim 18, wherein the elastic layer has an elastic modulus of less than 0.01 GPa.

20. The abrasive rotary tool of claim 18, further comprising a coupling layer disposed between the shank and the abrasive layer.

21. The abrasive rotary tool of claim 20, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

22. The abrasive rotary tool of claim 20, wherein the elastic layer is disposed between the shank and the coupling layer.

23. The abrasive rotary tool of claim 20, wherein the elastic layer is disposed between the coupling layer and the rigid support layer.

24. The abrasive rotary tool of claim 20, wherein the elastic layer is disposed between the rigid support layer and the abrasive layer.

25. The abrasive rotary tool of claim 20, wherein the coupling layer comprises at least one of a hook and loop coupling layer, a magnetic coupling layer, an adhesive coupling layer, and a mechanical coupling layer.

26. The abrasive rotary tool of claim 25, wherein the magnetic coupling layer comprises a magnet and the rigid support layer comprises a ferromagnetic material.

27. The abrasive rotary tool of claim 26, wherein the ferromagnetic material comprises at least one of ferromagnetic steel and ferromagnetic stainless steel.

28. The abrasive rotary tool of claim 18, wherein the elastic layer comprises at least one of an elastomer, a fabric, or a nonwoven material.

29. The abrasive rotary tool of claim 18, wherein the rigid support layer comprises at least one of a metal or a plastic.

30. The abrasive rotary tool of claim 18, wherein the contact surface of the abrasive layer includes a microstructured surface.

31. The abrasive rotary tool of claim 30, wherein the contact surface comprises a plurality of precisely shaped abrasive composites.

32. The abrasive rotary tool of claim 18, wherein the elastic layer has a relaxation modulus of less than 25%.

33. The abrasive rotary tool of claim 18, wherein the contact surface of the abrasive layer is parallel to the axis of rotation of the rotary tool.

34. The abrasive rotary tool of claim 18, wherein an included angle between contact surface of the abrasive layer and the axis of rotation is between 5 degrees and 90 degrees.

35. A polishing system, comprising:

an abrasive rotary tool comprising:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

a first abrasive assembly coupled to the abrasive assembly holder, comprising:

a first rigid support layer; and

a first abrasive layer having a first contact surface; and

a coupling layer disposed between the shank and the abrasive layer;

a second abrasive assembly, comprising:

a second rigid support layer; and

a second abrasive layer having a second contact surface; and

a rotary tool replacement apparatus configured to:

remove the first abrasive assembly from the rotary tool; and

attach the second abrasive assembly to the abrasive assembly holder.

36. The polishing system of claim 35, wherein the abrasive assembly holder further comprises the coupling layer.

37. The polishing system of claim 35, wherein the coupling layer has a detachment pressure between about 70 kPa and about 10 MPa.

38. The polishing system of claim 35,

wherein the abrasive rotary tool further comprises an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a Shore A hardness less than about 70, and

wherein the first and second rigid support layers have a Shore A hardness greater than about 90.

39. The polishing system of claim 35,

wherein the abrasive rotary tool further comprises an elastic layer disposed between the shank and the abrasive layer, wherein the elastic layer has a compressibility at 25% deflection of less than about 1.5 MPa, and

wherein the first and second rigid support layers have a compressibility at 25% deflection of greater than about 2 MPa.

40. The polishing system of claim 35, wherein the rotary tool replacement apparatus includes a removal device configured to secure the first abrasive assembly.

41. The polishing system of claim 35, wherein the rotary tool replacement device is configured to remove the first abrasive assembly from the rotary tool using any one of a friction mechanism, a threading mechanism, and a magnetic mechanism.

42. An assembly, comprising:

a computer-controlled machining system comprising a computer controlled rotary tool holder and a substrate platform;

a substrate secured to the substrate platform; and

an abrasive rotary tool of any of claims 1-34.

43. The assembly of claim 42, wherein the substrate is a component for an electronic device.

44. The assembly of claim 43, wherein the component for an electronic device is a transparent, display element.

45. The assembly of claim 42, wherein an abrasive assembly of the abrasive rotary tool is a first abrasive assembly, and wherein the assembly further includes a rotary tool replacement apparatus configured to:

remove the first abrasive assembly from the abrasive assembly holder of the rotary tool; and

attach a second abrasive assembly to an abrasive assembly holder of the rotary tool.

46. A method for polishing a substrate, comprising:

providing a computer-controlled machining system including a computer controlled rotary tool holder and a substrate platform;

securing an abrasive rotary tool to the rotary tool holder of the computer-controlled machining system, wherein the abrasive rotary tool comprises:

an abrasive assembly holder comprising a shank defining an axis of rotation for the rotary tool;

a first abrasive assembly coupled to the abrasive assembly holder, comprising:

a first rigid support layer; and

a first abrasive layer having a first contact surface; and

a coupling layer disposed between the shank and the abrasive layer;

operating the computer-controlled machining system to abrade a contact surface of the substrate using the first abrasive assembly of the abrasive rotary tool;

removing the first abrasive assembly from the abrasive assembly holder of the abrasive rotary tool; and

attaching a second abrasive assembly to the abrasive assembly holder of the abrasive rotary tool, wherein the second abrasive assembly comprises:

a second rigid support layer; and

a second abrasive layer having a second contact surface.

47. The method of claim 46, wherein the contact surface is a chamfered surface and the abrasive layer of the abrasive rotary tool abrades the chamfered surface.

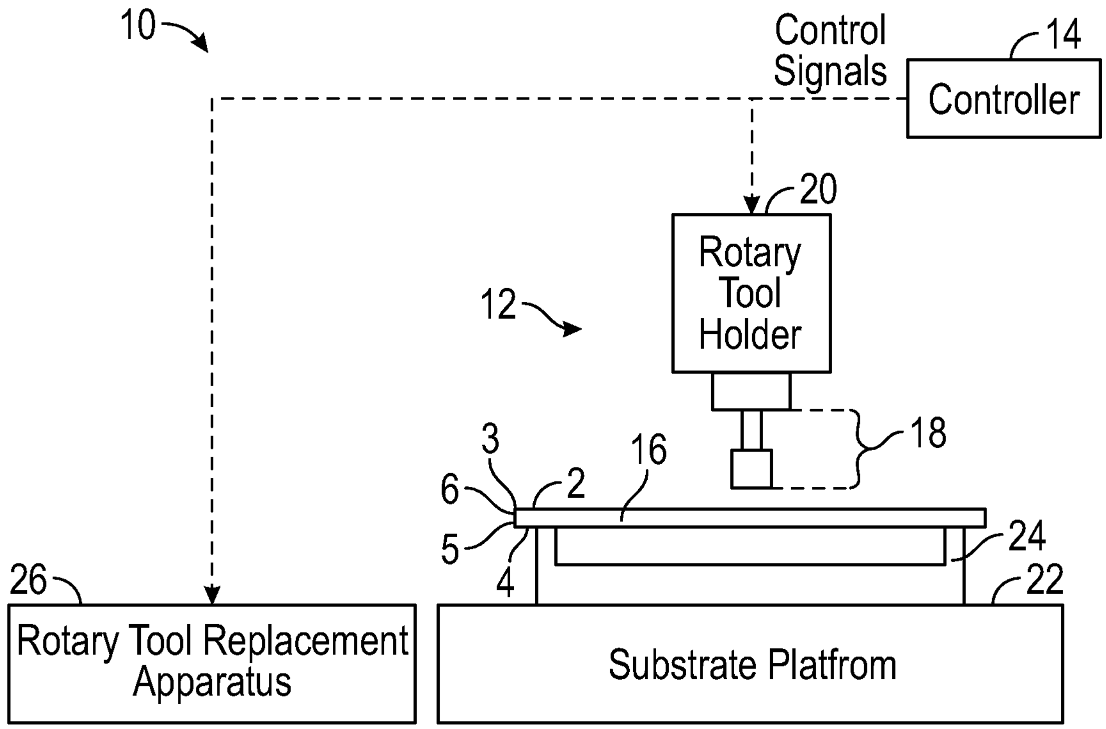
10
Control Signals
14
Controller
20
Rotary Tool Holder
12
18
3
16
6
2
5
24
4
22
26
Rotary Tool Replacement Apparatus
Substrate Platfrom

FIG. 1A

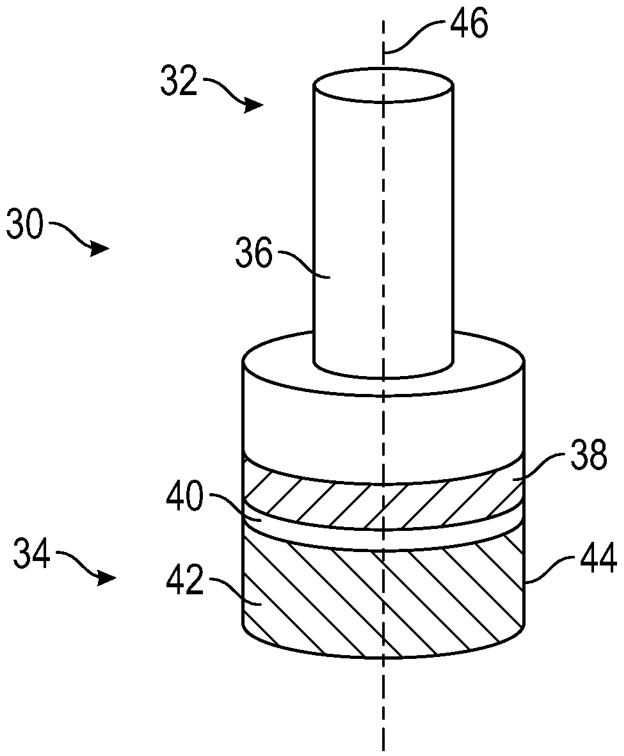
46
32
30
36
38
40
34
44
42

FIG. 1B

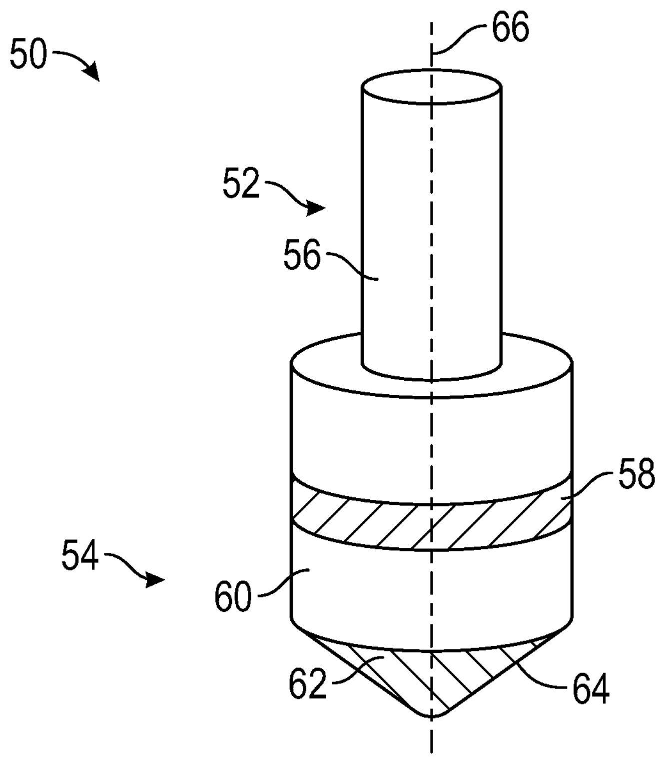

FIG. 1C

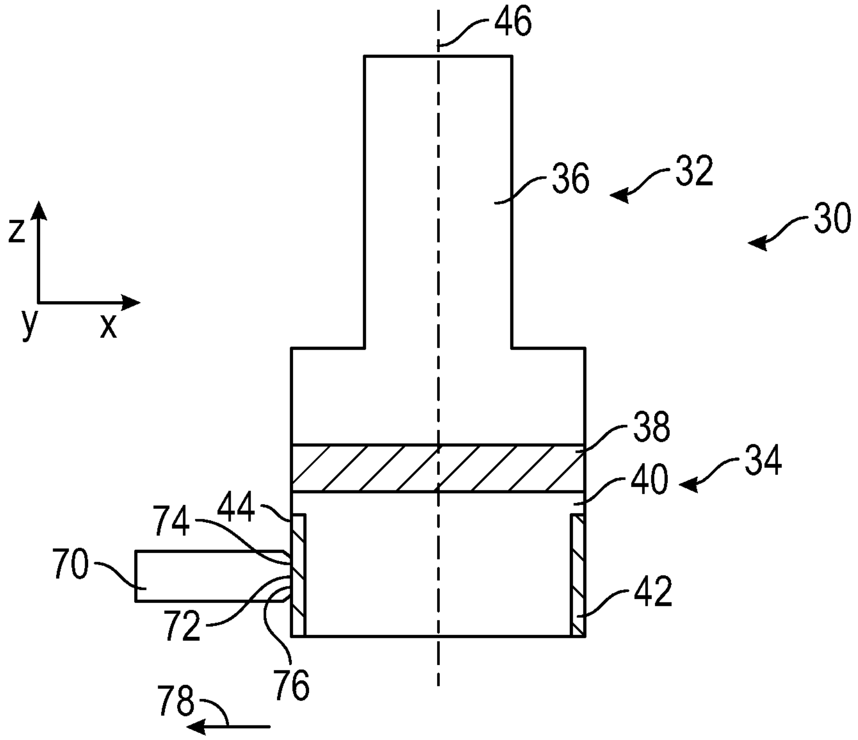

FIG. 1D

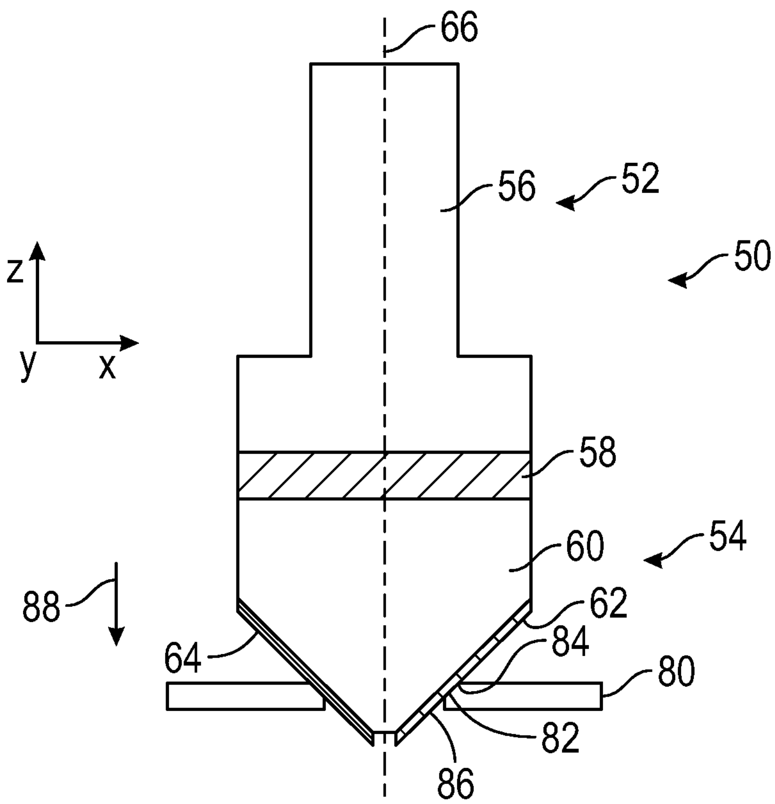

FIG. 1E

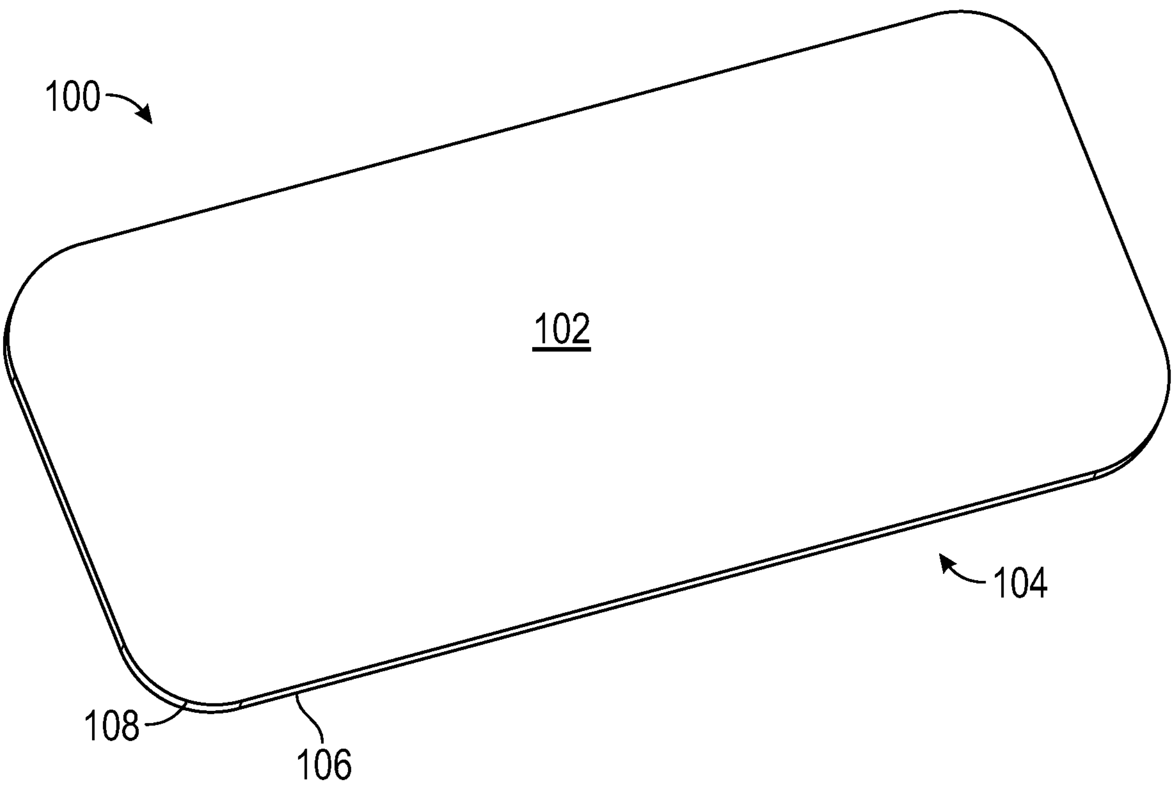

FIG. 2A

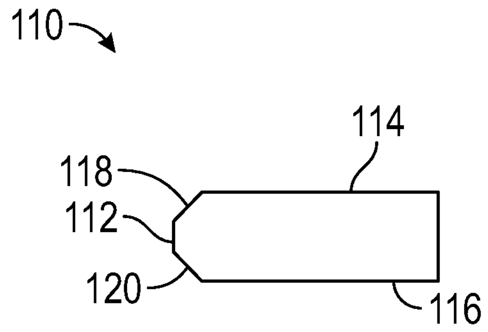

FIG. 2B

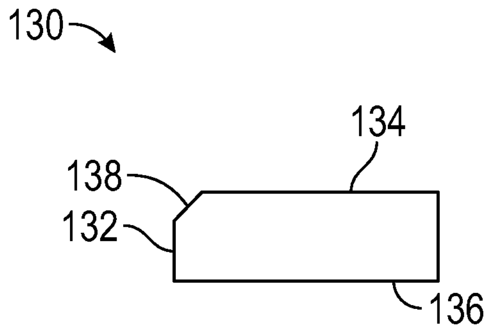

FIG. 2C

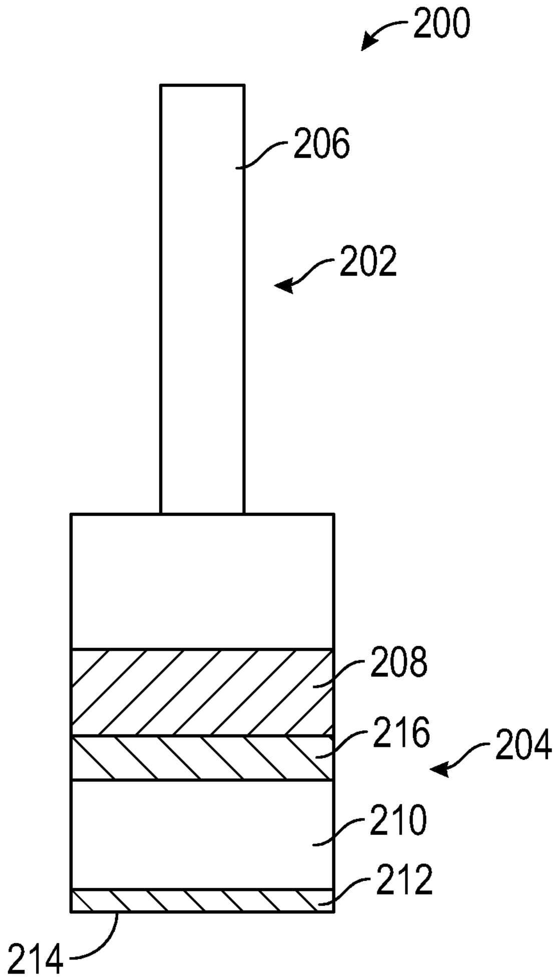

FIG. 3A

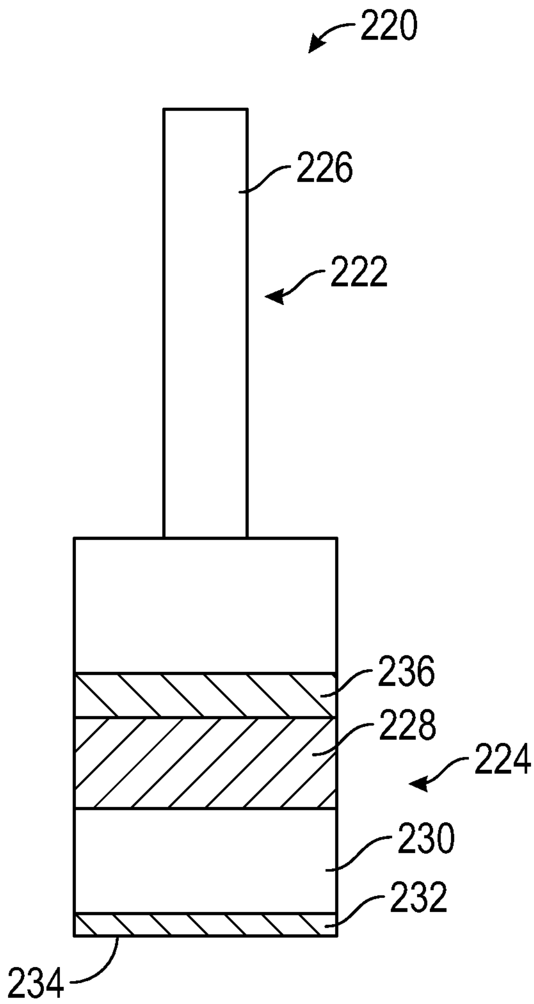

FIG. 3B

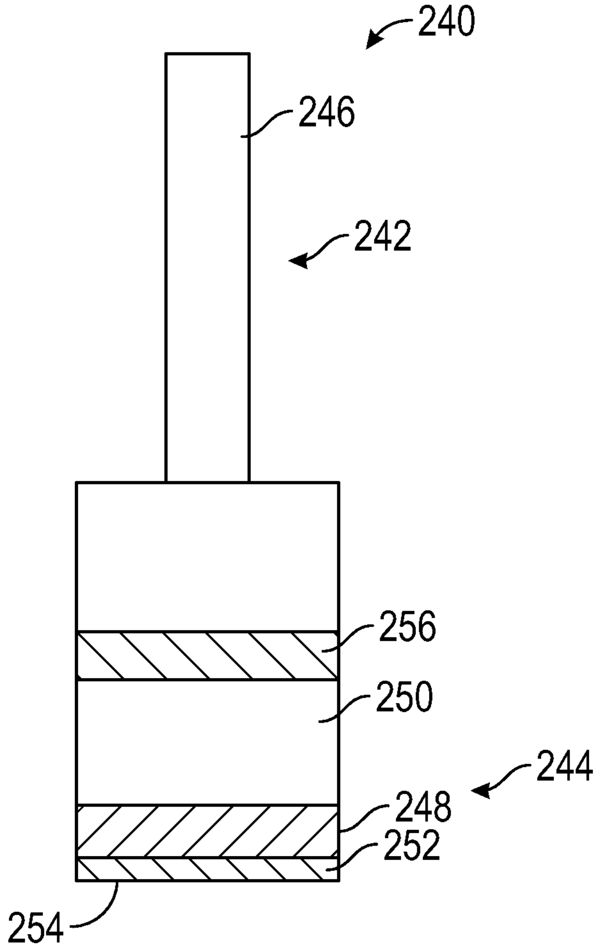
240
246
242
256
250
244
248
252
254

FIG. 3C

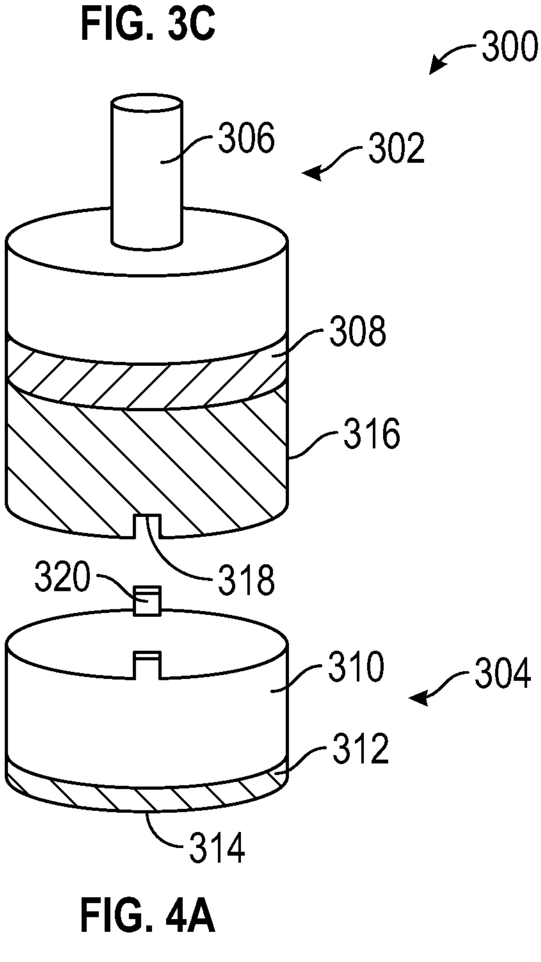
300
306
302
308
316
318
320
310
304
312
314

FIG. 4A

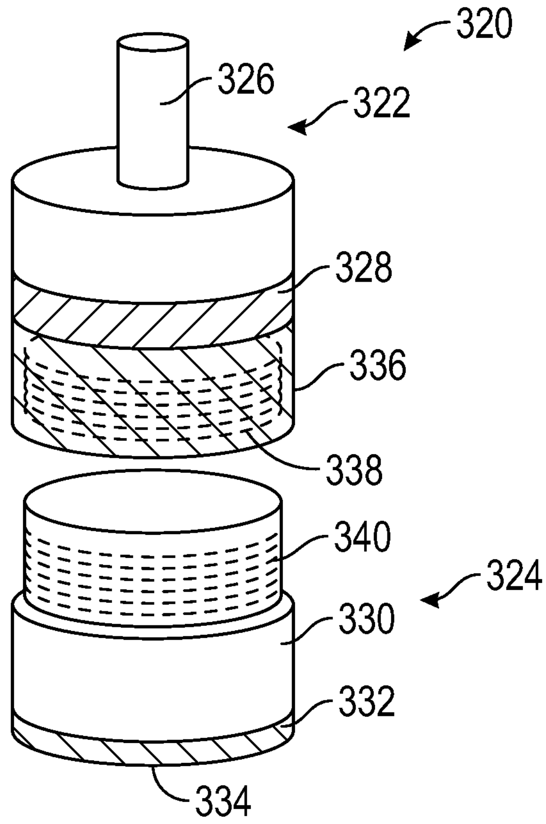
320
326
322
328
336
338
340
324
330
332
334

FIG. 4B

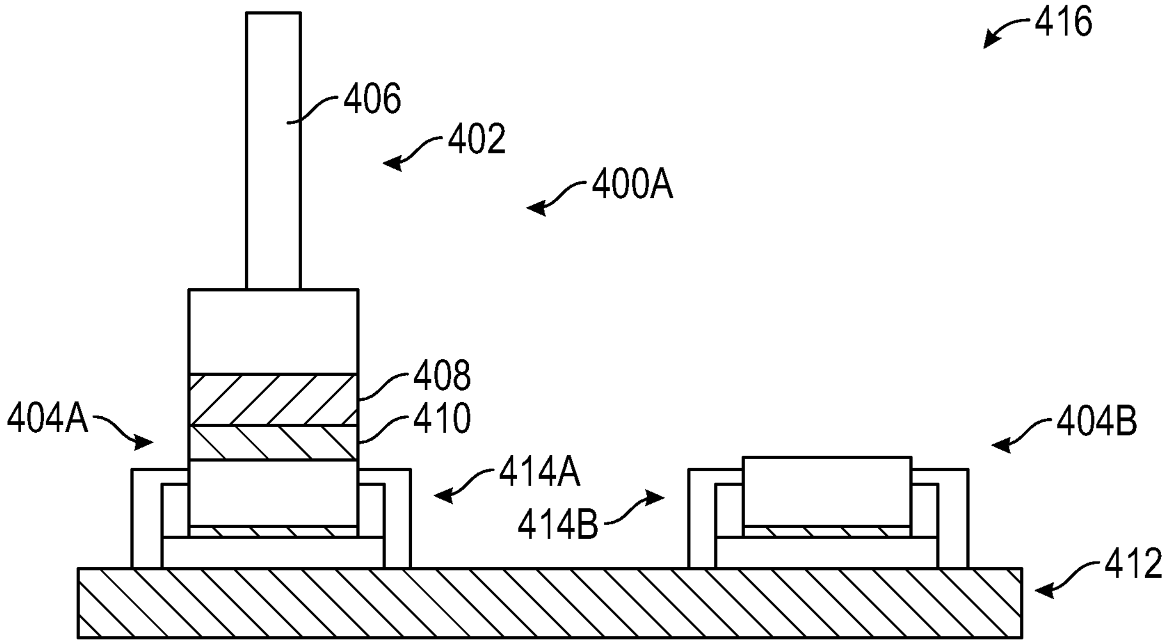
416
406
402
400A
408
410
404A
414A
414B
404B
412

FIG. 5A

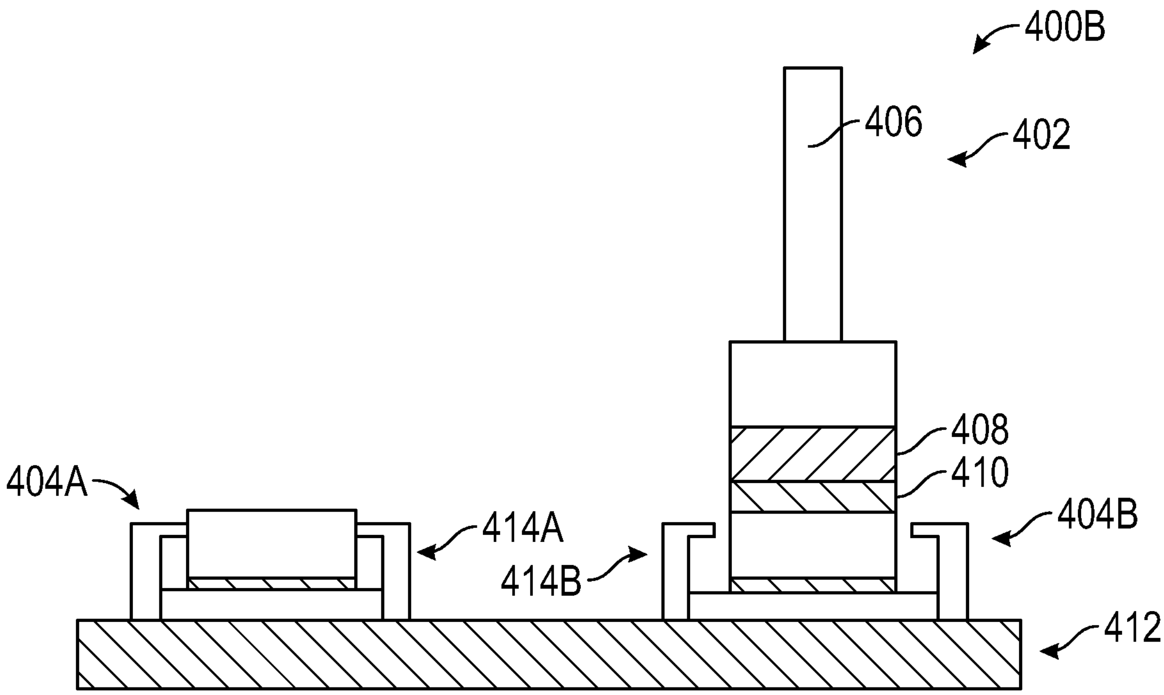
400B
406
402
408
410
404A
414A
414B
404B
412

FIG. 5B

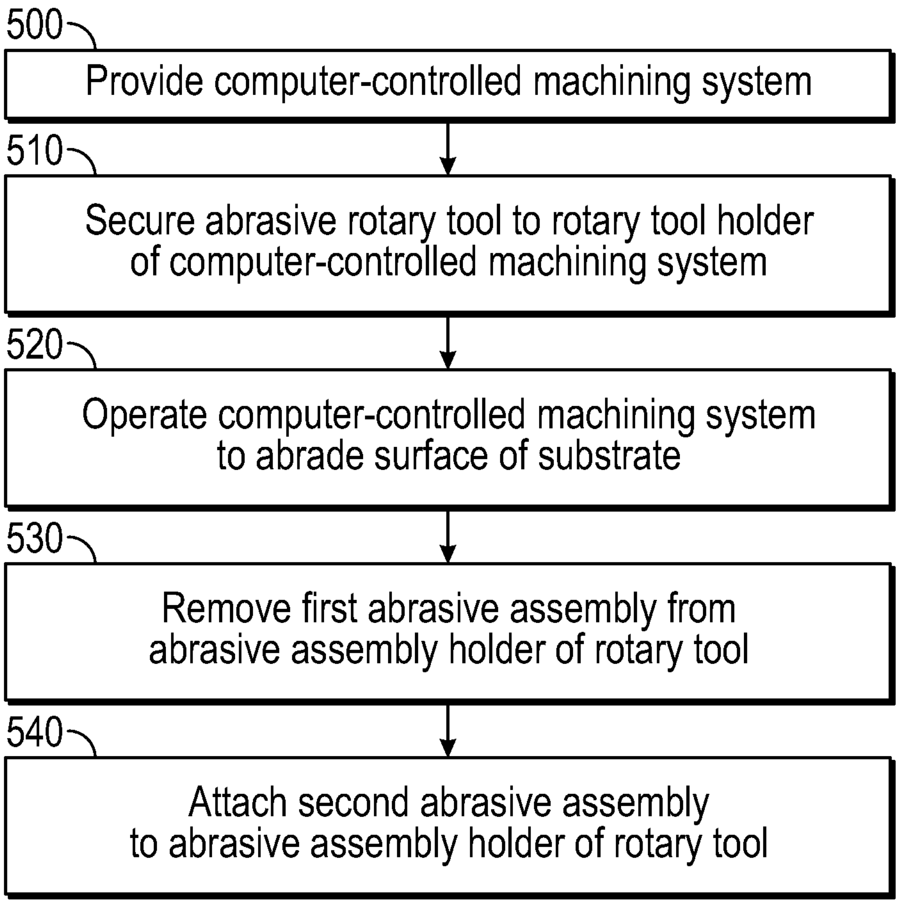
500
Provide computer-controlled machining system
510
Secure abrasive rotary tool to rotary tool holder of computer-controlled machining system
520
Operate computer-controlled machining system to abrade surface of substrate
530
Remove first abrasive assembly from abrasive assembly holder of rotary tool
540
Attach second abrasive assembly to abrasive assembly holder of rotary tool

FIG. 6

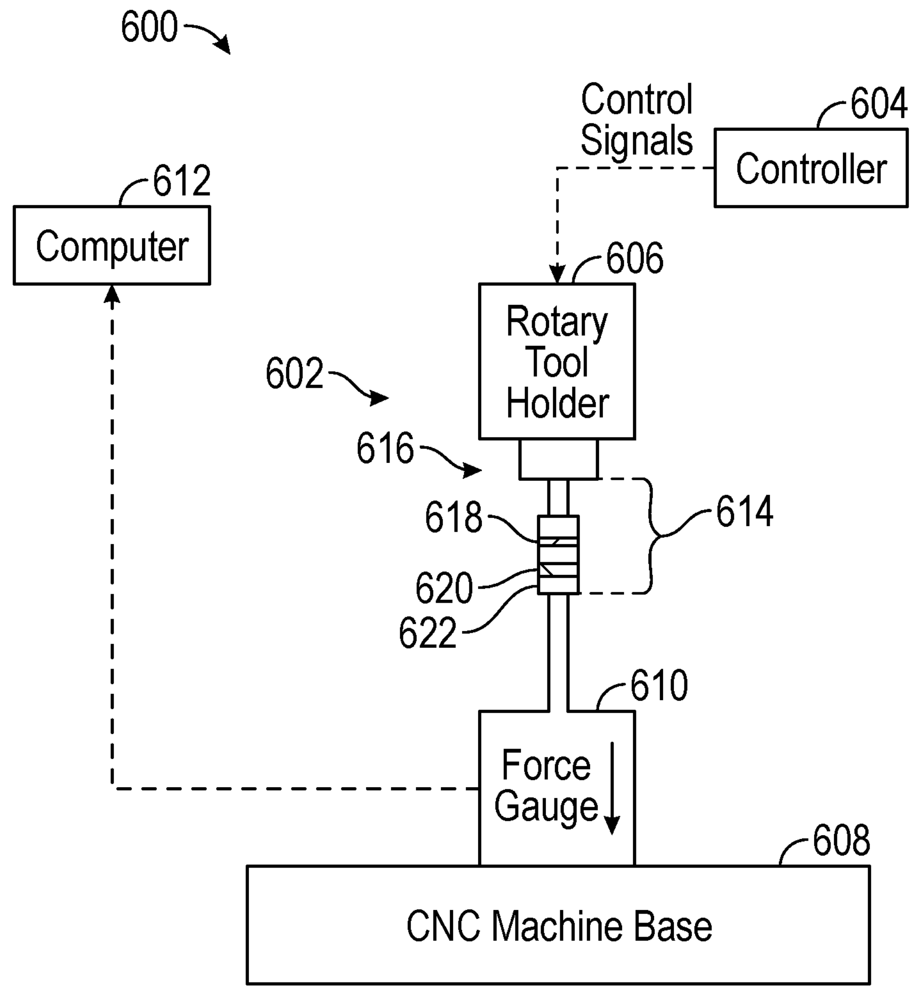
600
Control
Signals
604
Controller
612
Computer
606
Rotary
Tool
Holder
602
616
618
614
620
622
610
Force
Gauge
608
CNC Machine Base

FIG. 7

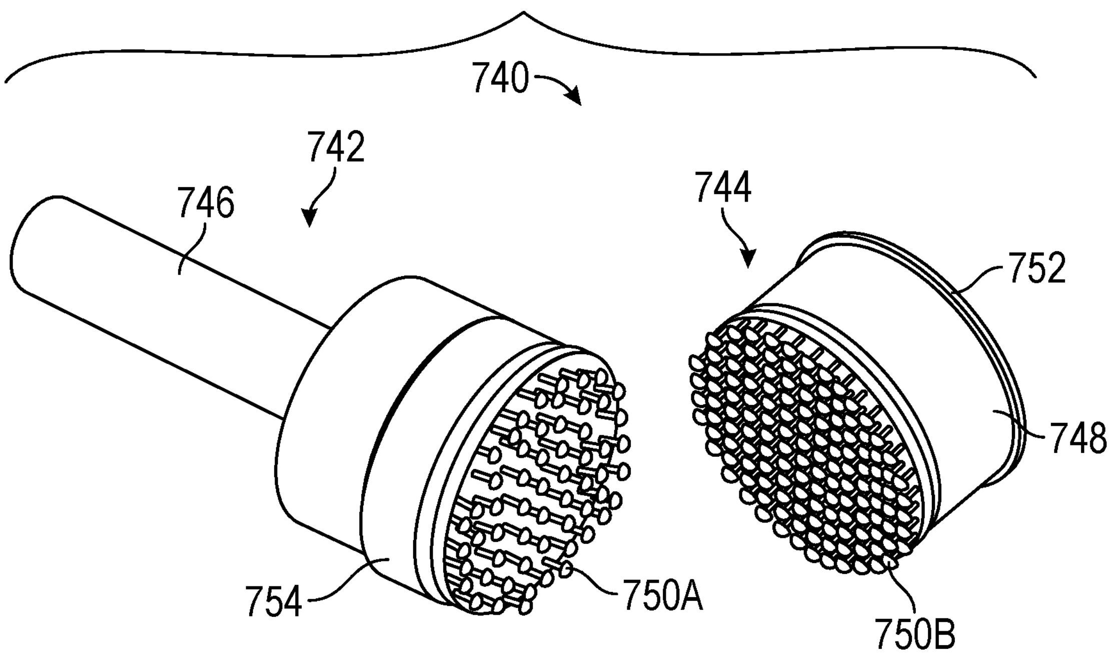
740
742
746
744
752
748
754
750A
750B

FIG. 8

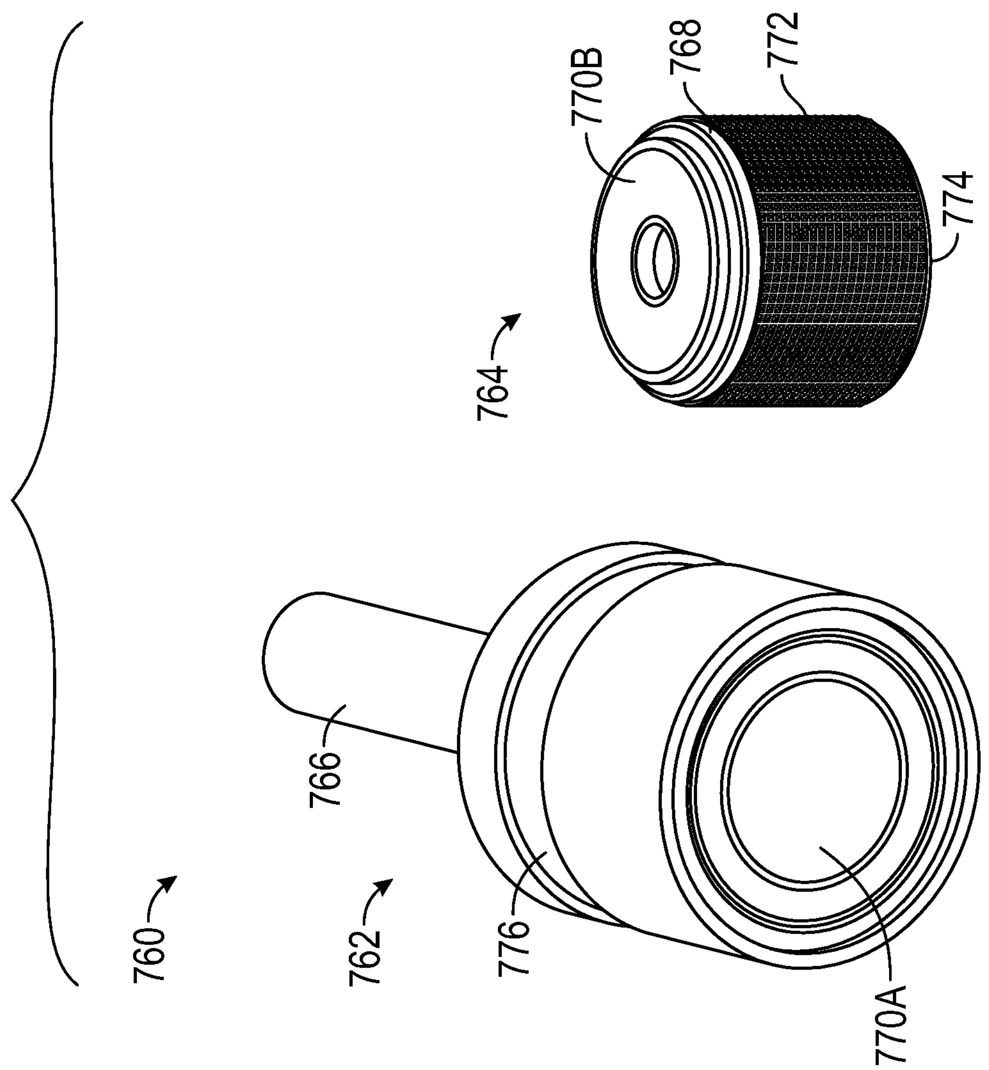
760
762
764
766
776
770A
770B
768
772
774

FIG. 9B

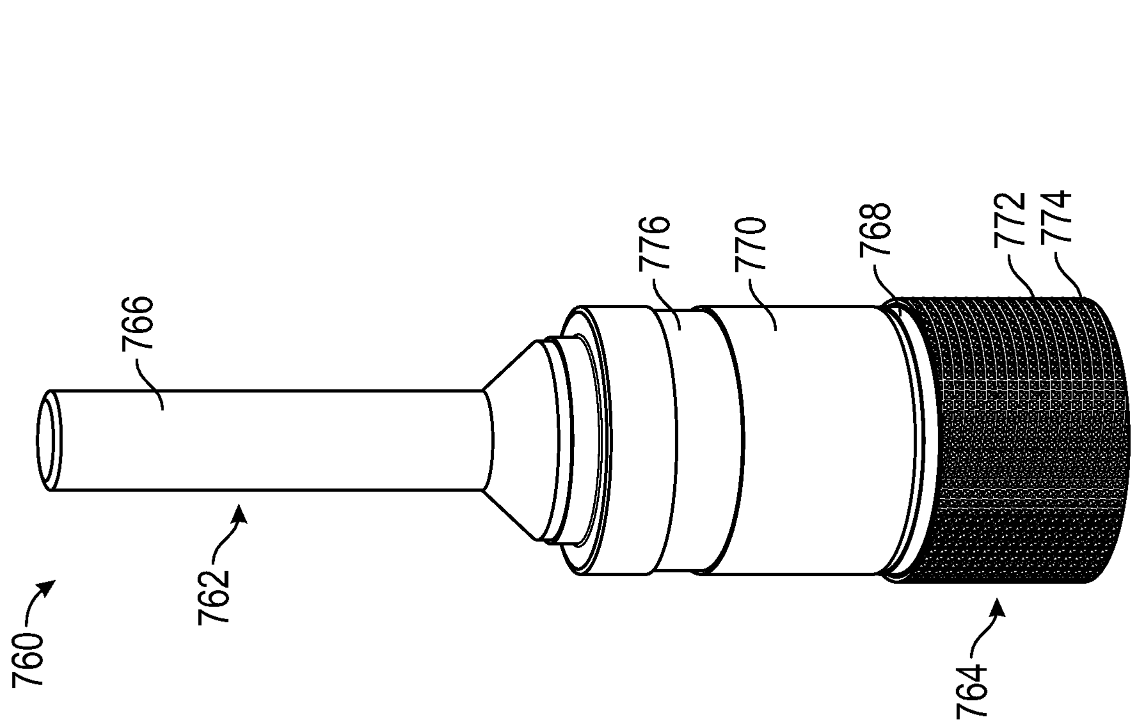
760
762
764
766
776
770
768
772
774

FIG. 9A

INTERNATIONAL SEARCH REPORT	International application No. PCT/IB2019/054339

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B24D 9/00; B24D 7/00; B24D 9/08; B24D 13/02; B24D 13/14 (2019.01)

CPC - B24D 9/00; B24D 7/00; B24D 9/08; B24D 13/02; B24D 13/14 (2019.08)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

USPC - 451/359; 451/177; 451/178; 451/358 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2012/0276824 A1 (MARTON MIKSA) 01 November 2012 (01.11.2012) entire document	1-3, 5-8, 11-14, 18-20, 22-25, 28-31, 42-44
Y	US 2004/0121713 A1 (COOPER et al) 24 June 2004 (24.06.2004) entire document	1-3, 5-8, 11-14, 18-20, 22-25, 28-31, 42-44
Y	WO 2017/044403 A1 (3M INNOVATIVE PROPERTIES COMPANY) 16 March 2017 (16.03.2017) entire document	42-44
A	15-20 Shore 'A' Durometer Neoprene Rubber Sheets. Ace Hose & Rubber Company. 13 January 2017 (13.01.2017). [retrieved on 09.13.2019]. Retrieved from the Internet: <URL: https://web.archive.org/web/20170113180238/https://www.acehose.com/15-durometer-neoprene-sheet-rubber.htm>.	1-47
A	Materials in Design: Stethoscope. Blogger. 29 April 2016 (29.04.2016). [retrieved on 09.13.2017] Retrieved from the Internet: <URL:http://designstethoscope.blogspot.com/>.	1-47
A	Hardness of Rubber Rollers. Imperial Rubbers. April 2012 (04.2012). [retrieved on 09.13.2019]. Retrieved from the Internet: <URL: http://www.imperialrubber.com/imperial-rubber-hardness-of-rubber-rollers.asp>. Page 5.	1-47
A	Overview of materials for Polycarbonate, Extruded. MatWeb. 03 December 2017 (03.12.2017). [retrieved on 09.13.2019]. Retrieved from the Internet: <URL: https://web.archive.org/web/20171203145454/http://www.matweb.com/search/DataSheet.aspx?MatGUID=501acbb63cbc4f748faa7490884cdbca&ckck=1>.	1-47

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 September 2019	09 OCT 2019
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, VA 22313-1450 Facsimile No. 571-273-8300	Authorized officer Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Plasticizer-Induced Stress Cracking of Rigid PVC and Polycarbonate. Medical Design Briefs. 01 March 2016 (01.03.2016). [retrieved on 09.13.2019]. Retrieved from the Internet: <URL: https://www.medicaldesignbriefs.com/component/content/article/mdb/features/articles/24145>. Page 1	1-47