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(54) **EXTERNAL PORT**

(57) An external port (100) for bidirectional transmission of radio frequency, RF, signals for an integrated circuit, IC, package, wherein the IC package (1000) comprises a case (1010) having an access wall (1020) and an IC chip (1030) established on a first substrate (1040)

contained in the case (1010), the external port (100) comprising a dielectric waveguide structure (IC DRW 1) embeddable in the access wall (1020) of the case, the dielectric waveguide structure (IC DRW 1) configured for bidirectional transmission of RF signals.

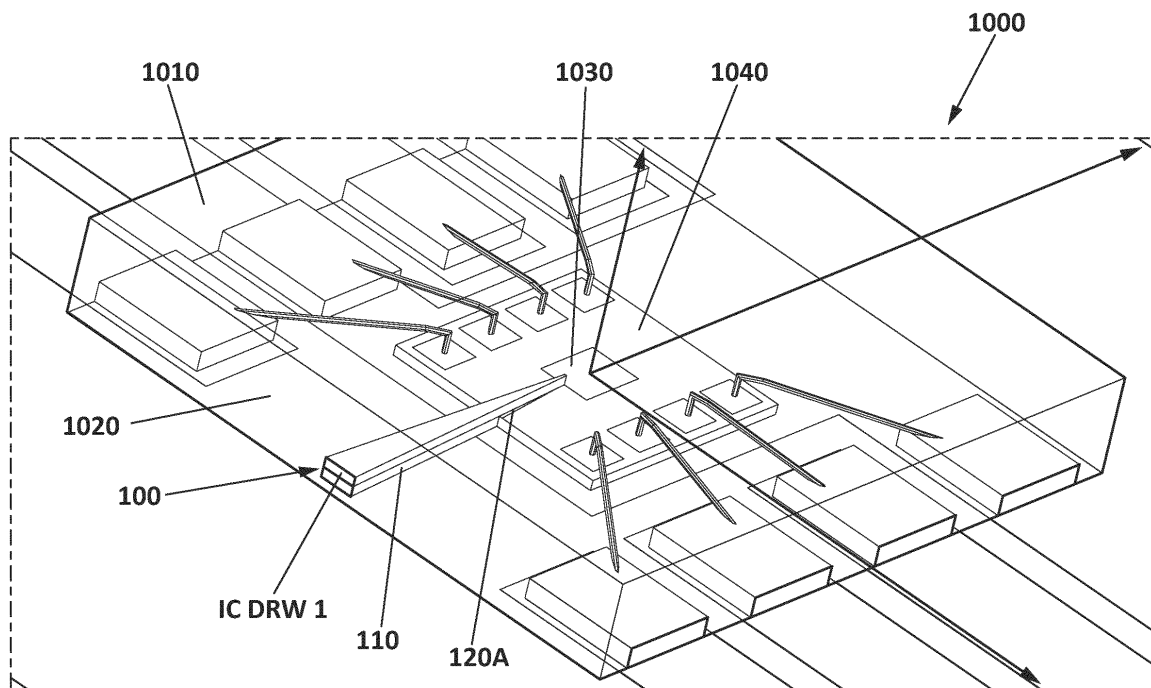


FIG. 3

Description

[0001] The present invention refers to an external port for bidirectional ultra-broadband transmission of radio frequency, RF, signals for an integrated circuit, IC, package.

BACKGROUND OF THE INVENTION

[0002] In the last years, solid-state semiconductors devices have been pushing their frequency limitations to higher frequencies, and their adoption in various terahertz, THz, applications such as communication, instrumentation, imaging, and sensing is steadily increasing. Several packaging strategies have been investigated since proper housing is key to improving the stability and reliability of the integrated circuits, IC. As frequency increases, interconnecting the ICs becomes challenging due to the losses and the impact of the manufacturing tolerances on the signal integrity.

[0003] For IC operating at frequencies below 30 GHz the use of plastic-molding packages is well established. The interconnection is then made via beam leads or balls, commonly in a ground-signal-ground configuration, which creates a coplanar waveguide, CPW. Internally, the IC chip is interconnected to the pad via wire bonding or ribbon bonding. However, as frequency increases, the parasitic series inductance becomes significant, which makes it impossible to use this technique for millimeter and sub-millimeter wave frequencies. The use of other techniques, such as low-temperature co-fired ceramics, LTCC, and multiple wire bonds per connection, can partially mitigate the losses, but there is still a practical limitation for sub-millimeter wave frequencies.

[0004] Other waveguides can be used for interconnection but either become impractical in size for frequencies above 100 GHz, like the coaxial line or unsuitable for integration in IC packages, like the rectangular waveguide. The use of integrated antennas for chip-to-chip communication has also been proposed. Although this solution can easily fit inside standard plastic packages, it is frequency-limited by the chosen antenna topology.

[0005] Our current approach is shown in Figure 1. A single-mode excited dielectric waveguide achieves a low-loss high-frequency ultra-wideband signal interconnection. The rod is truncated and established as a bidirectional high-frequency port in the IC package wall. It can be used for connecting an external dielectric waveguide, an antenna, or another IC.

[0006] The present invention overcomes the aforementioned limitations and drawbacks.

DESCRIPTION OF THE INVENTION

[0007] The present invention provides a solution to bidirectional ultra-broadband transmission of radio frequency, RF, signals for an integrated circuit, IC, package.

It is compatible to several integrated circuit packaging types.

[0008] Hence, the present invention relates to an external port comprising at least a waveguide port for bidirectional transmission of radio frequency, RF, signals for an integrated circuit, IC, package. Any signal coupled to the external port can be efficiently coupled to another dielectric structure, waveguide, antenna, or resonator, so it can be used for implementing telecommunication devices and high-frequency sensors. The dielectric waveguide structure can be used for either radiating or receiving through the proposed IC port.

[0009] Our invention has the following improvements: The external port is a novel ultra-wideband signal port that can be integrated into already existing IC packages. Depending on the device configuration, many external ports can be fitted into one single package.

[0010] The external port comprises a dielectric waveguide structure e.g., a dielectric rod waveguide (DRW) integrated into the IC package. The dielectric waveguide structure can be made of a high permittivity substrate, such as Silicon, GaAs or InP. On the external side, dielectric waveguide structure can be flat truncated. On the internal side, the dielectric waveguide structure can be connected to the IC chip.

[0011] The external port can have a lower cut-off frequency that depends on the port cross-section dimensions, e.g., with a width of 1 mm that leads to a cut-off frequency of approximately 65 GHz.

[0012] The external port can have a higher cut-off frequency of at least 100 GHz that depends on the manufacturing tolerances, so a trade-off between manufacturing costs and bandwidth can be set.

[0013] The external port can extend the frequency range to the lower frequencies (up to DC) by using additional metal pins.

[0014] Hence, a first aspect of the present invention relates to an external port for bidirectional transmission of radio frequency, RF, signals for an integrated circuit, IC, package, wherein the IC package comprises a case having an access wall and an IC chip established on a first substrate contained in the case, the external port comprising a dielectric waveguide structure embeddable in the access wall of the case, the dielectric waveguide structure is configured for bidirectional transmission of RF signals.

[0015] In an example, the dielectric waveguide structure works as an ultra-wide band dielectric IC port and is configured to be connectable to a second IC chip, an external waveguide, a dielectric structure, or an antenna.

[0016] In an example, the dielectric waveguide structure provides a high-pass characteristic interconnection operating over a high frequency range starting from a low cut-off frequency f_0 in the microwave range or in the millimeter-wave range, up to a higher cut-off frequency of at least 100 GHz.

[0017] In another example, the external port further comprises a second substrate connected to the dielectric

waveguide structure and connectable to the first substrate and a first metallization connectable to the IC chip and established on the second substrate. The second substrate comprises RF substrates such as quartz, laminates and ceramics or Silicon.

[0018] In a preferred example, the dielectric waveguide structure comprises a tapered end.

[0019] In an example, the external port comprises a second metallization electrically connected to the first metallization. In this example, the first metallization and the second metallization are metal waveguide structures providing a low-pass characteristic interconnection, operating over a low frequency range from DC up to a high cut-off frequency f_{CH} in the millimeter wave range. Furthermore, the external port can comprise a first electrical interconnection configured to electrically connect the first metallization and the second metallization.

[0020] In one example, the first electrical interconnection comprises epoxy.

[0021] In one example, the external port further comprises two metal pins embeddable in the access wall and connectable to the IC chip by metallic connecting means. The metallic connecting means can comprise wire bonding, epoxy or ribbon bonding.

[0022] In one example, the external port further comprises a second electrical interconnection configured to electrically connect the two metal pins to the second metallization.

[0023] Another aspect of the present invention relates to an IC, package for transmitting or receiving RF signals, comprising the external port according to the first aspect of the present invention.

[0024] In one example, the first substrate of the IC package comprises RF substrates such as quartz, laminates and ceramics or Silicon.

[0025] In one example an access wall of the IC package comprises a dovetail shape or a V-groove shape that serve as a mechanical aid for aligning an external waveguide, antenna, connector, or any other component or device connected to the IC package port.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] For a better understanding the above explanation and for the sole purpose of providing an example, some non-limiting drawings are included that schematically depict a practical embodiment.

Figures 1 and 2 show a first example of the external port according to the present invention.

Figures 3 and 4 show a second example of the external port according to the present invention, wherein the dielectric waveguide structure has as tapered end.

Figures 5 shows a third example of the external port according to the present invention that comprises metal pins and a metallization.

Figures 6 and 7 show a fourth example of the external

port according to the present invention that comprises two metallizations.

Figure 8 shows a fifth example of the external port according to the present invention that comprises metal pins and electrical connections.

Figures 9 and 10 show examples of IC packages with mechanical aids in the access wall.

DESCRIPTION OF A PREFERRED EMBODIMENT

[0027] Figures 1 shows a first example of the external port (100) for bidirectional transmission of radio frequency, RF, signals for an integrated circuit, IC, package, wherein the IC package (1000) comprises a case (1010) having an access wall (1020). The external port (100) comprises a dielectric waveguide structure (IC DRW 1) embedded in the access wall (1020) of the case (1010), the dielectric waveguide structure (IC DRW 1) is configured for bidirectional transmission of RF signals.

[0028] In this particular example, an 8-lead TDFN plastic IC package (1000) is shown as an example. The access wall (1020) in the case (1010) has been reserved for the dielectric waveguide structure (IC DRW 1). The metallic pins of the case (1010) can be used for conventional electric connections.

[0029] A dielectric rod waveguide of similar or equal permittivity as the dielectric waveguide structure (IC DRW 1) can be attached to the access wall (1020). The dielectric waveguide structure (IC DRW 1) works as an ultra-wide band dielectric IC port and can be used to connect the IC package (1000) to another ultra-wideband IC port, to an external waveguide (i.e., rectangular waveguides), dielectric structures (i.e. a resonator), or an antenna.

[0030] Figure 2 shows an internal view of the example of figure 1. The IC package (1000) comprises an IC chip (1030) established on a substrate (1040) contained in the case (1010). The IC package (1000) is solder in any low or intermediate permittivity substrate (1040), such as FR-4, Rogers, Duroid, etc. The first substrate (1040) comprises RF substrates such as quartz, laminates and ceramics or Silicon.

[0031] The dielectric waveguide structure (IC DRW1) connects the IC chip (1030) with the access wall (1020) for bidirectional transmission of RF signals and provides a high-pass characteristic interconnection operating over a high frequency range starting from a low cut-off frequency f_0 in the microwave range or in the millimeter-wave range, up to a higher cut-off frequency of at least 100 GHz.

[0032] Figure 3 shows an internal view of a second example of the external port (100) according to the present invention, wherein dielectric waveguide structure (IC DRW1) comprises. The tapered tip of the dielectric waveguide structure (IC DRW1) lies on top of the IC chip (1030).

[0033] In the example of figure 3, the external port (100) further comprises a second substrate (110) connected

to the dielectric waveguide structure (IC DRW1) and connected to the first substrate (1040) of the IC chip (1030) and a first metallization (120A) connected to the IC chip (1030) and established on the substrate (1040). The second substrate (110) comprises RF substrates such as quartz, laminates and ceramics or Silicon. The first metallization (120A) can be a (tapered) metal waveguide structure providing a low-pass characteristic interconnection, operating over a low frequency range from DC up to a high cut-off frequency f_{CH} in the millimeter wave range.

[0034] Figure 4 shows a detailed view of the example of figure 3. The dielectric waveguide structure (IC DRW1) propagates the RF signal with low losses and no transmission nulls in a broad bandwidth if there is no intermodal interference. Because of this, most of the signal power must be coupled to the waveguide fundamental mode for all frequencies. The main bandwidth limitations come from the presence of higher-order modes. The higher-order modes may be excited due to misalignments between elements so the manufacturing capabilities will determine the maximum frequency. To extend the high-frequency limit, the first metallization (120A) (e.g., a tapered metallic waveguide structure) can be printed into the IC chip (1030).

[0035] The horizontal dielectric waveguide structure (IC DRW1) cross-section dimension is the (IC DRW1) width, and the vertical dimension is the (IC DRW1) thickness. Both are related to the low-frequency limit of the external port (100).

[0036] Figure 5 shows a third example of the external port according to the present invention that comprises two metal pins (150) and the first metallization (120A) providing a DC extension. In the third example, the external port (100) further comprises two metal pins (150) embeddable in the access wall (1020) and connectable to the IC chip (1030) by metallic connecting means (150A) that connect the two metal pins (150) to the first metallization (120A). The metallic connecting means (150A) comprise wire bonding for this particular case. In other examples, the metallic connecting means (150A) can comprise epoxy or ribbon bonding.

[0037] Figure 6 shows a fourth example of the external port (100) according to the present invention that comprises two metallizations. In particular, in this fourth example, the external port (100) comprises the first metallization (120A) and a second metallization (120B) electrically connected to the first metallization (120A). The first metallization (120A) and the second metallization (120B) can be (tapered) metal waveguide structures providing a low-pass characteristic interconnection, operating over a low frequency range from DC up to a high cut-off frequency f_{CH} in the millimeter wave range.

[0038] For this example, to achieve a bandwidth from 65 GHz to 300 GHz, the second metallization (120B) length is 14.5 mm. For avoiding this increase in length, it can be possible to extend the second metallization (120B) outside the IC chip (1030).

[0039] The fourth example of the external port (100) further comprises a first electrical interconnection (140A) configured to electrically connect the first metallization (120A) and the second metallization (120B). The first metallization (120A) is connected to the second metallization (120B) by means of the first electrical interconnection (140A) that can comprise conductive epoxy or similar. The quality of this electric contact (in terms of its maximum frequency f_m) linearly depends on a truncation point. A truncation point close to the external port (100) leads to an f_m close to f_0 . For frequencies above f_m , the signal is coupled to the dielectric waveguide structure (IC DRW 1) before the transition between the IC chip (1030) and the second metallization (120B).

[0040] Figure 7 shows a detailed view of figure 6. In this figure, the first electrical interconnection (140A) configured to electrically connect the first metallization (120A) and the second metallization (120B) is shown in detail as well as the second substrate (110) connected to the dielectric waveguide structure (IC DRW1) and connected to the first substrate (1040).

[0041] Figure 8 shows a fifth example of the external port (100) according to the present invention that comprises two metal pins (150) and electrical interconnection. The external port (100) comprises the two metal pins (150) embeddable in the access wall (1020) and connectable to the IC chip (1030) by metallic connecting means (150A) and a second electrical interconnection (140B) configured to electrically connect the two metal pins (150) to the second metallization (120B) providing a DC extension. The DC extension is internally implemented by connecting the two metal pins (150) to the second metallization (120B) (e.g., a tapered metallic waveguide structure).

[0042] As mentioned above, it is possible to extend the bandwidth to the lower frequencies by adding two metal pins (150) to the external port (100). Hence, the external port (100) comprises the dielectric waveguide structure (IC DRW1) and the two metal pins (150). In this example, the external port (100) is hybrid as it comprises the dielectric waveguide structure (IC DRW 1) and two metal pins (150). For the lower frequencies, it works as a balanced bifilar line. For frequencies above f_0 , the signal is coupled into the HE_{11} mode.

[0043] Figures 9 and 10 show examples of IC packages (1000) with mechanical aids in the access wall (1020). In the previous examples, a flat surface is assumed in the access wall (1020). It is also possible to add mechanical aids in the access wall (1020) for enhancing the alignment between an external waveguide and the external port (100). In figures 9 and 10, the access wall (1020) can be dovetail- and v-groove-shaped, respectively, to accommodate an external waveguide (not part of the invention) with a cover made of any material with a permittivity lower than the DRW one (i.e., plastic or epoxy) that matches the IC port shape, since shaping may be easier if it is not directly done in the DRW.

Claims

1. An external port (100) for bidirectional transmission of radio frequency, RF, signals for an integrated circuit, IC, package, wherein the IC package (1000) comprises a case (1010) having an access wall (1020) and an IC chip (1030) established on a first substrate (1040) contained in the case (1010), the external port (100) comprising:
 - a dielectric waveguide structure (IC DRW 1) embeddable in the access wall (1020) of the case, the dielectric waveguide structure (IC DRW 1) configured for bidirectional transmission of RF signals.
2. The external port (100) according to claim 1, wherein the dielectric waveguide structure (IC DRW 1) works as an ultra-wide band dielectric IC port and is configured to be connectable to a second IC chip, an external waveguide, a dielectric structure, or an antenna.
3. The external port (100) according to claims 1 or 2, wherein the dielectric waveguide structure (IC DRW1) provides a high-pass characteristic interconnection operating over a high frequency range starting from a low cut-off frequency f_0 in the microwave range or in the millimeter-wave range, up to a higher cut-off frequency of at least 100 GHz.
4. The external port (100) according to claims 1 to 3, further comprising:
 - a second substrate (110) connected to the dielectric waveguide structure (IC DRW1) and connectable to the first substrate (1040); and
 - a first metallization (120A) connectable to the IC chip (1030) and established on the substrate (1040).
5. The external port according to the previous claim, wherein the second substrate (110) comprises RF substrates such as quartz, laminates and ceramics or Silicon.
6. The external port according to the previous claim, wherein dielectric waveguide structure (IC DRW1) comprises a tapered end.
7. The external port according to claims 4 to 6, further comprising:
 - a second metallization (120B) electrically connected to the first metallization (120A) and mechanically connected to the dielectric waveguide structure (IC DRW 1).
8. The external port according to claim 7, wherein the first metallization (120A) and the second metallization (120B) are metal waveguide structures providing a low-pass characteristic interconnection, operating over a low frequency range from DC up to a high cut-off frequency f_{CH} in the millimeter wave range.
9. The external port (100) according to the previous claim, further comprising:
 - a first electrical interconnection (140A) configured to electrically connect the first metallization (120A) and the second metallization (120B).
10. The external port (100) according to the previous claim, wherein the first electrical interconnection (140A) comprises conductive epoxy, wire bonding, or ribbon bonding.
11. The external port (100) according to any of the preceding claims, further comprising:
 - two metal pins (150) embeddable in the access wall (1020) and connectable to the IC chip (1030) by metallic connecting means (150A).
12. The external port (100) according to the preceding claim, wherein the metallic connecting means (150A) comprises wire bonding, epoxy or ribbon bonding.
13. The external port (100) according to claims 11 or 12, further comprising a second electrical interconnection (140B) configured to electrically connect the two metal pins (150) to the second metallization (120B).
14. An integrated circuit, IC, package (1000) for transmitting or receiving RF signals, the IC package (1000) comprising the external port according to claims 1 to 13.
15. The IC package according to claim 14, wherein the first substrate (1040) comprises RF substrates such as quartz, laminates and ceramics or silicon.
16. The IC package (1000) according to claims 14 or 15, wherein the access wall (1020) comprises a dovetail shape or a V-groove shape.

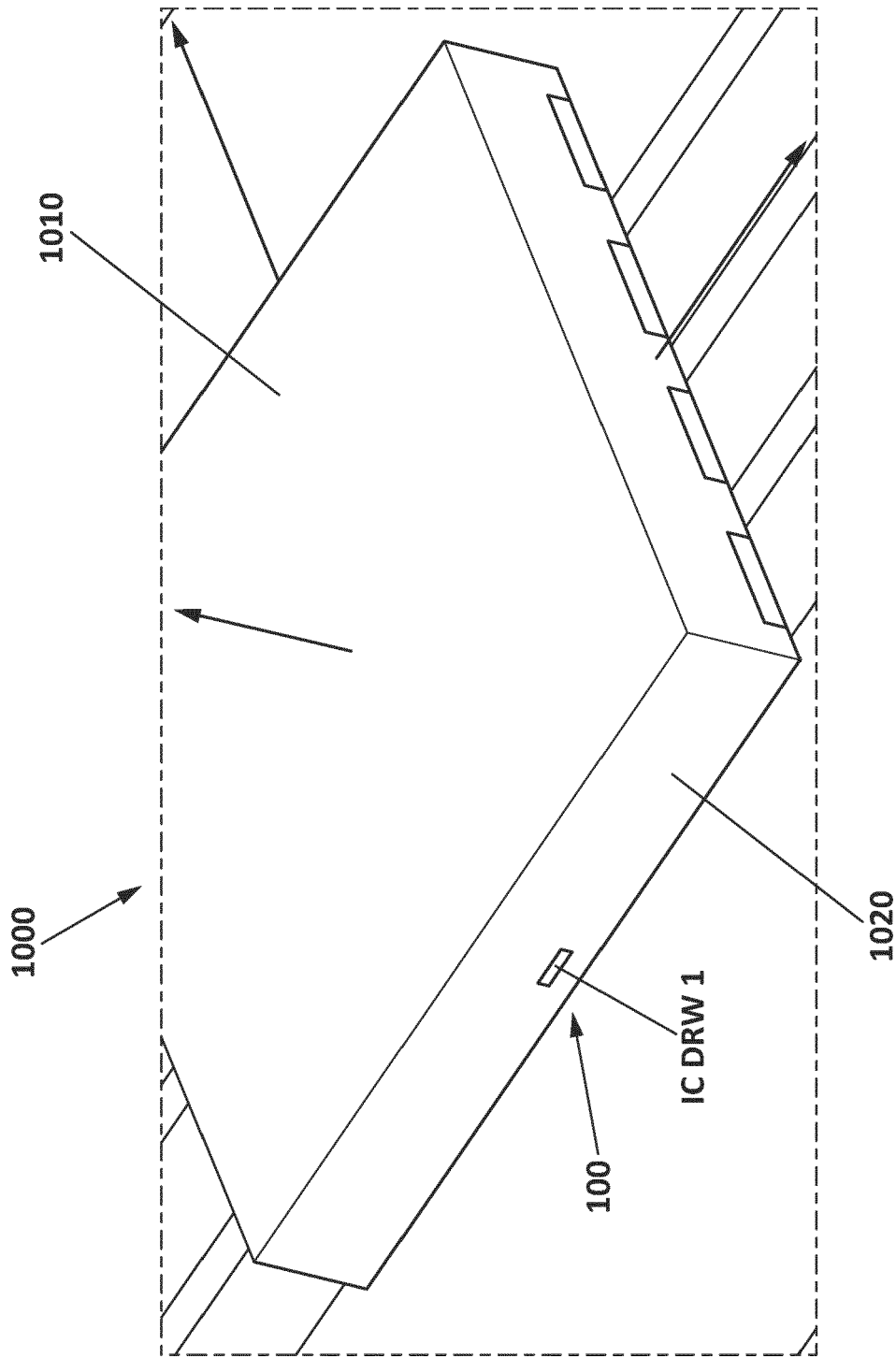


FIG. 1

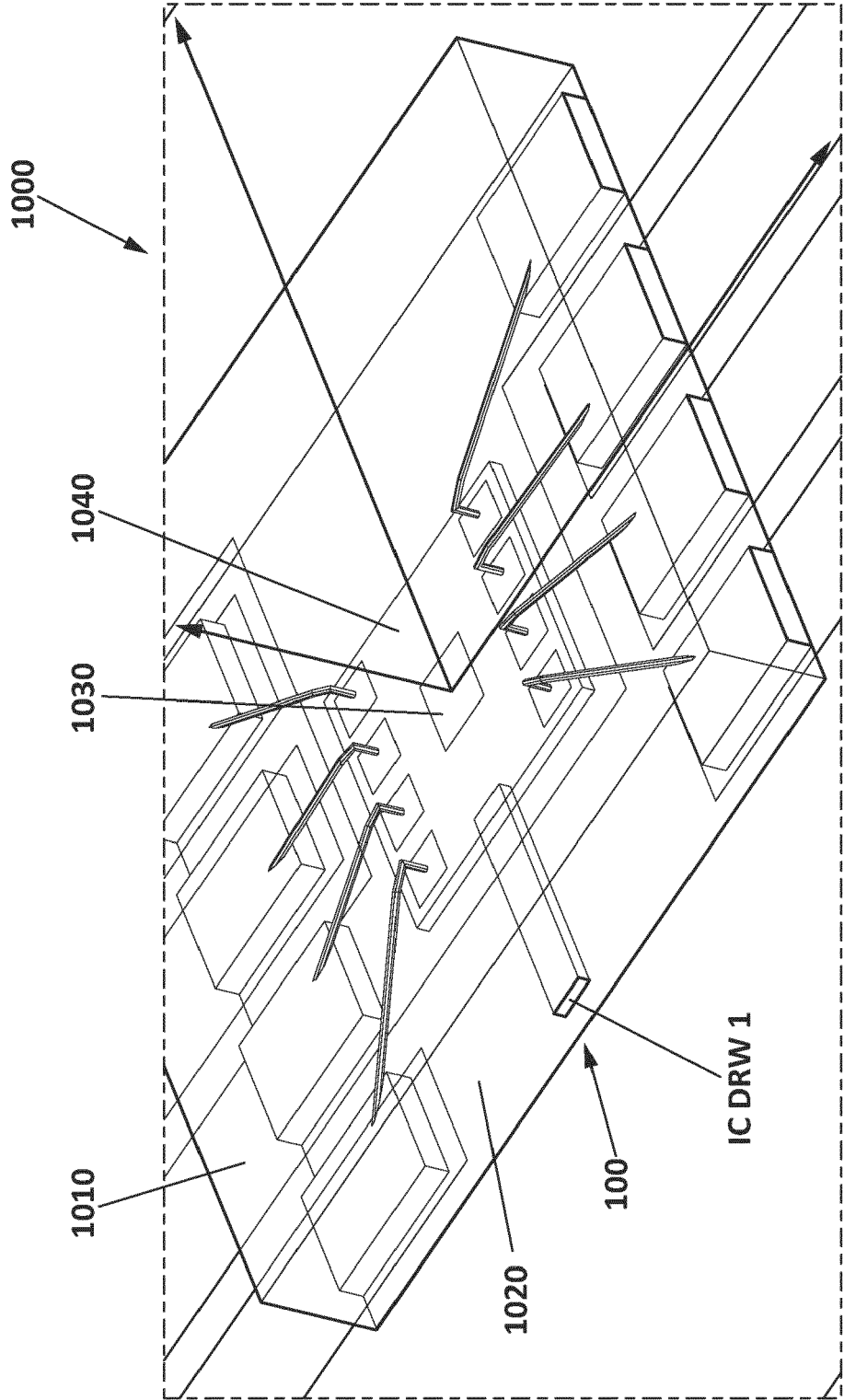
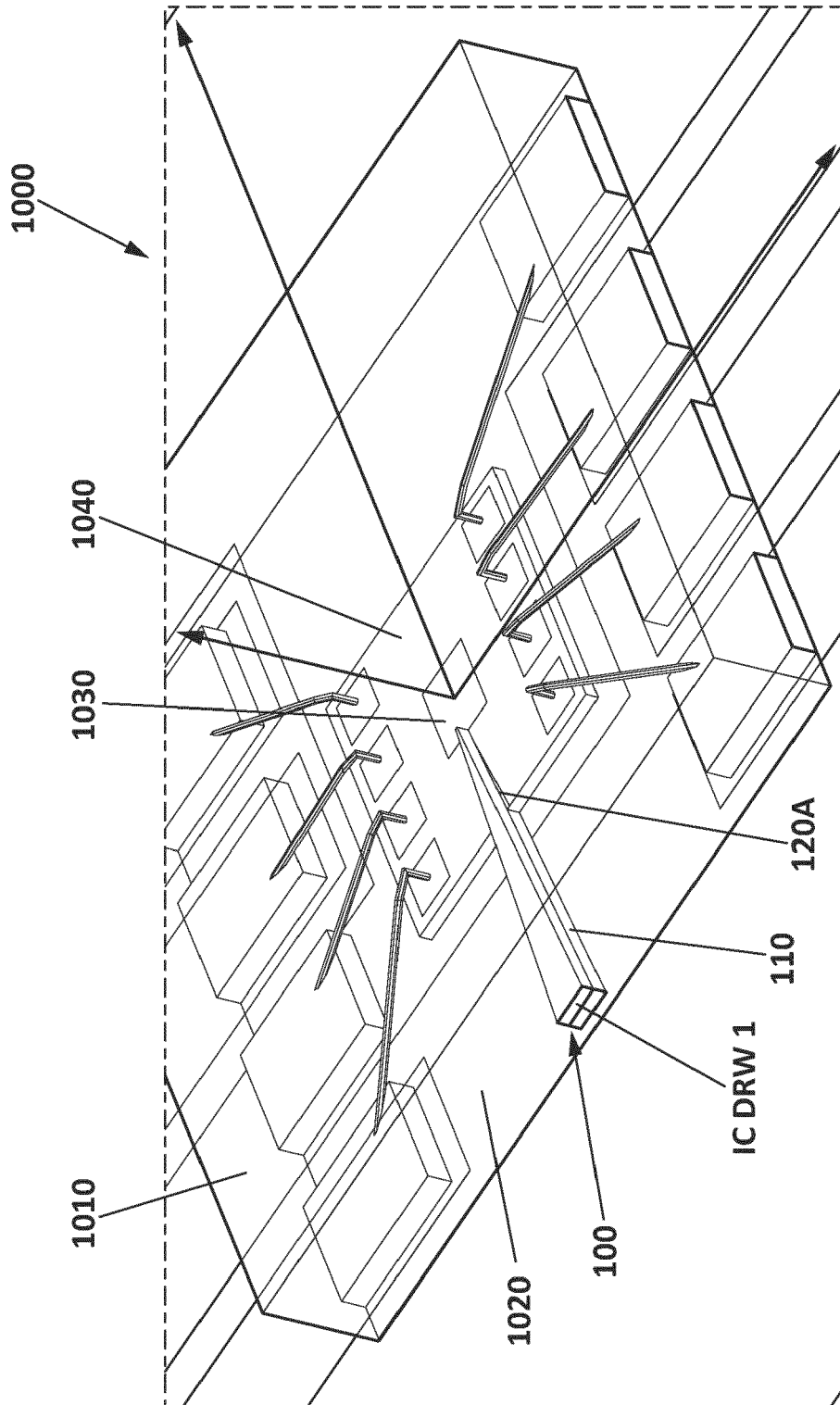
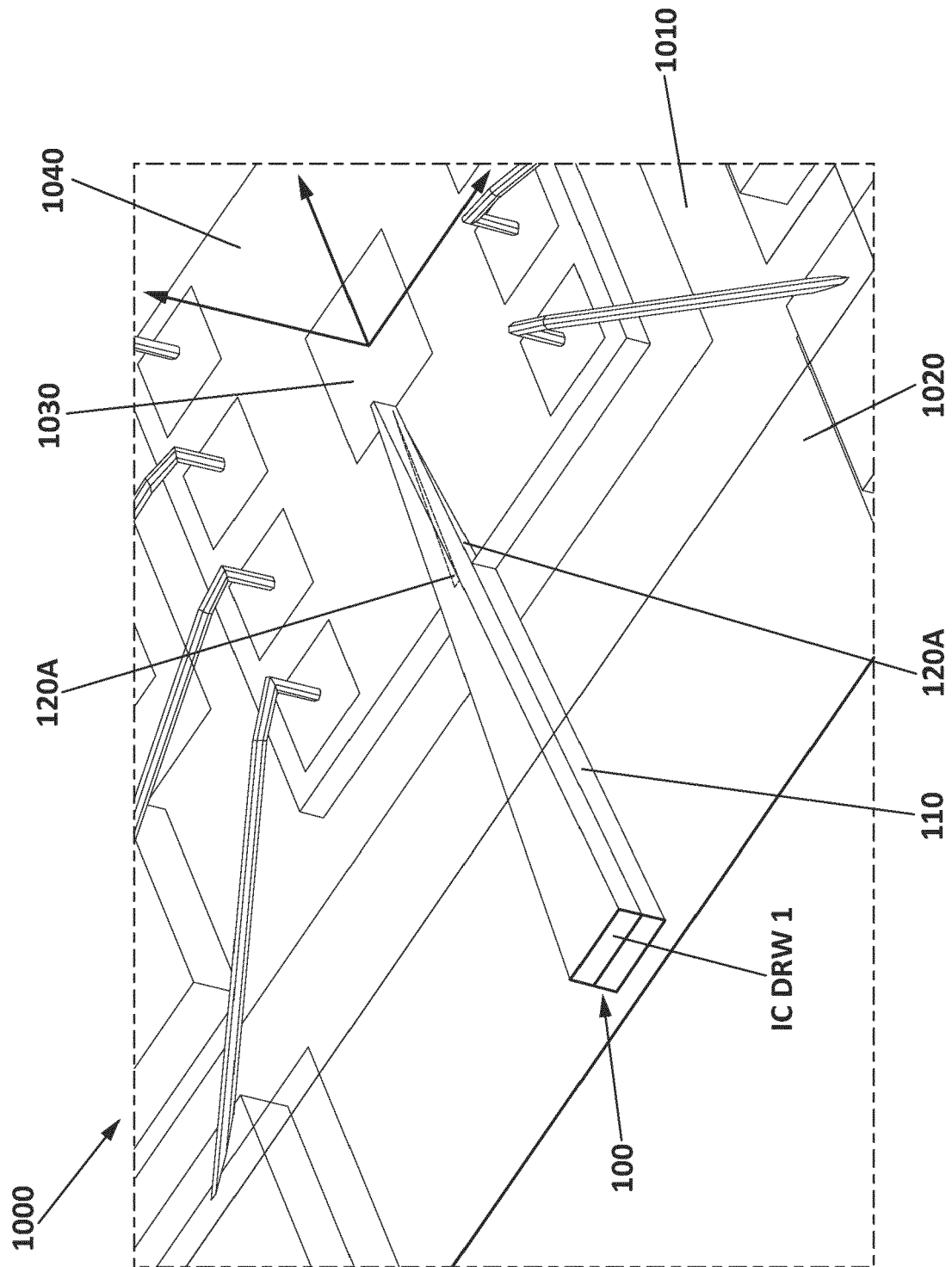


FIG. 2



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**Fig. 4**

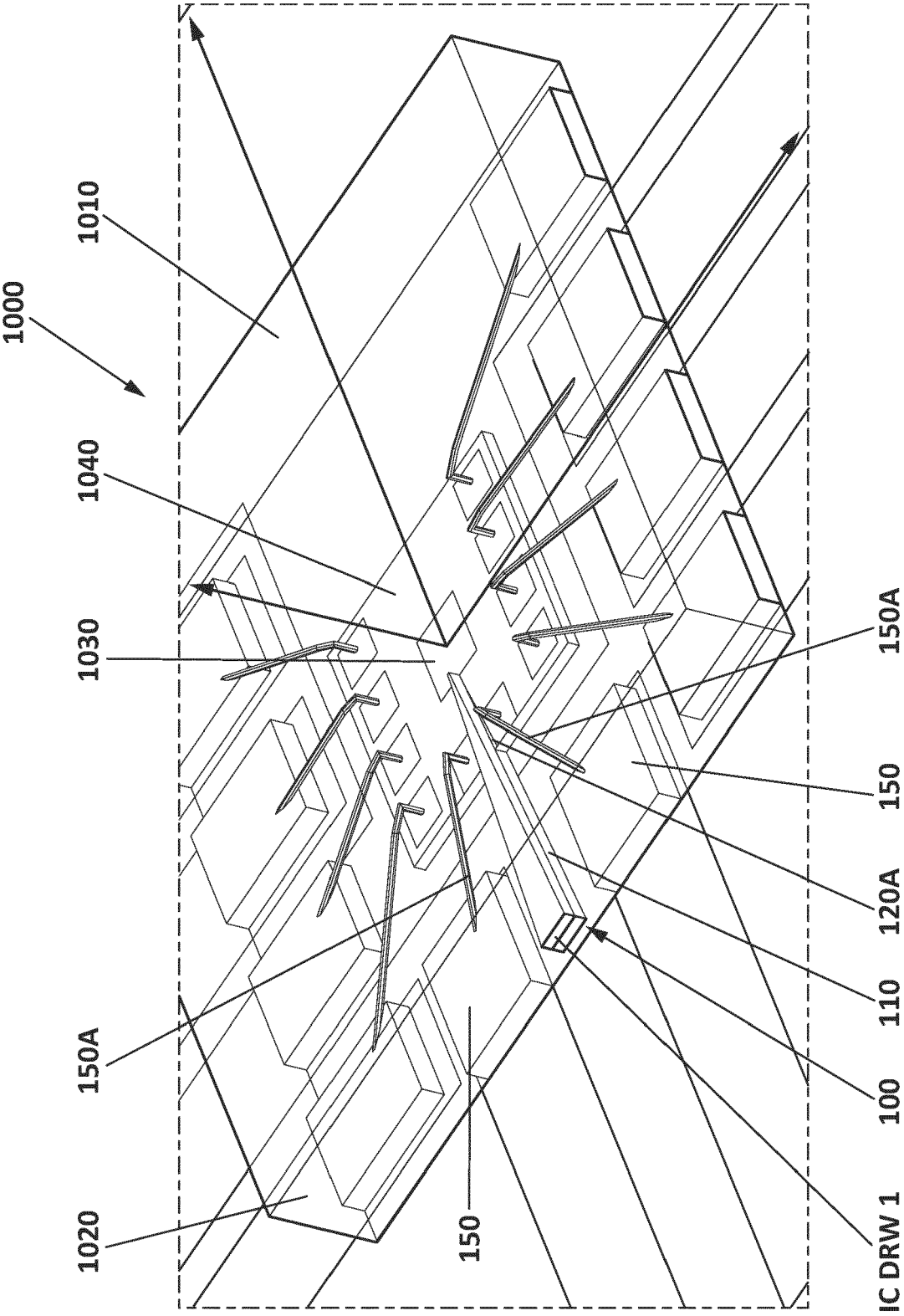
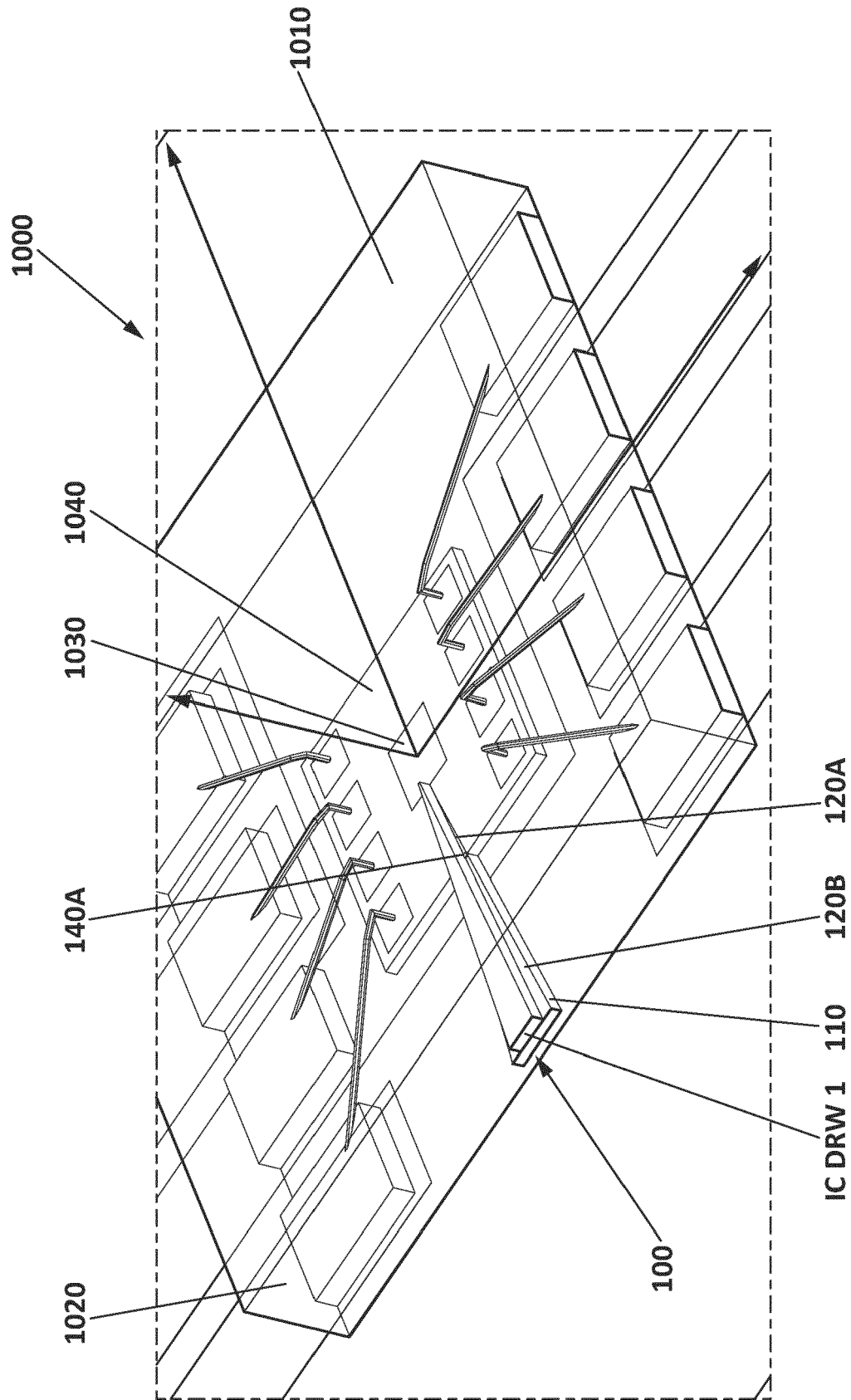


FIG. 5



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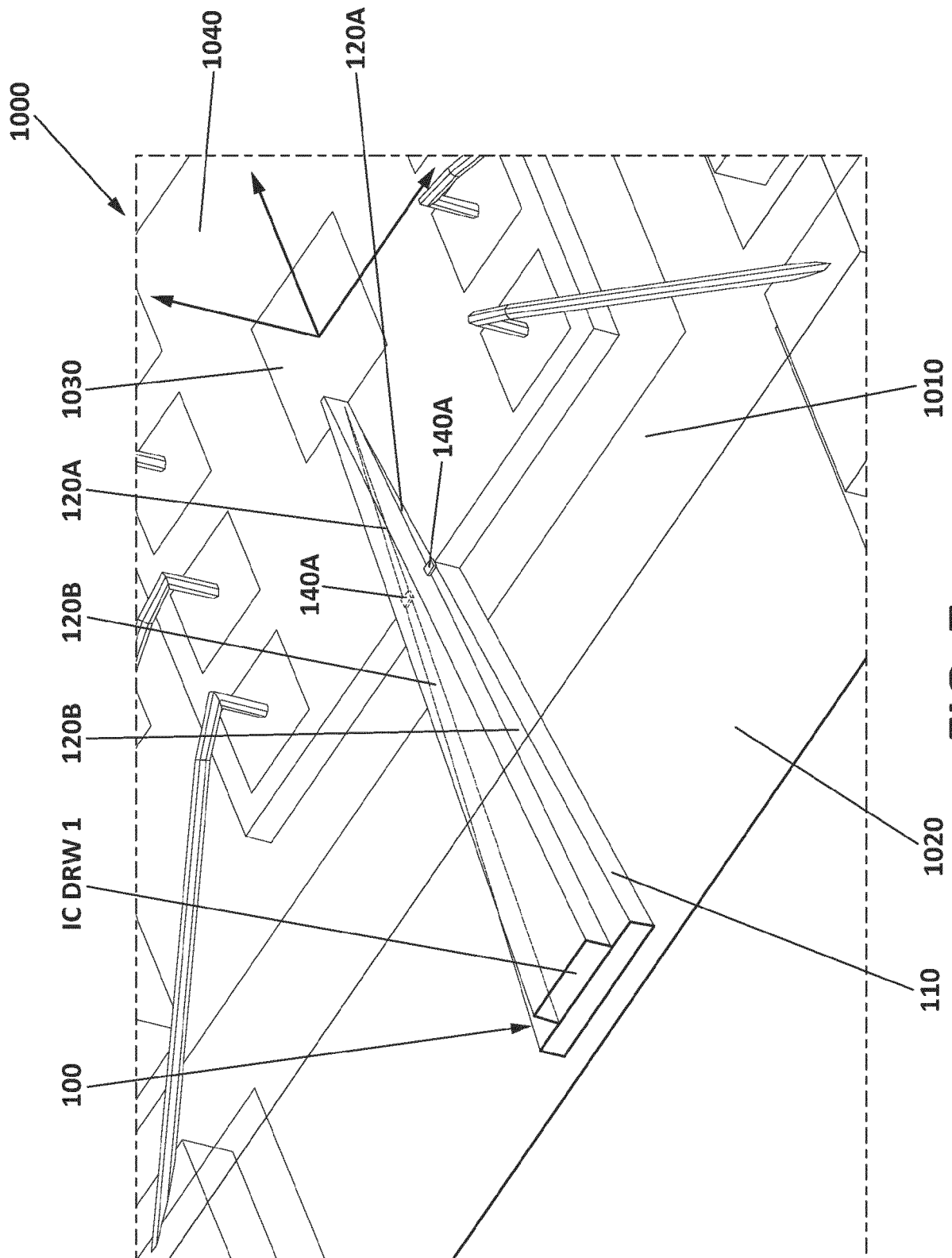


Fig. 7

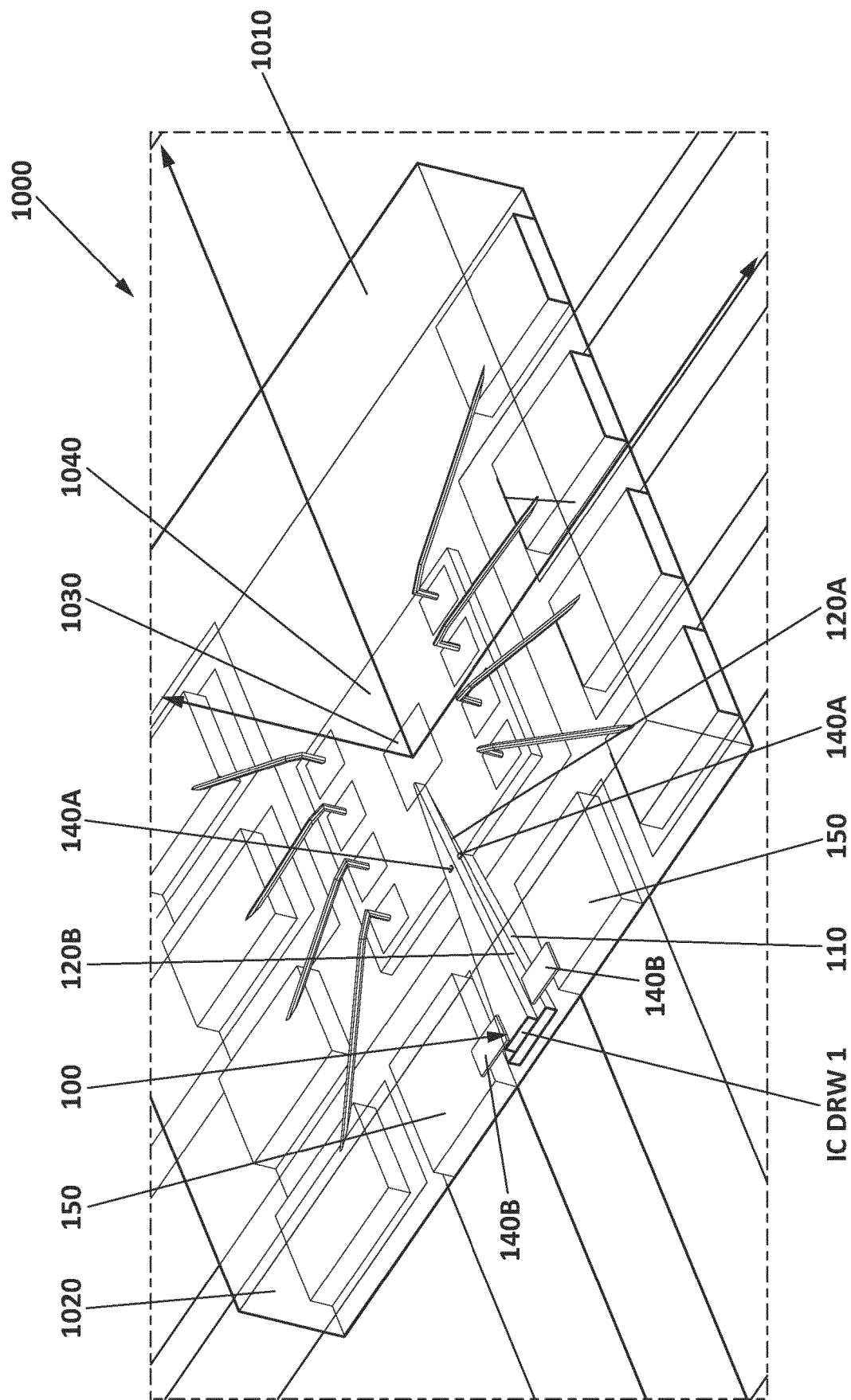


FIG. 8

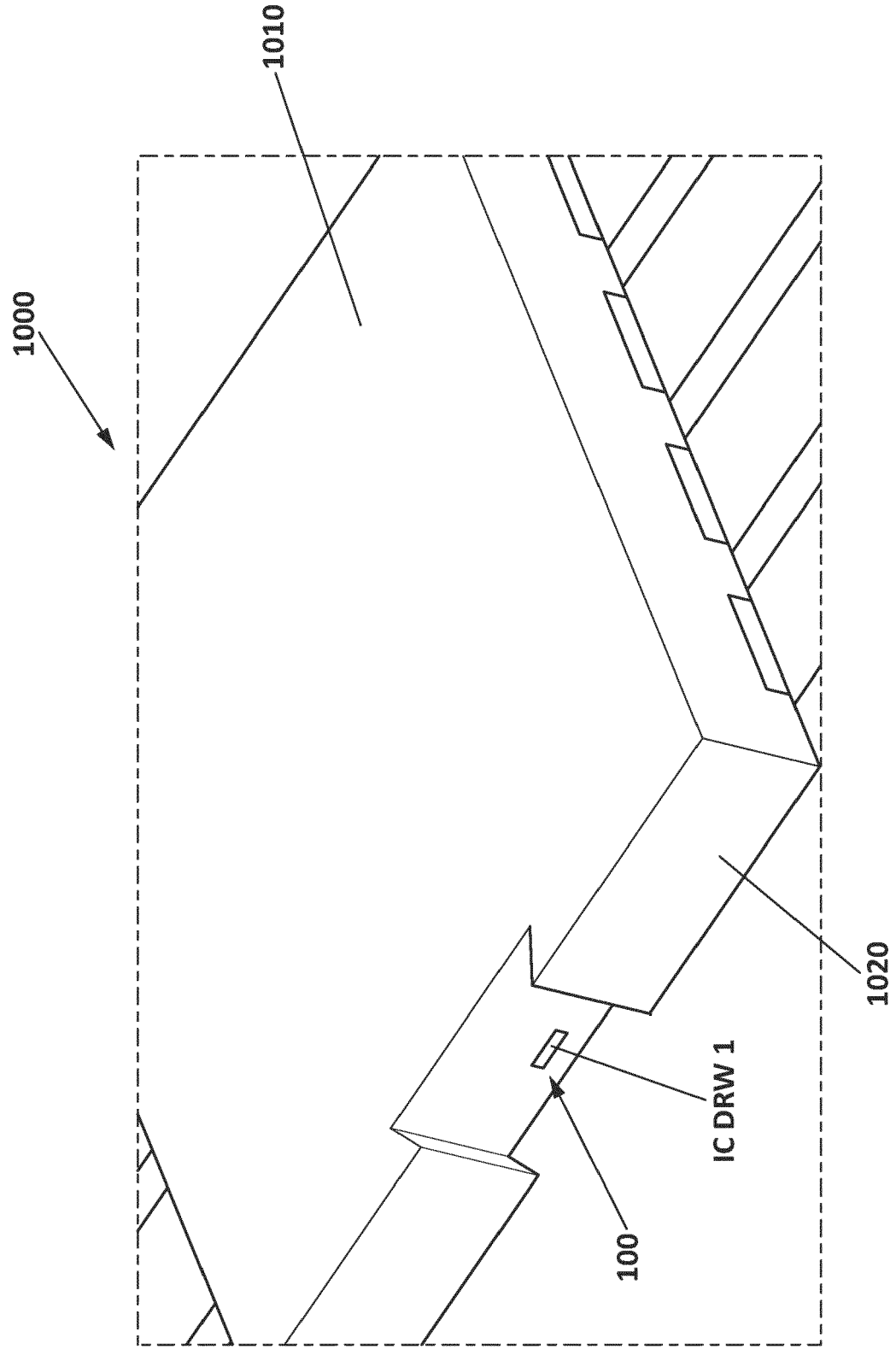


FIG. 9

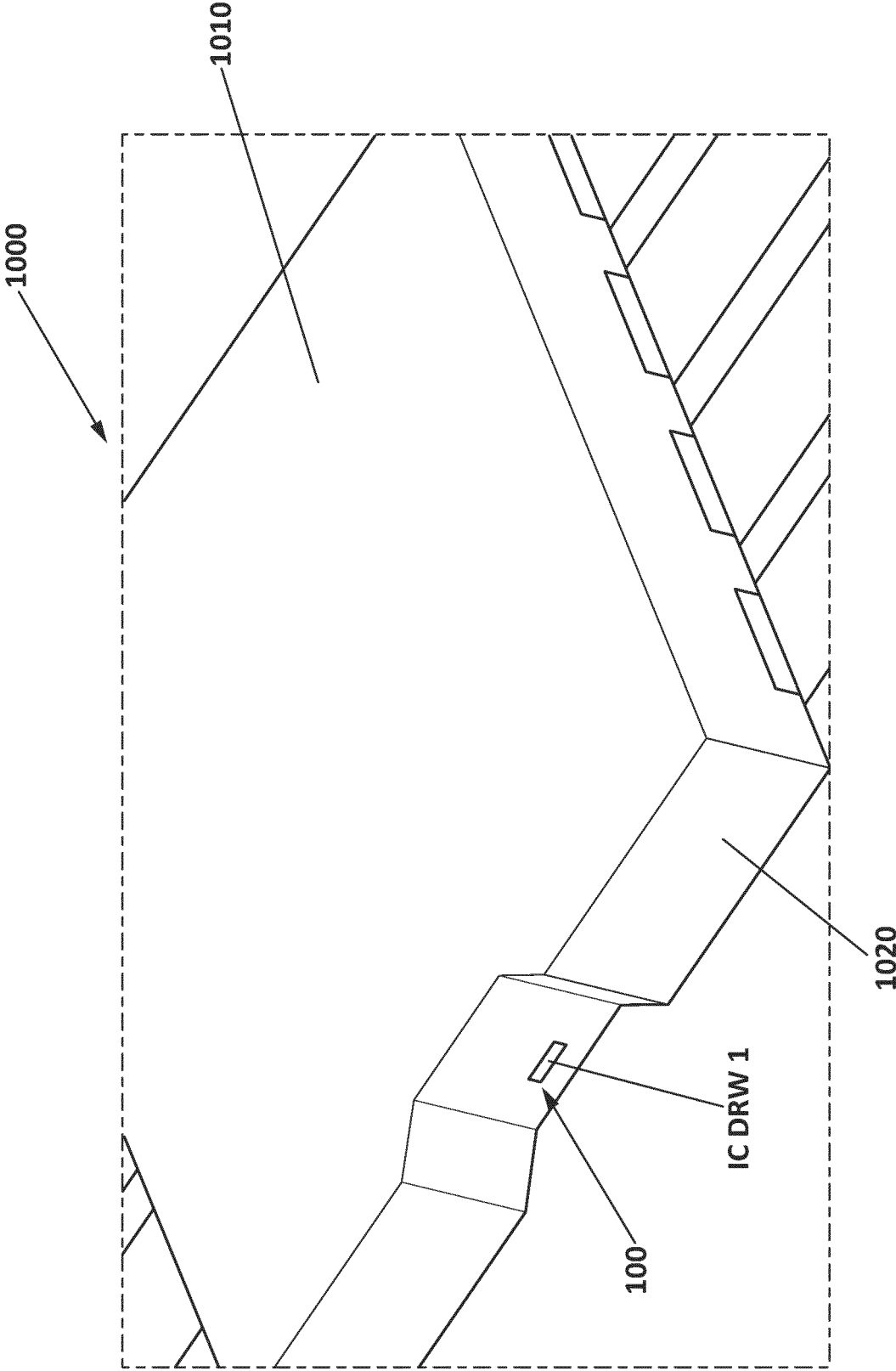


FIG. 10



EUROPEAN SEARCH REPORT

Application Number

EP 23 38 2117

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EP 23 38 2117

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