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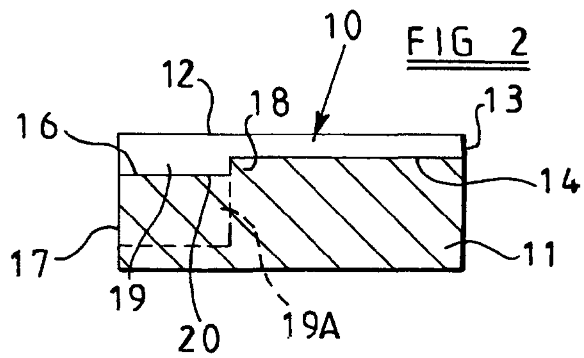
(54) **Preform cutting element**

(57) A preform cutting element, for use in a drag-type drill bit, includes a facing table (10) of polycrystalline diamond having a front face (12), a peripheral surface (13), and a rear surface (14) bonded to the front face of a tungsten carbide substrate (11). The rear face (14) ofthe diamond facing table is integrally formed with a single protuberance (19), adjacent the periphery ofthe element, which extends into a correspondingly shaped recess in the substrate (11).

FIG 2



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Description

[0001] The invention relates to elements faced with superhard material, and particularly to preform elements comprising a facing table of superhard material having a front face, a peripheral surface, and a rear surface bonded to a substrate of material which is less hard than the superhard material.

[0002] Preform elements of this kind are often used as cutting elements on rotary drag-type drill bits, and the present invention will be particularly described in relation to such use. However, the invention is not restricted to cutting elements for this particular use, and may relate to preform elements for other purposes. For example, elements faced with superhard material, of the kind referred to, may also be employed in workpiece-shaping tools, high pressure nozzles, wire-drawing dies, bearings and other parts subject to sliding wear, as well as elements subject to percussive loads as may be the case in tappets, cams, cam followers, and similar devices in which a surface of high wear resistance is required.

[0003] Preform elements used as cutting elements in rotary drill bits usually have a facing table of polycrystalline diamond, although other superhard materials are available, such as cubic boron nitride. The substrate of less hard material is often formed from cemented tungsten carbide, and the facing table and substrate are bonded together during formation of the element in a high pressure, high temperature forming press. This forming process is well known and will not be described in detail.

[0004] Each preform cutting element may be mounted on a carrier in the form of a generally cylindrical stud or post received in a socket in the body of the drill bit. The carrier is often formed from cemented tungsten carbide, the surface of the substrate being brazed to a surface on the carrier, for example by a process known as "LS bonding". Alternatively, the substrate itself may be of sufficient thickness as to provide, in effect, a cylindrical stud which is sufficiently long to be directly received in a socket in the bit body, without being brazed to a carrier. The bit body itself may be machined from metal, usually steel, or may be moulded using a powder metallurgy process.

[0005] Such cutting elements are subjected to extremes of temperature during formation and mounting on the bit body, and are also subjected to high temperatures and heavy loads when the drill is in use down a borehole. It is found that as a result of such conditions spalling and delamination of the superhard facing table can occur, that is to say the separation and loss of the diamond or other superhard material over the cutting surface of the table.

[0006] This may also occur in preform elements used for other purposes, and particularly where the elements are subjected to repetitive percussive loads, as in tappets and cam mechanisms.

[0007] Commonly, in preform elements of the above type the interface between the superhard table and the substrate has usually been flat and planar. However, particularly in cutting elements for drill bits, attempts have been made to improve the bond between the superhard facing table and the substrate by configuring the rear face of the facing table so as to provide a degree of mechanical interlocking between the facing table and substrate.

[0008] One such arrangement is shown in U.S. Patent Specification No. 5120327 where the rear surface ofthe facing table is integrally formed with a plurality of identical spaced apart parallel ridges of constant depth. The facing table also includes a peripheral ring of greater thickness, the extremities of the parallel ridges intersecting the surrounding ring. U.S. Specification No. 4784023 illustrates a similar arrangement but without the peripheral ring.

[0009] Other types of non-planar interface between the superhard table and substrate of a preform element are described in British Patent Specifications Nos. 2283772, 2283773, 2290326, 2290328, 2299109, 2300016, and 2305449.

[0010] Such prior art arrangements have met with some success in the field in that they may reduce the incidence of spalling or delamination ofthe superhard facing table during both the manufacture and operation of the drill bit. However, problems may be encountered in the manufacture of preform elements with a non-planar interface. In particular it may often be found that a significant proportion of such elements are defective, do not pass the required quality tests, and must be rejected. A common form of defect is the incomplete sintering of regions of the superhard layer and, in the case where the superhard material is diamond, graphitisation of the diamond in such regions.

[0011] The usual process for the manufacture of preform elements is first to form the substrate by compacting a mixture oftungsten carbide and cobalt powder in a press to produce a self-supporting "green" compact of appropriate shape. If the preform element is to have a non-planar interface, one surface of the compact will be pre-configured with a pattern of recesses and/or projections. This compact is then located in a container (which may be the container in which it is formed) and a layer of fine diamond particles is applied to the configured surface of the substrate. The whole assembly is then subjected to very high temperature and pressure in a press so that the substrate sinters and the diamond particles become bonded to one another, and the diamond layer as a whole becomes bonded to the configured surface of the substrate.

[0012] During the sintering process cobalt in the substrate migrates into the diamond layer and acts as a catalyst to effect the necessary diamond-to-diamond bonding in the diamond layer. However, if insufficient cobalt reaches any region of the diamond layer, such diamond-to-diamond bonding will not occur, or may occur incompletely, and the diamond may graphitise.

[0013] In a preform element having a planar interface between the diamond layer and substrate the cobalt migrates into the diamond particles along a substantially continuous front so that cobalt reaches all parts of the diamond layer quickly and evenly to ensure that bonding takes place and graphitisation is avoided. However, in cases where the interface between the substrate and diamond layer is configured with recesses and projections, some parts of the substrate are inevitably closer to the front surface of the diamond layer than others and, as a result, cobalt migrates from the substrate into the diamond layer unevenly and along an irregularly shaped front. It is believed that this uneven migration of cobalt into the diamond layer is at least partly the cause of imperfect sintering and graphitisation of regions of the diamond layer, resulting in the diamond layer being defective and the preform element being unacceptable for use.

[0014] The present invention sets out to provide a preform element where the interface between the facing table and substrate is so configured that the above-mentioned problems may be reduced or overcome, while at the same time still providing a configured interface which enhances the bonding of the facing table to the substrate, when compared to a planar interface.

[0015] According to the invention there is provided a preform element including a facing table of superhard material having a front face, a peripheral surface, and a rear surface bonded to a front face of a substrate which is less hard than the superhard material, the rear face of the facing table being integrally formed with a single protuberance which extends into a correspondingly shaped recess in the substrate.

[0016] The protuberance may project from the rear face of the facing table by a distance which is substantially equal to the thickness of the rest of the facing table, or by a distance which is no greater than two or three times the thickness of the rest of the facing table.

[0017] The maximum thickness of the facing table, including the protuberance, may be greater than half the overall thickness of the preform element.

[0018] Preferably the protuberance has a rear surface which is substantially planar and mates with a substantially planar bottom surface in the recess in the substrate. The rear surface of the protuberance may be substantially parallel to the front face of the facing table. Preferably the rest of the rear surface of the facing table, apart from said protuberance, is also substantially planar.

[0019] In an alternative arrangement the protuberance may have a rear surface which is non-planar, for example is stepped. For example, the protuberance may comprise two or more portions which decrease in cross-dimension as they extend into the substrate. The portions of the protuberance may be of similar shape but decrease in size. Alternatively, the portions of the protuberance may be of difference shapes.

[0020] In arrangements according to the invention the single protuberance serves to enhance the bonding between the facing table and the substrate, but since only a single protuberance is provided, and the rear face of the protuberance and the rest of the rear face of the facing table is preferably substantially planar, the migration of cobalt from the substrate into the facing table, during manufacture, may take place along a substantially continuous front, or along only two fronts, thus ensuring that cobalt migrates to all parts of the facing table quickly and reliably.

[0021] As used in this specification the term "substantially planar" includes smoothly curvilinear surfaces as well as flat surfaces. No surface can be absolutely flat or smooth, and in practice the front surface of the substrate, which normally defines the configuration of the rear surface of the facing table, will have a textured configuration which may be detected at an appropriate magnification. Such texture may arise naturally from the process of forming the substrate or may be deliberately applied, for example as very small ribs and grooves. Within the terms of the present invention, therefore, a textured surface is also regarded as "substantially planar" if the maximum dimension between the highs and lows ofthe texture is no greater than about 0.5mm. The essential characteristic of a planar surface, according to the present invention, is the absence of recesses and/or projections in the surface of sufficient dimensions to significantly affect the regularity of the migration of cobalt from the substrate into the facing table.

[0022] Preferably opposite portions of the peripheral edge of the protuberance are engaged by opposite portions ofthe peripheral wall of the recess in the substrate. Since the coefficient of thermal expansion of the material of the substrate will generally be greater than the coefficient of thermal expansion of the superhard material, as the temperature of the preform element rises this arrangement will have the effect of the peripheral wall of the recess in the substrate exerting greater pressure on the protuberance so that the protuberance is effectively gripped more tightly by the substrate, thereby enhancing the strength of the attachment of the facing table to the substrate.

[0023] The protuberance may decrease in cross-sectional area as it extends away from the rear surface of the facing table. For example, the protuberance may have a peripheral edge at least a part of which is bevelled or curved in cross-section.

[0024] In any of the above arrangements the protuberance preferably has a peripheral surface comprising an outer portion which is coincident with part of the peripheral surface of the facing table, and an inner portion which is bonded to a corresponding inner peripheral surface of the recess in the substrate. In this arrangement the protuberance provides part of the outer peripheral surface of the facing table and thus increases the effective thickness, and hence the strength, of the facing table in that region. Thus, in the case where the preform element is a cutting element for a rotary drill bit, the portion of the peripheral surface of the element which is partly formed by the peripheral surface of the protuberance may be arranged to provide the cutting edge of the cutting element.

[0025] The inner part of the peripheral surface of the protuberance, extending into the recess in the substrate, may be arcuate, for example it may be part circular. Preferably the arcuate portion is convexly curved, but it might also be concavely curved. For example, the peripheral surface of the protuberance may be wholly or partly circular. In an alternative arrangement the inner portion of the peripheral surface of the protuberance may be substantially straight.

[0026] The preform element as a whole may be generally in the form of a circular tablet or a tablet having a periphery which is partly circular. The peripheral surface of the preform element may also include an edge portion which is substantially straight, the protuberance lying adjacent said straight edge portion. Again, the straight edge portion may provide the cutting edge in the case where the preform element is a cutting element for use in a drag-type drill bit.

[0027] In any of the arrangements according to the invention a third material may be interposed between the facing table and substrate. Such material may be at least partly exposed at the periphery of the preform element.

[0028] The invention also provides a method of forming a plurality of preform elements, the method comprising the steps of: forming an intermediate element having a facing table, a peripheral surface, and a rear surface bonded to a front face of a substrate, the rear surface of the facing table being integrally formed with a single protuberance which extends into a correspondingly shaped recess in the substrate, the method including the further step of cutting from the intermediate member a plurality of preform elements, each element being cut from a region of the intermediate member which overlaps the peripheral surface of the protuberance.

[0029] The protuberance on the intermediate member is preferably symmetrical, the preform elements being cut from regions thereof which are symmetrically arranged around the protuberance and overlap it. For example, the protuberance on the intermediate member may be circular, the preform elements being equally angularly spaced about the centre of the protuberance. The preform elements themselves may also be circular.

[0030] The following is a more detailed description of embodiments of the invention, by way of example, reference being made to the accompanying drawings in which:

Figure 1 is a plan view ofthe substrate of a preform element in accordance with the present invention;

Figure 2 is a section of the whole element, along the line 2-2 of Figure 1, showing the facing table applied to the substrate;

Figures 3 and 4 are similar views to Figure 2, showing alternative configurations;

Figure 5 is a similar view to Figure 1 of the substrate of an alternative embodiment of the invention;

Figure 6 is a plan view of an intermediate element showing the method of forming a plurality of preform elements of the kind shown in Figure 5;

Figure 7 is a section along the line 7-7 of Figure 6;

Figures 8-13 are similar views to Figures 1 and 5, showing alternative configurations;

Figure 14 is a section on the Line 14-14 of Figure 13; and

Figures 15 and 16 are views, similar to Figures 6 and 7, of an alternative form of intermediate element for forming a plurality of preform elements of the kind shown in Figure 11.

[0031] The preform element shown in Figures 1 and 2 is in the form of a circular tablet and is usable as a cutting element for a drag-type drill bit for drilling deep holes in subsurface earthen formations. The manner of use of such cutting elements, and the types of drill bit on which they are used, are well known in the art, and will not therefore be described in detail.

[0032] Referring to Figure 2: the cutting element comprises a circular polycrystalline diamond front facing table 10 bonded to a cemented tungsten carbide substrate 11. The facing table comprises a front face 12, a peripheral surface 13 and a rear surface 14 which is bonded to the front surface of the substrate 11.

[0033] A plan view ofthe substrate 11, without the facing table 10, is shown in Figure 1. The front surface 15 of the substrate is formed with a recess 16 which extends inwardly from the peripheral surface 17 of the substrate and has a part-circular peripheral wall 18 which extends at right angles to the front surface of the substrate.

[0034] As may be seen from Figure 2, the rear surface of the diamond facing table 10 is formed with a single integral protuberance 19 which fits within the recess 16 in the substrate. The rear surface 14 ofthe facing table 10 is flat, apart from the protuberance 19, and the rear surface 20 of the protuberance 19 is also flat. However, as previously mentioned, either or each rear surface may be textured, for example formed with small-scale ribs and grooves where the difference between the highs and lows is no greater than 0.5m and is preferably of the order of 0.2mm.

[0035] The preform element may be manufactured by first moulding the substrate 11 from a compressed mixture of tungsten carbide and cobalt particles, the substrate being preformed with the recess 16 in its upper surface. The recess may be integrally moulded in the substrate, or the substrate may first be formed as a disc of substantially constant thickness, the recess being formed subsequently, for example by grinding. Alternatively, the recess may be formed by a combination of moulding and machining techniques. A layer of diamond particles is then applied to the upper surface of the substrate so as to fill the recess and cover the rest of the substrate to a required depth. The assembly is then subjected to very high temperature and pressure in a press. As previously described, during this process cobalt in the substrate migrates into the diamond layer across the interface between them and diffuses through the diamond layer, acting as a catalyst so that the diamond particles become bonded to each other and the diamond layer as a whole becomes bonded to the sintered substrate.

[0036] Since the rear surfaces 14 and 20 of the facing table and protuberance are substantially planar, the way in which the cobalt migrates into the diamond layer is similar to the way in which it migrates in the case where the whole interface is substantially planar and non-configured, i.e. it sweeps quickly and evenly through the whole of the diamond layer. At the same time, however, the bonding of the protuberance 19 into the recess 16 enhances and strengthens the attachment of the facing table 10 to the substrate 11.

[0037] It will be seen from Figure 1 that opposite portions of the peripheral wall 18 of the substrate embrace opposite sides of the protuberance 19 which fills the recess so that, since the substrate expands at a greater rate than the protuberance, when heated in use, the protuberance is effectively gripped by the surrounding material of the substrate, thus improving the attachment of the facing table to the substrate.

[0038] Since the protuberance 19 is located adjacent the periphery of the facing table 10, part of the periphery of the protuberance is coincident with the periphery of the facing table thus increasing its thickness and strength, as clearly shown in Figure 2.

[0039] Figure 3 shows an alternative configuration where the peripheral wall 21 of the recess 22 in the substrate 23 extends at an angle to the rear surface 24 of the facing table 25 so as to provide a chamfer around part of the periphery of the protuberance 19.

[0040] In the alternative arrangement shown in Figure 4, the peripheral wall 27 of the recess 28 in the substrate 29 is concavely curved so as to form a rounded chamfer around part of the periphery of the protuberance.

[0041] In the arrangements of Figures 2, 3 and 4 the single protuberance 19 which projects from the rear face of the diamond facing table projects rearwardly by a distance which is substantially equal to the thickness of the facing table. However, the protuberance may project to any lesser or greater extent. For example, as previously mentioned, the protuberance may project from the rear face of the facing table by a distance which is up to two or three times the thickness of the facing table, and arrangements are also possible where the protuberance projects rearwardly an even greater distance from this. There are indicated on Figures 2, 3 and 4, by way of example, alternative arrangements (shown in dotted lines at 19A) where the protuberance projects rearwardly from the facing table by a distance which is about five times the thickness of the rest of the facing table and where the protuberance extends through more than half the overall depth of the preform element. It will be appreciated that, as well as providing mechanical interlock between the substrate and facing table, the protuberance provides an increased thickness of diamond at the cutting edge of the element and thus increases the resistance of the element to wear and impact damage in that region. It may therefore be advantageous to increase the depth of the protuberance in this region, for example as indicated at 19A, to improve the wear and impact resistance. The main part of the facing table 10, from which the protuberance 19 projects, may also be of any desired thickness.

[0042] Figure 5 is a similar view to Figure 1 where the recess 32 in the substrate 33 has a part circular peripheral wall 34 which is of greater radius than the peripheral wall 18 in the arrangement of Figure 1. Figures 6 and 7 show how a number of preform elements of the kind shown in Figure 5 may be cut from a single intermediate member.

[0043] As may be seen from Figures 6 and 7, the intermediate member 35 is circular and comprises a front facing table 36 of polycrystalline diamond bonded to a tungsten carbide substrate 37. The rear surface 38 of the facing table 36 is formed with a central circular protuberance 39 which is bonded within a correspondingly shaped circular recess 40 in the upper surface of the substrate 37. The peripheral surface 41 of the recess 40 may be angled as shown in Figure 7, to form a bevelled periphery on the protuberance 39.

[0044] The intermediate member 35 is formed by the conventional process used for forming preform elements, but is larger in diameter. This enables three or more preform elements to be subsequently cut from the intermediate member, as indicated at 42 in Figure 6. Each preform element 42 overlaps the central protuberance 39 of the intermediate member so that each element is of similar shape to that shown in Figure 5.

[0045] Figures 8 to 13 are similar views to Figure 1 showing alternative configurations.

[0046] In the arrangement of Figure 8 the recess 43 in the substrate 44 is circular and the outer periphery of the recess is tangent to the outer periphery 45 of the substrate.

[0047] In Figure 9 the recess 46 is generally fan-shaped and has two convexly curved side walls 47 meeting at a point within the inner part of the substrate 48.

[0048] In the arrangement of Figure 10 the recess 49 extends inwardly from the periphery of the substrate 50 and has a single convexly curved inner wall 51.

[0049] The arrangement of Figure 11 is similar except that the inner wall 52 of the recess 53 is straight.

[0050] In Figure 12 the recess 54 has a peripheral wall 55 which is curved but non-circular. For example the recess may be in the shape of part of an ellipse or a parabola or any other curved shape.

[0051] In the element of Figures 13 and 14 the single recess 56 is stepped having a shallower portion 56A and a deeper portion 56B. In this arrangement the two portions are of similar and concentric shape, but this is not essential and other configurations are possible.

[0052] Figures 15 and 16 are similar views to Figures 6 and 7 and show an intermediate member 57 from which may be cut a number of preform elements of the kind shown in Figure 11. The intermediate member 57 is circular and comprises a front facing table 58 of polycrystalline diamond bonded to a tungsten carbide substrate 59. The rear surface 60 of the facing table is formed with two spaced parallel ribs 61 which are bonded within correspondingly shaped elongate grooves 62 formed in the upper surface of the substrate 59.

[0053] The intermediate member 57 is formed by the conventional process used for forming preform elements, but is larger in diameter. This enables the number of smaller preform elements to be subsequently cut from the intermediate member, as indicated at 63 in Figure 15. Each preform element 63 overlaps one of the ribs 61 of the intermediate member so that each element is of similar shape to that shown in Figure 11.

[0054] In all of the arrangements of Figures 5 to 13, the wall of the recess in the substrate may be of any of the shapes shown in Figures 2 to 4, or of any other desired cross-sectional shape.

[0055] In all of the arrangements described above and shown in the drawings, the protuberance which is integrally formed on the rear face of the facing table may project from the rear face of the facing table by any desired distance, for example as described above in relation to Figures 2, 3 and 4.

[0056] In any of the arrangements according to the present invention, also, a third material may be located between the facing table and substrate, and may be exposed at the periphery of the element. For example, there may be provided a transition layer between the facing table and substrate formed from a material which is in some respect intermediate in characteristics to the superhard material of the facing table and the less hard material of the substrate. For example, the transitional layer material may have a coefficient of thermal expansion which is intermediate the coefficients of thermal expansion of the substrate and facing table. This then serves to reduce stresses across the interface when the preform element is subjected to heating in use, or when being mounted, for example on a drill bit. For the purposes of the present invention, such transition layer may be regarded either as forming a part of the facing table or as forming a part of the substrate in the case where the protuberance or recess is partly or wholly formed in the transition layer. Alternatively, the transition layer may be of substantially constant thickness and may follow the contour of the interface between the facing table and substrate.

Claims

1. A preform element including a facing table (10) of superhard material having a front face (12), a peripheral surface (13), and a rear surface (14) bonded to a front face of a substrate (11) which is less hard than the superhard material, characterised in that the rear face of the facing table (10) is integrally formed with a single protuberance (19) which extends into a correspondingly shaped recess (16) in the substrate (11).

2. A preform element according to Claim 1, wherein the protuberance (19) projects from the rear face of the facing table (10) by a distance which is substantially equal to the thickness of the facing table.

3. A preform element according to Claim 1, wherein the protuberance (19) projects from the rear face of the facing table (10) by a distance which is no greater than twice the thickness of the rest of the facing table.

4. A preform element according to Claim 1, wherein the protuberance (19) projects from the rear face of the facing table (10) by a distance which is no greater than three times the thickness of the rest of the facing table.

5. A preform element according to any of the preceding claims, wherein the maximum thickness of the facing table (10), including the protuberance (19), is greater than half the overall thickness of the preform element.

6. A preform element according to any of the preceding claims, wherein the protuberance (19) has a rear surface which is substantially planar and mates with a substantially planar bottom surface in the recess (16) in the substrate.

7. A preform element according to any of the preceding claims, wherein the rear surface (14) of the facing table, apart from said protuberance (19), is substantially planar.

8. A preform element according to any of the preceding claims, wherein the rear surface of the protuberance (19) is substantially parallel to the front face (12) of the facing table.

9. A preform element according to any of the preceding claims, wherein the protuberance has a rear surface which is stepped.

10. A preform element according to Claim 9, wherein the protuberance comprises at least two portions which decrease in cross-dimension as they extend

into the substrate.

11. A preform element according to Claim 10, wherein the portions of the protuberance are of similar shape but decrease in size.

12. A preform element according to any of the preceding claims, wherein opposite portions of the peripheral edge of the protuberance (19) are engaged by opposite portions of the peripheral wall (18) of the recess in the substrate.

13. A preform element according to any of the preceding claims, wherein the protuberance decreases in cross-sectional area as it extends away from the rear surface (24) of the facing table (25).

14. A preform element according to Claim 13, wherein the protuberance has a peripheral edge at least a part of which is bevelled or curved in cross-section.

15. A preform element according to any of the preceding claims, wherein the protuberance (19) has a peripheral surface comprising an outer portion which is coincident with part of the peripheral surface (13) of the facing table, and an inner portion which is bonded to a corresponding inner peripheral surface (18) of the recess (16) in the substrate.

16. A preform element according to any of the preceding claims, wherein the inner part ofthe peripheral surface ofthe protuberance (19), extending into the recess (16) in the substrate, is arcuate.

17. A preform element according to Claim 16, wherein the arcuate portion of the peripheral surface of the protuberance is convexly curved.

18. A preform element according to any of Claims 1 to 15, wherein the inner portion of the peripheral surface of the protuberance is substantially straight.

19. A preform element according to any of the preceding claims, wherein the preform element as a whole is generally in the form of a circular tablet.

20. A preform element according to any of Claims 1 to 18, wherein the preform element as a whole is generally in the form of a tablet having a periphery which is partly circular.

21. A preform element according to any of Claims 1 to 18, wherein the peripheral surface of the preform element includes an edge portion which is substantially straight, the protuberance lying adjacent said straight edge portion.

22. A preform element according to any of the preceding claims, wherein a third material is interposed between the facing table and substrate.

23. A preform element according to Claim 22, wherein said third material is at least partly exposed at the periphery of the preform element.

24. A method of forming a plurality of preform elements, the method characterised by the steps of forming an intermediate element (35) having a facing table (36), a peripheral surface, and a rear surface (38) bonded to a front face of a substrate (37), the rear surface of the facing table being integrally formed with a single protuberance (39) which extends into a correspondingly shaped recess (40) in the substrate, the method including the further step of cutting from the intermediate member (35) a plurality of preform elements (42), each element being cut from a region of the intermediate member which overlaps the peripheral surface ofthe protuberance (39).

25. A method according to Claim 24, wherein the protuberance (39) on the intermediate member is symmetrical, the preform elements (42) being cut from regions thereof which are symmetrically arranged around the protuberance and overlap it.

26. A method according to Claim 25, wherein the protuberance (39) on the intermediate member (35) is circular, the preform elements (42) being equally angularly spaced about the centre of the protuberance.

27. A method according to Claim 26, wherein the preform elements (42) cut from the intermediate member are circular.

FIG 1

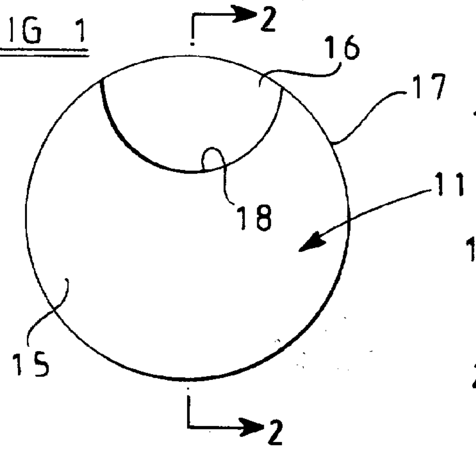


FIG 2

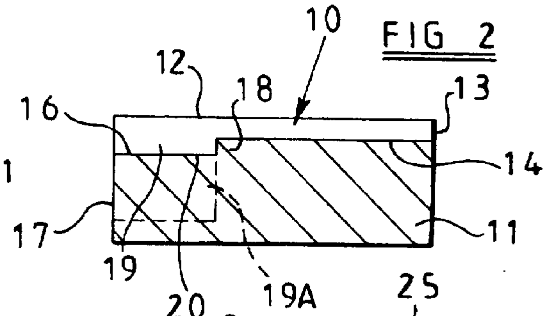


FIG 3

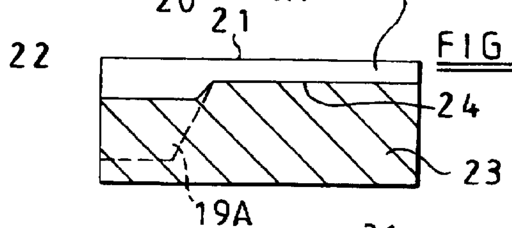
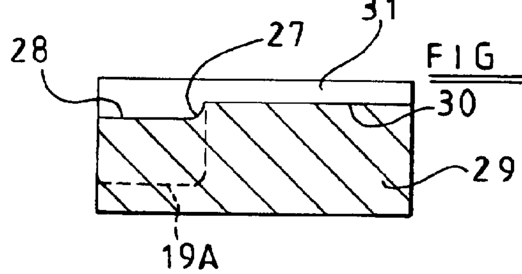


FIG 4



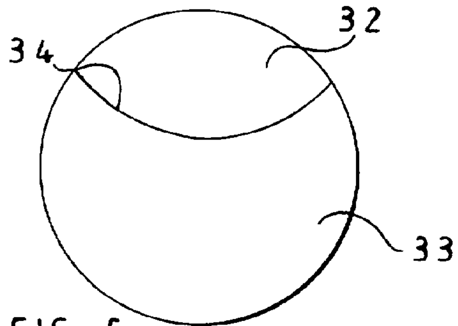


FIG 5

FIG 6

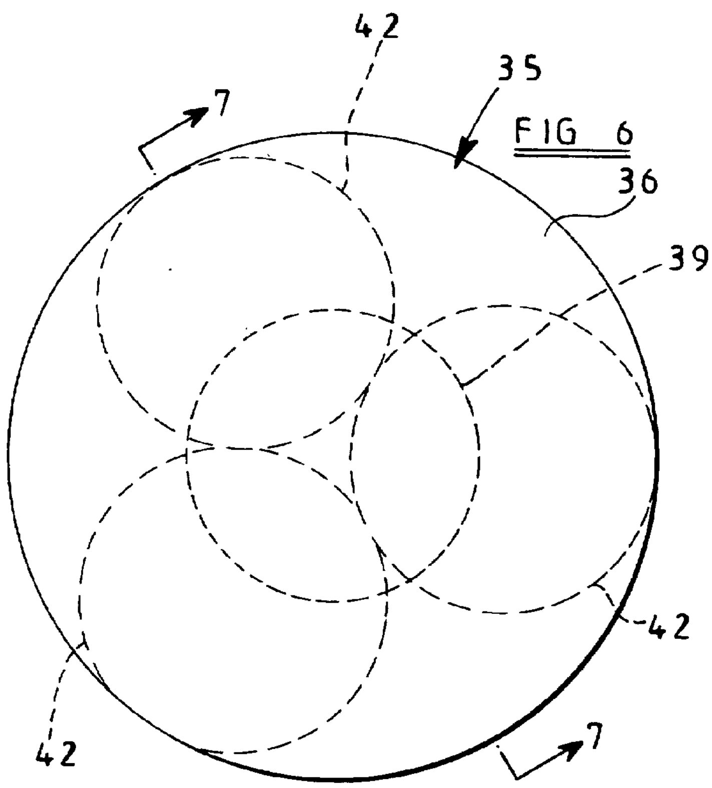
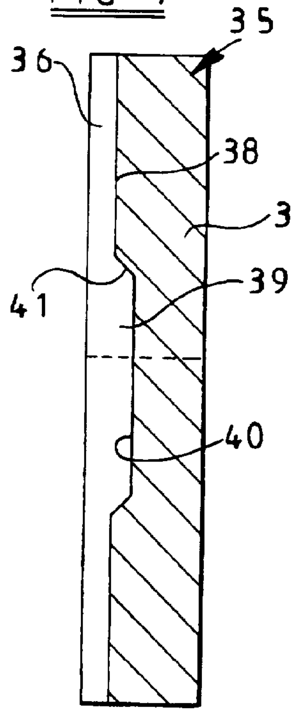


FIG 7



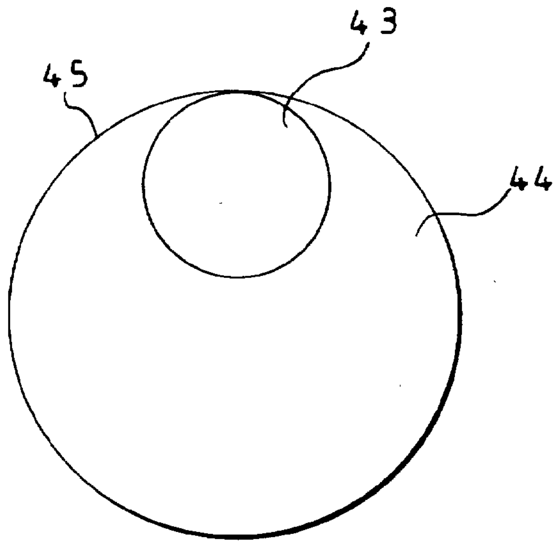


FIG 8

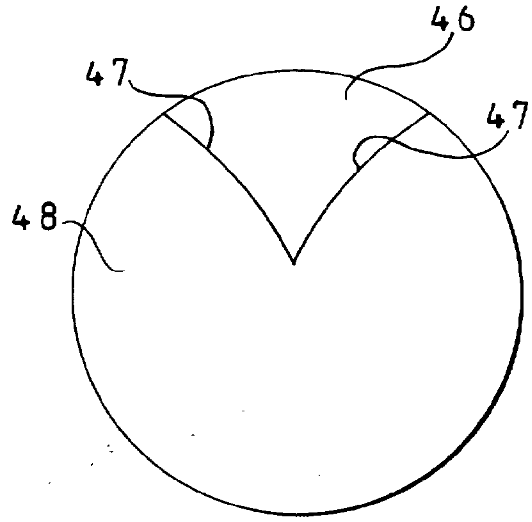


FIG 9

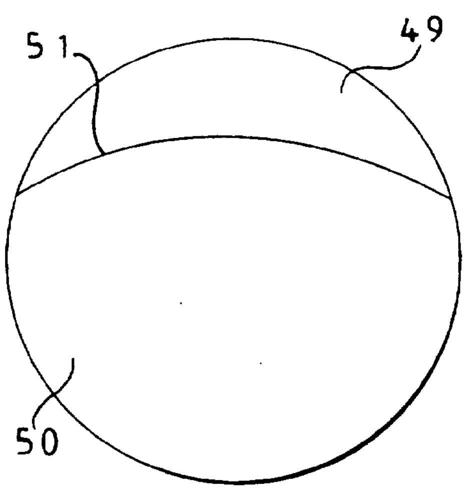


FIG 10

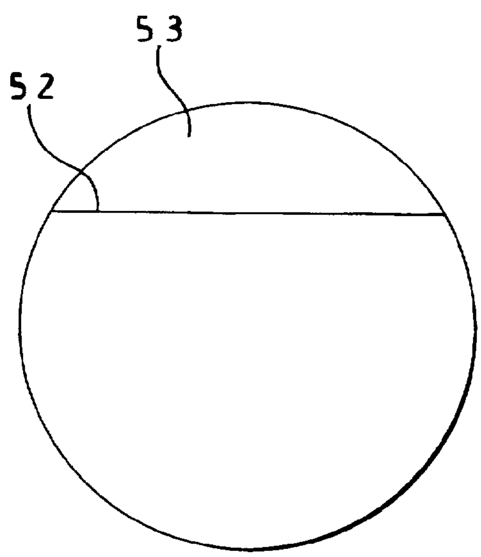


FIG 11

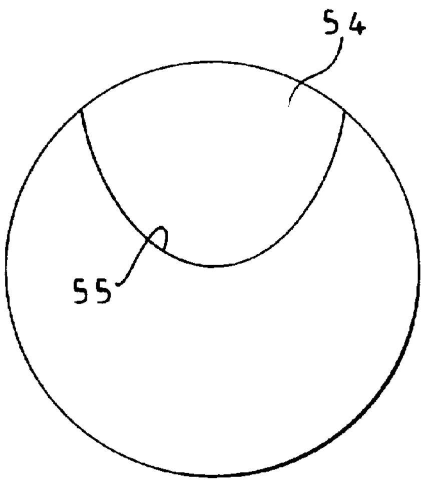


FIG 12

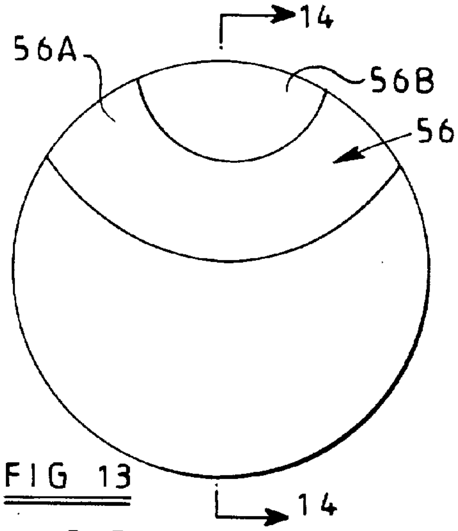


FIG 13

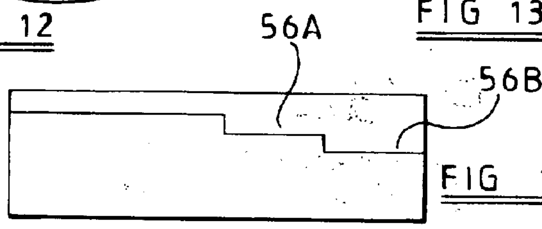


FIG 14

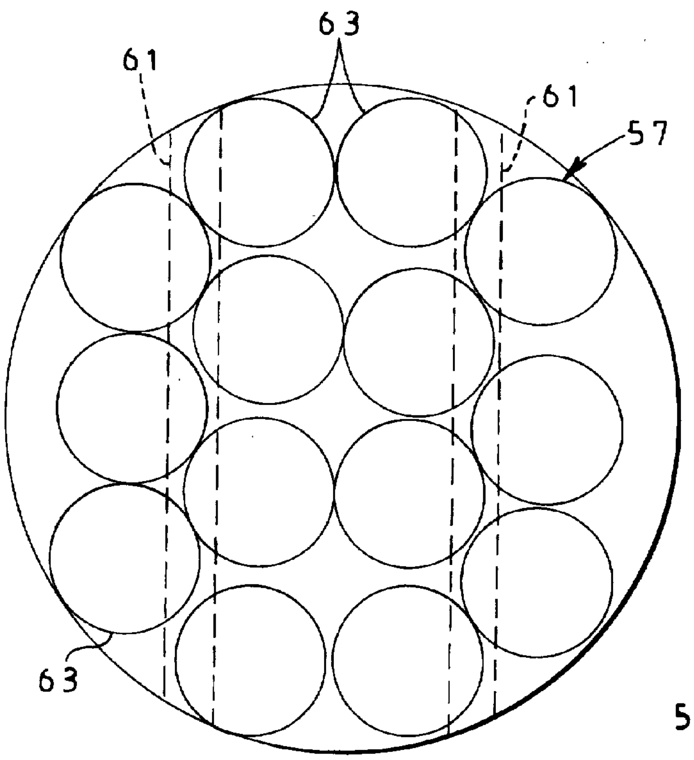


FIG 15

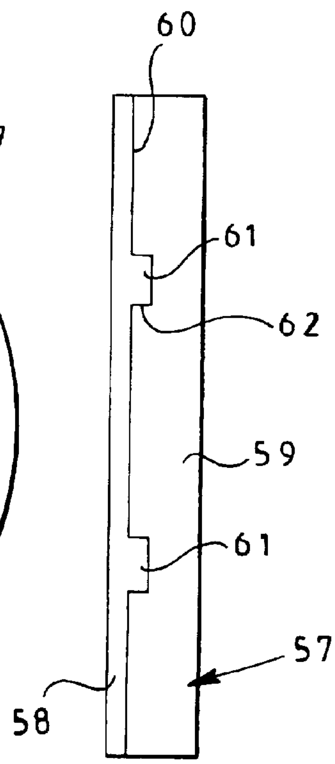


FIG 16