US011678445B2

(12) **United States Patent**
Prest et al.

(10) **Patent No.: US 11,678,445 B2**
(45) **Date of Patent: Jun. 13, 2023**

(54) **SPATIAL COMPOSITES**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

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(73) Assignee: **APPLE INC.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 106 days.

(21) Appl. No.: **15/716,086**

(22) Filed: **Sep. 26, 2017**

(65) **Prior Publication Data**

US 2018/0213660 A1 Jul. 26, 2018

Related U.S. Application Data

(60) Provisional application No. 62/450,530, filed on Jan. 25, 2017.

(51) **Int. Cl.**
H05K 5/02 (2006.01)
B29C 33/38 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H05K 5/0217*** (2013.01); ***B22D 19/04*** (2013.01); ***B22D 19/14*** (2013.01); ***B29C 33/38*** (2013.01); ***B29C 35/02*** (2013.01); ***B29C 45/14311*** (2013.01); ***B29C 70/72*** (2013.01); ***H05K 5/0208*** (2013.01); *B29C 2035/0827* (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC B44C 1/28; H04M 1/0283; H05K 5/0243; H05K 5/0217; Y10T 428/24355; Y10T 428/25; Y10T 428/24802; Y10T 428/24893; Y10T 428/1471; Y10T 428/2982; Y10T 428/22; Y10T 428/23921; Y10T 428/24736; Y10T 428/29
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,106,839 A 8/1978 Cooper
4,256,412 A 3/1981 Tybus et al.
(Continued)

FOREIGN PATENT DOCUMENTS

CN 101087500 12/2007
CN 102159045 8/2011
(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion, PCT/US2018/015091, 13 pages, dated Apr. 17, 2018.
(Continued)

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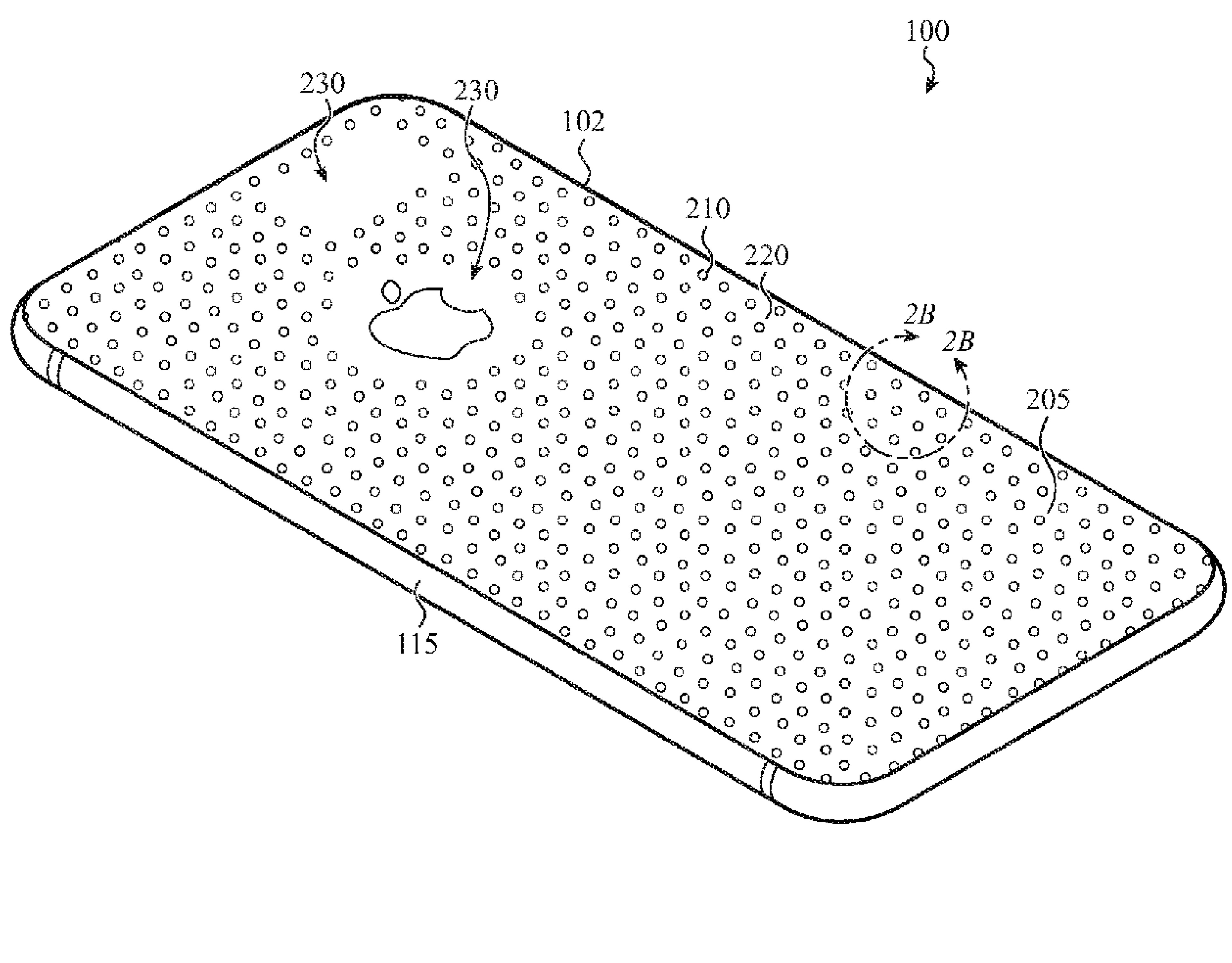
(57) **ABSTRACT**

A housing of an electronic device includes a substrate defining an external surface and internal surface of the housing, at least one sidewall extending from the substrate, and abrasion-resistant members at least partly embedded in the substrate and extending beyond the external surface. The abrasion-resistant members may be formed from metal or ceramic. The substrate comprises a moldable matrix. The abrasion-resistant members are harder than the moldable matrix.

15 Claims, 11 Drawing Sheets



(51) **Int. Cl.**

B29C 35/02	(2006.01)
B22D 19/14	(2006.01)
B29C 70/72	(2006.01)
B29C 45/14	(2006.01)
B22D 19/04	(2006.01)
H04M 1/02	(2006.01)
H05K 5/04	(2006.01)
H05K 5/00	(2006.01)
B29L 31/34	(2006.01)
B29K 105/16	(2006.01)
B29C 35/08	(2006.01)

(52) **U.S. Cl.**

CPC .. *B29C 2035/0877* (2013.01); *B29K 2105/16* (2013.01); *B29L 2031/3437* (2013.01); *B29L 2031/3481* (2013.01); *H04M 1/0202* (2013.01); *H05K 5/0086* (2013.01); *H05K 5/04* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,855,174	A *	8/1989	Kawamoto B65D 90/06 428/67
4,989,622	A	2/1991	Kozuka et al.
5,055,347	A	10/1991	Bacon, Jr.
5,512,374	A	4/1996	Wallace et al.
6,061,104	A	5/2000	Evanicky et al.
6,093,887	A	7/2000	Ponto et al.
6,189,938	B1	2/2001	Nakadaira et al.
6,278,873	B1	8/2001	Itakura et al.
6,288,330	B1	9/2001	Chen
6,359,768	B1	3/2002	Eversley et al.
6,392,873	B1	5/2002	Honda
6,424,338	B1	7/2002	Anderson et al.
6,442,826	B1	9/2002	Staudt et al.
6,473,069	B1	10/2002	Gerpheide
6,483,024	B1	11/2002	Smithson et al.
6,589,891	B1	7/2003	Rast
6,654,256	B2	11/2003	Gough
6,671,160	B2	12/2003	Hayden
6,940,731	B2	9/2005	Davis et al.
6,996,425	B2	2/2006	Watanabe
7,048,242	B2	5/2006	Oddsen, Jr.
7,436,653	B2	10/2008	Yang et al.
7,491,900	B1	2/2009	Peets et al.
7,586,753	B2	9/2009	Lu
7,604,377	B2	10/2009	Yu et al.
7,755,913	B2	7/2010	He
7,829,812	B2	11/2010	Tolbert et al.
7,920,904	B2	4/2011	Kim et al.
7,986,525	B2	7/2011	Wang
8,066,233	B2	11/2011	Fujikawa et al.
8,164,898	B2	4/2012	Lin et al.
D660,193	S	5/2012	Neuner
8,195,244	B2	6/2012	Smoyer et al.
8,199,488	B2	6/2012	Zou et al.
8,358,513	B2	1/2013	Kim et al.
8,396,521	B2	3/2013	Horimoto et al.
8,456,847	B2	6/2013	Hwang et al.
8,509,863	B2	8/2013	Vedurmudi et al.
8,553,907	B2	10/2013	Thomason et al.
8,558,977	B2	10/2013	Gettemy et al.
8,587,935	B2	11/2013	Lee
8,654,524	B2	2/2014	Pance et al.
8,665,236	B2	3/2014	Myers
8,675,359	B2	3/2014	Chen
8,681,115	B2	3/2014	Kurita
8,744,529	B2	6/2014	Freund et al.
8,773,848	B2	7/2014	Russell-Clarke et al.
8,824,140	B2	9/2014	Prest et al.
8,974,924	B2	3/2015	Weber et al.
8,975,540	B2	3/2015	Mareno et al.
9,007,748	B2	4/2015	Jarvis
9,086,748	B2	7/2015	Nam et al.
9,124,676	B2	9/2015	Allore et al.
9,135,944	B2	9/2015	Jenks
9,162,519	B2	10/2015	Suehiro et al.
9,173,306	B2	10/2015	Lim et al.
9,192,072	B2	11/2015	Shin et al.
9,203,463	B2	12/2015	Asrani et al.
9,218,116	B2	12/2015	Benko et al.
9,390,869	B2	7/2016	Lee et al.
9,429,997	B2	8/2016	Myers et al.
9,448,631	B2	9/2016	Winter et al.
9,489,054	B1	11/2016	Sumsion et al.
9,532,723	B2	1/2017	Kim et al.
9,621,218	B1	4/2017	Glickman et al.
9,642,241	B2	5/2017	Huitema et al.
9,654,164	B2	5/2017	Irei et al.
9,740,237	B2	8/2017	Moore et al.
9,804,635	B2	10/2017	Kim et al.
9,898,903	B2	2/2018	Khoshkava et al.
9,955,603	B2	4/2018	Kiple et al.
10,013,075	B2	7/2018	Shipman
10,042,442	B2	8/2018	Kwak
10,110,267	B2	10/2018	Kim et al.
10,321,590	B2	6/2019	Cater et al.
10,468,753	B2	11/2019	Kim et al.
10,705,570	B2	7/2020	Kuna et al.
11,379,010	B2	7/2022	Kuna et al.
2002/0006687	A1	1/2002	Lam
2002/0072335	A1	6/2002	Watanabe
2002/0130981	A1	9/2002	Ma et al.
2004/0190239	A1	9/2004	Weng
2005/0140565	A1	6/2005	Krombach
2006/0110599	A1*	5/2006	Honma B32B 5/10 428/413
2006/0203124	A1	9/2006	Park et al.
2007/0195495	A1	8/2007	Kim et al.
2007/0229702	A1	10/2007	Shirono et al.
2007/0287512	A1	12/2007	Kilpi et al.
2008/0018475	A1	1/2008	Breed et al.
2008/0084384	A1	4/2008	Gregorio et al.
2008/0174037	A1*	7/2008	Chen B44C 1/28 264/40.1
2009/0003141	A1	1/2009	Ozawa et al.
2009/0041984	A1	2/2009	Mayers et al.
2009/0175020	A1*	7/2009	Zadesky G06F 1/1626 361/818
2010/0105452	A1	4/2010	Shin et al.
2010/0137043	A1	6/2010	Horimoto et al.
2010/0151925	A1	6/2010	Vedurmudi et al.
2010/0157515	A1	6/2010	Tseng et al.
2010/0265182	A1	10/2010	Ball et al.
2010/0302016	A1	12/2010	Zaborowski et al.
2010/0315399	A1	12/2010	Jacobson et al.
2011/0038114	A1	2/2011	Pance et al.
2011/0047459	A1	2/2011	Van Der Westhuizen
2011/0065479	A1	3/2011	Nader
2011/0091051	A1	4/2011	Thomason et al.
2011/0095994	A1	4/2011	Birnbaum
2011/0205169	A1	8/2011	Yasutake et al.
2012/0088072	A1*	4/2012	Pawloski B29C 70/58 428/143
2012/0094594	A1	4/2012	Rofougaran et al.
2012/0175165	A1	7/2012	Merz et al.
2012/0212424	A1	8/2012	Sharma et al.
2012/0236477	A1	9/2012	Weber
2012/0268412	A1	10/2012	Cruz-Hernandez et al.
2012/0274575	A1	11/2012	Solomon et al.
2013/0051000	A1	2/2013	Yu et al.
2013/0273295	A1	10/2013	Kenney et al.
2013/0308282	A1	11/2013	Shin et al.
2013/0323579	A1*	12/2013	Hwang H01M 2/0404 429/175
2014/0015773	A1	1/2014	Loeffler
2014/0084770	A1	3/2014	Tsai et al.
2014/0091688	A1	4/2014	Narajowski et al.
2014/0288438	A1	9/2014	Venkatraman et al.
2014/0347799	A1	11/2014	Ono et al.
2014/0368455	A1	12/2014	Croisonnier et al.
2015/0001104	A1*	1/2015	Kim B65D 81/022 206/37

(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0062419	A1	3/2015	Hooton et al.
2015/0090571	A1	4/2015	Leong et al.
2015/0109223	A1	4/2015	Kessler et al.
2015/0124401	A1	5/2015	Prest et al.
2015/0171916	A1	6/2015	Asrani et al.
2015/0183185	A1	7/2015	Chang
2015/0185946	A1	7/2015	Fourie
2015/0255853	A1	9/2015	Kwong et al.
2016/0029899	A1	2/2016	Kim et al.
2016/0055729	A1	2/2016	Maddox et al.
2016/0064820	A1	3/2016	Kim et al.
2016/0098016	A1	4/2016	Ely et al.
2016/0098107	A1	4/2016	Morrell et al.
2016/0103544	A1	4/2016	Filiz et al.
2016/0147257	A1	5/2016	Yamazaki
2016/0255944	A1	9/2016	Baranski et al.
2016/0270247	A1	9/2016	Jones et al.
2016/0308563	A1	10/2016	Ouyang et al.
2016/0316574	A1	10/2016	Chang et al.
2016/0327980	A1	11/2016	Farahani et al.
2016/0327986	A1	11/2016	Farahani et al.
2017/0010771	A1	1/2017	Bernstein et al.
2017/0038793	A1	2/2017	Kallman
2017/0048495	A1	2/2017	Scalisi et al.
2017/0230073	A1	8/2017	Youn et al.
2017/0264722	A1	9/2017	Zhong
2017/0303048	A1	10/2017	Hooton et al.
2018/0020208	A1	1/2018	Woo et al.
2018/0026341	A1	1/2018	Mow et al.
2018/0026353	A1	1/2018	Tseng et al.
2018/0077328	A1	3/2018	Park et al.
2018/0210515	A1	7/2018	Lyles et al.
2018/0217668	A1	8/2018	Ligtenberg et al.
2018/0217669	A1	8/2018	Ligtenberg et al.
2018/0218859	A1	8/2018	Ligtenberg et al.
2018/0284845	A1	10/2018	Honma et al.
2019/0083715	A1	3/2019	Redmond et al.
2019/0101960	A1	4/2019	Silvanto et al.
2019/0128669	A1	5/2019	Nobayashi et al.
2019/0361543	A1	11/2019	Zhang
2019/0377385	A1	12/2019	Bushnell
2020/0057525	A1	2/2020	Prest et al.
2020/0076056	A1	3/2020	Froese et al.
2020/0076057	A1	3/2020	Leutheuser et al.
2020/0076058	A1	3/2020	Zhang et al.
2020/0409023	A1	12/2020	Kazuo et al.
2021/0149458	A1	5/2021	Silvanto et al.
2021/0234403	A1	7/2021	Ku et al.
2021/0353226	A1	11/2021	Hiemstra et al.
2022/0004837	A1	1/2022	Perkins et al.
2022/0006176	A1	1/2022	Froese et al.
2022/0057885	A1	2/2022	Prest et al.
2022/0059928	A1	2/2022	Leutheuser et al.
2022/0317740	A1	10/2022	Kuna et al.
2022/0326777	A1	10/2022	Ligtenberg et al.

FOREIGN PATENT DOCUMENTS

CN	202281978	6/2012
CN	102984904	3/2013
CN	103168280	6/2013
CN	203054674	7/2013
CN	103390793	11/2013
CN	203416294	1/2014
CN	103681061	3/2014
CN	104742308	7/2015
CN	105228966	1/2016
CN	107221506	9/2017
CN	107275751	10/2017
CN	107735903	2/2018
CN	207216299	4/2018
CN	108400425	8/2018
CN	108594622	9/2018
CN	108594623	9/2018
CN	112532263	3/2021
CN	112799294	5/2021
EP	2565742	3/2013
EP	2843501	3/2015
EP	2993730	3/2016
EP	3144768	3/2017
EP	3438786	2/2019
GB	2516439	1/2015
GB	2529885	3/2016
JP	S58151619	9/1983
JP	H61039144	2/1986
JP	H10102265	4/1998
JP	2001216077	8/2001
JP	20023431	11/2002
JP	2004272690	9/2004
JP	2006243812	9/2006
JP	2007072375	3/2007
JP	2011014149	1/2011
JP	2011159276	8/2011
JP	2011239139	11/2011
JP	2011248888	12/2011
JP	2012027592	2/2012
JP	2012222553	11/2012
JP	2013508818	3/2013
JP	2014501070	1/2014
JP	2014512879	5/2014
JP	2014186075	10/2014
JP	2015031952	2/2015
KR	20110049416	5/2011
KR	20130096048	8/2013
KR	20150012312	2/2015
KR	20160019833	2/2016
KR	20160052275	5/2016
KR	20160134504	11/2016
KR	20180025126	3/2018
TW	201129285	8/2011
TW	201532835	9/2015
TW	201701119	1/2017
WO	WO2009/002605	12/2008
WO	WO2009/049331	4/2009
WO	WO2009/129123	10/2009
WO	WO2012/129247	9/2012
WO	WO2014/037945	3/2014
WO	WO2015/153701	10/2015
WO	WO2016/039803	3/2016
WO	WO2016/053901	4/2016
WO	WO2018/013573	1/2018
WO	WO2018/142132	8/2018

OTHER PUBLICATIONS

Author Unknown, "Improved Touchscreen Products," Research Disclosure, Kenneth Mason Publications, Hampshire, UK, GB, vol. 428, No. 53, Dec. 1, 1999.

Kim et al., "Ultrathin Cross-Linked Perfluoropolyether Film Coatings from Liquid CO_2 and Subsequent UV Curing," Chem. Matter, vol. 22, pp. 2411-2413, 2010.

Author Unknown, "Smart Watch—New Fashion Men/women Bluetooth Touch Screen Smart Watch Wrist Wrap Watch Phone," https://www.fargoshopping.co.ke/, 5 pages, Mar. 2016.

* cited by examiner

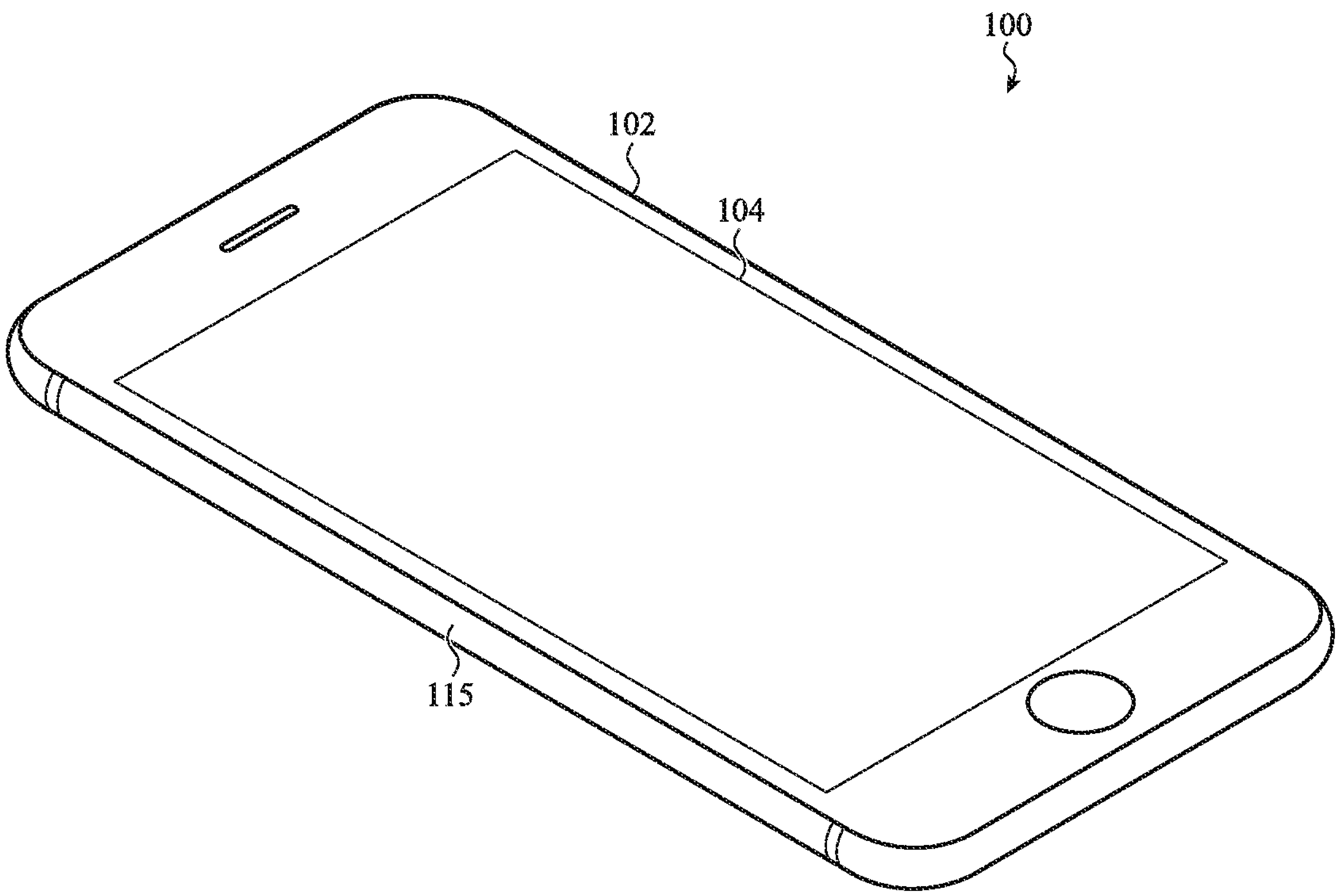


FIG. 1

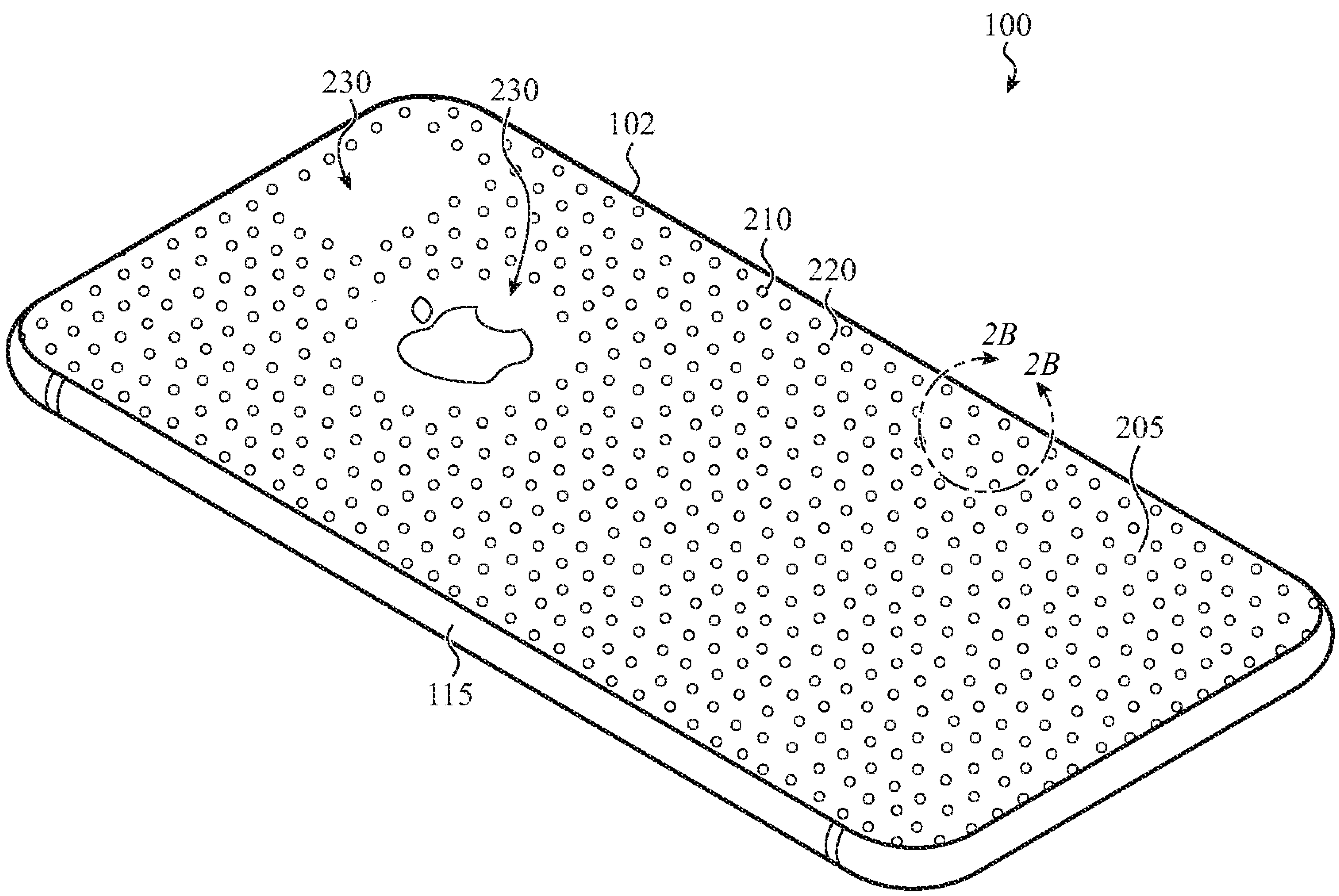
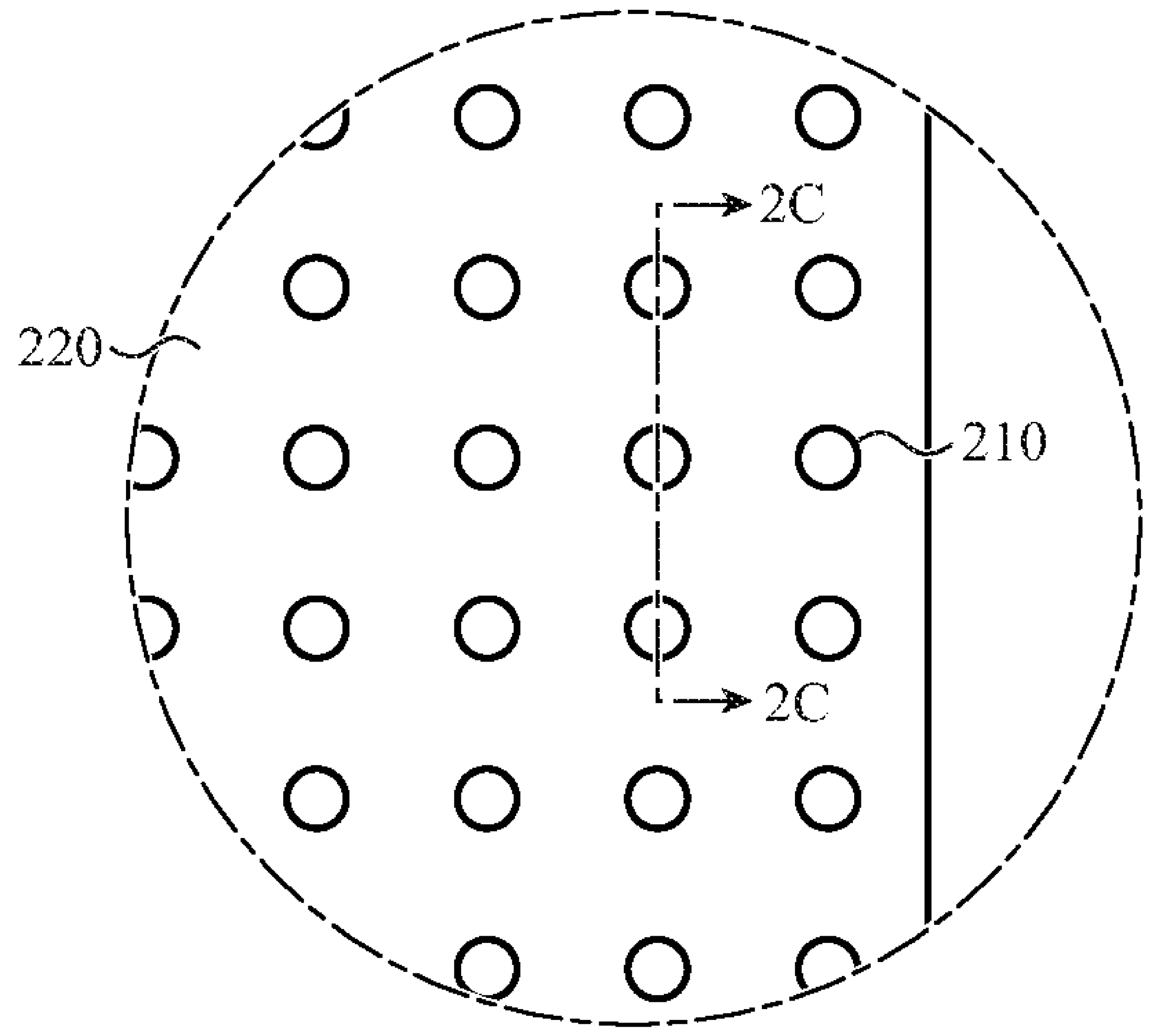


FIG. 2A



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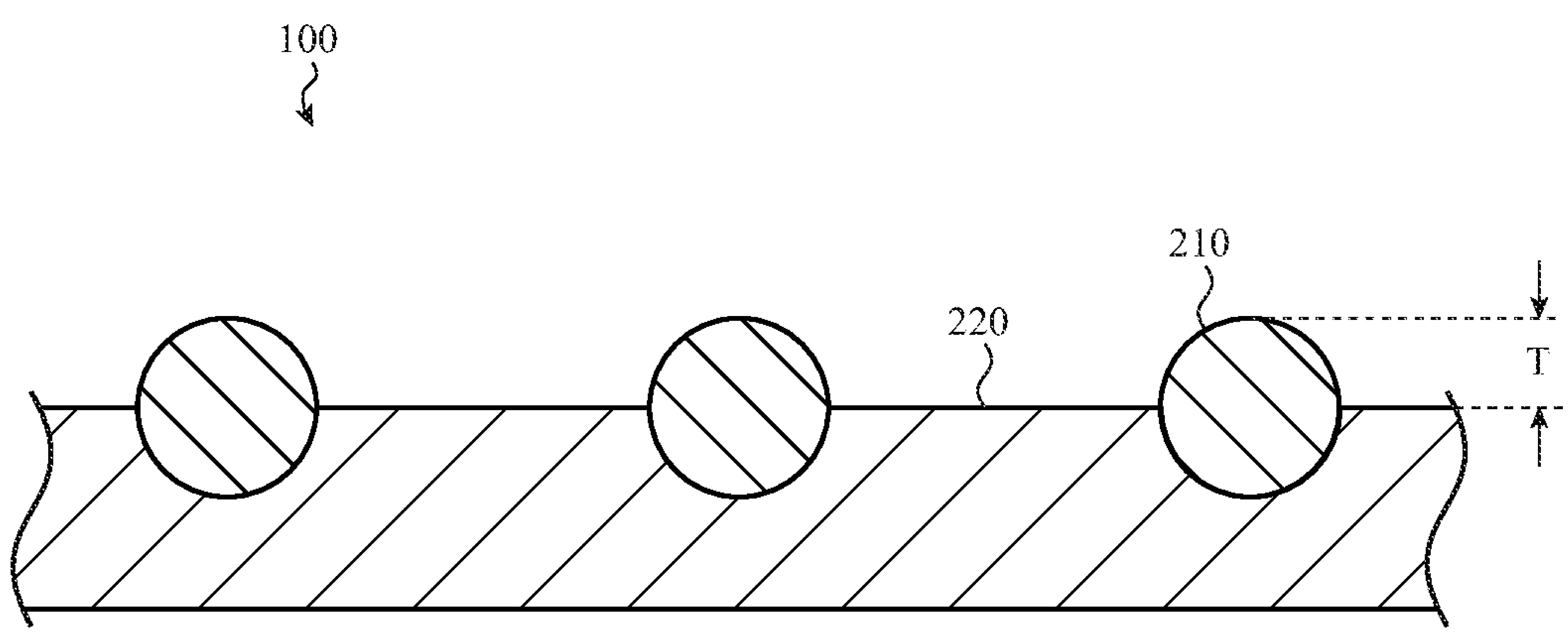

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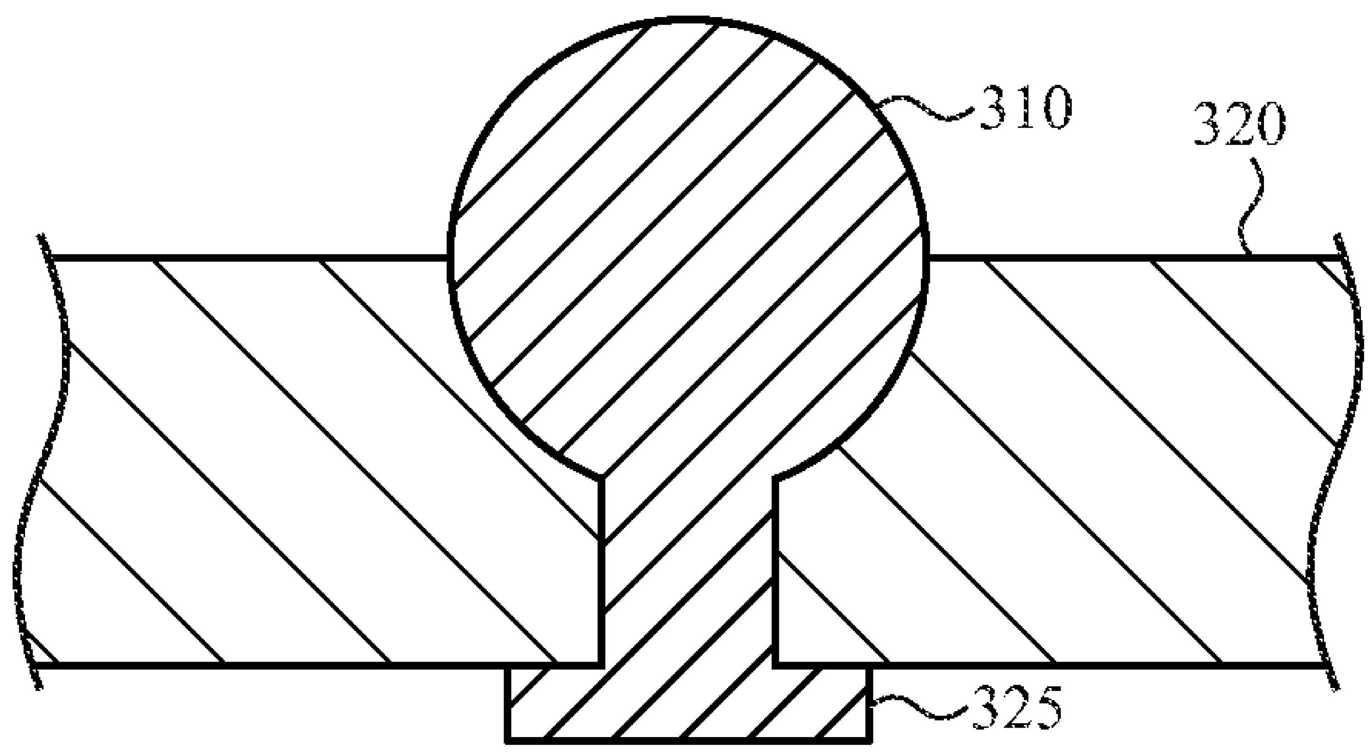

FIG. 3A

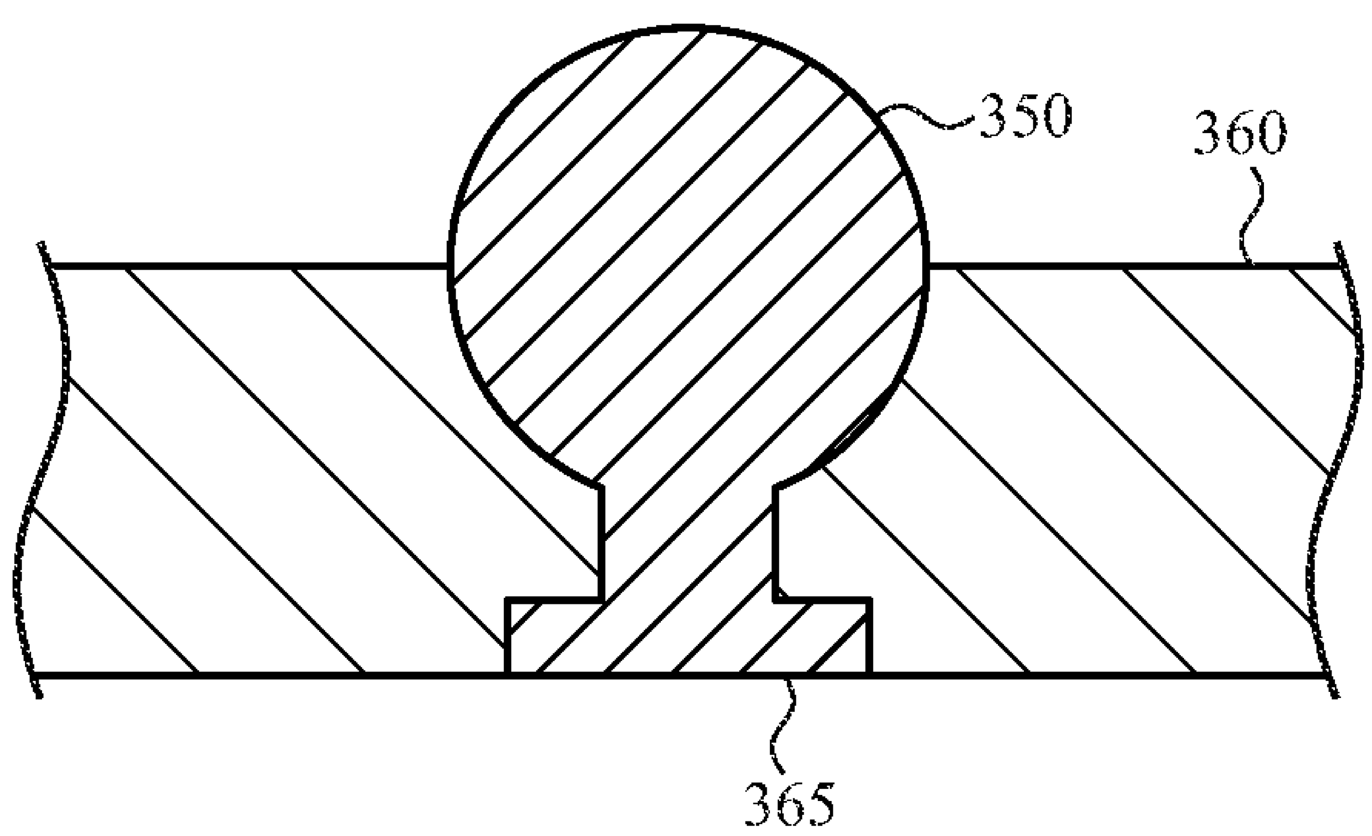

FIG. 3B

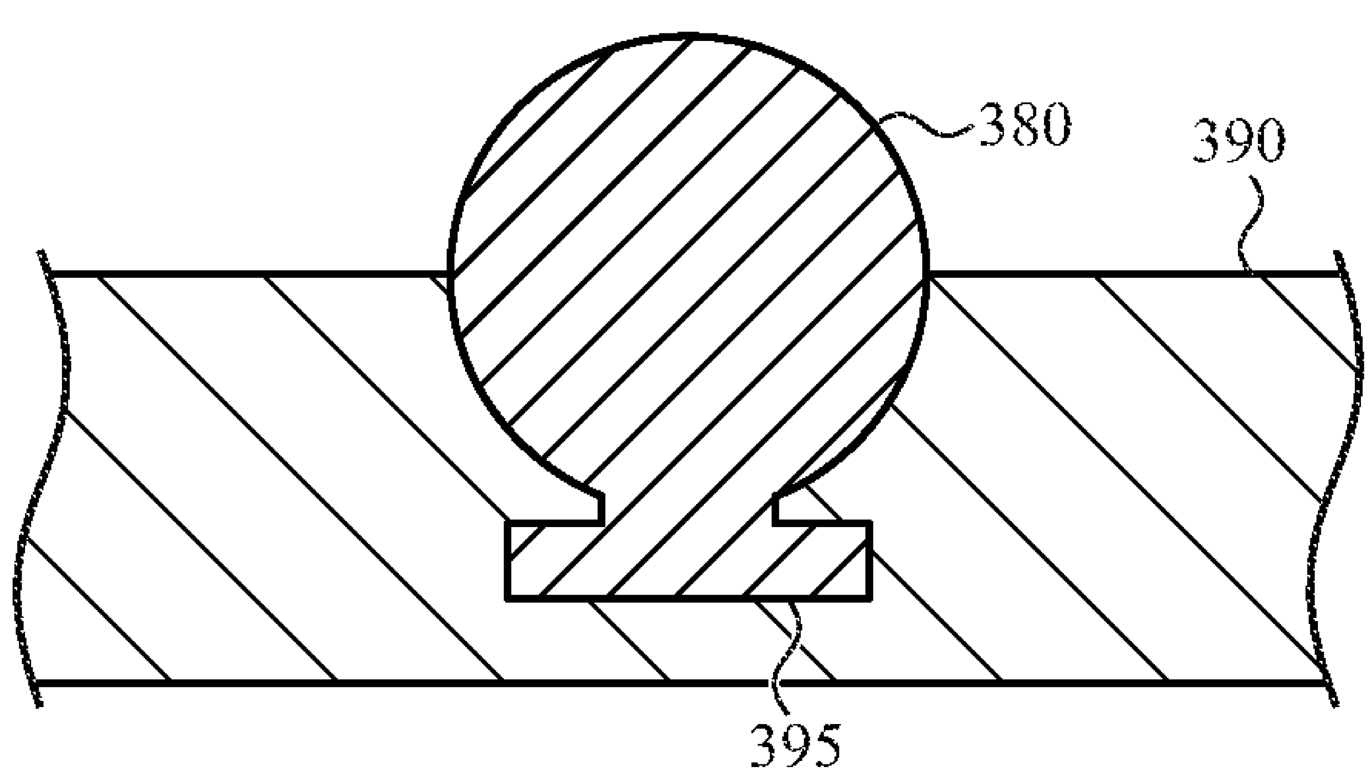

FIG. 3C

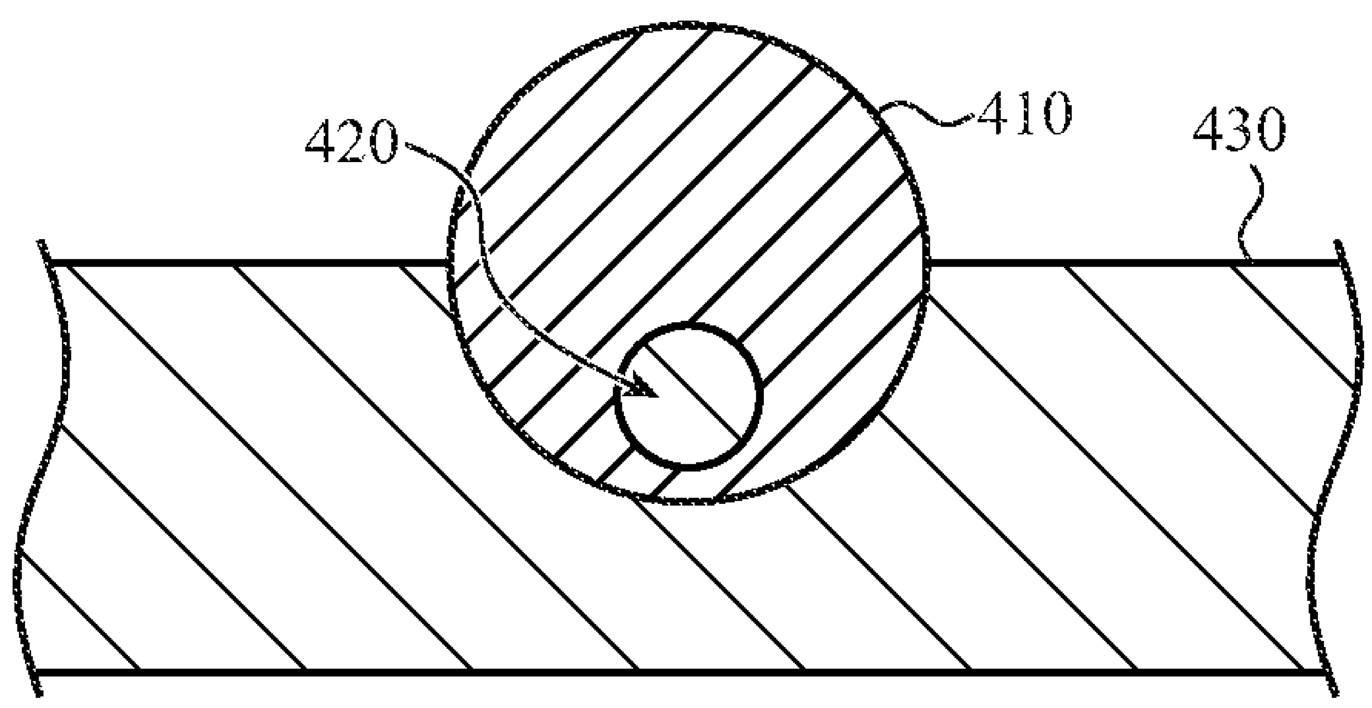

FIG. 4A

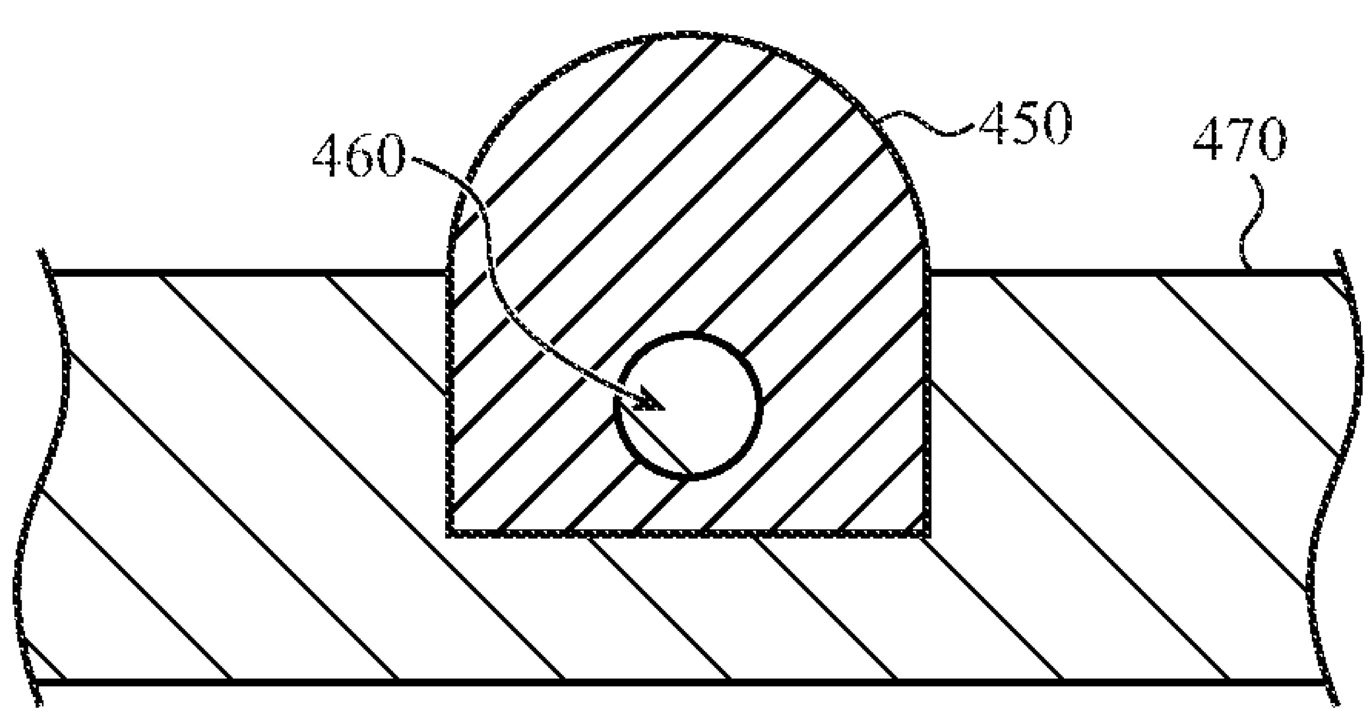

FIG. 4B

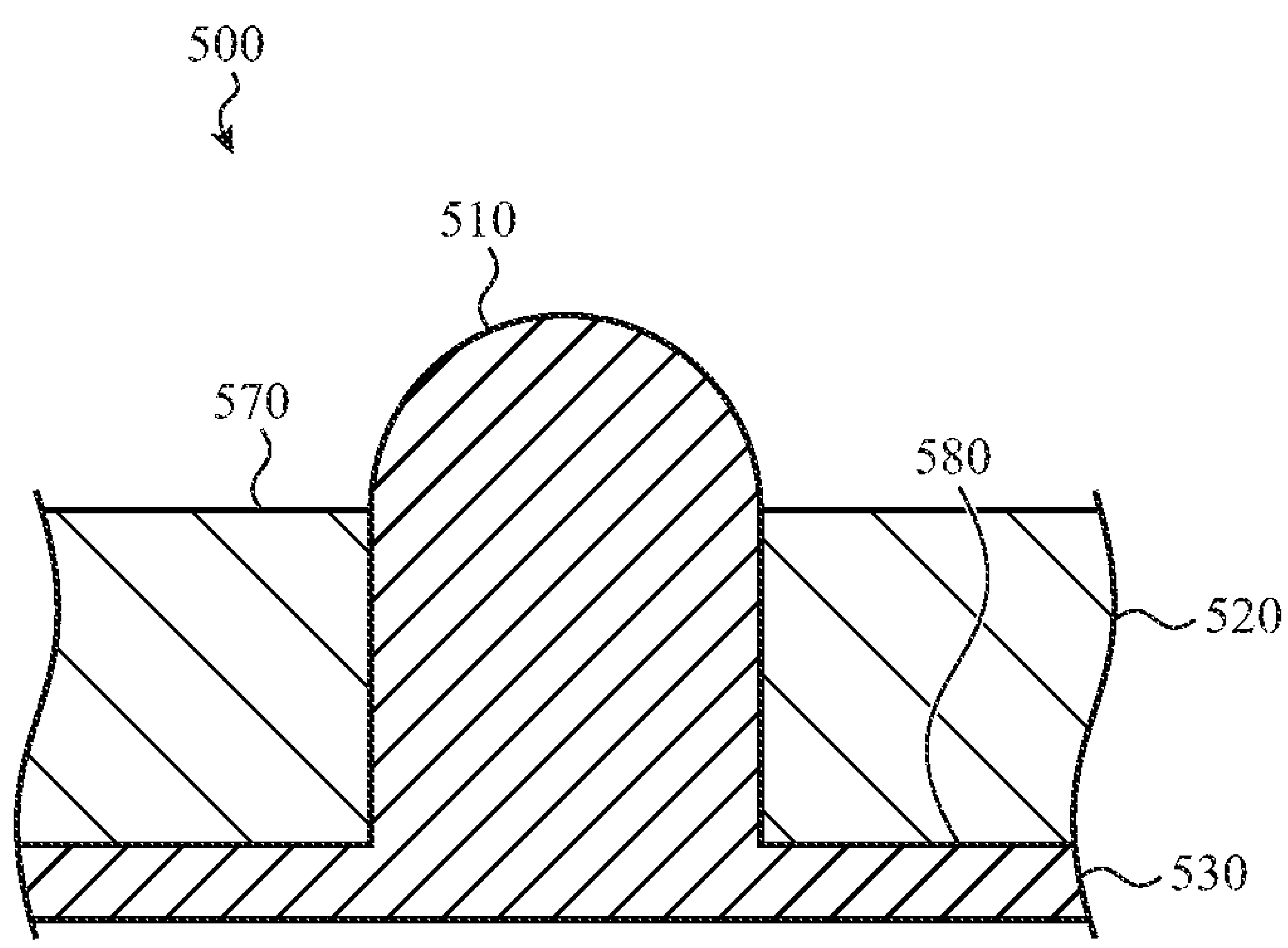

FIG. 5

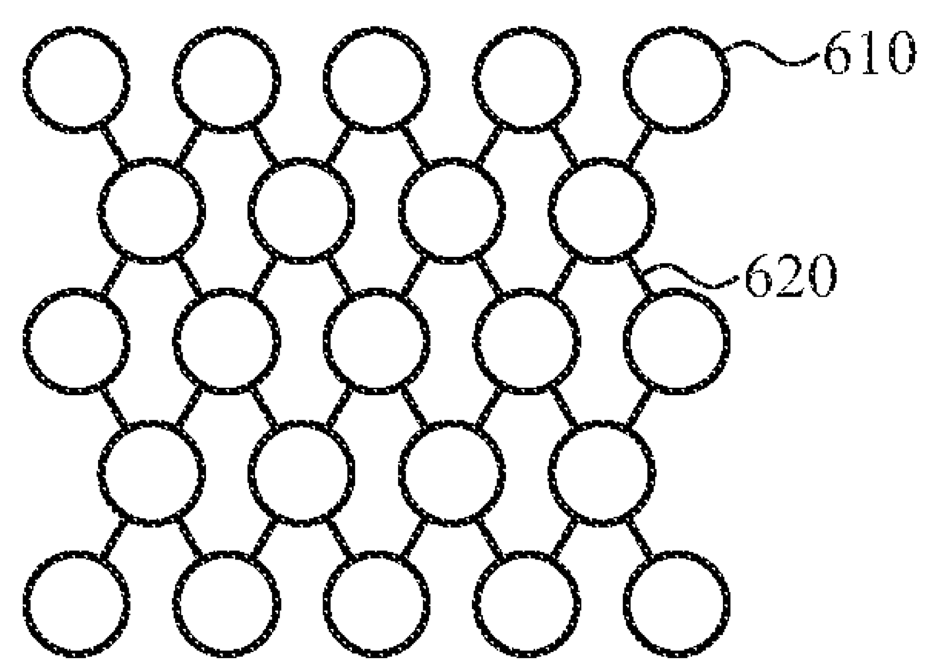

FIG. 6A

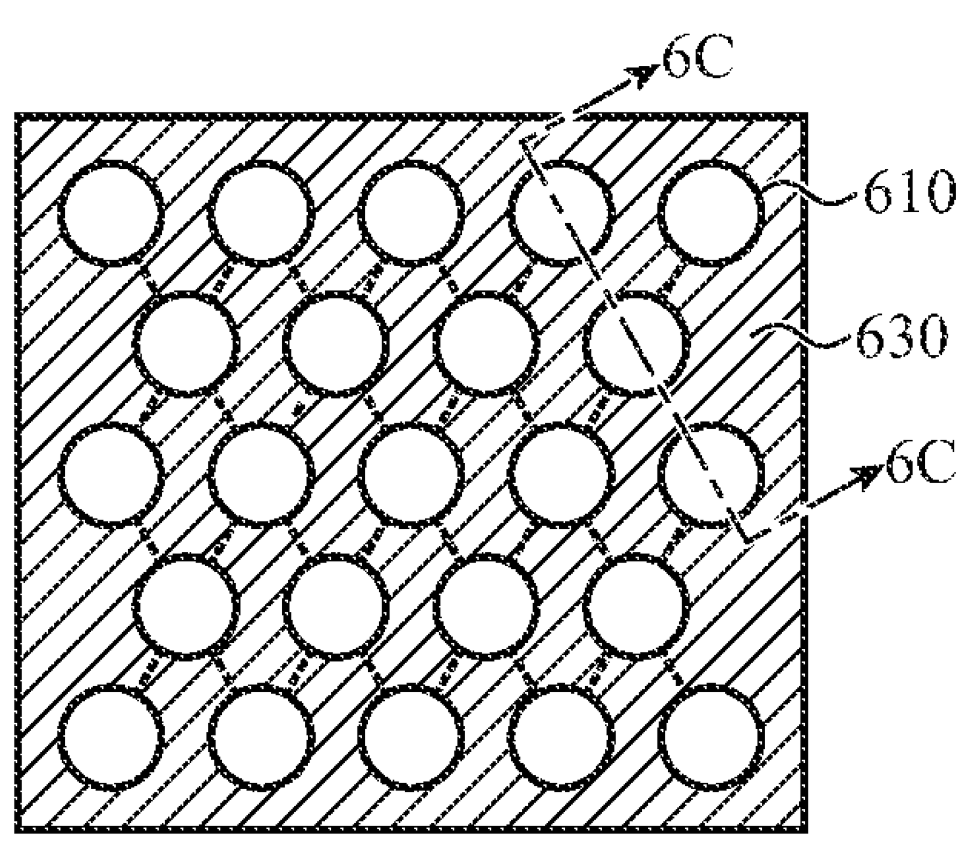

FIG. 6B

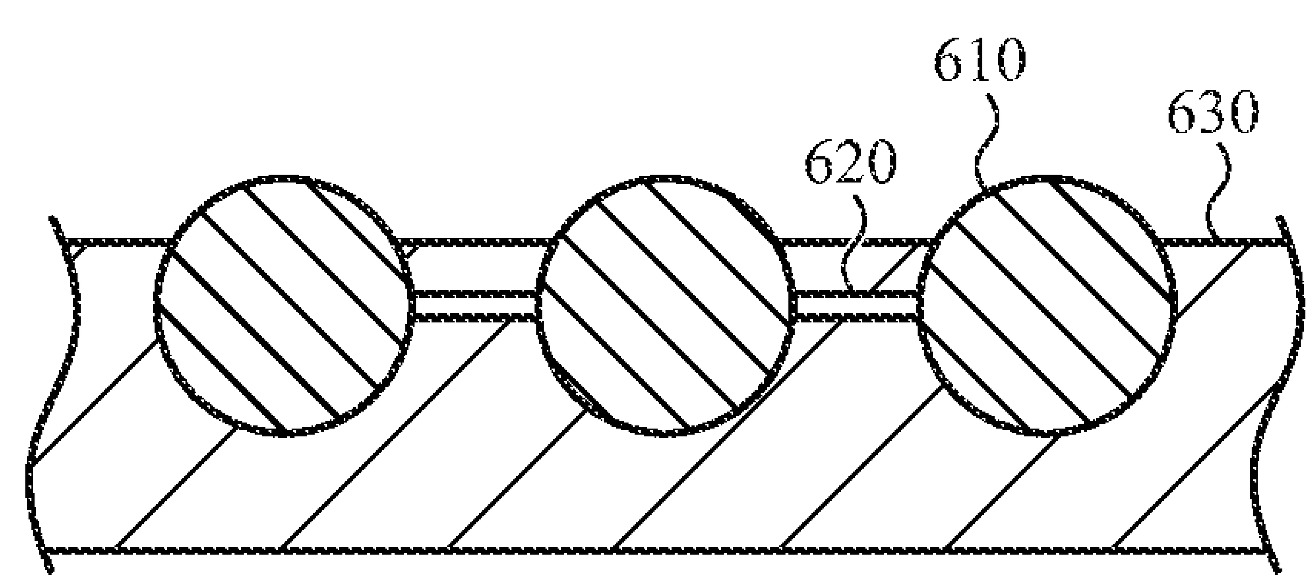

FIG. 6C

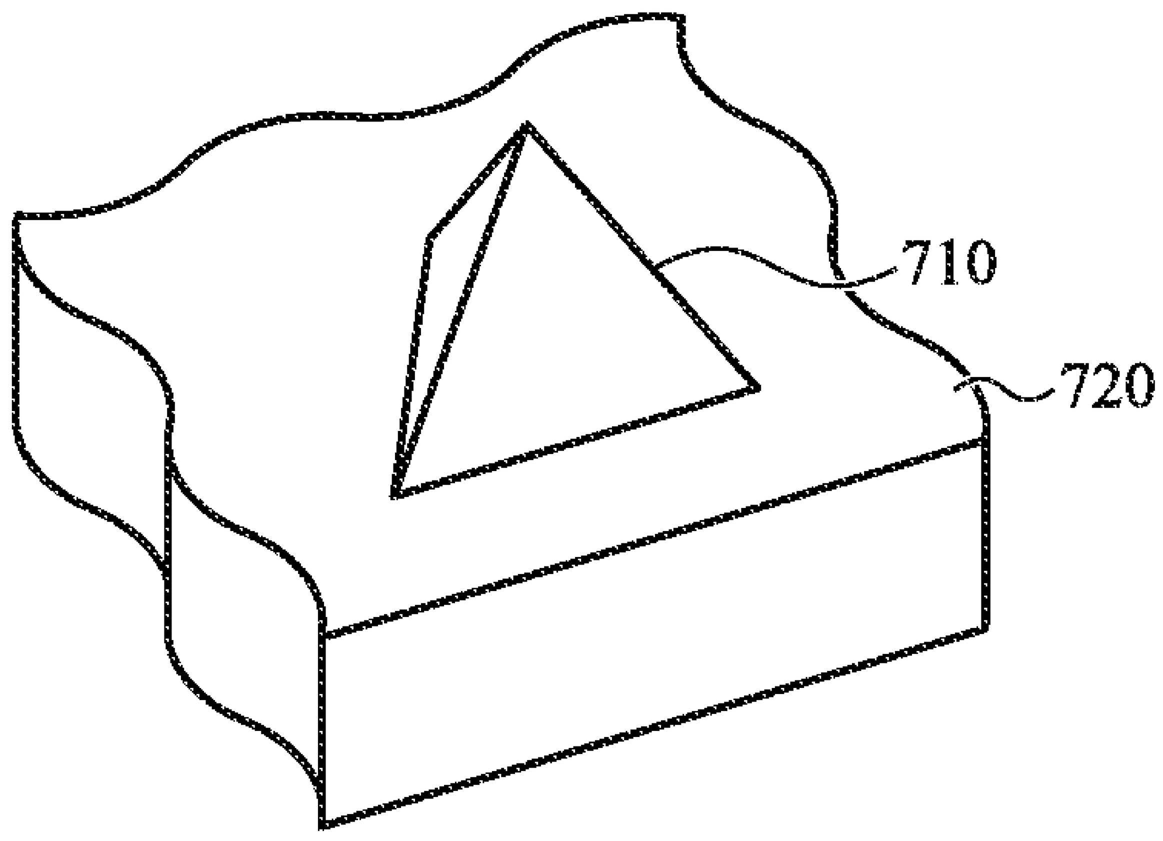

FIG. 7A

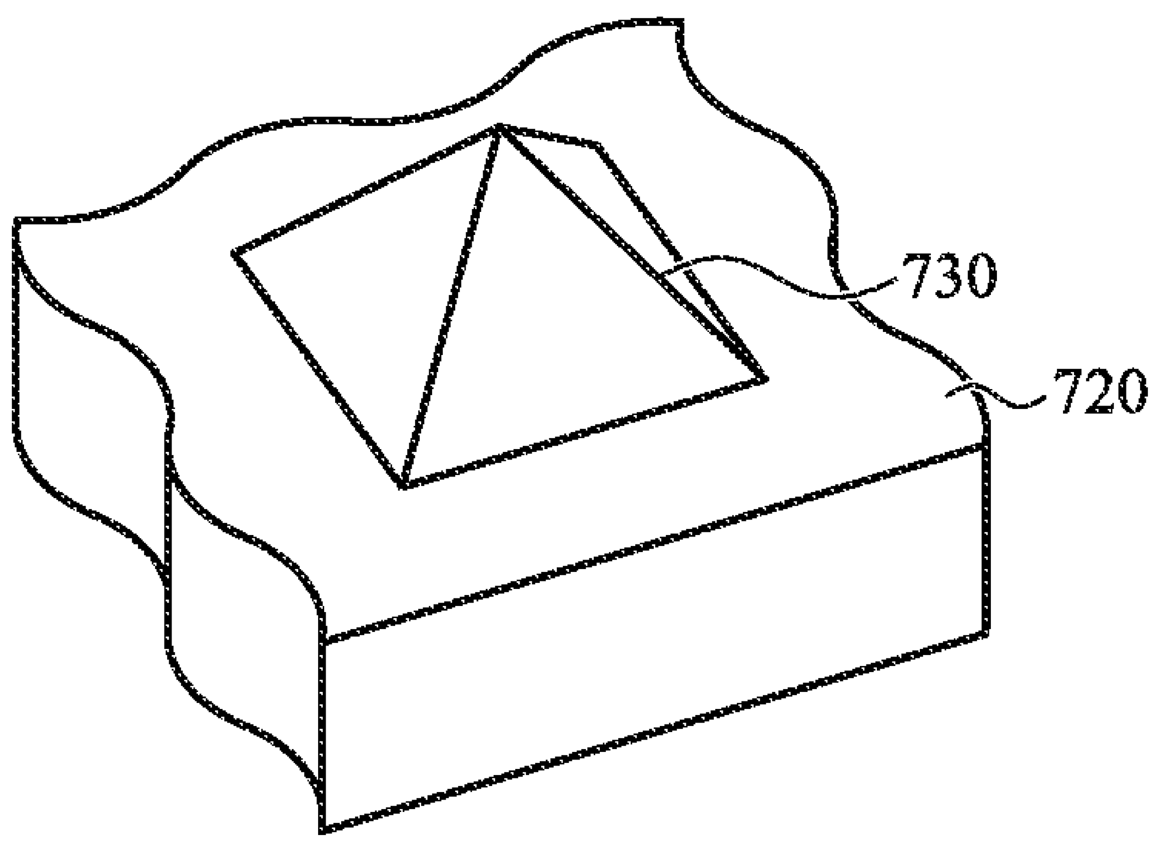

FIG. 7B

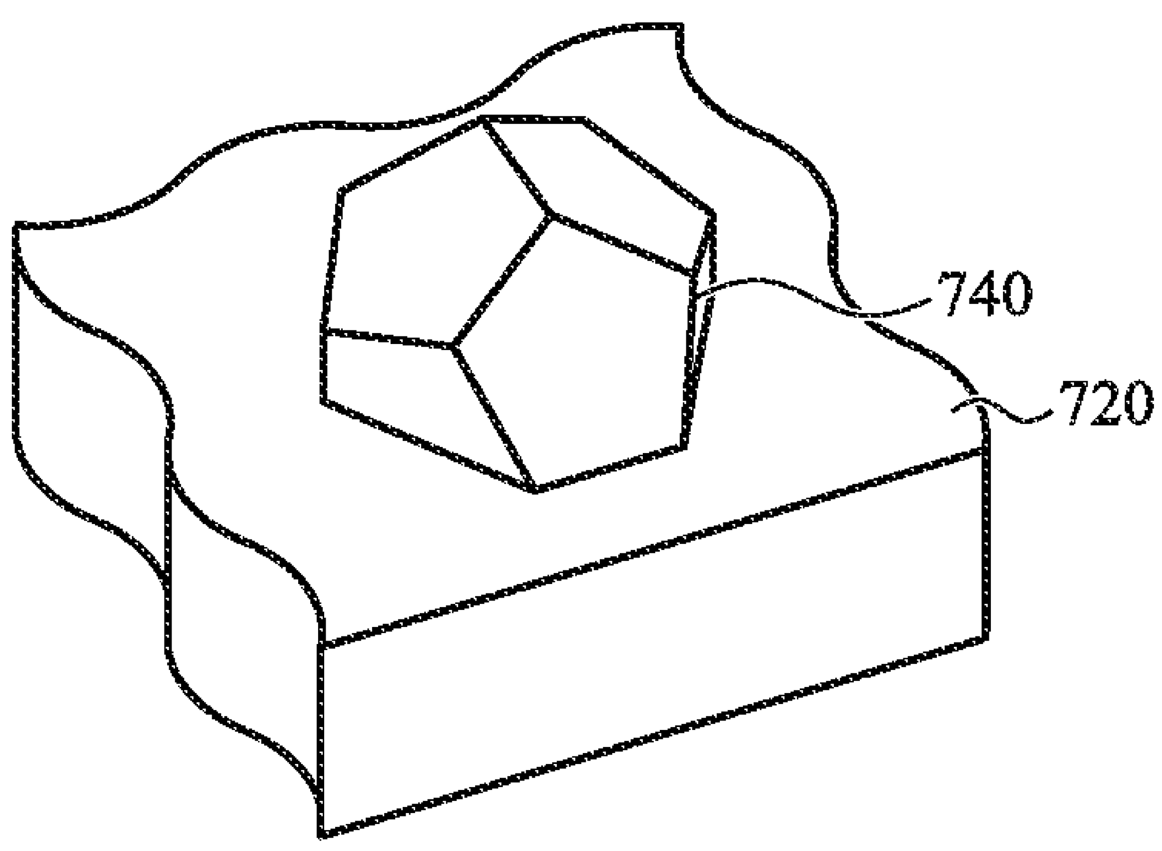

FIG. 7C

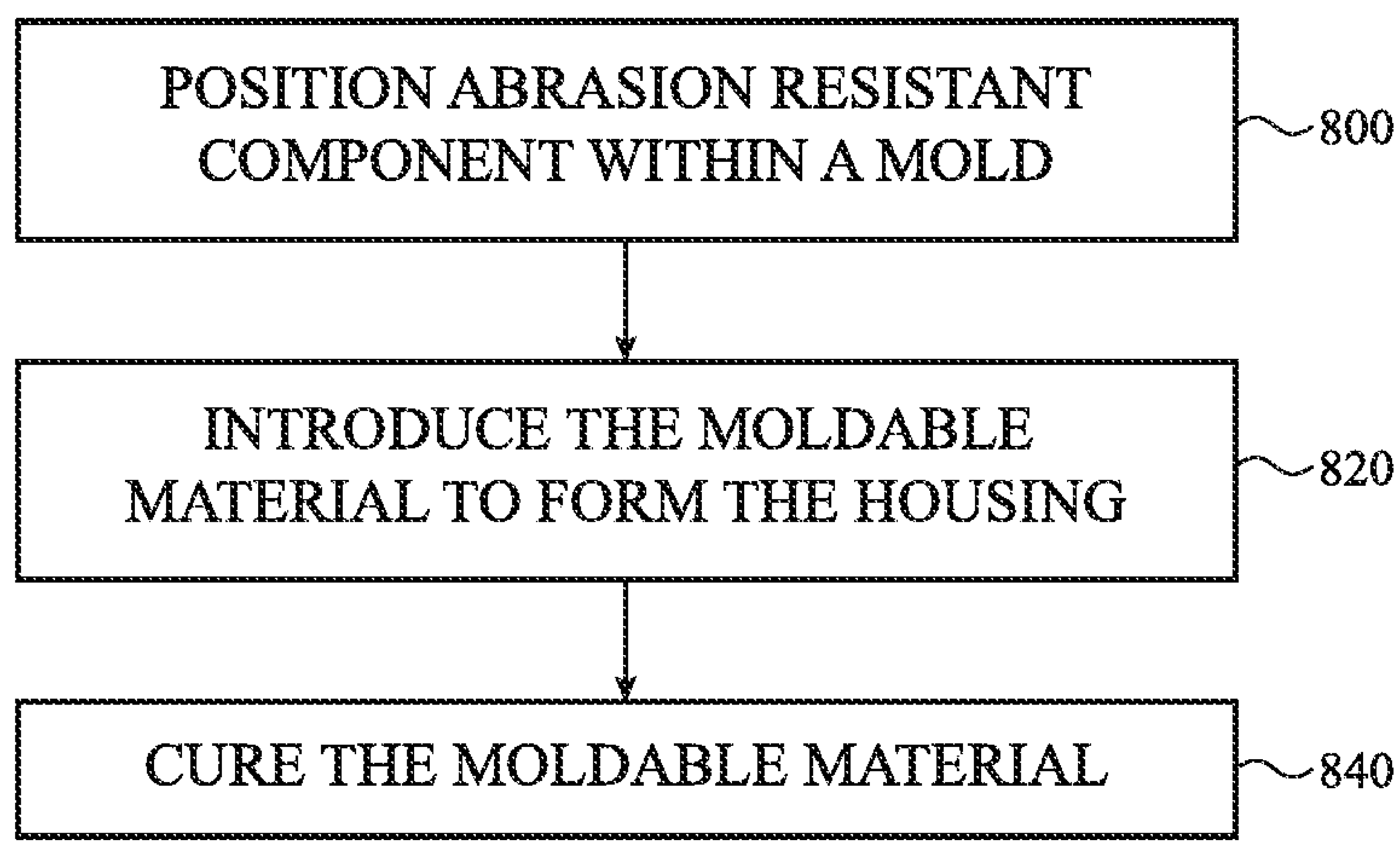
POSITION ABRASION RESISTANT COMPONENT WITHIN A MOLD
800
INTRODUCE THE MOLDABLE MATERIAL TO FORM THE HOUSING
820
CURE THE MOLDABLE MATERIAL
840

FIG. 8

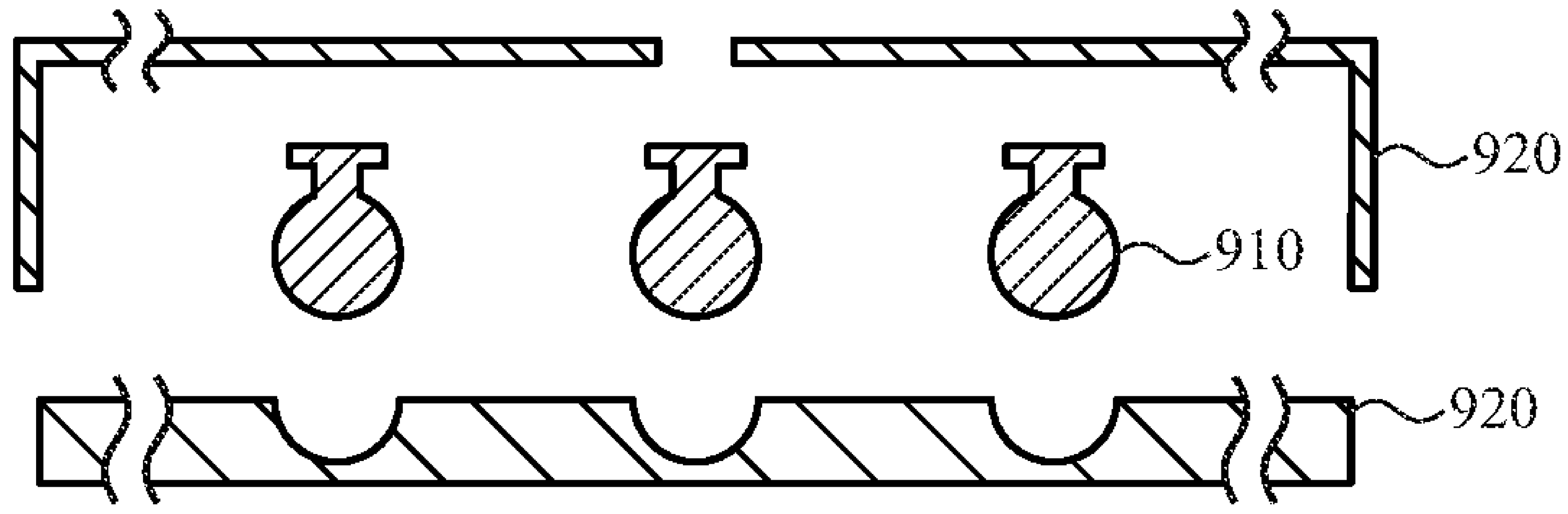

FIG. 9A

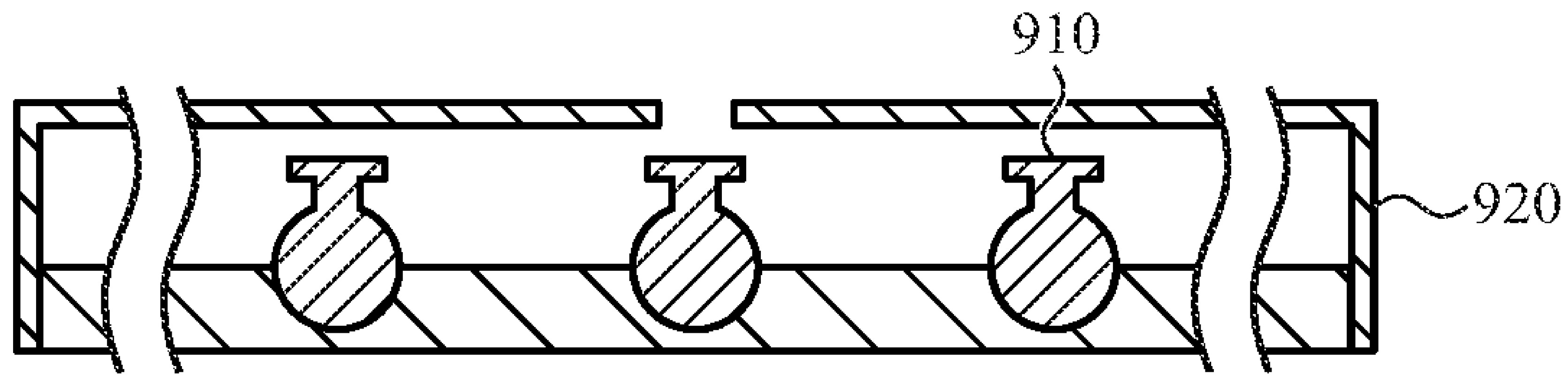

FIG. 9B

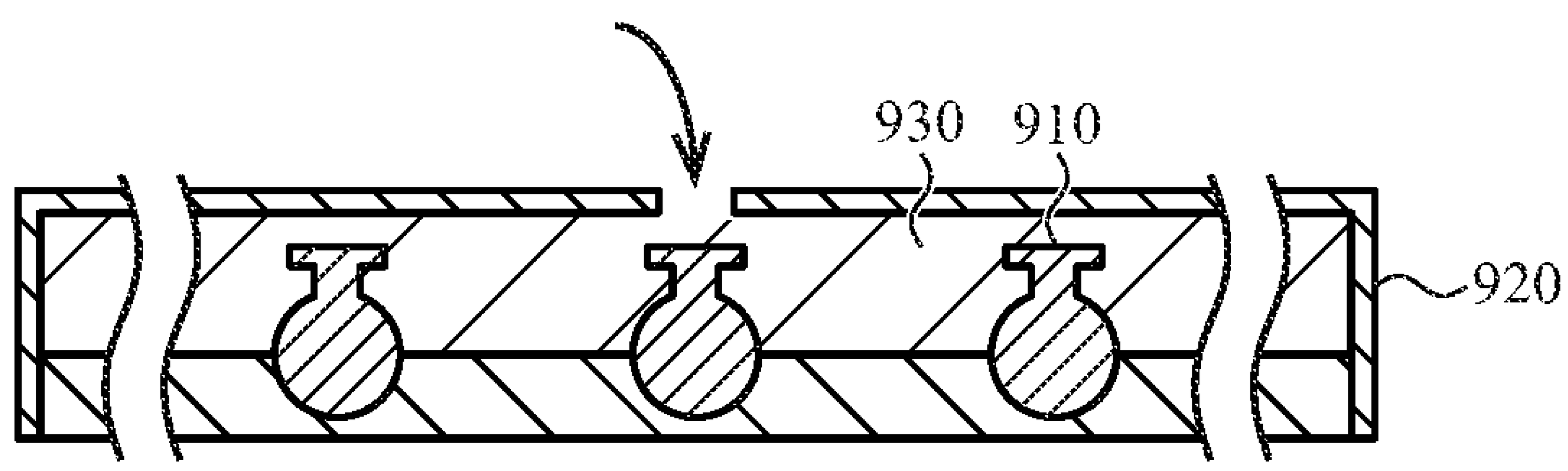

FIG. 9C

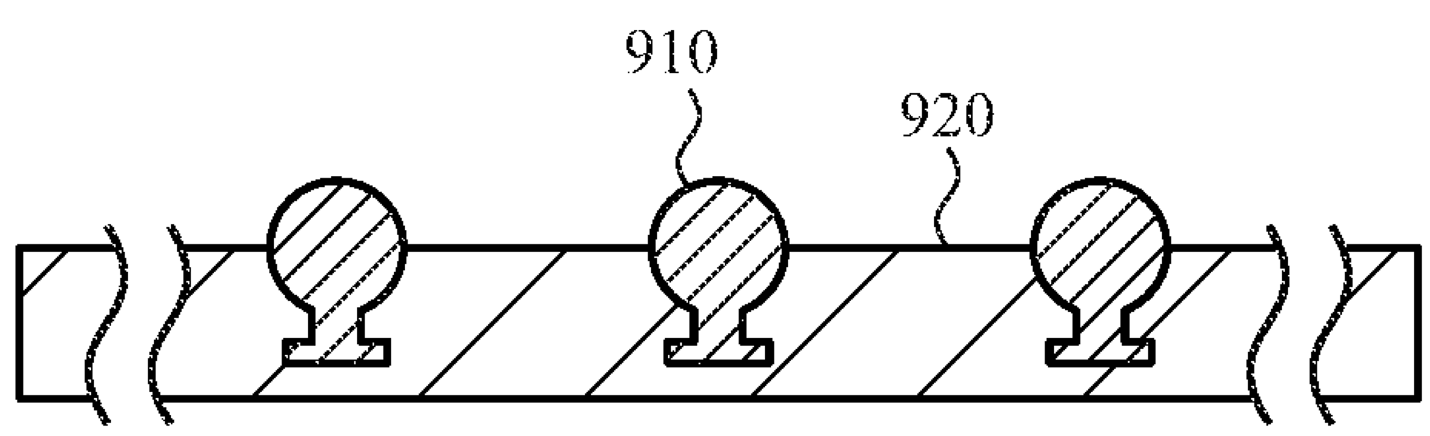

FIG. 9D

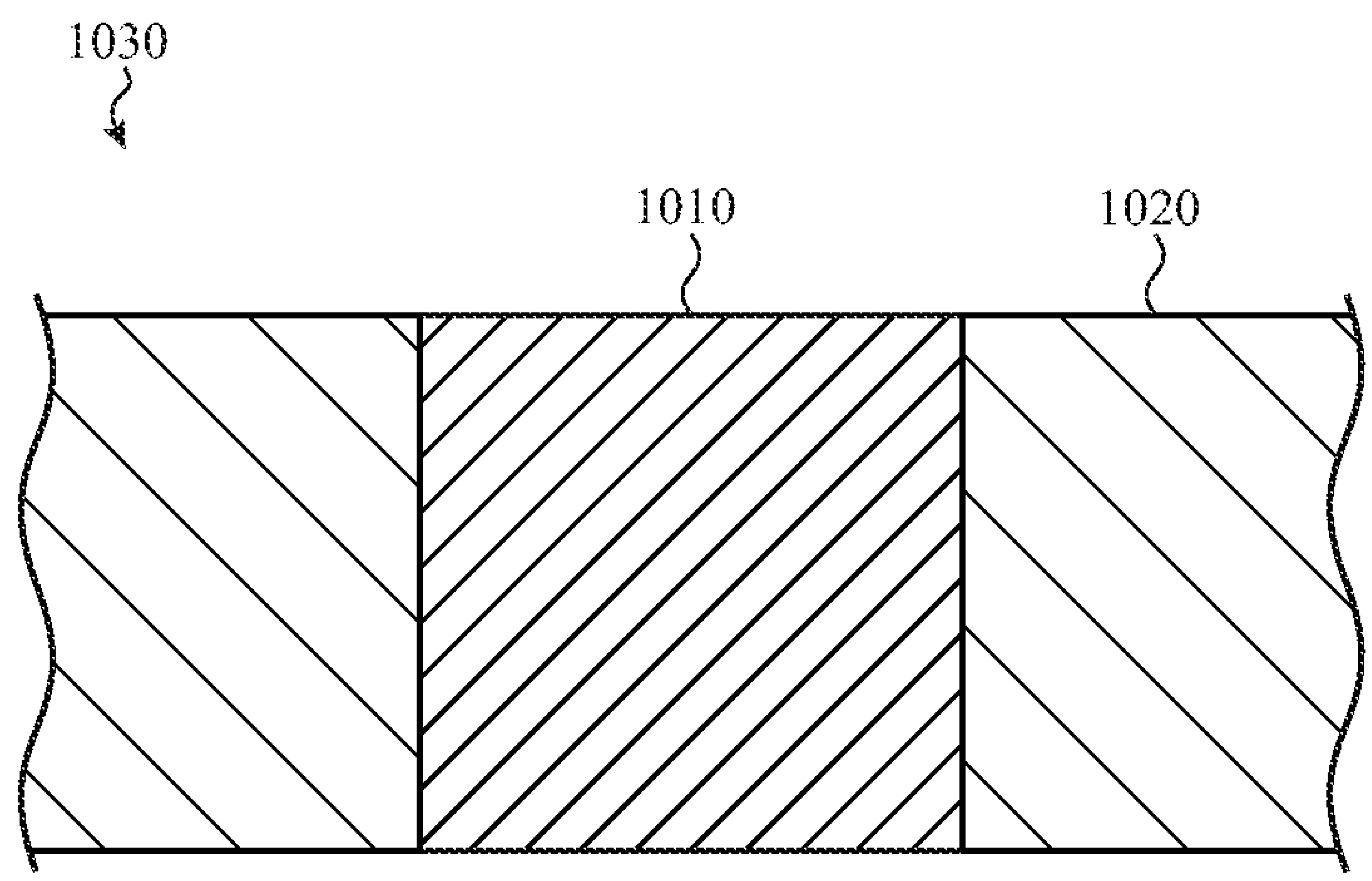

FIG. 10A

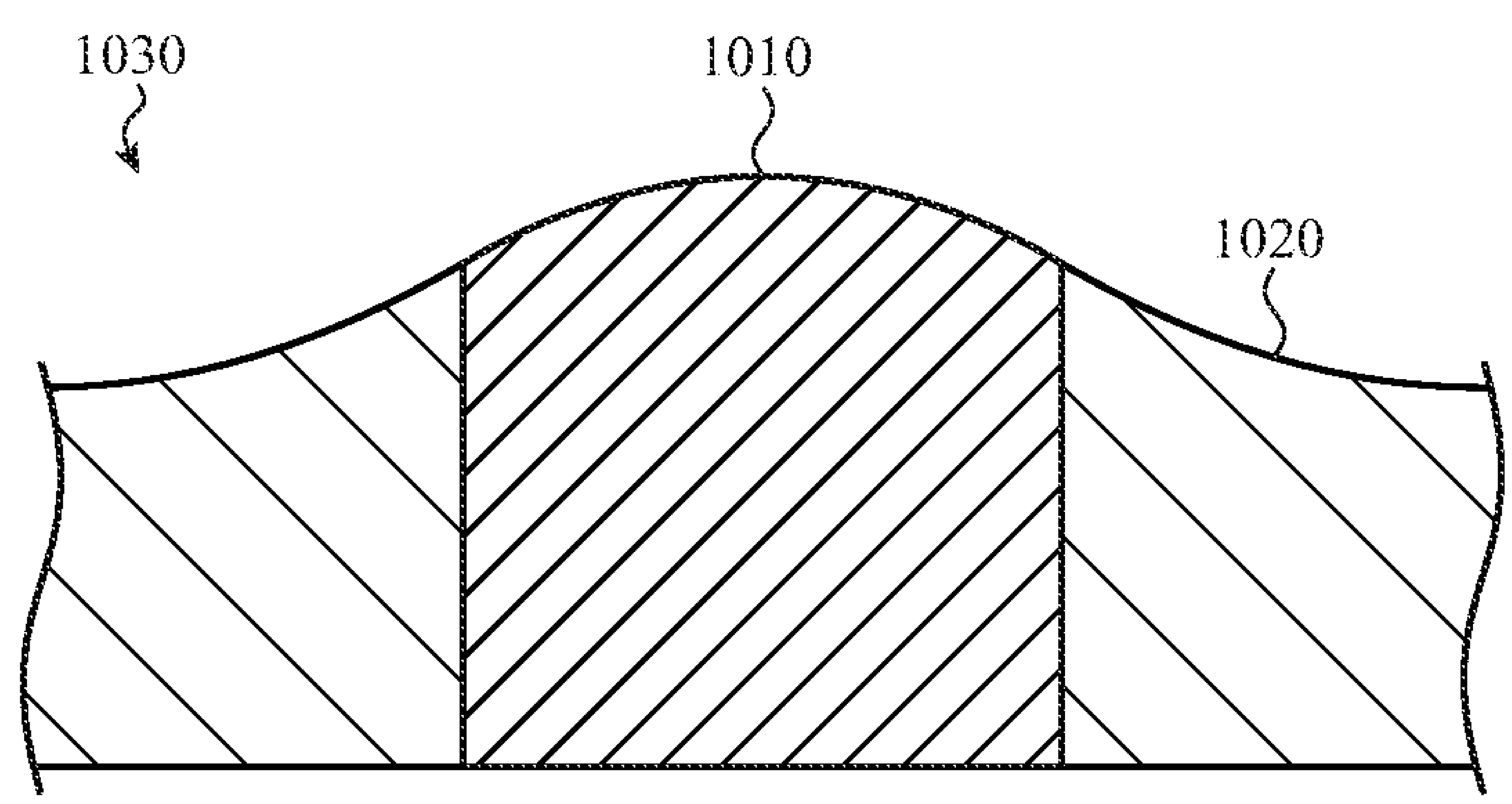

FIG. 10B

SPATIAL COMPOSITES

This application is a nonprovisional patent application of and claims the benefit of U.S. Provisional Patent Application No. 62/450,530, filed Jan. 25, 2017 and titled "Spatial Composites," the disclosure of which is hereby incorporated herein by reference in its entirety.

FIELD

Embodiments described herein relate generally to abrasion-resistant surfaces for electronic devices, and more particularly to incorporating abrasion-resistant elements into material of a housing to form abrasion-resistant surfaces.

BACKGROUND

Electronic devices are ubiquitous in society and can be found in everything from wristwatches to computers. Such electronic devices, especially portable electronic devices such as handheld mobile phones, watches, and tablet computers, can experience contact with various surfaces that leads to marring, or abrasion, of the surface of the device. Housing materials for such devices may have different combinations of properties relating to strength, appearance, abrasion resistance, electromagnetic shielding, and the like. For example, metal housings may be strong and relatively scratch resistant, but may provide undesirable electromagnetic shielding. Plastic may have better electromagnetic shielding properties than metal, but may be less scratch or abrasion-resistant. Other materials may provide different combinations of properties.

SUMMARY

A housing of an electronic device includes a substrate defining an external surface and internal surface of the housing, at least one sidewall extending from the substrate, and abrasion-resistant members at least partly embedded in the substrate and extending beyond the external surface.

The abrasion-resistant members are formed from metal or ceramic. The substrate may comprise a moldable matrix. The abrasion-resistant members are harder than the moldable matrix. An average distance between the adjacent abrasion-resistant members is between about 10 and 100 microns.

The abrasion-resistant members each may have a faceted surface. The abrasion-resistant members may be configured to reflect light at an angle. The substrate may have a Young's modulus greater than, or equal to about 5 GPa. The beads may have a diameter between 0.5 and 5 mm.

A housing of an electronic device including a housing structure defining an external surface and internal surface of the housing, at least one sidewall extending from the external surface, and beads having interlocking features and being at least partially embedded in the housing structure, such that the interlocking features mechanically engage the housing structure and portions of the beads protrude above the external surface. The beads are distributed in a regular pattern over a first portion of the external surface. A second portion of the external surface may be substantially free of beads. The second portion of the external surface corresponds to a location of an antenna within the housing.

The housing structure may comprise a moldable material. The beads may comprise a hard material embedded within at least a portion of the moldable material. A hardness of the hard material is greater than a hardness of the moldable material.

The moldable material may be a polymer. The moldable material may be an amorphous metal. The beads may each have a faceted surface, such that a portion of the housing structure having the beads at least partially embedded therein produces a specular reflection. The interlocking features include at least one of through-holes, flanges, or indentations. The interlocking features may comprise connecting elements joining at least a subset of the beads to one another. The subset of the beads and the connecting elements are a monolithic structure.

A method for producing an abrasion-resistant housing of an electronic device including disposing abrasion-resistant components with interlocking structures in a mold cavity having a shape corresponding to a housing of an electronic device, introducing a moldable material into the mold cavity, thereby at least partially encapsulating the interlocking structures while maintaining a portion of the abrasion-resistant components outside of the moldable material, and curing the moldable material, thereby engaging the cured moldable material with the interlocking structures and forming the housing. The interlocking structures may include at least one of holes, meshes, swages, and undercuts.

The method may further include, after the curing, forming a facet on at least a subset of the plurality of the abrasion-resistant components such that an external surface of the housing produces a visual effect visible from at least an orientation. The method may further include the portion of the abrasion-resistant components is a first portion. The first portion may extend above an external surface of the housing, and the abrasion-resistant components may extend through the moldable material such that a second portion of the abrasion-resistant components mechanically engages with an internal surface of the housing.

The interlocking structures may comprise a plurality of connection elements joining a plurality of the abrasion-resistant components. Introducing the moldable material may comprise encapsulating the connection elements within the moldable material.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements.

FIG. **1** shows an example electronic device.

FIG. **2**A shows the back of the electronic device of FIG. **1**.

FIG. **2**B is a detail view of a portion of the electronic device in region **2**B-**2**B of FIG. **1**.

FIG. **2**C shows a cross-sectional view of a housing of the device of FIG. **1** viewed along line **2**C-**2**C in FIG. **2**B, showing example abrasion-resistant members embedded in the housing of the electronic device.

FIG. **3**A shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating an example of abrasion-resistant members having an interlocking structure that extends beyond the bottom of the substrate.

FIG. **3**B shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating an example of abrasion-resistant members having an interlocking structure that extends to the bottom of the substrate.

FIG. **3**C shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating an example of abrasion-resistant members having an interlocking structure that is positioned within the substrate.

FIG. **4**A shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating an example of a substantially spherical abrasion-resistant member with an interlocking structure embedded in a substrate.

FIG. **4**B shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating an example of a non-spherical (e.g., bullet-shaped) embodiment of an abrasion-resistant member with a hole as an interlocking structure.

FIG. **5** illustrates an embodiment of an electronic device housing wherein the abrasion-resistant member has an interlocking feature that extends along the bottom of the substrate.

FIG. **6**A shows a top view of the interconnected abrasion-resistant members joined by connectors prior to being embedded in the substrate.

FIG. **6**B shows a top view of the interconnected abrasion-resistant members embedded in the substrate.

FIG. **6**C shows a partial cross-sectional view of the housing shown in **6**B viewed along line **6**C-**6**C in FIG. **6**B, illustrating a portion of interconnected abrasion-resistant members extending above the surface of substrate, and the connectors below the surface of substrate.

FIG. **7**A illustrates a three-sided pyramidal faceted abrasion-resistant structure and the substrate surface.

FIG. **7**B illustrates a four-sided pyramidal faceted abrasion-resistant structure and the substrate surface.

FIG. **7**C illustrates a dodecahedron- or icosahedron-shaped abrasion-resistant member may be embedded at least partially in the substrate.

FIG. **8** shows an example process of forming an electronic housing.

FIG. **9**A shows abrasion-resistant components having interlocking structures positioned over a mold.

FIG. **9**B shows abrasion-resistant components having interlocking structures positioned within the mold.

FIG. **9**C shows moldable material being introduced into the mold to form the housing.

FIG. **9**D shows an example of an abrasion-resistant housing produced by the described method.

FIG. **10**A shows cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating a combination of a first material and a second material that align flush along a top surface.

FIG. **10**B shows a cross-sectional view of the device of FIG. **1**, viewed along line **2**C-**2**C in FIG. **2**B, illustrating a combination of materials such that the second material is differentially relieved relative to the first material.

DETAILED DESCRIPTION

Reference will now be made in detail to representative embodiments illustrated in the accompanying drawings. It should be understood that the following descriptions are not intended to limit the embodiments to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as can be included within the spirit and scope of the described embodiments as defined by the appended claims.

Housings or enclosures for electronic devices may be manufactured from various materials, such as plastics, metals, ceramics, or the like. Different materials provide advantages for certain applications. For example, metal housings may be particularly resistant to dents, scratches or breakage, but may interfere with radio signals entering or emanating from the device. Ceramic housings may be scratch resistant and transparent to radio signals, but may be brittle. Plastic housings may be transparent to radio signals and fairly strong, but may be prone to scratches or dents. In some products, it is useful to provide housings which are abrasion-resistant, e.g., not readily scratched or marred when they come into contact with hard or sharp surfaces such as keys, coins, sand, debris, or other objects. The incorporation of abrasion-resistant members may increase the impact and dent resistance of the housings.

Described herein are housings that include abrasion-resistant materials or members that are embedded in, or otherwise affixed to, the housing. Such housings may exhibit a desirable balance of properties, such as strength (e.g., toughness, shatter resistance, yield strength), appearance, radio transparency, and scratch or abrasion resistance. For example, a housing may include a plastic material that forms structural walls of the housing, and abrasion-resistant members composed of metals, glasses, ceramics, or other suitable materials may be embedded in the plastic material and may extend above a top surface of the plastic material. The abrasion-resistant members may be harder than the plastic housing structure, and as such may improve the abrasion resistance of the housing as a whole. Accordingly, the housing may be more scratch resistant than other housings, such as housings with a single material forming the exterior surface.

The abrasion-resistant members (or simply "members") may be formed in a variety of shapes and sizes. For example, the abrasion-resistant members may be spherical, substantially spherical, or faceted. The abrasion-resistant members **210** may be shaped like a bead, or may be substantially bead-like. The members, or beads, may include interlocking structures that mechanically engage the housing structure. The members may also have interconnecting structures that connect the abrasion-resistant members to each other, and may be below the surface of the housing structure. The members may have a range of sizes. For example, the members may have a diameter that is between about 0.5 and about 5.0 mm. Furthermore, the portion of the abrasion-resistant members that protrudes above the surface of the housing structure may be faceted. Such facets may reflect light in certain directions, which may produce a desirable appearance, reflection, image, or color. The facets may be present in the members prior to incorporation into the housing structure, or may be produced in the members by treating the members after the formation of the abrasion-resistant housing structure.

In some cases an entire exterior surface of a housing may have abrasion-resistant members incorporated therein (e.g., the exterior surface of the housing may be substantially uniformly coated with the abrasion-resistant members). In other cases, one or more distinct or differentiated portions of the housing are substantially free of abrasion-resistant materials or members. For example, a region of the housing displaying a logo and/or other indicia may be free of abrasion-resistant members in order to make the logo and/or other indicia visible or more visually distinctive. As another example, a region may be free of abrasion-resistant members so the region is more transparent to or transmissive of electromagnetic radiation, such as radio waves or mobile phone signals, as compared to a region that includes abrasion-resistant members.

Also described herein are techniques for forming abrasion-resistant housings for electronic devices. For example, one method to produce the abrasion-resistant housing structures includes positioning abrasion-resistant components or members having interlocking structures in a mold, introducing a moldable material into the mold such that the moldable material forms around the interlocking structures, thus securing the members to the moldable material to form the housing, and curing the moldable material to securely retain the members in the abrasion-resistant housing. The housings formed according to this method, or others described herein, may be used for electronic devices including mobile phones, watches, tablet computers, music playback devices, laptops, notebooks, or the like.

Although one or more of these components and/or processes may be described in the context of handheld devices, such as mobile phones, laptops, and notebooks, the embodiments disclosed herein should not be interpreted or otherwise used as limiting the scope of the disclosure, including the claims. In addition, one skilled in the art will understand that the following description has broad application. Accordingly, the discussion of any embodiment is meant only to be exemplary and is not intended to suggest that the scope of the disclosure, including the claims, is limited to these embodiments.

FIG. **1** shows an example device **100**. The device **100** shown in FIG. **1** is a mobile phone (e.g., a smartphone), but this is merely one representative example of a device that may be used in conjunction with the ideas disclosed herein. Other example devices include, without limitation, music/media players, tablet computers, laptop computers, wearable electronic devices, watches (e.g., mechanical, electrical, or electromechanical), and the like.

The electronic device **100** includes a housing **102** and a cover **104**, such as a glass, plastic, or other substantially transparent material, component, or assembly, attached to the housing **102**. The housing **102** includes side walls **115** and a back panel **205** (FIG. **2**A), which together may substantially define a back surface and four exterior side surfaces of the electronic device **100**. The cover **104** may cover or otherwise overlie a display and/or a touch sensitive surface (e.g., a touchscreen) of the device **100**, and may define a front exterior surface of the device **100**. The housing **102** and the cover **104** may be secured together and may substantially define the entire exterior of the device **100**.

The device **100** may also include internal components, such as processors, memory, circuit boards, batteries, sensors, and the like. Such components may be disposed within an internal volume defined at least partially by the housing **102**, and may be affixed to the housing **102** via internal surfaces, attachment features, threaded connectors, studs, posts, or the like, that are formed into, defined by, or otherwise part of the housing **102** (and/or the cover **104**).

The housing **102** may be formed from or include any suitable material or combination of materials. As described herein, the housing **102** may include abrasion-resistant members embedded in a matrix. The matrix may be formed from or include plastic, glass, polymer, ceramic, metal, or the like. The abrasion-resistant members, described herein, may be formed from or include ceramic, metal, glass, or the like. The housing **102** may be a single unitary component (e.g., a single monolithic structure, with or without embedded abrasion-resistant members). In other cases, the housing **102** may be formed from multiple components (e.g., multiple unitary housing structures, each of which may include or may omit embedded abrasion-resistant members), such as multiple components fused, bonded, sintered, or otherwise attached to each other. For example, the back panel **205** (FIG. **2**A) and one or more of the sidewalls **115** may be distinct components that are joined, bonded, or otherwise secured together to form the housing **102**.

FIG. **2**A shows a back view of the device **100**, showing an example of the housing **102** with a plurality of abrasion-resistant members **210** embedded in a material of the back panel **205** of the housing **102**. Abrasion-resistant members **210** may also or instead by embedded in one or more sidewalls **115** of the housing **102** (or portions thereof). The device housing **102** shown in FIG. **2**A comprises a substrate **220** that defines external and internal surfaces of the housing **100**. The housing **102** may also include abrasion-resistant members **210**, which may be at least partially embedded in the substrate **220**. The abrasion-resistant members **210** may be at least partly embedded in the substrate and may extend (e.g., protrude) beyond the external surface, as shown in FIG. **2**C. By protruding beyond the external surface of the housing, the abrasion-resistant members may prevent or reduce scratching of the external surface of the housing.

The substrate **220** may be made of a moldable material such as a polymer, amorphous metal, glass, plastic, acrylic, ultraviolet-cured resin, ceramic or any other suitable material. The polymers may be thermosetting resins and/or thermoplastics. Moldable materials may be introduced into a shaped mold and may mechanically engage with the abrasion-resistant members **210** (e.g., via interlocking structures on the abrasion-resistant members **210**) to secure the abrasion-resistant members **210** to the moldable material. In this way, housings may be fabricated in any shape while also exhibiting enhanced scratch resistance.

The abrasion-resistant members **210** (or simply members **210**, or beads **210**) may be formed of metal, glass, hard plastic, or ceramic, such as zirconia, alumina, silicon carbide, yttria, silicon nitride, or the like. The abrasion-resistant members **210** may be harder than the substrate. For example, the members **210** may have a higher hardness value than does the substrate **220**. The abrasion-resistant members **210** may be fabricated by nano-molding techniques, or any other suitable technique or process.

The housing **102**, or enclosure, may be substantially rigid (e.g., non-compliant). For example, the housing **102** may be formed from or include a moldable material that is hardened, or cured, into a solid form. For example, the housing may have a Young's modulus greater than or equal to about 1 GPa, 2 GPa, 5 GPa, 7 GPa, or 10 GPa. Accordingly, the substrate, or base material in which the abrasion-resistant members **210** is embedded may be sufficiently stiff to form the housing **102** itself, and may not require additional structural layers, walls, or other housing members in order to form a sufficiently stiff or rigid housing **102**.

The surface density of the arrangement of the abrasion-resistant members **210** may vary across the surface of the housing **102**. The abrasion-resistant members may be distributed in a random or pseudorandom arrangement, or in an ordered array such as a grid or other non-random pattern. Even though the abrasion-resistant members **210** may be in a random or pseudorandom arrangement, it may be possible to control the average distance between nearest neighbors, such that an average distance between members is between about 10 and about 100 microns, or any other suitable range. The surface density of the abrasion-resistant members **210** may have effect on the stiffness of the housing. A greater surface density of the abrasion-resistant members **210** may increase the stiffness of the housing beyond the inherent stiffness of the substrate material. A lower density of the abrasion-resistant members **210** may permit the housing to be more flexible.

By varying the surface density of abrasion-resistant members **210**, it may be possible to tune structural qualities, such as stiffness, hardness, flexibility, and the like. For example, the surface density of the abrasion-resistant members **210** may be increased in regions of the housing, such as the corners or edges (e.g., at a transition between a back and a sidewall of a housing), relative to other areas of the housing. Fracture and impact resistance in the regions of the corners and/or edges may be increased by having a higher density of abrasion-resistant members in those regions. In some embodiments, it may be advantageous to have a reduced surface density of the abrasion-resistant members in some areas of the housing. For example, having a lower surface density of abrasion-resistant members at the corners or edges of the housing (relative to other areas, such as the back of the housing) may increase the stiffness of the corners or edges. In this way, by varying the surface densities of the abrasion-resistant members, different areas of the housing may have different mechanical properties (e.g., different scratch resistance, strength, toughness, stiffness, or the like).

Furthermore, the housing **102** may also have regions **230** that substantially lack abrasion-resistant members **210**. In some cases, the regions **230** have no abrasion-resistant members **210**. The regions **230** may coincide with or surround areas with logos and/or other indicia, which may increase the visibility or otherwise improve the appearance of the logos and/or other indicia. Also, the regions lacking abrasion-resistant members **230** may be transparent to or transmissive of electromagnetic radiation, such as radio waves, microwaves, and/or mobile phone signals, and may be more transparent to such radiation than the portions of the housing **102** that include the abrasion-resistant members **210**. Accordingly, antennas may be positioned inside the housing below or near the regions **230** lacking abrasion-resistant members, such that the antennas can transmit and/or receive wireless signals with less interference, attenuation, or shielding than if abrasion-resistant members **210** were positioned in those regions.

The abrasion-resistant members **210**, or beads **210**, may be provided in a variety of colors. The colors of the beads **210** may be substantially the same as that of the substrate or they may be of a different color. It may be desirable for the beads **210** to be camouflaged, or to be of contrasting colors. It may be desirable for the entire housing surface to be colored such that the beads are not visible and the entire housing appears to be one material. Furthermore, the beads **210** may be transparent, so that they can function as light pipes. It may be desirable for light to emanate from the beads in the housing.

FIG. **2**B is a detail view of the area of the device **100** indicated by line **2**B in FIG. **2**A, showing the substrate **220** and the abrasion-resistant members **210**. The abrasion-resistant members **210**, or the portion of the abrasion-resistant members **210** extending above the surface of the substrate **220**, may be substantially spherical. For example, the housing may include, embedded in the substrate, spheres of one or more materials (e.g., abrasion-resistant members) that are substantially harder than the material of the substrate. The abrasion-resistant members **210** may have shapes other than spheres, such as cubes, octahedrons, tetrahedrons, dodecahedrons, icosahedrons, cuboids, triangular prisms, pyramidal prisms, cones, or any other suitable regular or irregular shape. The abrasion-resistant members may protrude from the housing surface **220** a distance above the surface of the substrate **220** (as shown in FIG. **2**C).

The abrasion-resistant members **210** may be porous. The porous abrasion-resistant members may be produced by any suitable technique, including drilling, etching, additive manufacturing, or any other suitable process (including natural processes, such as where a naturally porous material, such as pumice, is used for the abrasion-resistant members **210**). The sizes of the pores may be from about 10 nm to about 1,000 nm, or any other suitable size. The structure of the porous members may be lattice-like or an open-cell structure. The pores may act as interlocking members or structures, permitting the moldable material to mechanically engage with the pores of the porous abrasion-resistant members **210**. The interlocking structures are described in detail below.

FIG. **2**C is cross sectional view of the device **100**, viewed along the line **2**C-**2**C in FIG. **2**B. In this embodiment of the invention, the abrasion-resistant members **210** are spherical and are at least partially embedded in the substrate **220**. The top of the members **210** extend a distance T above the substrate **220**. Depending on the specific application, and composition of the abrasion-resistant members **210** and the composition of the substrate **220**, the distance T from the top of the sphere (e.g., abrasion-resistant member) to the surface of the substrate **220** may be between about 0.1 mm and about 3.0 mm, between about 0.2 mm and about 1.5 mm, or between about 0.3 and about 0.6 mm.

The distance T from the top of the sphere, or bead (e.g., abrasion-resistant member) forming the protrusion on the surface of the substrate **220** may be varied from one region to another region. By varying the height of the protrusions, it may be possible to create tactile differences over the surface of the substrate. In some embodiments, it may be possible to feel the tactile differences when it is difficult to visually see the differences in height of the protrusions (with an unaided eye). For example, in some embodiments, it may desirable to provide a first region containing or outlining a logo, indicia, number, or the like with a height of the protrusions having a first distance T_1, and provide a second region with a height of the protrusions having a second distance T_2, and so on. The variations in height of the protrusions may be used to indicate input regions (e.g., buttons, keys, fingerprint sensors, or the like) of the device, which may be enabled by or include components embedded in the substrate **220** or below the substrate **220** (e.g., within an inner volume defined by the housing).

In some embodiments, some of the abrasion-resistant members may be below the surface of the substrate **220**. For example, some abrasion-resistant members may protrude above the surface of the substrate, while others may be positioned entirely below the surface of the substrate **220**. The submerged abrasion-resistant members may convey added strength to the substrate.

The abrasion-resistant members **210** may be beads manufactured from metal, glass, ceramic, or hard plastic. The abrasion-resistant members **210** may have non-spherical shapes. They may also have a substantially spherical portion that extends above the substrate surface **120**, but may have non-spherical portions embedded below the substrate surface **220**. For example, the abrasion-resistant members may include interlocking structures as described herein.

FIGS. **3**A-**3**C illustrate several examples of abrasion-resistant members having interlocking structures. The housing may be fabricated with abrasion-resistant members by disposing abrasion-resistant members with interlocking structures in a moldable material with at least a portion of each of the abrasion-resistant members extending above the surface of the material. For example, the abrasion-resistant members having the interlocking structures may be positioned within a mold, whereupon the moldable material is introduced into the mold to form the housing. The moldable material is cured around and/or through the interlocking structures of the members, thereby retaining the abrasion-resistant members **210** to the moldable material and thus the housing. Alternatively, the abrasion-resistant members **210** may be interlocked with the housing after the housing is formed and/or cured. For example, the abrasion-resistant members **210** may be riveted, bonded, swaged, heat staked, or otherwise attached to a substantially rigid (e.g., cured) housing material.

FIG. **3**A shows an abrasion-resistant member **310** with an interlocking structure **325** (e.g., feature) embedded in a substrate **320** (which may correspond to the substrate **220**). The interlocking structure **325** extends (e.g., protrudes) beyond the bottom of the substrate **320**, such that a portion of the abrasion-resistant members **325** locks onto (e.g., engages with) the bottom of the substrate. The interlocking structure **325** may be or may resemble a post-formed rivet. For example, the abrasion-resistant member **310** may include a bead portion (which may be spherical or any other suitable shape) and a rivet portion (e.g., a rod or post) extending from the bead portion. The rivet portion may be extended through an opening in the housing and then deformed to form the interlocking structure **325**. Alternatively, the abrasion-resistant member **310** may be formed as shown in FIG. **3**A, and the material of the substrate **320** may be flowed around at least part of the abrasion-resistant member **310** such that the substrate **320** overlaps the interlocking structure **325** as shown in FIG. **3**A.

FIG. **3**B illustrates another example of an abrasion-resistant member **350** with an interlocking member **365** that extends to (e.g., is substantially flush with) the bottom of the substrate **360** (which may correspond to the substrate **220**). The interlocking member **365** of the abrasion-resistant member **350** may be a post-formed rivet, as described above (e.g., where the interlocking member **365** is formed by deforming the abrasion-resistant member **350** to form the interlocking member **365** after being assembled with the substrate **360**). Alternatively, the interlocking member **365** may be formed prior to being incorporated with the substrate **360**, such as where the abrasion-resistant member **350** is insert-molded with the substrate **360**.

FIG. **3**C illustrates an abrasion-resistant member **380** with an interlocking structure **395** that is positioned within the substrate **390** (which may correspond to the substrate **220**). More particularly, the interlocking structure **395** may not be exposed on an inner surface of the substrate **390**. The abrasion-resistant member **380** may be incorporated with the material of the substrate **390** by insert molding, as described herein.

The interlocking structures illustrated in FIGS. **3**A-**3**C are non-limiting examples of interlocking structures that can provide mechanical engagement with the substrate. Other interlocking structures may include dovetails, protrusions, holes, fins, threads, or the like.

FIGS. **4**A and **4**B illustrate additional non-limiting examples of abrasion-resistant members having interlocking structures. More particularly, the interlocking structures in the abrasion-resistant members illustrated in FIGS. **4**A and **4**B include holes that extend into or through the abrasion-resistant members. In some embodiments, the moldable material of the housing is in, through, and/or around the interlocking structures, thus securing the members to the housing, or enclosure.

FIG. **4**A shows a substantially spherical abrasion-resistant member **410** with an interlocking structure **420** embedded in a substrate **430** (which may correspond to the substrate **220**). As illustrated in FIG. **4**A, the abrasion-resistant member may be an insert-molded sphere or bead **410** with a through-hole **420**. FIG. **4**B shows a non-spherical (e.g., bullet-shaped) embodiment of an abrasion-resistant member **450** with a hole **460** as an interlocking structure. The substrates **430** and **470** in FIGS. **4**A and **4**B, respectively, are interlocked through the holes in the members. For example, the abrasion-resistant members **410**, **450** may be positioned in a mold or die, and the material for the substrates **430**, **470** (which forms structural walls of an electronic device housing) is introduced into the mold such that it extends into and/or through the holes. In some cases, the molding process may be performed in a vacuum environment to allow the material to flow into and/or through the holes without trapping air in the holes.

The abrasion-resistant member **450** illustrates an embodiment where the abrasion-resistant member **450** has a substantially spherical portion above the substrate **470** with a non-spherical portion below an exterior surface of the substrate **470** and mechanically engaged with the substrate. Engagement features such as undercuts may be included in the abrasion-resistant members instead of or in addition to the holes shown in FIGS. **4**A-**4**B.

FIG. **5** illustrates an embodiment of an electronic device housing **500** wherein the abrasion-resistant member **510** has an interlocking feature **530** that extends along the bottom of the substrate **520** (which may correspond to the substrate **220**). The moldable material (e.g., substrate) is disposed above the interlocking feature **530**, and the abrasion-resistant member protrudes above the substrate surface **570**. In this embodiment, the inner surface of the housing is substantially defined by the interlocking feature **530** of the abrasion-resistant member **510**. The material comprising the abrasion-resistant member **510** and interlocking feature **530** may be harder than the material comprising the moldable material of the substrate **520**. For example, the abrasion-resistant material may be formed of or include metal, glass, hard plastic, or ceramic such as zirconia, alumina, silicon carbide, yttria, silicon nitride, or the like. The moldable material may be a polymer, amorphous metal, bulk metallic glass, glass, plastic, acrylic, ultraviolet-cured resin, or any other suitable material.

Several methods could be used to fabricate electronic device housing **500**. One method to fabricate the housing **500** may include forming the abrasion-resistant member **510** and interlocking feature **530** in a mold, such that the interlocking feature **530** forms a contiguous surface **580**. Subsequent to the forming of the abrasion-resistant member **510**, the moldable material of the substrate may be introduced onto the contiguous surface **580** of the interlocking feature **530**, such that a portion of the abrasion-resistant member **510** protrudes above the substrate surface **570**. This method can be performed with molds, such as in an injection molding process.

FIGS. **6**A-**6**C illustrate an embodiment of the abrasion-resistant housing with interconnected abrasion-resistant members **610**. FIG. **6**A shows a top view of the interconnected abrasion-resistant members **610** joined by connectors **620** prior to being embedded in the substrate. FIG. **6**B shows a top view of the interconnected abrasion-resistant members **610** embedded in the substrate **630** (which may correspond to the substrate **220**). A portion of the surface of the interconnected abrasion-resistant members **610** is above the surface of the substrate **630**, and the connectors **620** are below the surface of the substrate **630**. For example, FIG. **6**C shows a partial cross-sectional view of the housing shown in **6**B viewed along line **6**C-**6**C in FIG. **6**B, illustrating a portion of interconnected abrasion-resistant members **610** extending above the surface of substrate **630**, and the connectors **620** below the surface of substrate **630**. The interconnected abrasion-resistant member **610** and connector **620** may be formed from or include an abrasion-resistant material, such as metal, amorphous metal (e.g., bulk metallic glass), ceramic, glass, or hard plastic. The interconnected abrasion-resistant members **610** and connectors **620** may be fabricated by molding, pressing, additive manufacturing (e.g., 3D printing), machining, or any like process. The substrate **630** may be made of a moldable material such as a polymer, amorphous metal, glass, plastic, acrylic, ultraviolet-cured resin, or any other suitable material.

The incorporation of the connectors **620** may increase the stiffness of the housing, serving as a structural reinforcement within the substrate. The thickness and length of the connectors **620** may be designed to tailor the rigidity of the housing.

The interconnected abrasion-resistant members **610** may further comprise interlocking structures (not shown in FIG. **6**C), such as any of the interlocking structures shown or described herein (e.g., holes, dovetails, threads, flanges, etc.). The interlocking structures may extend partially into the moldable (e.g., substrate) material, to the bottom of the moldable material, or may extend all the way through the moldable material and protrude through the bottom surface, as illustrated in FIGS. **3**A-**3**C.

The abrasion-resistant components may be treated or configured to create various optical effects, such as to produce a different appearance when the housing is viewed from different angles. For example, facets could be fashioned in the exposed surfaces of the members. FIGS. **7**A-**7**C illustrate non-limiting embodiments of faceted abrasion-resistant members (e.g., components). The members may be multifaceted such that the exposed portions have 3, 4, 5, 6, or any number of sides to achieve the desired optical effect. FIG. **7**A illustrates a three-sided pyramidal faceted structure **710** and the substrate surface **720**. FIG. **7**B illustrates a four-sided pyramidal faceted structure **730** and the substrate surface **720**.

The faceted abrasion-resistant components are not limited to pyramidal structures. Non-pyramidal geometrical shapes may be used in the faceted abrasion-resistant members. For example, abrasion-resistant components that otherwise have spherical or semi-spherical exposed regions may have one (or more) substantially flat facets formed on the exposed surface. As another example, as shown in FIG. **7**C, dodecahedron- or icosahedron-shaped abrasion-resistant members **740** may be embedded at least partially in the substrate **720**. As the number of facets on the abrasion-resistant members increases, the precision with which the abrasion-resistant members must be positioned may decrease. For example, where an icosahedron-shaped abrasion-resistant member is used, the maximum deviation in positioning (e.g., rotational alignment) of any two members may be limited due to the shape and symmetry of the icosahedron.

The facets in the abrasion-resistant components may be fabricated after formation of the housing, from components that were substantially spherical (or any other suitable shape) prior to being disposed in the substrate. The facets may be formed by treating the abrasion-resistant components with grinders, polishers, chemical etchants, and lasers. For example, the faceted abrasion-resistant components in FIGS. **7**A-**7**C may be fabricated after formation of the housing.

In some embodiments, the portion of the abrasion-resistant member protruding above the substrate surface may be spherical. It may be desirable to form a single facet in each of the members such that they all align to create a specular reflection or other optical or visual appearance that is visible from at least one orientation (e.g., the optical or visible appearance or effect may be visible when a device or surface of the device is viewed from some angles or orientations but not from others). In some cases, an optical or visible appearance or effect may be visible when a device or surface is viewed from any angle or orientation.

In some embodiments, the facets may be fabricated by ablating each member to create an arrangement of the facets. Optical effects, such as a specular reflection, could be achieved by having at least one treated (e.g., faceted) surface on each abrasion-resistant member (or a subset of abrasion-resistant members) aligned to face in substantially the same direction. Alternate embodiments may include having unaligned facets that may provide a glittery or sparkling appearance. Other optical or visual appearances that may be achieved using faceted members include an image, a hologram, a lenticular image (e.g., a transforming, animated, or stereoscopic image), or the like.

Furthermore, in embodiments it may be preferable to utilize pre-faceted abrasion-resistant components. The abrasion-resistant component may be substantially bead-like. In embodiments, non-spherical abrasion-resistant preformed beads may be incorporated into the housings. An example of a preformed bead **740** is presented in FIG. **7**C, where a dodecahedron is incorporated into a housing structure. In embodiments, beads with any number of facets may be incorporated in the housing structure. The abrasion-resistant members, or beads, may be egg shaped (e.g., ovoid). The beads may be rectangular with or without rounded corners and/or side edges. In some embodiments, the shape of the bead and its corresponding weight distribution may cause the bead to align preferentially in the moldable material (e.g., matrix). For example, the bead may be heavier or denser on one end, such that bead naturally orients itself with the heavier or denser end pointing down (e.g., aligned with gravity).

FIG. **8** illustrates an example process for forming a housing for an electronic device, such as the housing **100** illustrated in FIG. **1**. In operation **800**, abrasion-resistant components are positioned within a shaped mold that defines at least one contour, recess, protrusion, or the like. The positioning can be performed by hand, as well as by robotic processes. The abrasion-resistant members may include interlocking features (e.g., as described with respect to FIGS. **3**A-**5**), connectors that join the abrasion-resistant members (e.g., as described with respect to FIGS. **7**A-**7**C), or they may be free of interlocking structures or features.

In operation **820**, moldable material is introduced into the mold to form the housing. For example, the moldable material is raised above a melting/softening temperature and introduced (e.g., poured, flowed, and/or injected) into the mold. As the moldable material is introduced into the mold, it may flow around portions of the abrasion-resistant components, as well as any interlocking structures or connectors of the abrasion-resistant components. Accordingly, once cured or hardened, the moldable material will be engaged with the abrasion-resistant components, interlocking structures, and/or connectors, thus retaining the abrasion-resistant components to the cured or hardened material.

The moldable materials may include polymers, glasses, amorphous metals, or the like. Polymers may be thermosetting resins, thermoplastics, acrylics, and the like. The amorphous metals can include bulk metallic glasses and low melting metallic alloys.

In operation **840**, the moldable material is cured. For example, polymer moldable material may be cured by electron beams, heat, ultraviolet radiation, or chemical additives. As another example, an amorphous alloy may be used as the moldable material. In this example, the curing is achieved by cooling the amorphous alloy.

FIGS. **9**A-**9**D illustrate a method for producing an abrasion-resistant housing. FIG. **9**A shows abrasion-resistant components **910** having interlocking structures positioned over a mold **920**. The abrasion-resistant components **910** may be positioned by a variety of positioning methods, including by hand, by robotic methods, and the like.

In embodiments, it may be desirable to use interconnected abrasion-resistant components, or substantially spherical or bead-like abrasion-resistant components free of interlocking structures, or features.

In FIG. **9**B, the abrasion-resistant components having interlocking structures are positioned within the mold **920**. The mold **920** may include recesses, contours, or other features or shapes that receive and hold the abrasion-resistant members **910** in place. In some cases, the abrasion-resistant members **910** may be adhered, bonded, magnetically secured, mechanically secured (e.g., clamped), or otherwise retained to the mold **920** to prevent them from becoming displaced or moved during injection of the material (described below). The mold may be an injection mold or any other suitable mold or die.

In FIG. **9**C, the moldable material **930** is introduced into the mold to form the housing. The moldable material **930** may be introduced into the mold by nozzle. The nozzles may use a modular design that offers the ability to inject more than one component at flow rates that optimize the distribution of the moldable material.

In FIG. **9**D, the abrasion-resistant housing produced by the described method is shown. As shown in FIG. **9**D, the abrasion-resistant members have interlocking features mechanically engaged with the material of the substrate in the midst of the moldable material. In embodiments, the abrasion-resistant members may have interlocking features that reach to the bottom of the substrate (as illustrated in FIG. **3**B), or may extend beyond the bottom of the substrate and lock onto the back of the housing (as illustrated in FIG. **3**C).

In the forgoing examples of housings, the shape of the abrasion-resistant members **210** prior to being incorporated into the material of the housing may be maintained in the completed housing. In some cases, however it may be desirable to impart a shape to the abrasion-resistant members **210** after an abrasion-resistant material or precursor is integrated with a substrate material.

FIGS. **10**A-**10**B illustrate an embodiment of forming an abrasion-resistant housing in which an abrasion-resistant material is formed or processed after integration with a matrix material. For example, FIG. **10**A shows a combination of a first material **1010** and a second material **1020** that align flush along a top surface **1030**. The first material **1010** has a higher hardness value than the second material **1020**. The combination of materials can be polished such that the second material **1020** is differentially relieved relative to the first material **1010**, as illustrated in FIG. **10**B. The polishing of the combination material results in a textured housing surface such that the first material forms the abrasion-resistant member in the housing structure. The combination of a first material **1010** and a second material **1020** may be produced by pressing and/or fusing the first and second materials together, or by inserting abrasion-resistant materials and/or members into a mold and then flowing the second material **1020** around the abrasion-resistant materials and/or members, as described with respect to FIGS. **9**A-**9**D, for example.

Housings with abrasion-resistant members **210** may furthermore include embodiments in which the abrasion-resistant members **210** are incorporated into the housings after the substrate is formed. For example, abrasion-resistant members **210** may be fabricated by spot-welding metal abrasion-resistant members **210** on the substrate. A welder may be used to apply spot-welds at a desirable surface density. Furthermore, the size and shape of the welded abrasion-resistant member **210** may be controlled by the parameters of the welding apparatus.

In an embodiment, the abrasion-resistant member **210** may be incorporated into the substrate using selective laser melting (SLM), wherein the abrasion-resistant members **210** are built up one layer at a time (each layer being as small as 1 atom in thickness). Using SLM, an array of the abrasion-resistant members **210** may be fabricated at a desired diameter, height, and surface density.

While the present disclosure has been described with reference to various examples, it will be understood that these examples are illustrative and that the scope of the disclosure is not limited to them. Many variations, modifications, additions, and improvements are possible. More generally, examples in accordance with the present disclosure have been described in the context or particular embodiments. Functionality may be separated or combined in blocks differently in various embodiments of the disclosure or described with different terminology. These and other variations, modifications, additions, and improvements may fall within the scope of the disclosure as defined in the claims that follow

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the described embodiments. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the described embodiments. Thus, the foregoing descriptions of the specific embodiments described herein are presented for purposes of illustration and description. They are not targeted to be exhaustive or to limit the embodiments to the precise forms disclosed. It will be apparent to one of ordinary skill in the art that many modifications and variations are possible in view of the above teachings. For example, while the methods or processes disclosed herein have been described and shown with reference to particular operations performed in a particular order, these operations may be combined, subdivided, or re-ordered to form equivalent methods or processes without departing from the teachings of the present disclosure. Moreover, structures, features, components, materials, steps, processes, or the like, that are described herein with respect to one embodiment may be omitted from that embodiment or incorporated into other embodiments.

What is claimed is:

1. A housing of an electronic device, comprising:

a monolithic substrate formed of a moldable polymer material having a uniform composition and defining:

an external surface and an internal surface of the housing;

a back panel; and

a set of sidewalls extending from the back panel and defining a curved corner portion of the monolithic substrate; and

a plurality of members bonded directly to the monolithic substrate in respective recesses defined in the monolithic substrate, the plurality of members protruding from the external surface and having a hardness greater than a hardness of the monolithic substrate, the plurality of members comprising:

a first set of members protruding from the external surface along the curved corner portion, the first set of members defining a first surface density, each member of the first set of members retained to the monolithic substrate at least in part by a respective undercut defined by the monolithic substrate and in contact with a surface of the member of the first set; and

a second set of members protruding from the external surface along the back panel, the second set of members defining a second surface density, less than the first surface density, and each member of the second set of members retained to the monolithic substrate at least in part by a respective undercut defined by the monolithic substrate and in contact with a surface of the member of the second set.

2. The housing of claim **1**, wherein an average distance between adjacent members of the first set of members is between about 10 and 100 microns.

3. The housing of claim **1**, wherein:

the members of the plurality of members each have a faceted surface; and

the members of the plurality of members are each configured to reflect light at an angle.

4. The housing of claim **1**, wherein the monolithic substrate has a Young's modulus greater than or equal to about 5 GPa.

5. The housing of claim **1**, wherein the members of the plurality of members each have a diameter between about 0.5 and about 5.0 mm.

6. A housing of an electronic device, comprising:

a unitary housing structure formed from a single moldable material and defining:

a back wall of the housing defining a flat portion of an external surface of the housing; and

at least one side wall extending from the back wall and defining a curved portion of the external surface;

a first set of members having first interlocking features and being at least partially embedded in the unitary housing structure such that the first interlocking features mechanically engage first undercuts defined in the single moldable material of the unitary housing structure, the members of the first set positioned in the at least one side wall, defining a first surface density, and each having a portion protruding above the curved portion of the external surface; and

a second set of members having second interlocking features and being at least partially embedded in the unitary housing structure such that the second interlocking features mechanically engage second undercuts defined in the single moldable material of the unitary housing structure, the members of the second set positioned in the back wall, defining a second surface density less than the first surface density, and each having a portion protruding above the flat portion of the external surface of the back wall, and each member of the first and the second sets of members having a hardness value greater than a hardness value of the single moldable material.

7. The housing of claim **6**, wherein the single moldable material has a Young's modulus greater than or equal to 2 GPa.

8. The housing of claim **7**, wherein the single moldable material is a polymer.

9. The housing of claim **7**, wherein the single moldable material is an amorphous metal.

10. The housing of claim **6**, wherein each member of the second set of members has a faceted surface, such that a region of the back wall including the second set of members produces a specular reflection.

11. The housing of claim **6**, wherein the first and the second interlocking features comprise flanges.

12. The housing of claim **6**, wherein:

the second set of members is positioned in a first region of the back wall;

a second region of the back wall is substantially free of members; and

the second region of the back wall corresponds to a location of an antenna within the housing.

13. The housing of claim **6** further comprising connecting elements joining at least a subset of the members of the second set of members to one another.

14. The housing of claim **13**, wherein the subset of the members of the second set of members and the connecting elements are a monolithic structure.

15. The housing of claim **6**, wherein the members of the second set of members are distributed in a regular pattern over the flat portion of the external surface of the back wall.

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