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Variyam

(54) SYSTEMS AND METHODS TO HANDLE SEMICONDUCTOR DEVICES FOR TESTING

(71) Applicant: **Anora, LLC**, Richardson, TX (US)

(72) Inventor: **Pramodchandran N. Variyam**, Plano, TX (US)

(73) Assignee: **Anora, LLC**, Richardson, TX (US)

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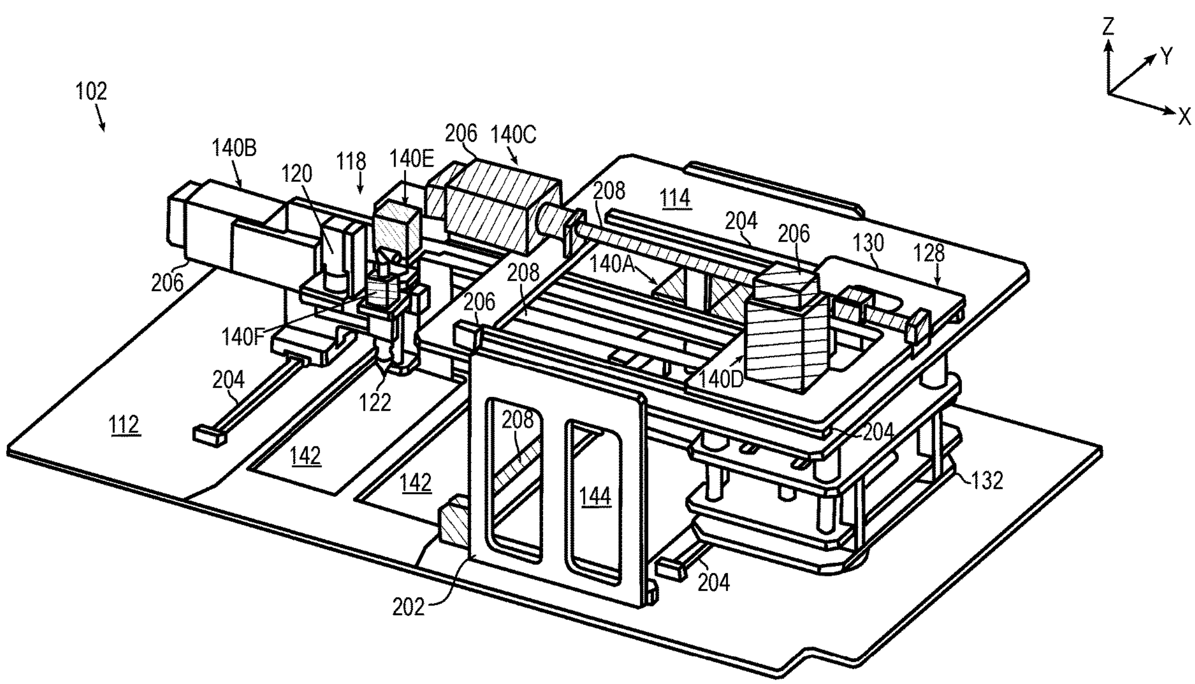
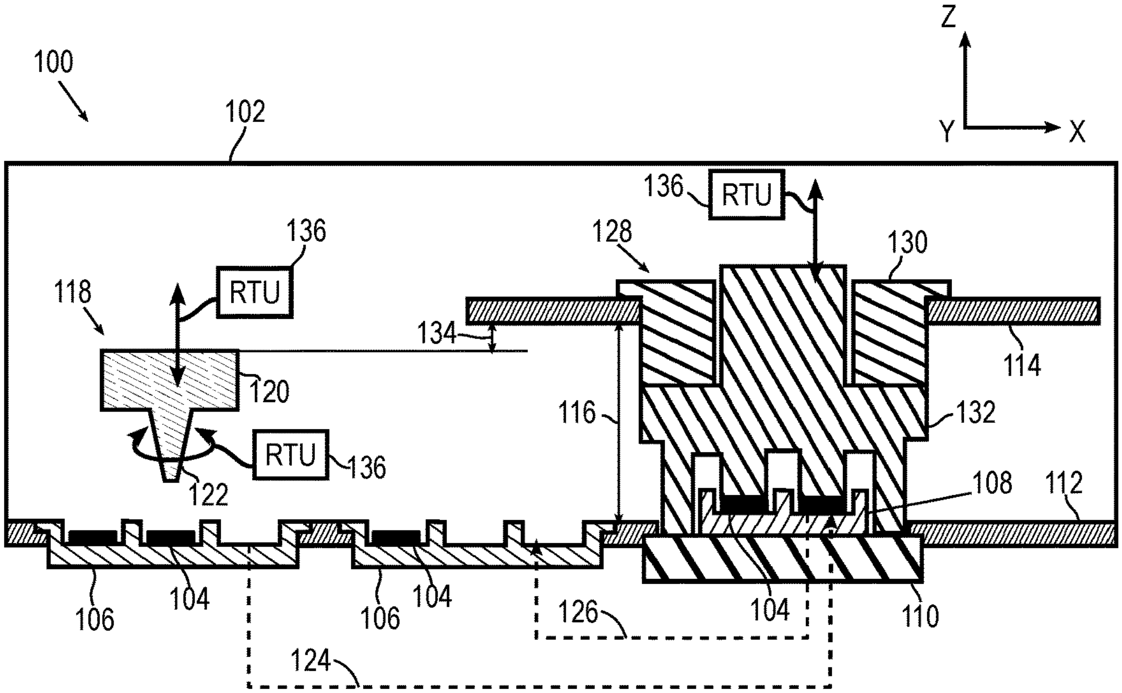
(57) **ABSTRACT**

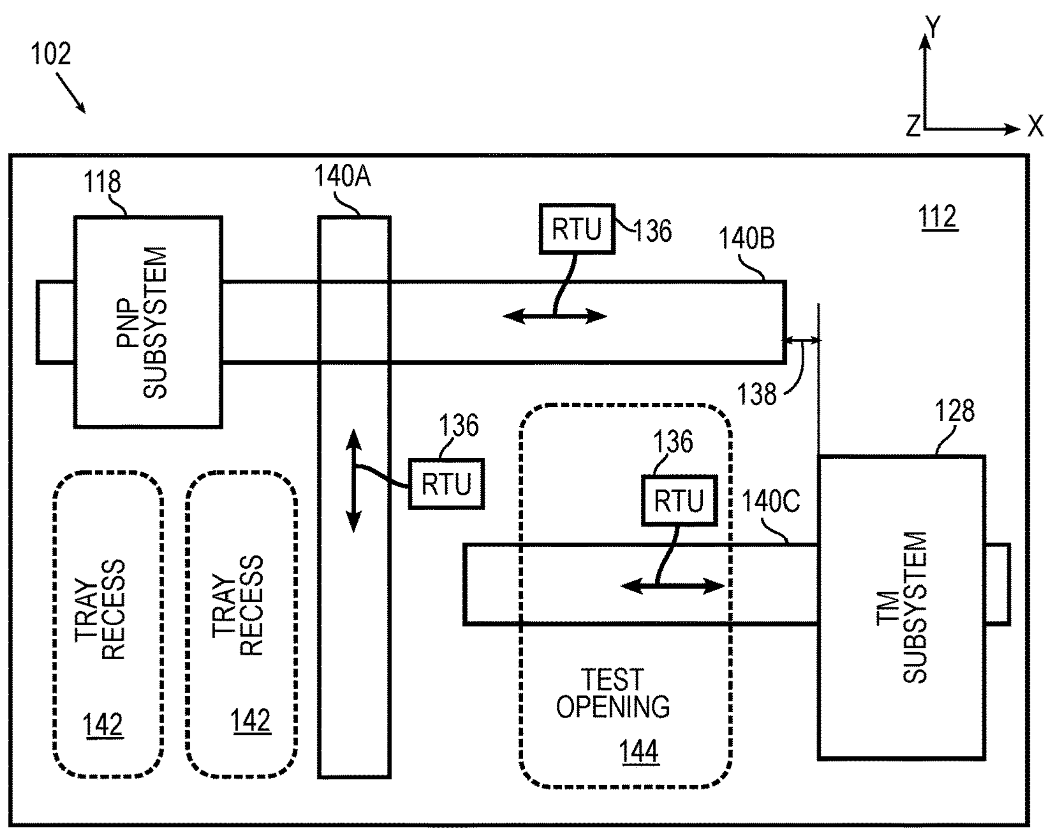
A method executed by a controller in a system for handling a semiconductor device, the method comprising: moving a pick-and-place (PNP) head in the system to an approximate location of the semiconductor device in a tray, the approximate location determined from a tray template stored in the system, the tray template comprising a virtual representation of the tray; automatically capturing an image of the semiconductor device in the tray using a camera in the PNP head; comparing the image to a device template stored in the system, the device template comprising a virtual representation of the semiconductor device; identifying a center of the semiconductor device based on the comparing; and moving a PNP nozzle in the PNP head to the identified center of the semiconductor device.





Z
Y
X
100
102
136
RTU
128
130
136
RTU
118
134
114
120
116
132
RTU
136
122
108
112
106
104
106
104
126
104
110
124

FIG. 1A



Y
Z
X
102
118
140A
RTU
136
140B
112
PNP SUBSYSTEM
138
136
128
136
RTU
RTU
140C
TRAY RECESS
142
TRAY RECESS
142
TEST OPENING
144
TM SUBSYSTEM

FIG. 1B

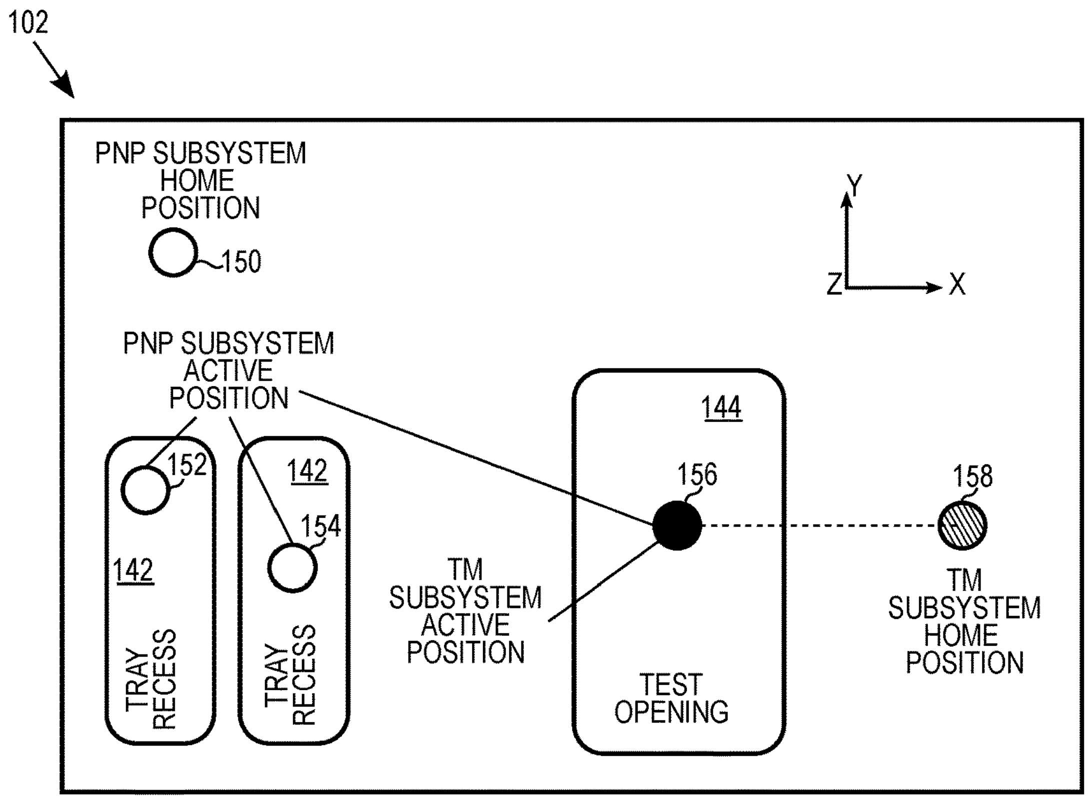

102
PNP SUBSYSTEM HOME POSITION
150
Y
Z
X
PNP SUBSYSTEM ACTIVE POSITION
144
152
142
156
158
154
142
TRAY RECESS
TRAY RECESS
TM SUBSYSTEM ACTIVE POSITION
TM SUBSYSTEM HOME POSITION
TEST OPENING

FIG. 1C

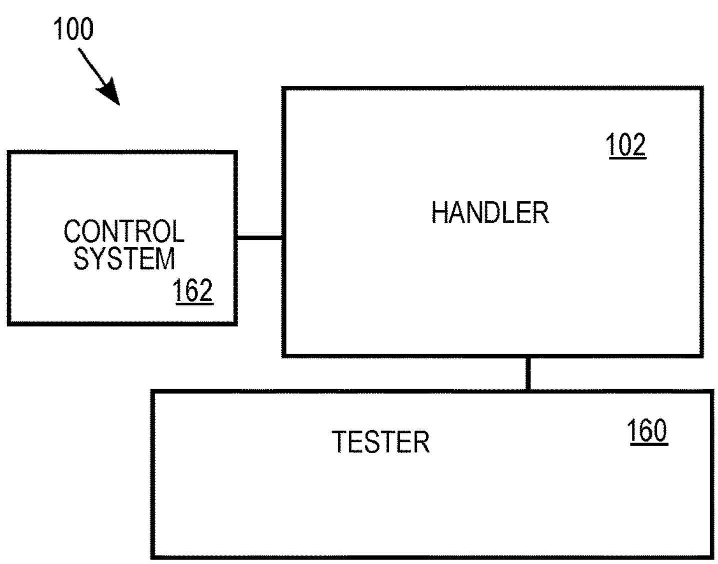

100
102
HANDLER
CONTROL SYSTEM
162
TESTER
160

FIG. 1D

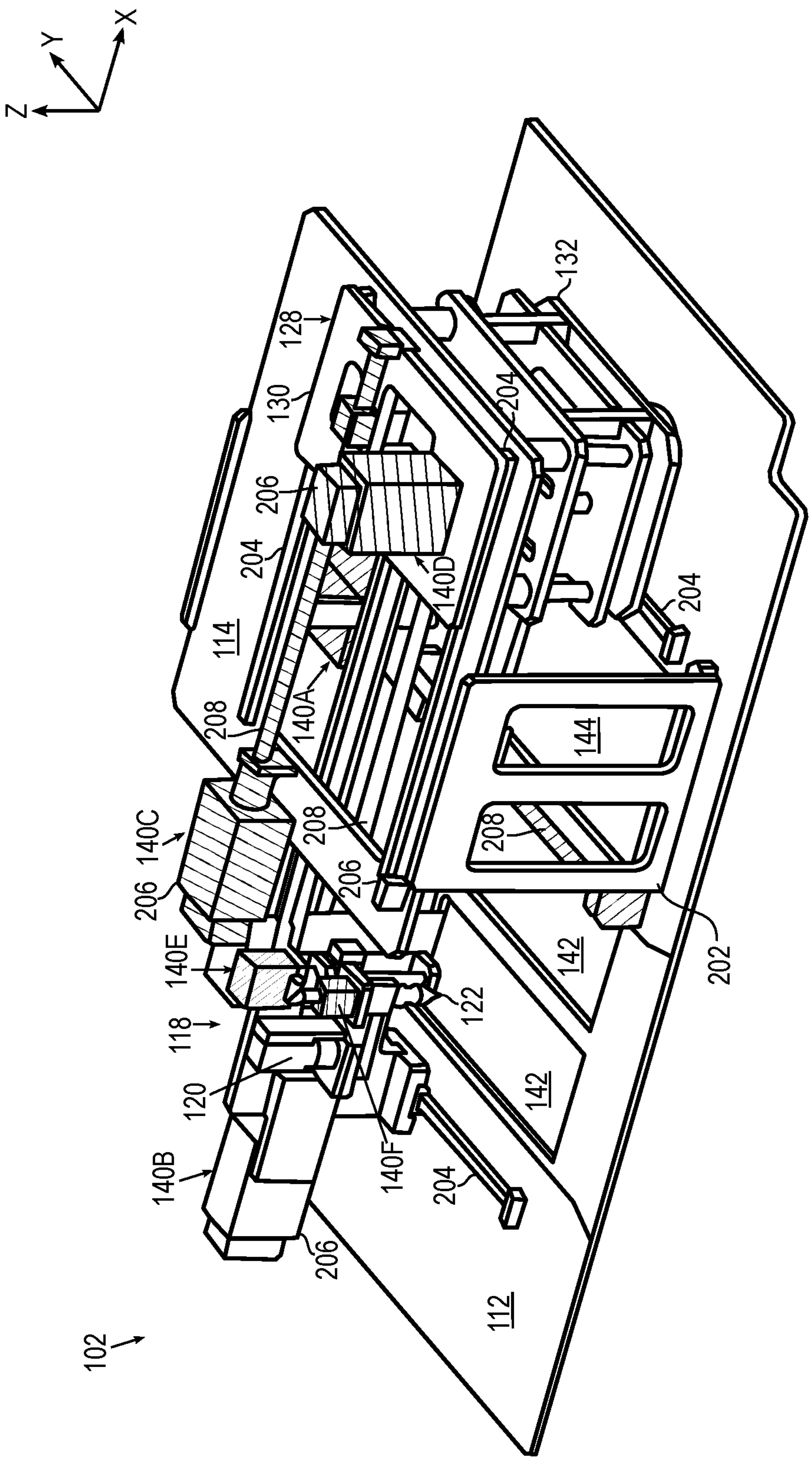

Z
Y
X
102
112
114
118
120
122
128
130
132
140A
140B
140C
140D
140E
140F
142
142
144
202
204
204
204
204
206
206
206
206
208
208
208

FIG. 2A

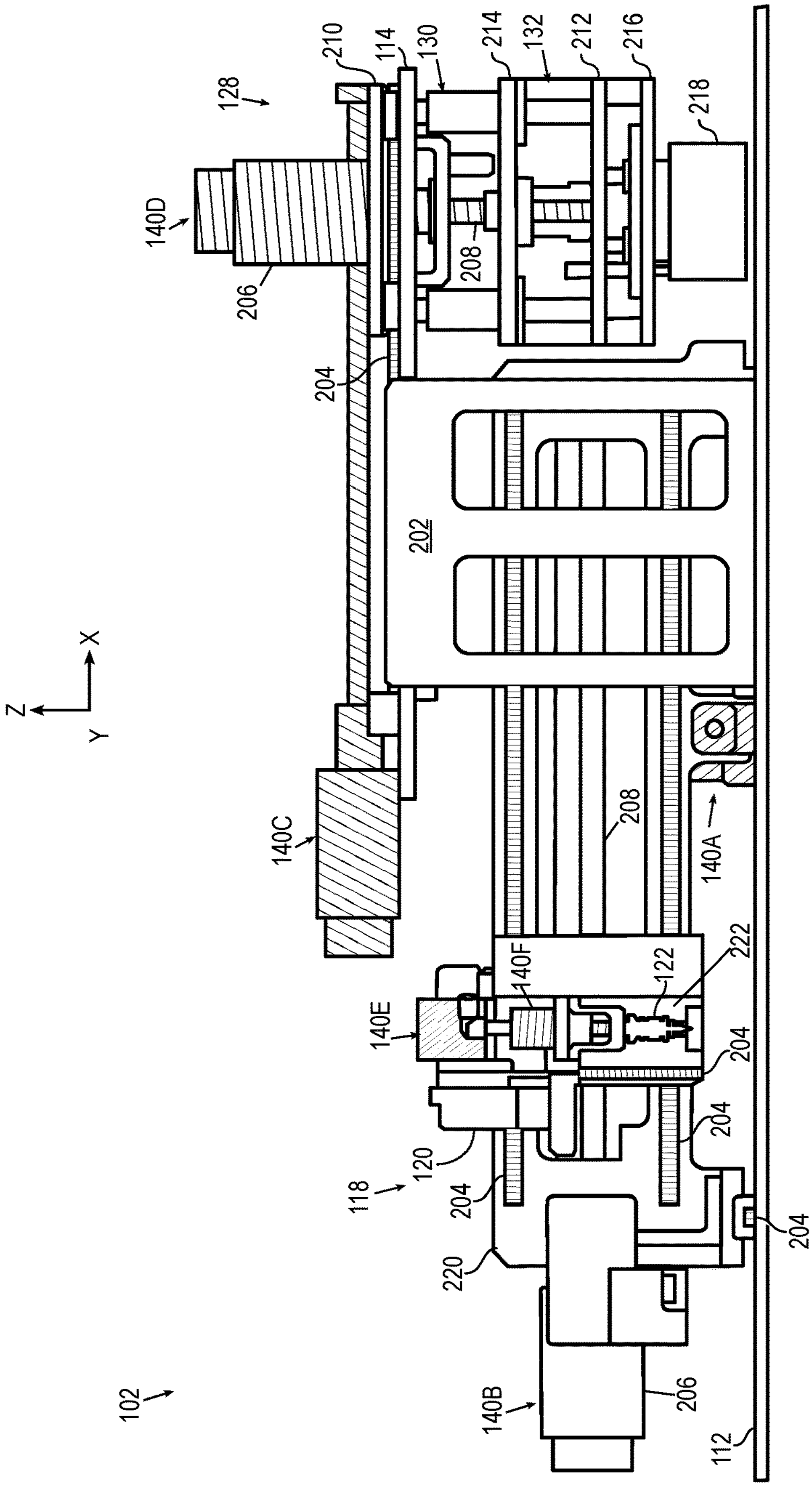

128
140D
206
210
114
130
214
132
212
216
218
208
204
202
Z
X
Y
140C
208
140A
140E
140F
122
222
204
120
118
204
220
204
204
102
140B
206
112

FIG. 2B

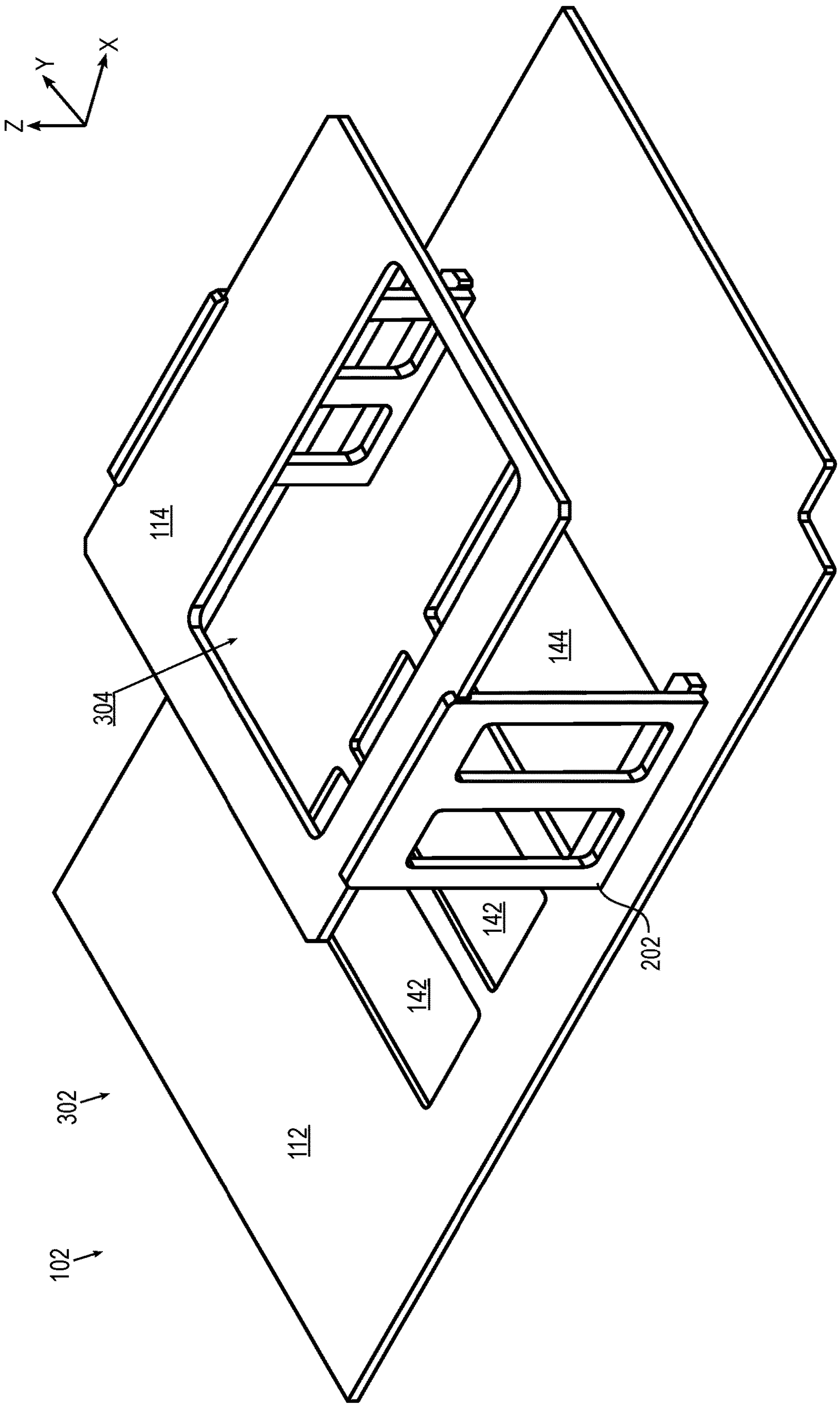


FIG. 3

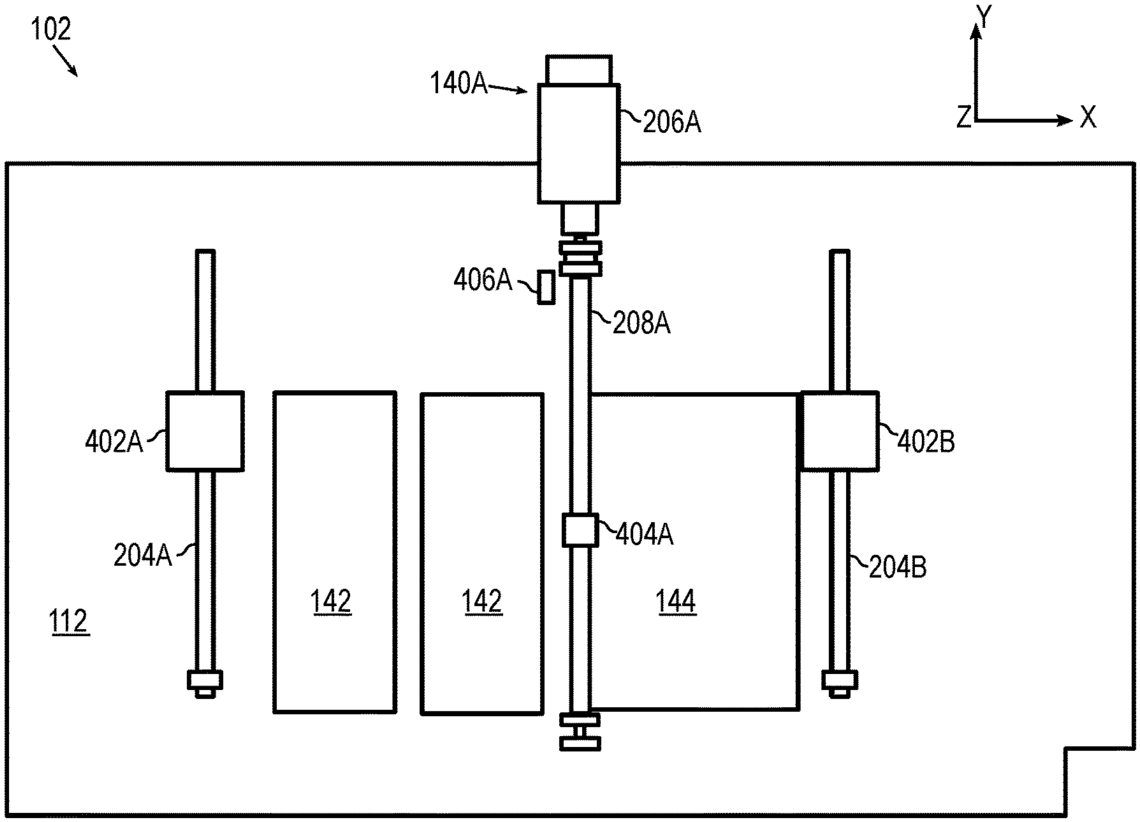

102
140A
206A
Y
Z
X
406A
208A
402A
402B
404A
204A
204B
112
142
142
144

FIG. 4

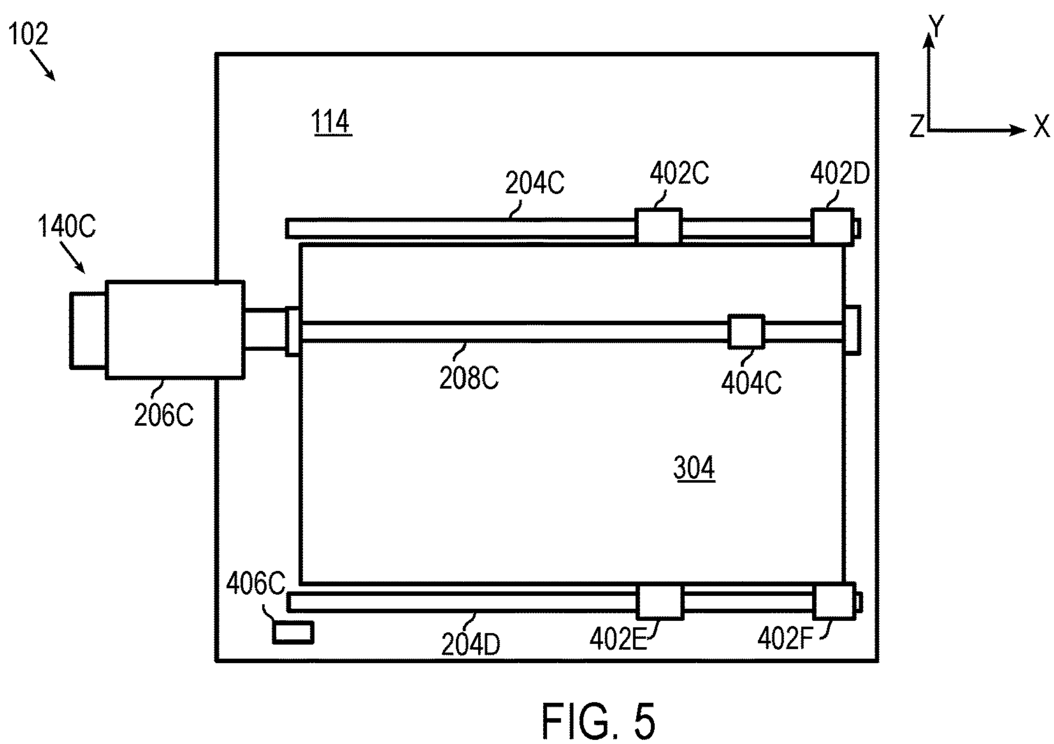

102
Y
Z
X
114
204C
402C
402D
140C
208C
404C
206C
304
406C
204D
402E
402F

FIG. 5

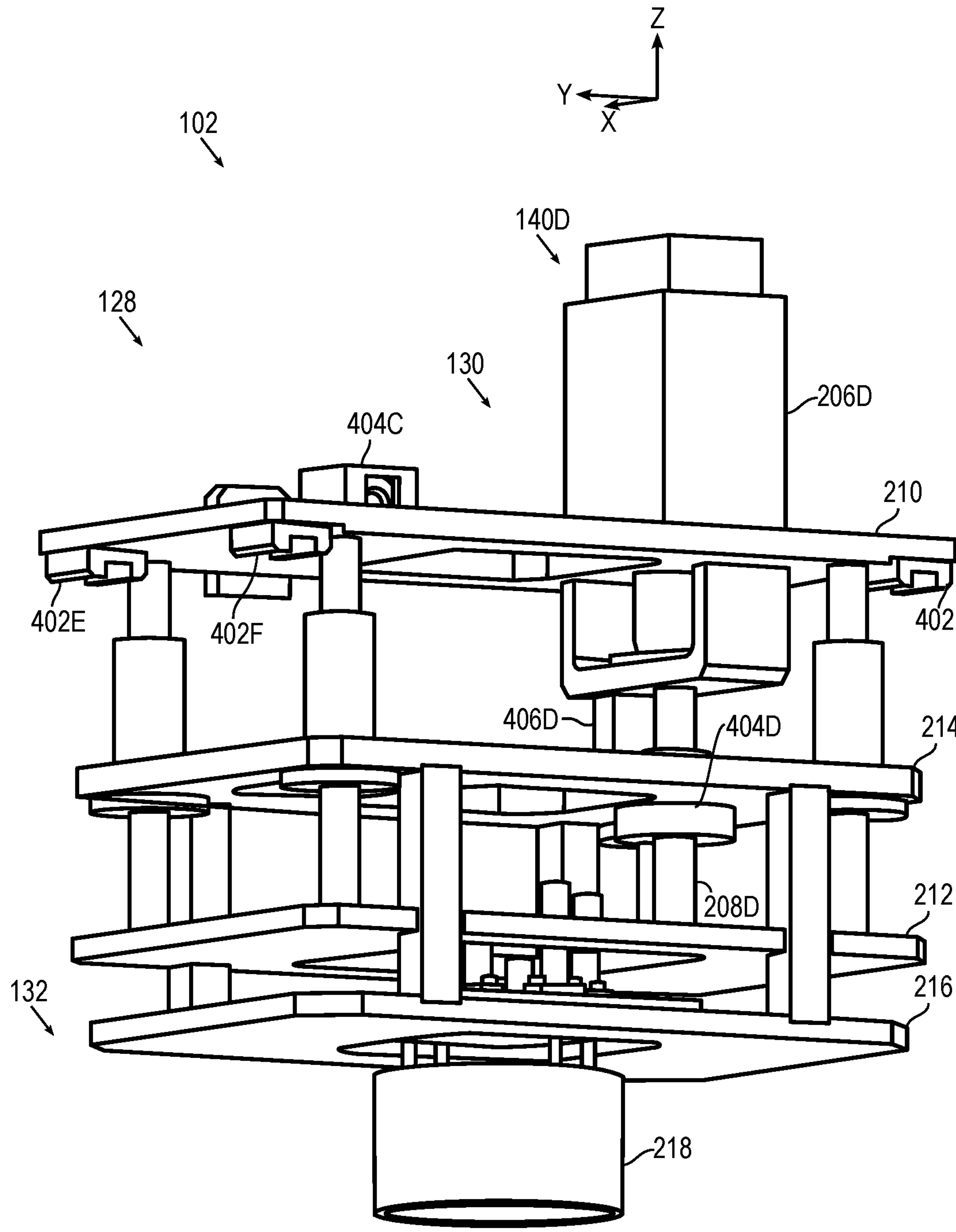
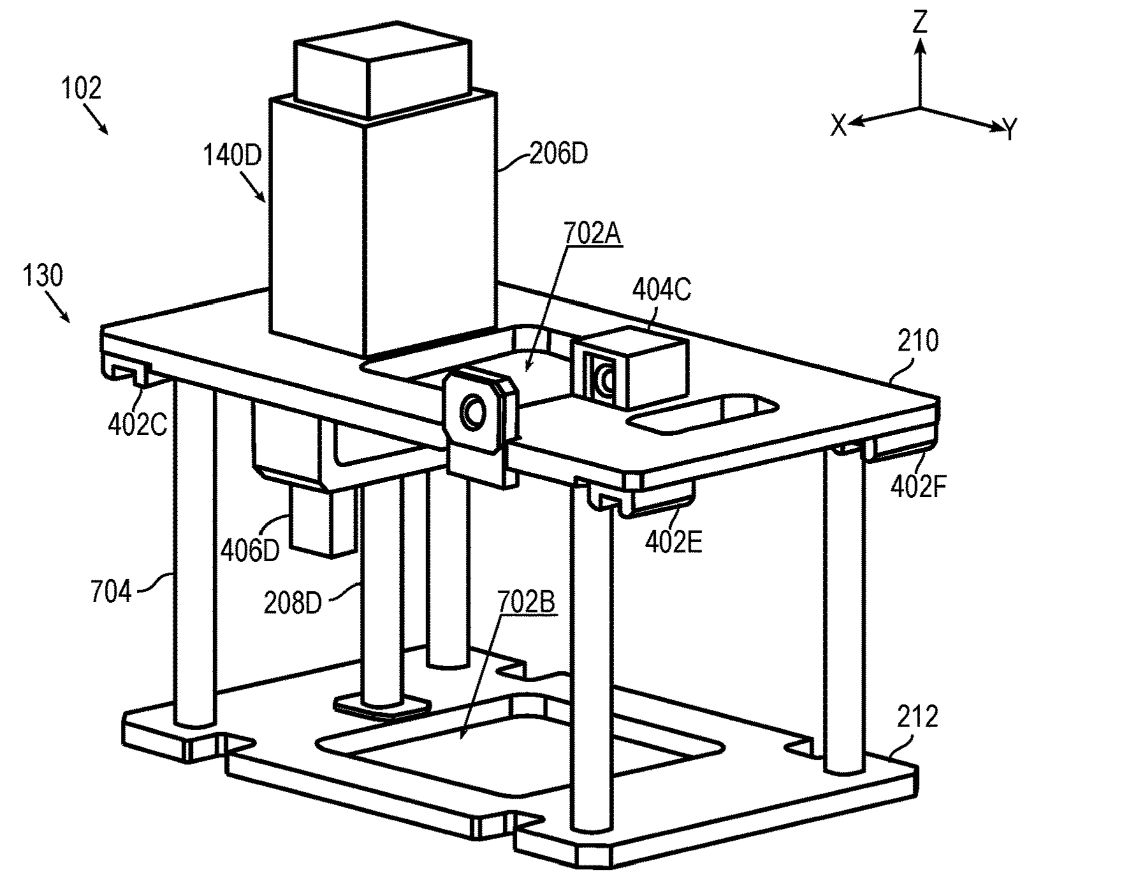
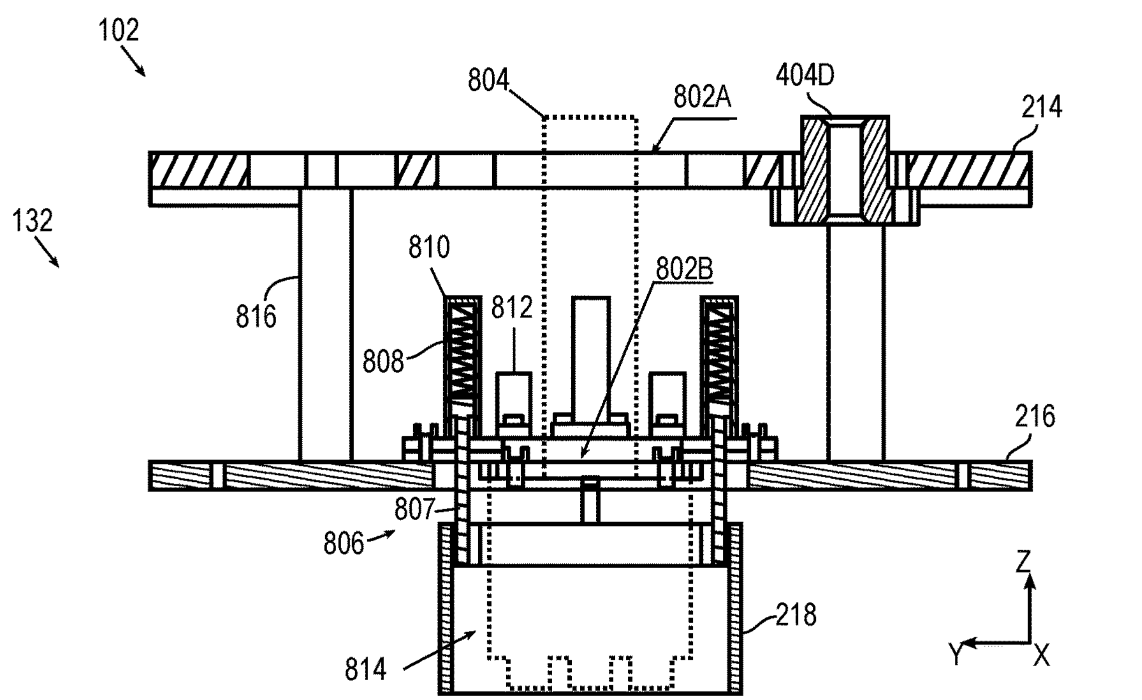

Z
Y
X
102
140D
128
130
206D
404C
210
402E
402F
402D
406D
404D
214
208D
212
132
216
218

FIG. 6



102
140D
206D
702A
404C
130
210
402C
402F
402E
406D
704
208D
702B
212
Z
X
Y

FIG. 7



102
804
802A
404D
214
132
810
802B
816
812
808
216
807
806
Z
218
Y
X
814

FIG. 8

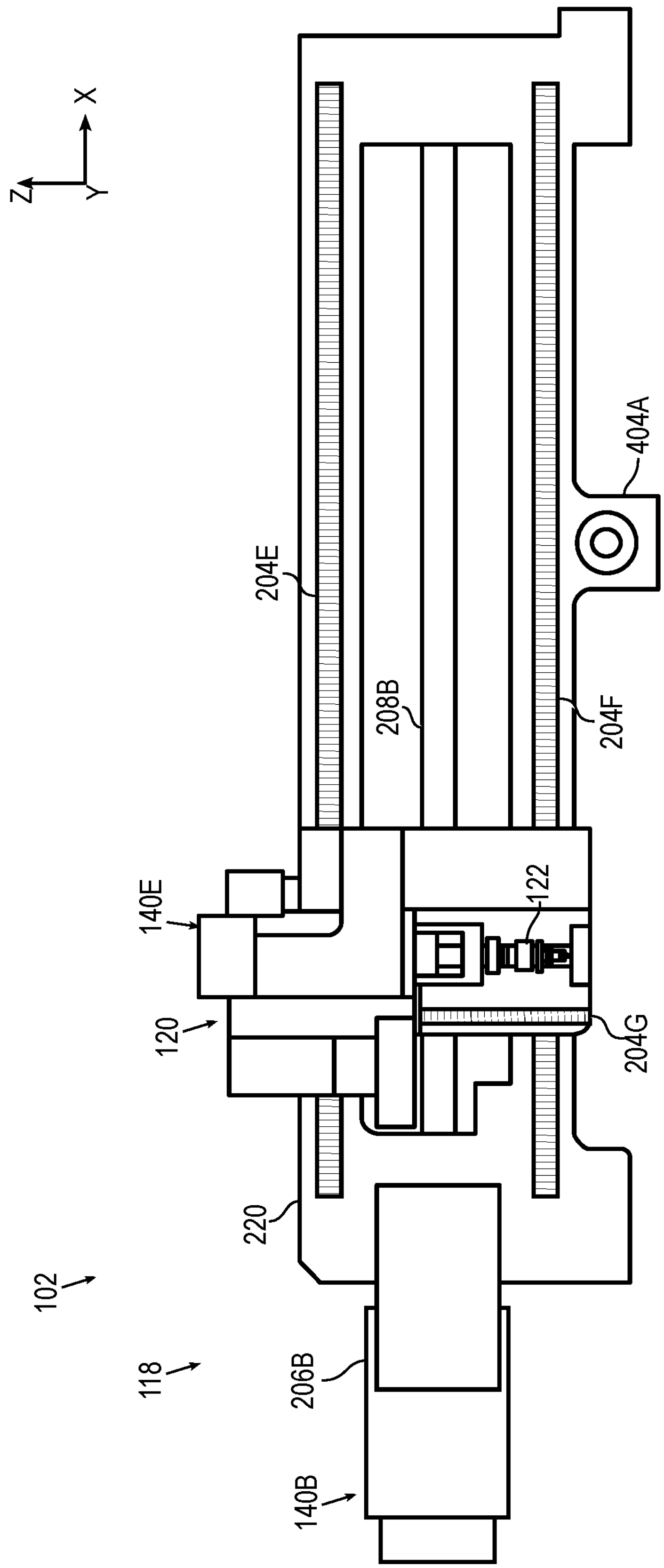

X
Z
Y
404A
204E
208B
204F
140E
122
120
204G
220
102
118
206B
140B

FIG. 9

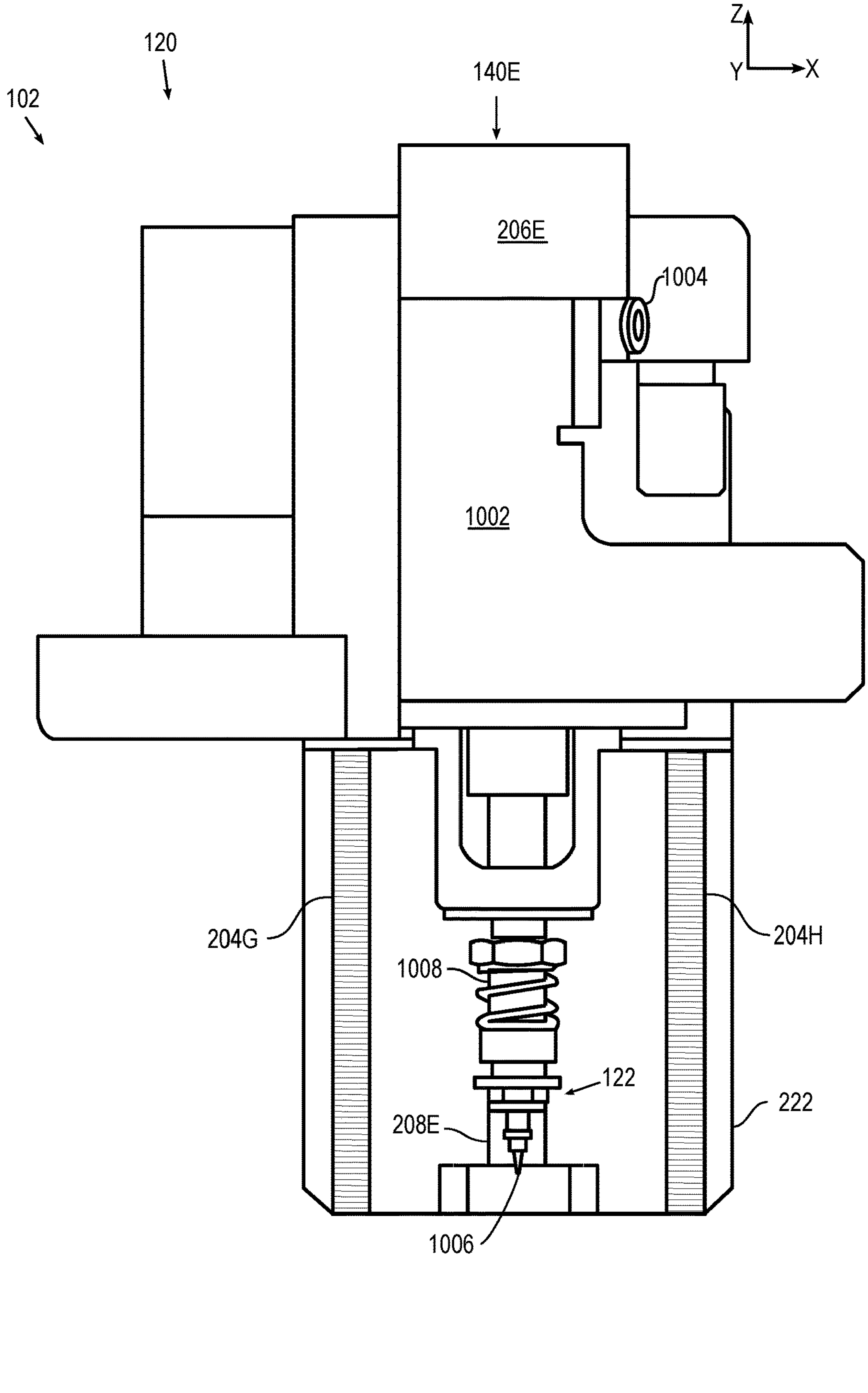

Z
Y
X
120
102
140E
206E
1004
1002
204G
204H
1008
122
222
208E
1006

FIG. 10

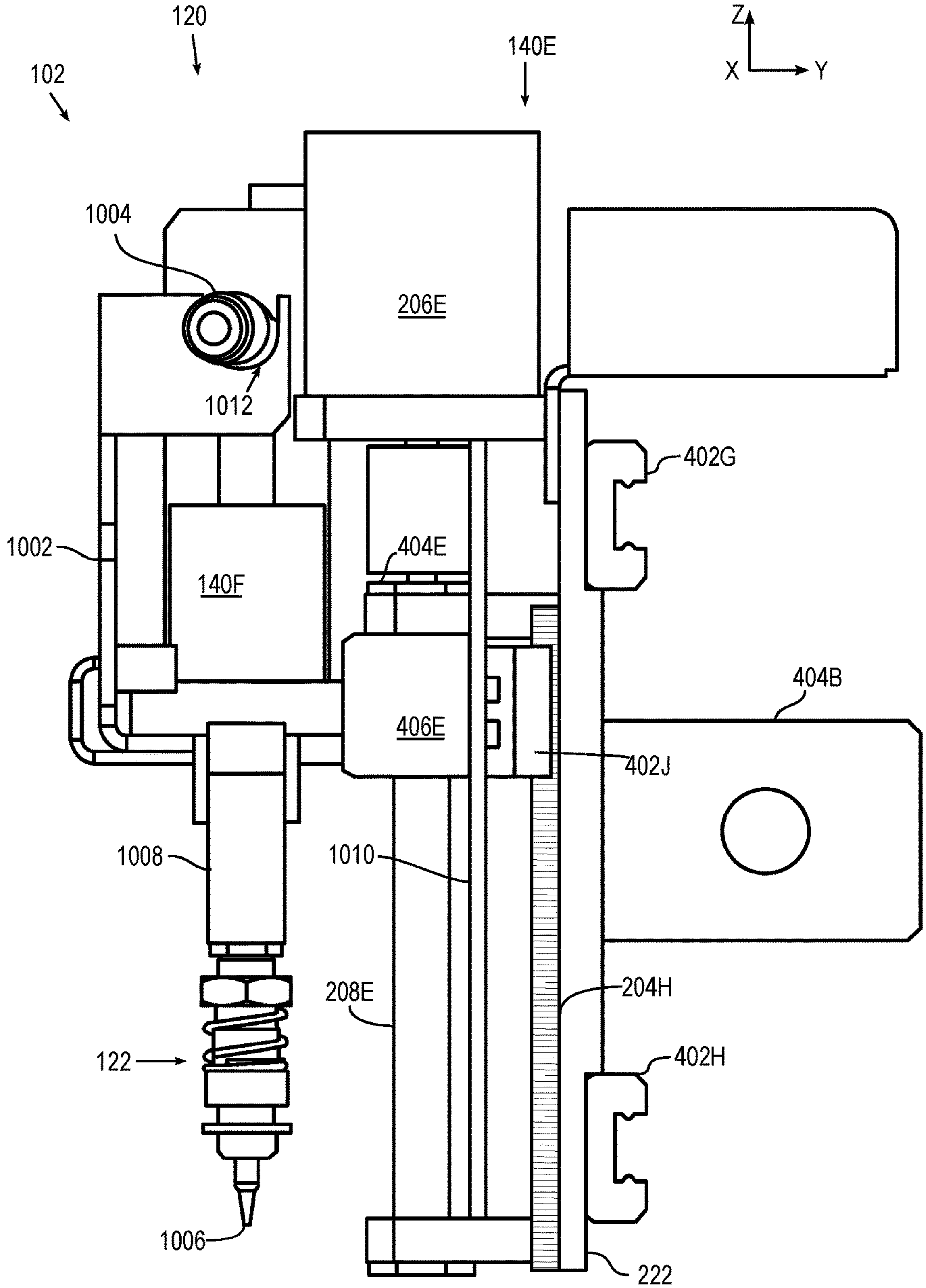
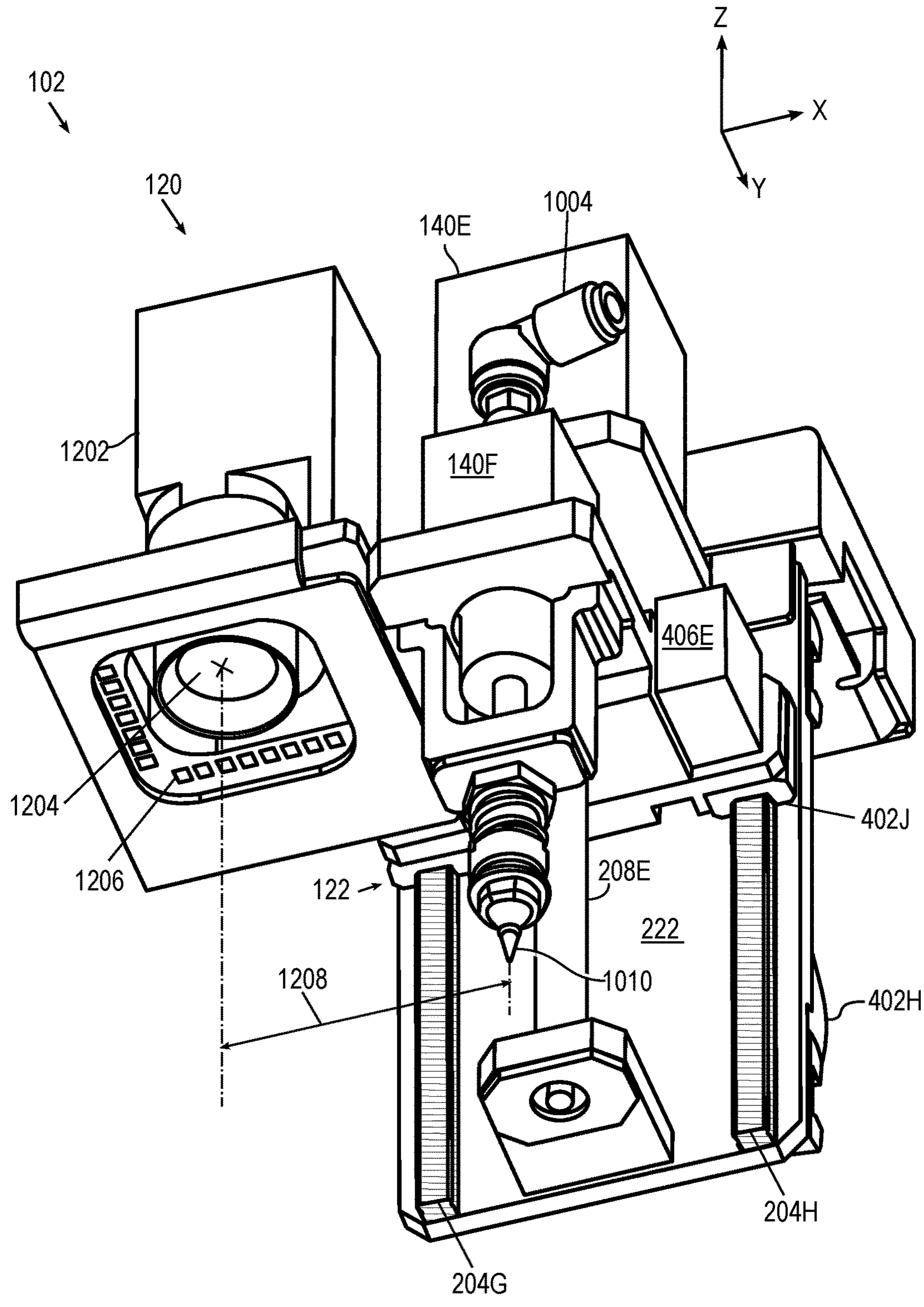

120
140E
Z
X
Y
102
1004
206E
1012
402G
1002
404E
140F
404B
406E
402J
1008
1010
208E
204H
122
402H
1006
222

FIG. 11



Z
X
Y
102
120
140E
1004
1202
140F
406E
1204
1206
122
402J
208E
222
1010
1208
402H
204H
204G

FIG. 12

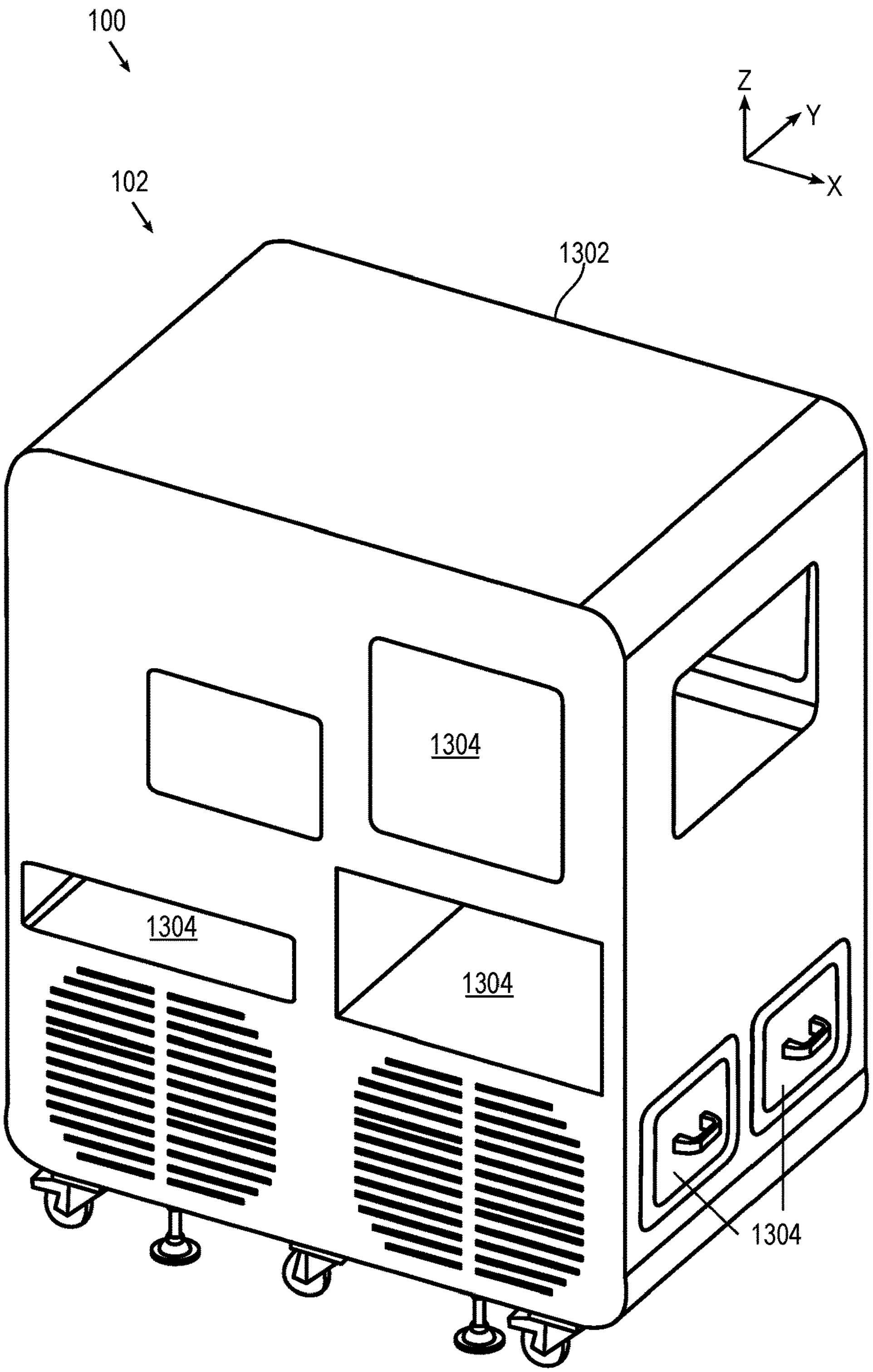


FIG. 13

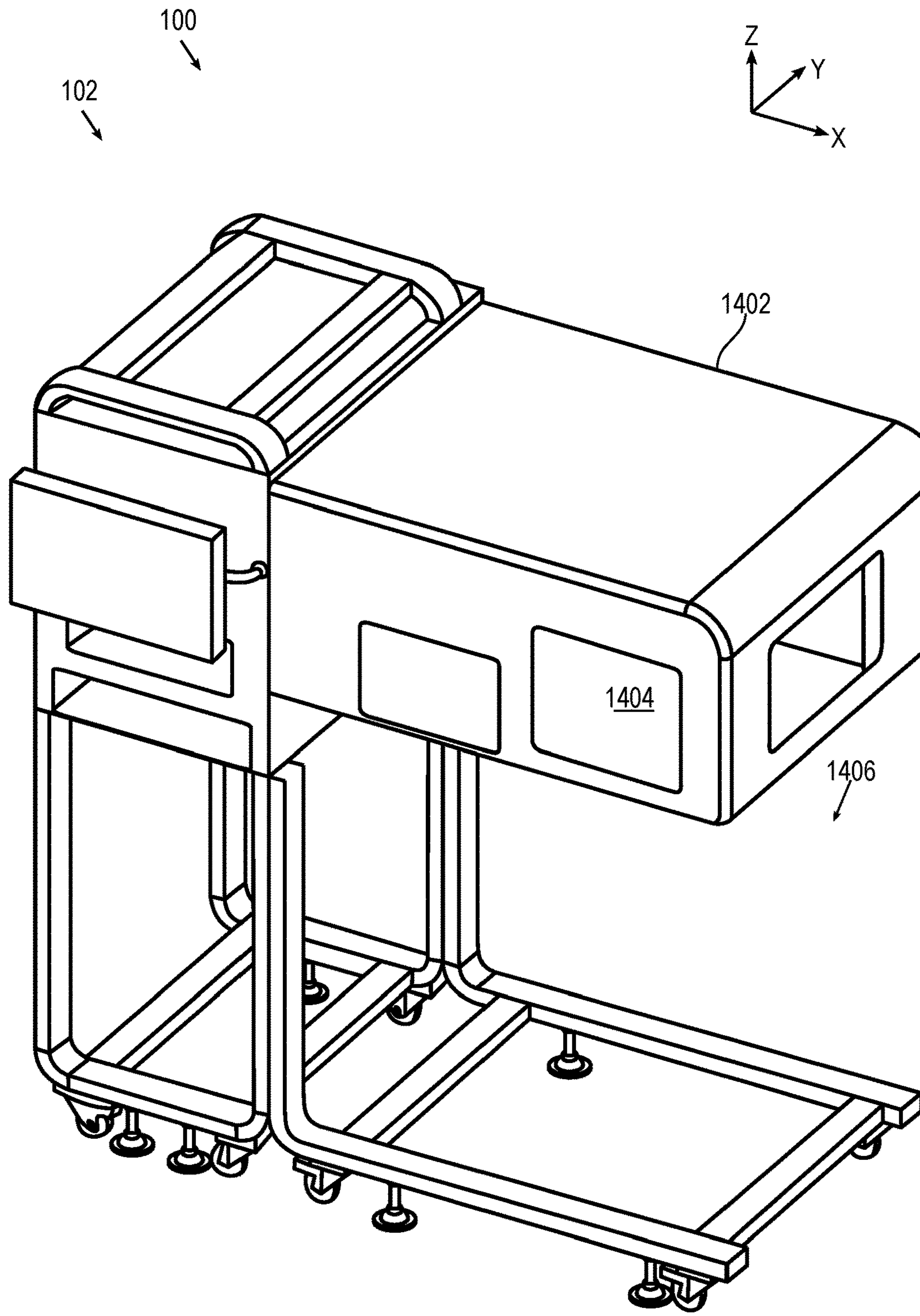


FIG. 14

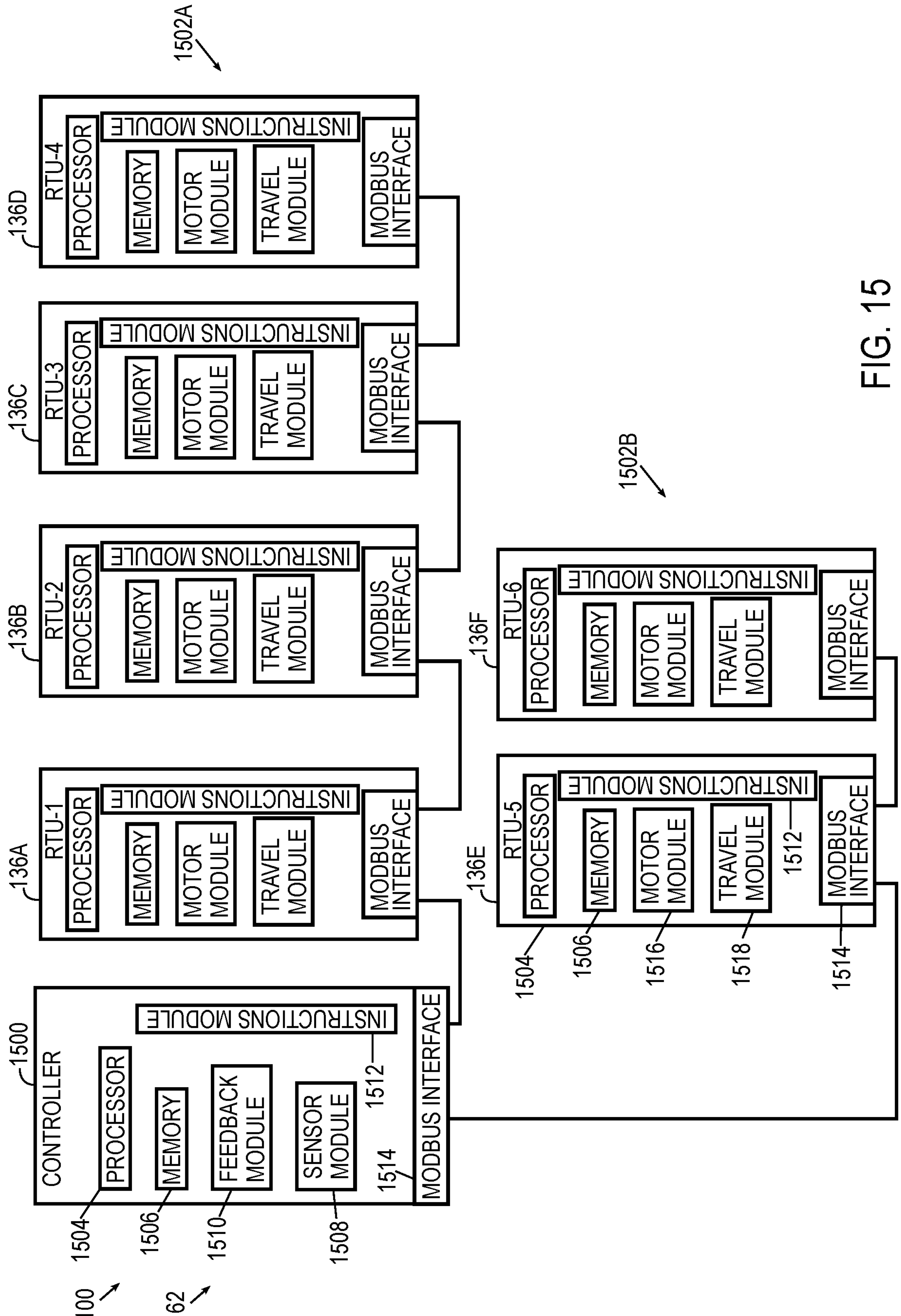

100
162
1500
CONTROLLER
PROCESSOR
MEMORY
FEEDBACK MODULE
SENSOR MODULE
INSTRUCTIONS MODULE
MODBUS INTERFACE
1504
1506
1510
1508
1512
1514
1502A
136A
RTU-1
136B
RTU-2
136C
RTU-3
136D
RTU-4
PROCESSOR
MEMORY
MOTOR MODULE
TRAVEL MODULE
INSTRUCTIONS MODULE
MODBUS INTERFACE
1502B
136E
RTU-5
136F
RTU-6
1516
1518

FIG. 15

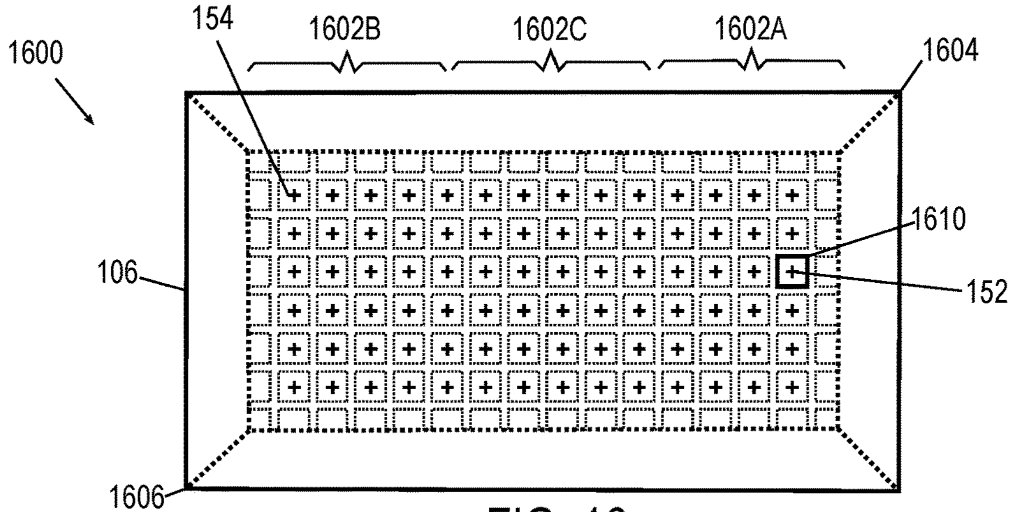


FIG. 16

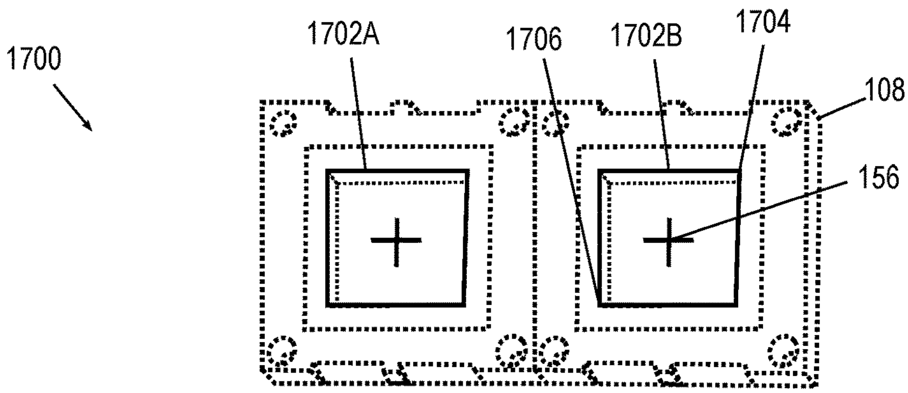


FIG. 17

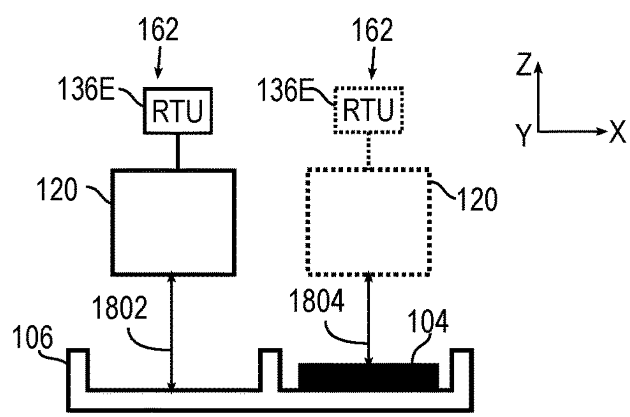


FIG. 18

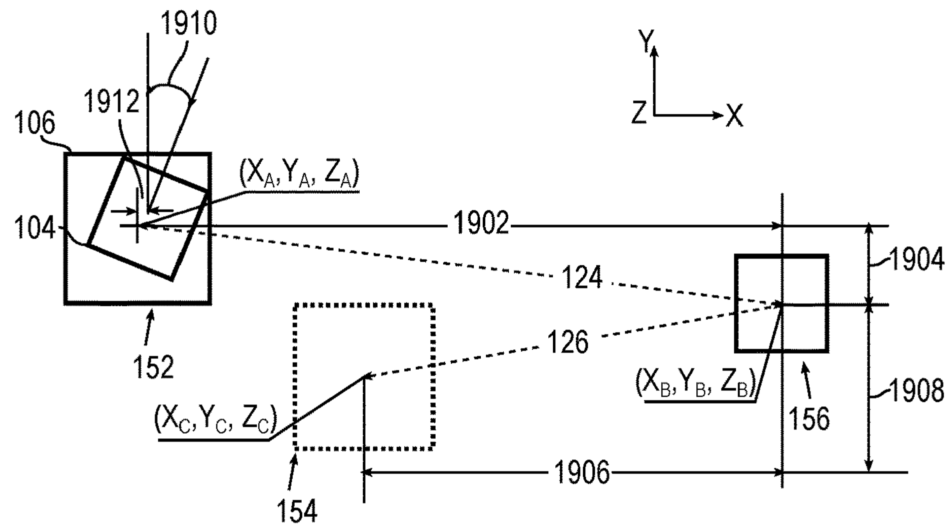


FIG. 19A

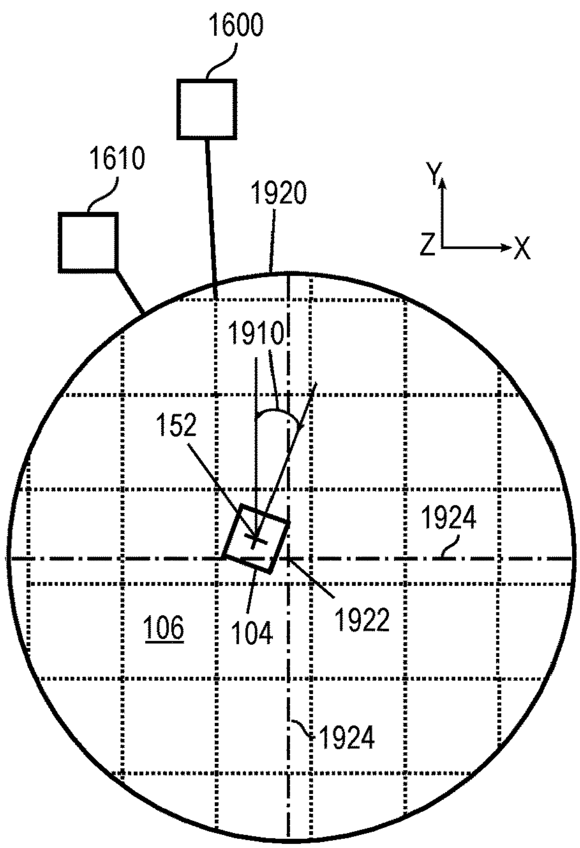


FIG. 19B

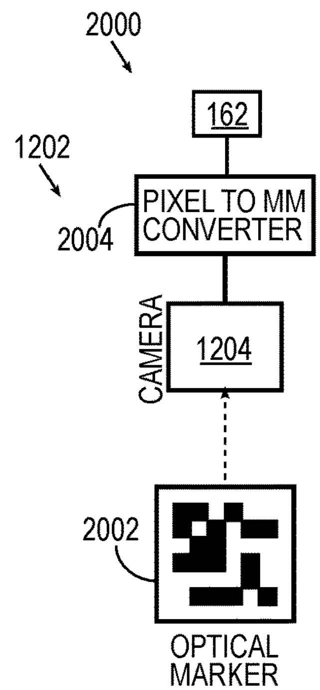


FIG. 20

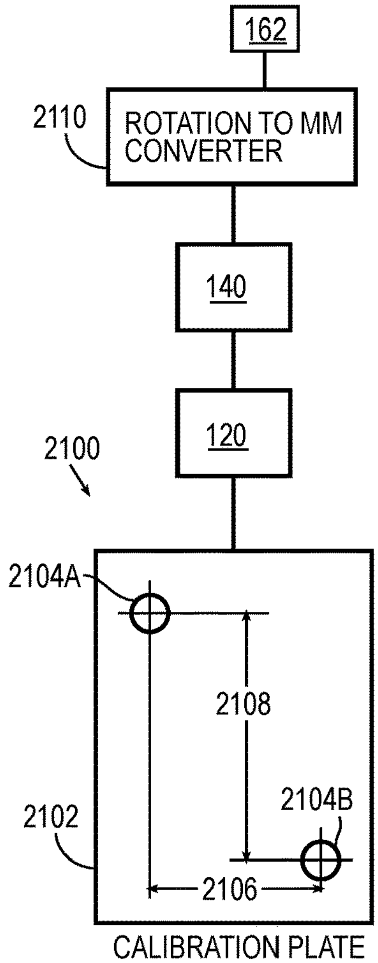

162
2110
ROTATION TO MM CONVERTER
140
120
2100
2104A
2108
2104B
2102
2106
CALIBRATION PLATE

FIG. 21

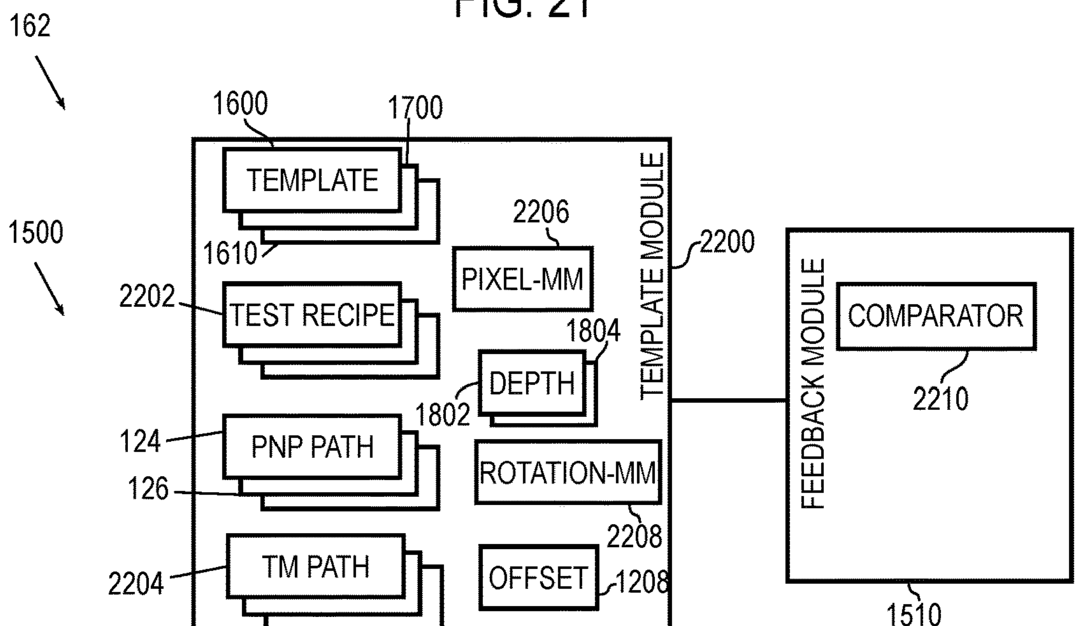

162
1500
1600
1700
TEMPLATE
1610
2206
PIXEL-MM
TEMPLATE MODULE
2200
2202
TEST RECIPE
1804
DEPTH
1802
124
PNP PATH
126
ROTATION-MM
2208
2204
TM PATH
OFFSET
1208
FEEDBACK MODULE
COMPARATOR
2210
1510

FIG. 22

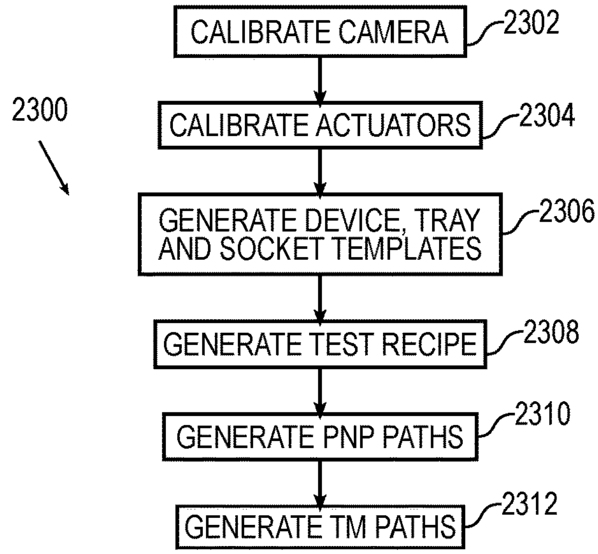

2300
CALIBRATE CAMERA
2302
CALIBRATE ACTUATORS
2304
GENERATE DEVICE, TRAY AND SOCKET TEMPLATES
2306
GENERATE TEST RECIPE
2308
GENERATE PNP PATHS
2310
GENERATE TM PATHS
2312

FIG. 23

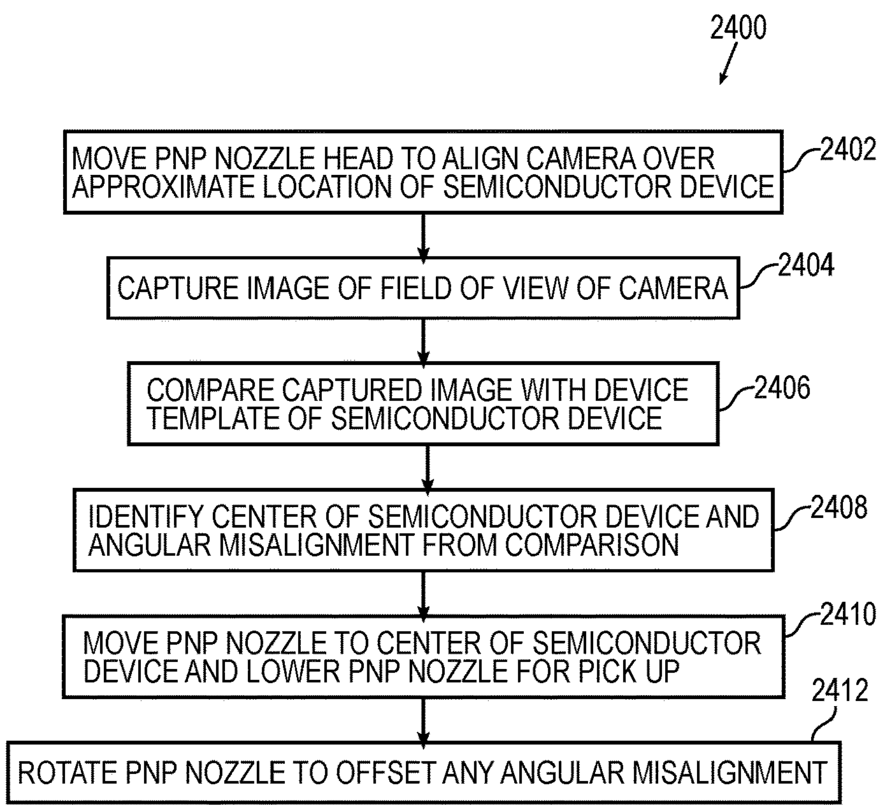

2400
MOVE PNP NOZZLE HEAD TO ALIGN CAMERA OVER APPROXIMATE LOCATION OF SEMICONDUCTOR DEVICE
2402
CAPTURE IMAGE OF FIELD OF VIEW OF CAMERA
2404
COMPARE CAPTURED IMAGE WITH DEVICE TEMPLATE OF SEMICONDUCTOR DEVICE
2406
IDENTIFY CENTER OF SEMICONDUCTOR DEVICE AND ANGULAR MISALIGNMENT FROM COMPARISON
2408
MOVE PNP NOZZLE TO CENTER OF SEMICONDUCTOR DEVICE AND LOWER PNP NOZZLE FOR PICK UP
2410
2412
ROTATE PNP NOZZLE TO OFFSET ANY ANGULAR MISALIGNMENT

FIG. 24

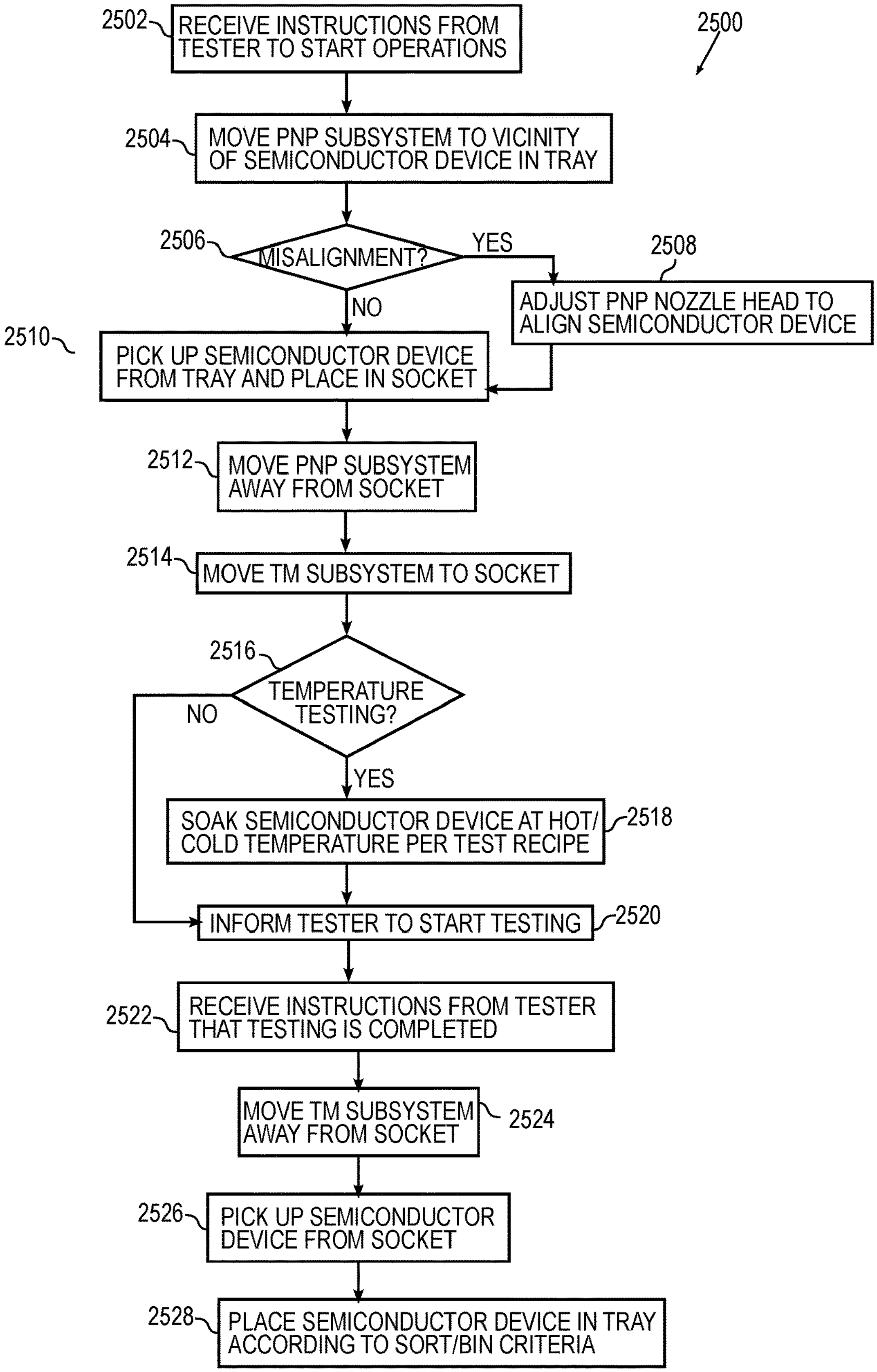

2500
2502
RECEIVE INSTRUCTIONS FROM TESTER TO START OPERATIONS
2504
MOVE PNP SUBSYSTEM TO VICINITY OF SEMICONDUCTOR DEVICE IN TRAY
2506
MISALIGNMENT?
YES
NO
2508
ADJUST PNP NOZZLE HEAD TO ALIGN SEMICONDUCTOR DEVICE
2510
PICK UP SEMICONDUCTOR DEVICE FROM TRAY AND PLACE IN SOCKET
2512
MOVE PNP SUBSYSTEM AWAY FROM SOCKET
2514
MOVE TM SUBSYSTEM TO SOCKET
2516
TEMPERATURE TESTING?
NO
YES
SOAK SEMICONDUCTOR DEVICE AT HOT/COLD TEMPERATURE PER TEST RECIPE
2518
INFORM TESTER TO START TESTING
2520
2522
RECEIVE INSTRUCTIONS FROM TESTER THAT TESTING IS COMPLETED
MOVE TM SUBSYSTEM AWAY FROM SOCKET
2524
2526
PICK UP SEMICONDUCTOR DEVICE FROM SOCKET
2528
PLACE SEMICONDUCTOR DEVICE IN TRAY ACCORDING TO SORT/BIN CRITERIA

FIG. 25

SYSTEMS AND METHODS TO HANDLE SEMICONDUCTOR DEVICES FOR TESTING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is a continuation application claiming priority under 35 U.S.C. § 120 to U.S. patent application Ser. No. 18/442,216, filed on Feb. 15, 2024, entitled "SYSTEMS AND METHODS TO HANDLE SEMICONDUCTOR DEVICES FOR TESTING". The disclosure of the prior application is considered part of and is hereby incorporated by reference in its entirety in the disclosure of this Application.

BACKGROUND

[0002] Semiconductor devices are typically tested to ensure they meet quality standards and performance specifications before they are released for production (i.e., large scale manufacture) or commercial use. Before production, semiconductor devices may be subject to engineering testing, for example, to validate their functionalities, to ensure design standards are met across various temperatures, and to assess their reliability in the field, among other reasons. Such engineering testing may be performed in testing laboratories. Production testing of semiconductor devices, on the other hand, typically takes place in controlled environments such as semiconductor fabrication or assembly facilities. These environments are equipped with specialized testing equipment and tools, such as automated test equipment (ATE), probe stations, test sockets, and test fixtures that enable efficient and accurate testing of semiconductor devices in high-volume production. In such engineering and production testing, automated robotic handlers play a crucial role in enabling rapid and precise testing of semiconductor devices.

BRIEF DESCRIPTION OF DRAWINGS

[0003] Embodiments will be readily understood by the following detailed description in conjunction with the accompanying drawings. To facilitate this description, like reference numerals designate like elements. Embodiments are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings.

[0004] FIGS. **1**A-**1**D are simplified block diagrams illustrating an example system for handling semiconductor devices during testing.

[0005] FIGS. **2**A and **2**B are a simplified perspective view and front view respectively of a portion of an example system for handling semiconductor devices during testing.

[0006] FIG. **3** is a simplified perspective view of another portion of an example system for handling semiconductor devices during testing.

[0007] FIG. **4** is a simplified top view of yet another portion of an example system for handling semiconductor devices during testing.

[0008] FIG. **5** is simplified top view of yet another portion of an example system for handling semiconductor devices during testing.

[0009] FIG. **6** is a simplified perspective view of yet another portion of an example system for handling semiconductor devices during testing.

[0010] FIG. **7** is a simplified perspective view of yet another portion of an example system for handling semiconductor devices during testing.

[0011] FIG. **8** is a simplified cross-sectional view of yet another portion of an example system for handling semiconductor devices during testing.

[0012] FIG. **9** is a simplified front view of yet another portion of an example system for handling semiconductor devices during testing.

[0013] FIG. **10** is a simplified front view of yet another portion of an example system for handling semiconductor devices during testing.

[0014] FIG. **11** is a simplified side view of the portion of the example system illustrated in FIG. **10**.

[0015] FIG. **12** is a simplified perspective view of the portion of the example system illustrated in FIG. **10**.

[0016] FIG. **13** is a simplified perspective view of an example engineering handler in a system for handling semiconductor devices during testing.

[0017] FIG. **14** is a simplified perspective view of an example production handler in a system for handling semiconductor devices during testing.

[0018] FIG. **15** is a simplified block diagram of a control system in an example system for handling semiconductor devices during testing.

[0019] FIG. **16** is a simplified top view of various templates in an example system for handling semiconductor devices during testing.

[0020] FIG. **17** is a simplified view of an example socket template in an example system for handling semiconductor devices during testing.

[0021] FIG. **18** is a simplified schematic diagram for illustrating some example operations of a vision head in an example system for handling semiconductor devices during testing.

[0022] FIGS. **19**A and **19**B are simplified schematic diagrams for illustrating other example operations of a vision head in an example system for handling semiconductor devices during testing.

[0023] FIG. **20** is a simplified block diagram illustrating example configuration operations that may be associated with embodiments of an example system for handling semiconductor devices during testing.

[0024] FIG. **21** is a simplified block diagram illustrating other example configuration operations that may be associated with embodiments of an example system for handling semiconductor devices during testing.

[0025] FIG. **22** is a simplified block diagram illustrating example details of an example system for handling semiconductor devices during testing.

[0026] FIG. **23** is a simplified flow diagram illustrating example operations associated with an example system for handling semiconductor devices during testing.

[0027] FIG. **24** is a simplified flow diagram illustrating other example operations associated with an example system for handling semiconductor devices during testing.

[0028] FIG. **25** is a simplified flow diagram illustrating yet other example operations associated with an example system for handling semiconductor devices during testing.

DETAILED DESCRIPTION

Overview

[0029] For purposes of illustrating the embodiments described herein, it is important to understand certain terminology and operations of technology networks. The following foundational information may be viewed as a basis from which the present disclosure may be properly explained. Such information is offered for purposes of explanation only and, accordingly, should not be construed in any way to limit the broad scope of the present disclosure and its potential applications.

[0030] In the following detailed description, various aspects of the illustrative implementations may be described using terms commonly employed by those skilled in the art to convey the substance of their work to others skilled in the art.

[0031] The term "semiconductor device" means any electronic component that is commonly manufactured using semiconductor materials but can also include components that do not contain any semiconductor materials, for example, integrated circuits (ICs), diodes, transistors, light emitting diodes (LEDs), resistors, capacitors, inductors, transformers, and the like that may be packaged together into one cohesive structure that can be handled as a unit. For example, the semiconductor device may include one or more semiconductor dies (e.g., chips) assembled on a package substrate and encapsulated by a mold compound. The semiconductor device may be any suitable package type, such as ball grid array, chip-scale package, quad flat no-leads package (QFN), etc.

[0032] The term "tester" refers to any instrument that can test a semiconductor device electrically, and includes, as examples and not as limitations, ATE, functional testers, boundary scan testers, parametric analyzers, probers, thermal testers, curve tracers, etc. The tester may be used to test the semiconductor device for functionality, reliability, quality, and other purposes.

[0033] The term "controller" is an electronic component that may be used to mange and regulate the operation of a system; in general, controllers receive electrical signals, process them using suitable algorithms and embedded logic, and generate output electrical signals that are used to control various aspects of a system's behavior, such as motions of actuators including motors, heaters, etc. The controller may be a standalone device, for example, a programmable logic controller (PLC), a dedicated computer, a laptop, electronic pad, etc. The controller may also be provisioned in another device, for example a general-purpose computer, laptop, electronic pad, etc.

[0034] The term "connected" means a direct connection (which may be one or more of a communication, mechanical, and/or electrical connection) between the things that are connected, without any intermediary devices, while the term "coupled" means either a direct connection between the things that are connected, or an indirect connection through one or more passive or active intermediary devices.

[0035] The term "computing device" means a server, a desktop computer, a laptop computer, a smartphone, or any device with a microprocessor, such as a central processing unit (CPU), general processing unit (GPU), or other such electronic component capable of executing processes of a software algorithm (such as a software program, code, application, macro, etc.).

[0036] The description uses the phrases "in an embodiment" or "in embodiments," which may each refer to one or more of the same or different embodiments.

[0037] Although certain elements may be referred to in the singular herein, such elements may include multiple subelements. For example, "a controller" may include one or more controllers.

[0038] Unless otherwise specified, the use of the ordinal adjectives "first," "second," and "third," etc., to describe a common object, merely indicate that different instances of like objects are being referred to and are not intended to imply that the objects so described must be in a given sequence, either temporally, spatially, in ranking or in any other manner.

[0039] In the following detailed description, reference is made to the accompanying drawings that form a part hereof, and in which is shown, by way of illustration, embodiments that may be practiced. It is to be understood that other embodiments may be utilized, and structural or logical changes may be made without departing from the scope of the present disclosure. Therefore, the following detailed description is not to be taken in a limiting sense.

[0040] The accompanying drawings are not necessarily drawn to scale. In the drawings, same reference numerals refer to the same or analogous elements shown so that, unless stated otherwise, explanations of an element with a given reference numeral provided in context of one of the drawings are applicable to other drawings where element with the same reference numerals may be illustrated. Further, the singular and plural forms of the labels may be used with reference numerals to denote a single one and multiple ones respectively of the same or analogous type, species, or class of element.

[0041] Note that in the figures, various components are shown as aligned, adjacent, or physically proximate merely for ease of illustration; in actuality, some or all of them may be spatially distant from each other. In addition, there may be other components, such as wires, cables, hoses, fasteners, cable carriers, energy chains, routers, switches, antennas, communication devices, etc. and features such as cable ties, holes, recesses, openings, rails, etc. in the systems and networks disclosed that are not shown in the figures to prevent cluttering. Systems and networks described herein may include, in addition to the elements described, other components and services, including communication interfaces, microprocessors, microcontrollers, network management and access software, connectivity services, routing services, firewall services, content delivery networks, virtual private networks, etc. Further, the figures are intended to show relative arrangements of the components within their systems, and, in general, such systems may include other components that are not illustrated (e.g., various mechanical components and electronic components related to handling functionality, electrical connectivity, etc.).

[0042] In the drawings, a particular number and arrangement of structures and components are presented for illustrative purposes and any desired number or arrangement of such structures and components may be present in various embodiments. Further, unless otherwise specified, the structures shown in the figures may take any suitable form or shape according to various design considerations, manufacturing processes, and other criteria beyond the scope of the present disclosure.

[0043] For convenience, if a collection of drawings designated with different letters are present (e.g., FIGS. **1**A-**1**D), such a collection may be referred to herein without the letters (e.g., as "FIG. **1**"). Similarly, if a collection of reference numerals designated with different letters are present (e.g., **206**A, **206**B), such a collection may be referred to herein without the letters (e.g., as "**206**") and individual ones in the collection may be referred to herein with the letters. Further, labels in upper case in the figures (e.g., **206**A) may be written using lower case in the description herein (e.g., **206**A) and should be construed as referring to the same elements.

[0044] Various operations may be described as multiple discrete actions or operations in turn in a manner that is most helpful in understanding the claimed subject matter. However, the order of description should not be construed as to imply that these operations are necessarily order dependent. In particular, these operations may not be performed in the order of presentation. Operations described may be performed in a different order from the described embodiment. Various additional operations may be performed, and/or described operations may be omitted in additional embodiments.

[0045] Handlers are specialized equipment used in semiconductor testing to automate the process of handling semiconductor devices during testing and sorting operations. Semiconductor devices are typically manufactured as packaged units placed in standardized trays, such as JEDEC trays. Handlers automatically pick up the semiconductor device from its tray, places it in a test socket for testing, and then returns them to the same or another tray based on the testing results. Devices that pass testing criteria may be sorted into different bins or trays based on their specifications, while defective devices may be separated for further analysis or disposition. Handlers ensure precise positioning of the semiconductor devices during testing to ensure accurate electrical contact with test sockets. This precision is essential for obtaining reliable test results and diagnosing any defects or performance issues in the devices being tested. Some handlers also feature temperature control capabilities to ensure that devices are tested under specified temperature conditions. Semiconductor handlers significantly increase the throughput and efficiency of semiconductor testing operations. By automating the handling process, handlers can process a large number of devices in a relatively short amount of time, improving overall production rates and reducing testing cycle times.

[0046] Various handlers are available in the market for performing such automated handling operations. They differ from each other in their mechanical and electrical efficiency, cost, ease of use and such other criteria. They also use different mechanical and electrical components and features to enable their operations, such choices being based on the respective handlers' functionality, performance, etc. Typically, they are all limited in their ability to visually identify different types of semiconductor devices in their trays. For example, some handlers can identify semiconductor devices that are larger than a particular size (e.g., 5 mm×5 mm), but need specialized additional visual components to identify smaller semiconductor devices. The reason for such differentiation arises from the optical components used to identify the semiconductor devices; typical handlers use lasers to identify larger semiconductor devices, with additional cameras having finer optical resolution for the smaller sized devices. Such a modular approach, while advantageous in certain scenarios (e.g., where the same sized semiconductor devices are tested routinely), may not be suitable in a factory or environment where semiconductor devices of quite different dimensions are tested serially. In the latter case, each time a different sized device is to be tested, the equipment needs to be recalibrated, adjusted, or otherwise made suitable for enabling or disabling the additional high-resolution camera, leading to loss of production time.

[0047] In addition, many of the handlers require a "precisor," which is a calibrated mechanism for precisely positioning the semiconductor device. In machines having the precisor, the pick-and-place nozzle initially picks up the semiconductor device from its tray and places it in the precisor. The precisor is structured to enable the semiconductor device placed in any orientation to realign to a predetermined, calibrated orientation. Thereafter, the nozzle picks up the semiconductor device and places it in the test socket with the correct alignment. Without the precisor, the semiconductor device may be misaligned in the test socket, leading to spurious test failures or device damage during testing. However, the precisor is an added part, which needs to be precisely machined separately for each device to be tested in many cases, leading to higher costs.

[0048] Further, some handlers that perform temperature-controlled testing (e.g., at different temperatures) use a thermal head coupled together with a pick-and-place nozzle, probably for ease of controlling both using a single set of sensors. The thermal head includes thermal hoses for the hot and cold fluids used in convective heat transfer, and/or wires used in conductive heat transfer. These hoses and/or wires are heavy and are usually managed by an energy chain (e-chain) that moves with the pick-and-place nozzle. Continuous movement of the hoses and/or wires within the e-chains lead to abrasion of the hoses and/or wires over time, leading to performance/reliability issues. Some other handlers overcome this problem by decoupling the thermal functionality from the pick-and-place functionality; in such systems, the thermal head and the pick-and-place head slide on the same gantry, for example, to ensure common alignment. However, placing them on the same gantry increases the load on the gantry while unnecessarily moving the heavy thermal head while the pick-and-place head is performing its functions, and vice versa.

[0049] Many handlers that perform temperature-controlled testing also enclose the entire test setup within a chamber during testing at hot and/or cold temperatures. Heating and cooling these large chambers can lead to inefficiencies in heat transfer, not to mention unnecessary waste of energy to bring the entire chamber to thermal equilibrium, particularly when only the heating or cooling of the much smaller semiconductor device is relevant to the testing.

[0050] Accordingly, embodiments of the handler disclosed herein separate the pick-and-place functionality and thermal functionality into two separate subsystems that are independently moveable relative to each other. Further, in some variations, the subsystem having thermal functionality can also facilitate exerting a predetermined pressure on the semiconductor device during testing. The predetermined pressure is calibrated in situ to be sufficient to enable electrical connectivity between the semiconductor device and the printed circuit board. Further, unlike other commonly available handlers, the system disclosed herein according to some embodiments use a casing to envelope the semiconductor device during testing so that heat transfer is contained within a smaller space within the handler, allowing for more efficient heat transfer.

[0051] Additionally, semiconductor devices within any suitable size range can be handled using a corresponding vision system having a field of vision. In other words, if the device can be located within the field of vision of the handler's vision system, the device can be handled by the handler without additional fixtures or adjustments. In addition, different device sizes may be easily accommodated simply by changing the cameras in the vision system without adding or modifying any other component of the handler. Such a single vision sensor system controlled by appropriate embedded algorithms permit a broad range of semiconductor devices to be handled precisely and seamlessly without any additional components such as the precisor or adjustments such as an added vision system for smaller devices. The embedded control algorithms enable the vision system comprising an optical camera to accurately identify a semiconductor device in its tray, determine its alignment, and inform a pick-and-place head to actuate a nozzle for appropriately picking up the semiconductor device from its tray, orienting it to the correct alignment and placing it accurately in the test socket. Movements of other components are accurately controlled by proximity sensors and motor sensors without using complex vision systems, enabling cost-effective, efficient and precise handling of semiconductor devices for testing.

EXAMPLE EMBODIMENTS

[0052] FIGS. **1**A-**1**D are simplified block diagrams illustrating a system **100** for handling semiconductor devices during testing according to an example embodiment. As illustrated in FIG. **1**A, system **100** includes a handler **102** for automatically picking a semiconductor device **104** from a tray **106** and placing it in a socket **108** on a printed circuit board **110**. Tray **106** and printed circuit board **110** may be positioned in a handler bottom plate **112**. In some embodiments, printed circuit board **110** may be fastened to handler bottom plate **112**. In other embodiments, printed circuit board **110** may be part of a tester (not shown) that may be placed underneath handler bottom plate **112**. Printed circuit board **110** has two opposing sides: one facing the components of handler **102** and on which, socket **108** is located, and the other facing the tester.

[0053] Handler bottom plate **112** is coupled to a handler top plate **114** that may be positioned away from handler bottom plate **112** by a Z-offset **116**. With reference to a three-dimensional space defined by mutually orthogonal axes X-axis, Y-axis and Z-axis, handler bottom plate **112** is fixed in the X-Y plane, and handler top plate **114** is fixed parallel to and offset from handler bottom plate **112** along the Z-axis by Z-offset **116**. In terms of semantics, widths of components in system **100** may be considered as being along the Y-axis, the lengths may be along the X-axis, and the heights may be along the Z-axis.

[0054] A pick-and-place (PNP) subsystem **118** is slidably coupled to handler bottom plate **112** such that PNP subsystem **118** can slide along the Y-axis. PNP subsystem **118** comprises a PNP head **120** which can slide along the X-axis. PNP head **120** includes a PNP nozzle head **122** which can slide along the Z-axis and some components in PNP nozzle head **122** can rotate around the Z-axis. PNP subsystem **118** has at least two functionalities: (1) picking up semiconductor device **104** from tray **106** and placing it in socket **108** as shown by PNP path **124**, and (2) picking up semiconductor device **104** from socket **108** and placing it in tray **106** as shown by PNP path **126**. In various embodiments, PNP head **120** is configured to pick up semiconductor device **104** and align it suitably for placing in socket **108** or tray **106**. In some embodiments (as shown), tray **106** to which the tested semiconductor device **104** is returned may be different from tray **106** from which untested semiconductor device **104** was picked up. In other embodiments (not shown), tray **106** to which the tested semiconductor device **104** is returned may be the same as tray **106** from which untested semiconductor device **104** was picked up.

[0055] A thermo-mechanical (TM) subsystem **128** is slidably coupled to handler top plate **114** such that TM subsystem **128** can slide along the X-axis. TM subsystem **128** comprises a TM carriage **130** movable along the X-axis and fixed relative to the Z-axis, and a TM head **132** slidably coupled to TM carriage **130** such that TM head **132** can slide along the Z-axis. TM subsystem **128** has at least two functionalities: (1) facilitate exertion of a predetermined pressure on semiconductor device **104** in socket **108**, and (2) optionally facilitate heating or cooling of semiconductor device **104** during testing. In scenarios where semiconductor device **104** is to be tested at room temperature, the second functionality may not be operational. In various embodiments, TM head **132** is configured to facilitate exertion of the predetermined pressure on semiconductor device **104** in socket **108**. The top of PNP subsystem **118** clears the bottom of handler top plate **114** by a Z-clearance **134** such that PNP subsystem **118** can move unimpeded in the X-Y plane without being obstructed by TM subsystem **128**. One or more remote terminal units (RTUs) **136** may be used to control each of the movements, i.e., translation (e.g., sliding) along the X-axis, the Y-axis and the Z-axis, and rotation around the Z-axis of the various components described herein.

[0056] A top view of handler **102** is schematically shown in FIG. **1**B. PNP subsystem **118** and TM subsystem **128** are shown in their respective home (e.g., resting, retracted) positions. The maximum travel of PNP head **120** along the X-axis is offset from the home position of TM subsystem **128** by an X-clearance **138**. Movements of various components in handler **102** may be facilitated by one or more of actuator **140**. For example, sliding of PNP subsystem **118** along the Y-axis may be facilitated by actuator **140**A. Sliding of PNP head **120** along the X-axis may be facilitated by actuator **140**B. Sliding of TM subsystem **128** along the X-axis may be facilitated by actuator **140**C. Not shown in the figure are actuators **140**D, **140**E, and **140**F that facilitate sliding of TM head **132** along the Z-axis, sliding of PNP nozzle head **122** along the Z-axis and rotation of PNP nozzle head **122** around the Z-axis, respectively.

[0057] Actuator **140** may be of any suitable kind for the functionality it provides. In a particular embodiment, actuator **140** for sliding may comprise a servo motor coupled with a rotating lead screw. In another embodiments, actuator **140** may comprise a stepper motor coupled with a rotating lead screw. In yet another embodiment, actuator **140** may comprise a theta-motor to facilitate rotation around the Z-axis. Various other choices of actuator **140** are included within the broad scope of the embodiments herein. In some embodiments, actuator **140** may comprise additional machine elements, such as gears and belts to enable separation of the motor and the lead screw. Each actuator **140** may be controlled by a separate one of RTU **136** in some embodiments. In other embodiments, more than one actuator **140** may be controlled commonly by a single one of RTU **136**. Various such arrangements are included in the broad scope of the various embodiments discussed herein.

[0058] Handler bottom plate **112** may include one or more tray recesses **142** for tray **106** configured for placing semiconductor devices **104** and a test opening **144** to receive printed circuit board **110**. In some embodiments, tray **106** comprises a matrix tray (e.g., waffle tray) having dimensions approximately according to JEDEC standards. Tray **106** may accommodate a plurality of semiconductor devices **104** suitably. In some embodiments, tray recess **142** may have a bottom to support the bottom of tray **106**. In other embodiments, tray recess **142** may be an opening with tray **106** hanging from a lip around tray recess **142**. Various other ways of placing tray **106** in tray recess **142** are included within the broad scope of the embodiments herein. Test opening **144** may be sized suitably to expose printed circuit board **110**, particularly, socket **108** to the various components of handler **102**.

[0059] Separate sets of rails (not shown) may enable sliding of the various components suitably. For example, one set of rails (e.g., tracks) may enable PNP subsystem **118** to slide along the Y-axis when powered by actuator **140**A; another set of rails may enable PNP head **120** to slide along the X-axis when powered by actuator **140**B; yet another set of rails may enable TM subsystem **128** to slide along the X-axis when powered by actuator **140**C; and so on. Note that rails are merely one example of a mechanical component to facilitate sliding; other components such as wheels, tracks, grooves, etc. may alternatively be used without departing from the scope of the embodiments.

[0060] TM subsystem **128** may be positioned to translate approximately around the middle of test opening **144** where socket **108** will be located during operation, so that sliding from its home position along the X-axis, TM subsystem **128** may reach socket **108** easily without additional movements, for example, along Y-axis. In some other embodiments, TM subsystem **128** may be configured with manual adjustment capabilities along the Y-axis (e.g., using screws, rods, etc.) to allow TM subsystem **128** to be placed accurately over socket **108** during operation.

[0061] FIG. **1**C shows details of the various positions of the components of handler **102**. PNP home position **150** represents the home (e.g., base, inactive, retracted, etc.) position of PNP subsystem **118**. PNP subsystem **118** moves between PNP home position **150** and a plurality of active positions **152-156**. Active position **152** represents the location to pick up semiconductor device **104** from tray **106** in tray recess **142**. Active position **154** represents the location to return semiconductor device **104** to tray **106** in tray recess **142**. Note that active positions **152** and **154** may be in the same tray **106** in tray recess **142** in some embodiments. In other embodiments, active positions **152** and **154** may be in different trays **106**. Active position **156** represents the location to place semiconductor device **104** in socket **108** in test opening **144**. In some embodiments, socket **108** may have a plurality of sites, each site configured for a single semiconductor device **104**. In such embodiments, active position **156** represents the specific site in socket **108** where semiconductor device **104** is to be placed. Active position **156** also represents the active position of TM subsystem **128**. TM home position **158** represents the home (e.g., base, inactive, retracted, etc.) position of TM subsystem **128**.

[0062] Note that while active positions **152-156** may be located in the X-Y plane relative to PNP home position **150** (i.e., offset in both X-axis and Y-axis relative to PNP home position **150**), active position **156** is only linearly offset from TM home position **158** along the X-axis in some embodiments. This follows from the independent motions of PNP subsystem **118** and TM subsystem **128**. While PNP subsystem **118** has separate and independent actuators **140**A and **140**B to allow movements independently along the X-axis and the Y-axis, TM subsystem **128** has only actuator **140**C to allow sliding along the X-axis in the X-Y plane. In some embodiments, TM subsystem **128** may be configured with manual adjustments to enable moving TM subsystem **128** slightly along the Y-axis, for example, to ensure accurate placement over socket **108**. Note that other actuators **140** (not shown) allow sliding of components in PNP subsystem **118** and TM subsystem **128** along the Z-axis.

[0063] FIG. **1**D illustrates a schematic block diagram showing the relationship between handler **102** and other components of system **100** during operation. A tester **160** and a control system **162** may communicate with handler **102** during various operations. Control system **162** may automate some operations of handler **102** suitably to enable it to operate without human intervention. For example, movements of PNP subsystem **118** and TM subsystem **128** may be controlled by control system **162** without human intervention. Control system **162** may include a controller that controls the various ones of RTU **136** to enable picking up semiconductor device **104** from tray **106** and placing it in socket **108**. In one example embodiment, these operations may comprise moving PNP subsystem **118** from PNP home position **150** to active position **152**, identifying alignment of semiconductor device **104** in tray **106**, adjusting PNP nozzle head **122** accordingly, picking up semiconductor device **104**, moving PNP subsystem **118** to active position **156**, and placing semiconductor device **104** in socket **108**. Thereafter, control system **162** may enable retracting PNP subsystem **118** to PNP home position **150**, or away from active position **156**, and moving TM subsystem **128** to active position **156**. Control system **162** may also control mechanical and thermal operations of TM subsystem **128**, for example, to apply pressure on semiconductor device **104** and/or soak semiconductor device **104** at a predetermined temperature according to testing criteria.

[0064] Control system **162** may also coordinate between handler **102** and tester **160** suitably. For example, after thermal operations are complete, and semiconductor device **104** is ready for testing, handler **102** may communicate to tester **160** that semiconductor device **104** is ready, upon which, tester **160** may commence testing operations. When testing is complete, in some embodiments, tester **160** may communicate to handler **102** the sorting bin to which semiconductor device **104** is to be returned. In such embodiments, handler **102** may relay the communication to control system **162**. In other embodiments, when testing is complete, tester **160** may communicate to control system **162** the sorting bin to which semiconductor device **104** is to be returned. Control system **162** determines active position **154** based on the sorting bin information from tester **160**. Control system **162** may then facilitate moving TM subsystem **128** back to TM home position **158** (or away from active position

156) and facilitate moving PNP subsystem **118** from PNP home position **150** to pick up semiconductor device **104** from socket **108** and return it to tray **106** (i.e., active position **154**).

[0065] In some embodiments, one or more of these features may be implemented in hardware, provided external to these elements, or consolidated in any appropriate manner to achieve the intended functionality. The various elements in system **100** may include communication software that can coordinate to achieve the operations as outlined herein. In still other embodiments, these elements may include any suitable algorithms, hardware, software, components, modules, interfaces, or objects that facilitate the operations thereof.

[0066] FIG. **2**A is a simplified perspective view of a portion of system **100**, specifically, handler **102**, according to an embodiment of the present disclosure. Handler **102** comprises a pair of handler side plates **202** in a X-Z plane directly coupled to handler bottom plate **112** and handler top plate **114**. Handler side plates **202** are sized appropriately such that handler top plate **114** is at Z-offset **116** from handler bottom plate **112**. Handler side plates **202** may be mounted to handler bottom plate **112** and handler top plate **114** using any suitable fastening mechanism, such as screws, nuts and bolts, nails, rivets, welds, etc.

[0067] In some embodiments, PNP subsystem **118** and TM subsystem **128** may translate on rails **204** affixed appropriately to suitable ones of handler bottom plate **112** and handler top plate **114**. For example, PNP subsystem **118** may translate along the Y-axis on rails **204** fixed to handler bottom plate **112**. TM subsystem **128** may translate along the X-axis on rails **204** fixed to handler top plate **114**. Sliding on rails **204** may be enabled by suitable sliders (not labeled in the figure to prevent crowding) fixed to the respective subsystems appropriately. Motion on rails **204** may be actuated by one or more actuator **140**. Some of actuator **140** (e.g., **140**A-**140**E), may comprise a motor **206** that enables rotation of a lead screw **208**. The rotation is converted to linear translation by a corresponding nut (not labeled to prevent crowding) that can move back and forth on lead screw **208**. Other ones of actuator **140** (e.g., **140**F) may comprise a theta-motor that enables rotation around a shaft.

[0068] In some embodiments, TM carriage **130** slides on rails **204** affixed to handler top plate **114**. TM carriage **130** extends partially between the top of handler top plate **114** and the top of handler bottom plate **112**. TM head **132** is slidably coupled to TM carriage **130** for motion along the Z-axis. The Z-axis motion is facilitated by actuator **140**D attached to TM carriage **130**. In some embodiments, actuator **140**D comprises a servo motor **206** coupled to a lead screw (not shown), and TM head **132** is fixed to the nut (not shown) that translates on the lead screw. Rotation of the lead screw enables TM head **132** to slide along the Z-axis suitably.

[0069] PNP head **120** is slidably coupled in PNP subsystem **118**, enabled by actuator **140**B to move along the X-axis, with PNP nozzle head **122** additionally configured to slide along the Z-axis. The Z-axis motion is facilitated by actuator **140**E in PNP subsystem **118**. In some embodiments, actuator **140**E comprises a stepper motor coupled to a lead screw (not shown), and PNP nozzle head **122** is fixed to the nut that translates on the lead screw. Rotation of the lead screw enables PNP nozzle head **122** to slide along the Z-axis suitably. A servo motor may be used instead of a stepper motor without departing from the scope of the embodiments. Actuator **140**F may enable a PNP nozzle in PNP nozzle head **122** to rotate around the Z-axis suitably.

[0070] During operation, actuators **140**A and **140**B enable PNP subsystem **118** to move from PNP home position **150** to active position **152**. Actuators **140**A and **140**B facilitate adjustment of PNP head **120** over semiconductor device **104**. Actuator **140**E enables PNP nozzle head **122** to move down and contact semiconductor device **104**. In some embodiments, PNP nozzle head **122** may be provisioned with a vacuum tube and activation of the vacuum may cause semiconductor device **104** to "stick" to PNP nozzle head **122**. Actuator **140**F adjusts the angle of PNP nozzle head **122** suitably so that semiconductor device **104** is aligned to be placed into socket **108** correctly. Actuator **140**E lifts PNP nozzle head **122** upwards, for example, to clear other components during subsequent travel. Thereafter, actuators **140**A and **140**B enable PNP head **120** to move to active position **156** over socket **108**. Actuator **140**E drops PNP nozzle head **122** down sufficiently to place semiconductor device **104** inside socket **108**. Thereafter, actuators **140**A, **140**B, and **140**E may lift PNP nozzle head **122** up and retract PNP subassembly **118** to PNP home position **150**.

[0071] Subsequently, actuator **140**C enables TM subsystem **128** to move from TM home position **158** to active position **156** over semiconductor device **104** in socket **108**. Actuator **140**D causes TM head **132** to move down and exert pressure on semiconductor device **104**. In some embodiments, TM subsystem **128** includes an opening for a removable fixture (not shown) attached by spring-loaded fasteners to TM head **132**. In such embodiments, TM head **132** moves down under the power of actuator **140**D, contacts printed circuit board **110** and stops further motion, while the fixture continues to move down. In some such embodiments, the spring-loaded fasteners enable TM subsystem **128** to maintain contact on printed circuit board **110**. The fixture exerts increasing pressure on semiconductor device **104** by action of the spring-loaded fasteners until the predetermined pressure is reached, at which point actuator **140**D shuts down and the Z-axis motion stops.

[0072] FIG. **2**B is a simplified front view of handler **102** of FIG. **2**A. TM subsystem **128** comprises TM carriage **130** and TM head **132**. TM carriage **130** comprises a carriage top plate **210** configured to translate over rails **204** affixed to handler top plate **114**. Motor **206** of actuator **140**D is affixed to carriage top plate **210**. TM carriage **130** further comprises a carriage bottom plate **212** parallel to and affixed to carriage top plate **210** at a distance therefrom. Lead screw **208** coupled to motor **206** of actuator **140**D is attached to carriage bottom plate **212**. The distance of carriage bottom plate **212** from carriage top plate **210** may be determined in some embodiments by the distance traveled by TM head **132** along the Z-axis (i.e., lead screw **208** coupled to motor **206** is long enough to enable the distance traveled by TM head **132**).

[0073] TM head **132** comprises a TM head top plate **214** and a TM head bottom plate **216**. TM head top plate **214** is between carriage top plate **210** and carriage bottom plate **212**. TM head bottom plate **216** is between carriage bottom plate **212** and handler bottom plate **112** such that carriage bottom plate **212** is between TM head top plate **214** and TM head bottom plate **216**. TM head top plate **214** is attached to a nut (not labeled) that translates on lead screw **208**. Movement of the nut up and down lead screw **208** causes TM head

132 to move accordingly along with it along the Z-axis. TM head bottom plate **216** is parallel to and affixed to TM head top plate **214** at a distance therefrom.

[0074] A casing **218** is affixed by spring-loaded fasteners (not labeled) to TM head bottom plate **216** in some embodiments. In some embodiments, the spring-loaded fasteners enable casing **218** to maintain contact on printed circuit board **110**. A removable fixture may also be attached by spring-loaded fasteners to TM head bottom plate **216**. In such embodiments, as TM head **132** moves down under the power of actuator **140**D, casing **218** initially contacts printed circuit board **110**. Further motion downwards results in pressure exerted on printed circuit board **110** by the spring-loaded fasteners and continued movement of the fixture downwards over semiconductor device **104**. When the predetermined pressure on semiconductor device **104** is reached, actuator **140**D shuts off. At this point, casing **218** provides an enclosure around semiconductor device **104**. The enclosure enables movement of air, for example, to remove frosting and/or condensation during cold/hot temperature testing. Unlike other handlers in the market that enclose the entire handler system within an enclosure for hot/cold testing, casing **218** may enable more efficient heat transfer and less energy wastage by confining the heated/cooled environment to within casing **218** around semiconductor device **104**.

[0075] PNP subsystem **118** includes a PNP carriage **220**, to which are affixed rails **204** that facilitate sliding of PNP head **120** along the X-axis. Actuator **140**B that enables PNP head **120** to slide along the X-axis is also mounted to PNP carriage **220**. Actuator **140**B comprises servo motor **206** coupled with lead screw **208** in the embodiment shown. PNP carriage **220** includes a nut (not shown) that moves along lead screw **208** of actuator **140**A, allowing sliding of PNP carriage **220** along the Y-axis. A PNP base plate **222** of PNP head **120** is slidably affixed to PNP carriage **220**. PNP base plate **222** is provisioned with rails **204** on which PNP nozzle head **122** slides along the Z-axis. Sliding of PNP nozzle head **122** along the Z-axis is powered by actuator **140**E. Rotation of PNP nozzle head **122** around the Z-axis is enabled by actuator **140**F.

[0076] FIG. **3** is a simplified perspective view of a frame **302** in handler **102** according to an embodiment of the present disclosure. Frame **302** comprises handler bottom plate **112**, handler top plate **114** and handler side plates **202**. Handler top plate **114** includes an opening **304** for movement of TM subsystem **128** from TM home position **158** to active position **156**. Frame **302** may be made of any suitable material, including steel, aluminum, etc. as desired and based on particular needs.

[0077] FIG. **4** is a simplified top view of handler bottom plate **112** and additional components according to an embodiment of the present disclosure. Rail **204**A and rail **204**B are affixed to handler bottom plate **112**. One or more slider **402** enables motion over rail **204**. For example, slider **402**A enables motion over rail **204**A and slider **402**B enables motion over rail **204**B. Sliders **402**A and **402**B are affixed to PNP carriage **220** (not shown) so that PNP subsystem **118** moves over rails **204**A and **204**B along the Y-axis when activated by actuator **140**A. Actuator **140**A is fixed to handler bottom plate **112**. In the embodiment shown, actuator **140**A comprises servo motor **206**A coupled with lead screw **208**A. One end of lead screw **208**A is coupled to servo motor **206**A and the other end is fixed to handler bottom plate **112**. A nut **404**A moves along lead screw **208**B, translating the rotary movement of lead screw **208**A to linear motion along the Y-axis. Nut **404**A is attached suitably to PNP carriage **220**. Note that lead screw **208**A may be supported suitably on bearings and other machine elements not shown with particularity to prevent clutter in the illustration. A proximity sensor **406**A fixed to handler bottom plate **112** enables detecting a base position of PNP subsystem **118**. In various embodiments, any proximity sensor **406** (including proximity sensor **406**A) in handler **102** may be of any suitable construction; for example, proximity sensor **406**A may be an optical reflective proximity sensor. Other types of sensors may be used in handler **102** without departing from the scope of the embodiments.

[0078] Distance traveled from the base position is calculated using the number of turns and angles rotated by servo motor **206**A. A limit positioning sensor (not shown) may also be included in handler **102** without departing from the scope of the embodiments. In some embodiments, the limit position (i.e., maximum travel) may be determined by sensors integrated with actuator **140**A; such sensors may identify the number of turns and angles of partial turns by servo motor **206**A and compute the linear travel therefrom.

[0079] FIG. **5** is a simplified top view of handler top plate **114** and additional components according to an embodiment of the present disclosure. Rail **204**C and rail **204**D are affixed to handler top plate **114**. Sliders **402**C and **402**D enable motion over rail **204**C and sliders **402**E and **402**F enable motion over rail **204**D. Sliders **402**C-**402**F are affixed to TM carriage **130** (not shown) suitably so that TM carriage **130** moves over rails **204**C and **204**D along the X-axis when activated by actuator **140**C. Actuator **140**C is fixed to handler top plate **114**. In the embodiment shown, actuator **140**C comprises servo motor **206**C coupled with lead screw **208**C. One end of lead screw **208**C is coupled to servo motor **206**C and the other end is fixed to handler top plate **114**. Nut **404**C moves along lead screw **208**C, translating the rotary movement of lead screw **208**C to linear motion along the X-axis. Nut **404**C is attached suitably to TM subsystem **128**. Note that lead screw **208**C may be supported suitably on bearings and other machine elements not shown with particularity to prevent clutter. Proximity sensor **406**C fixed to handler top plate **114** enables detecting a base position of TM subsystem **128**. Distance traveled from the base position is calculated using the number of turns and angles rotated by servo motor **206**C. A limit positioning sensor (not shown) may also be included in handler **102** without departing from the scope of the embodiments. In some embodiments, the limit position (i.e., maximum travel) may be determined by sensors integrated with actuator **140**C; such sensors may identify the number of turns and angles of partial turns by servo motor **206**C and compute the linear travel therefrom.

[0080] FIG. **6** is a simplified perspective view of TM subsystem **128** according to an example embodiment. Nut **404**C is affixed to top of carriage top plate **210**, enabling TM carriage **130** to translate along the X-axis when lead screw **208**C rotates. Sliders **402**C-**402**F are affixed to bottom of carriage top plate **210**, enabling TM carriage **130** to translate along the X-axis smoothly over rails **204**C and **204**D. TM subsystem **128** comprises TM carriage **130** that remains stationary with respect to the Z-axis and TM head **132** that is slidably coupled to TM carriage **130** for motion along the Z-axis. Motion of TM head **132** along the Z-axis is facilitated by actuator **140**D. Actuator **140**D is fixed to carriage top plate **210**. In the embodiment shown, actuator **140**D comprises servo motor **206**D coupled with lead screw **208**D. One end of lead screw **208**D is coupled to servo motor **206**D and the other end is fixed to carriage bottom plate **212**. Nut **404**D moves along lead screw **208**D, translating the rotary movement of lead screw **208**D to linear motion along the Z-axis. Nut **404**D is affixed to TM head top plate **214**, enabling TM head **132** to translate along the Z-axis when lead screw **208**D rotates, while TM carriage **130** remains stationary with respect to the Z-axis. Proximity sensor **406**D fixed to carriage top plate **210** enables detecting a base position of TM head **132**. Distance traveled from the base position is calculated using the number of turns and angles rotated by servo motor **206**D. A limit positioning sensor (not shown) may also be included in handler **102** without departing from the scope of the embodiments. In some embodiments, the limit position (i.e., maximum travel) may be determined by sensors integrated with actuator **140**D; such sensors may identify the number of turns and angles of partial turns by servo motor **206**D and compute the linear travel therefrom.

[0081] FIG. **7** is a simplified perspective view of TM carriage **130** according to an example embodiment. TM carriage **130** includes an opening **702** for a removable fixture (not shown). Opening **702** in the embodiment shown comprises opening **702**A in carriage top plate **210** and opening **702**B in carriage bottom plate **212**. Pillars **704** may fixedly couple carriage top plate **210** and carriage bottom plate **212**. Pillars **704** may be of any suitable cross-sectional shape (e.g., circular, polygonal, square, etc.) within the broad scope of the embodiments herein. In various embodiments, pillars **704** may guide movement (e.g., sliding) of TM head **132** along the Z-axis. In some embodiments, pillars **704** may also absorb moment forces to prevent damage to lead screw **208**D. Lead screw **208**D is coupled to servo motor **206**D fixed to carriage top plate **210** and to carriage bottom plate **212**.

[0082] FIG. **8** is a simplified cross-sectional view of TM head **132** according to an example embodiment. Nut **404**D is affixed to TM head top plate **214** to enable sliding of TM head **132** along Z-axis when lead screw **208**D rotates under action by servo motor **206**D. TM head **132** includes an opening **802** for a removable fixture **804** (shown in dotted lines). Opening **802** in the embodiment shown comprises opening **802**A in TM head top plate **214** and opening **802**B in TM head bottom plate **216**. In some embodiments, fixture **804** comprises a mechanical head with ends shaped to fit into socket **108** and on semiconductor device **104** therein. In some other embodiments, fixture **804** comprises a thermal head configured to press down on semiconductor device **104** while simultaneously heating or cooling it appropriately. Fixture **804** may include hoses and/or cables that are not shown for ease of illustration and so as not to clutter the drawing.

[0083] Casing **218** is coupled to TM head bottom plate **216** by spring-loaded fasteners **806**. Spring-loaded fastener **806** comprises a rod **807** having a head wider than its body, and a spring **808** in contact with the head between rod **807** and a cover **810**. Spring **808** is hidden inside cover **810** and is made visible merely for illustrative purposes. Spring **808** may remain in an uncompressed state until the bottom of casing **218** contacts printed circuit board **110** (not shown). After contact with printed circuit board **110**, further downward motion of TM head **132** causes rod **807** to move upwards, compressing spring **808** against cover **810**, leading to a pressure force on printed circuit board **110**. Similar spring-loaded fasteners **812** (shown covered, such that the springs are hidden under the cover) couple fixture **804** to TM head bottom plate **216**. During operation, after casing **218** contacts printed circuit board **110**, further downward motion of TM head **132** causes springs in similar spring-loaded fasteners **812** to compress, exerting pressure by fixture **804** on semiconductor device **104**. The pressure exerted on printed circuit board **110** and semiconductor device **104** may be suitably assessed by the travel of casing **218** and fixture **804** respectively and the spring constant of the springs (e.g., **808**) of spring-loaded fasteners **806** and **812**.

[0084] Space **814** between casing **218** and fixture **804** enables movement of air around semiconductor device **104** during thermal heating/cooling operations. In various embodiments, handler **102** may facilitate heating to 155° C. and cooling to −55° C. The air circulation inside casing **218** may prevent frosting on printed circuit board **110** and semiconductor device **104** during cold temperature testing. The air circulation may also remove moisture, and prevent local thermal hot spots or cold spots during heating or cooling, facilitating efficient heat transfer within casing **218**. Casing **218** may also prevent injury to the human operator during hot temperature testing by providing a barrier between the heated environment and the environment external to handler **102**. Pillars **816** may fixedly couple TM head top plate **214** and TM head bottom plate **216**. Pillars **816** may be of any suitable cross-sectional shape (e.g., circular, polygonal, square, etc.) within the broad scope of the embodiments herein.

[0085] FIG. **9** is a simplified front view of PNP subsystem **118** of handler **102** according to an example embodiment. PNP subsystem **118** includes PNP carriage **220**, to which are affixed rails **204**E and **204**F that facilitate sliding of PNP head **120** along the X-axis. Actuator **140**B that enables PNP head **120** to slide along the X-axis is fixed to PNP carriage **220**. Actuator **140**B comprises servo motor **206**B coupled with lead screw **208**B in the embodiment shown. One end of lead screw **208**B is coupled to servo motor **206**B and the other end is fixed to PNP carriage **220**. PNP carriage **220** includes nut **404**A that moves along lead screw **208**A (not shown) of actuator **140**A (not shown), allowing sliding of PNP carriage **220** along the Y-axis. PNP base plate **222** of PNP head **120** is affixed to PNP carriage **220**. PNP base plate **222** is provisioned with rails **204**G and **204**H (not shown) on which PNP nozzle head **122** slides along the Z-axis. Sliding of PNP nozzle head **122** along the Z-axis is powered by actuator **140**E. Rotation of PNP nozzle head **122** around the Z-axis is enabled by actuator **140**F (not shown). Other components that are not visible in the figure include sensors **406**, sliders, nuts, etc. in PNP subsystem **118**.

[0086] FIG. **10** is a simplified front view of PNP head **120** according to an example embodiment. PNP head **120** includes rails **204**G and **204**H fixed to PNP base plate **222** to enable PNP nozzle head **122** to slide along the Z-axis. A support plate **1002** provides support for an elbow coupler **1004** that facilitates providing vacuum to PNP nozzle head **122**. A hollow tube (not shown) such as a vacuum hose is coupled to elbow coupler **1004**. Actuator **140**E comprises stepper motor **206**E and a lead screw **208**E in some embodiments. PNP nozzle head **122** slides along the Z-axis facilitated by actuator **140**E that is fixed to PNP base plate **222**. A PNP nozzle **1006** is coupled to elbow coupler **1004**

through a hollow shaft **1008**. Hollow shaft **1008** may facilitate providing vacuum suction on demand at PNP nozzle **1006**.

[0087] FIG. **11** is a simplified side view of PNP head **120** according to an example embodiment. A nut **404**B is attached to PNP base plate **222** on a side of PNP base plate **222** opposite to PNP nozzle head **122**. Nut **404**B enables PNP head **120** to slide along the X-axis on lead screw **208**B of actuator **140**B (see FIG. **9**). Sliders **402**G, **402**H (and corresponding other sliders not visible in the view shown) on the side of PNP base plate **222** opposite to PNP nozzle head **122** enable PNP head **120** to slide on rails **204**E and **204**F (see FIG. **9**).

[0088] PNP nozzle head **122** slides along the Z-axis facilitated by actuator **140**E that is fixed to PNP base plate **222**. Actuator **140**E comprises stepper motor **206**E coupled to lead screw **208**E. One end of lead screw **208**E is coupled to stepper motor **206**E and the other end is fixed to PNP base plate **222**. PNP nozzle head **122** is attached to nut **404**E that slides on lead screw **208**E, converting rotation of stepper motor **206**E and lead screw **208**E to sliding along the Z-axis. On the side of PNP base plate **222** proximate to PNP nozzle **1006**, rails **204**G (not visible) and **204**H enable PNP nozzle head **122** to move up and down along the Z-axis. Sliders **402**J (and corresponding other sliders not visible in the view shown) enable sliding of PNP nozzle head **122** on rails **204**G and **204**H.

[0089] Proximity sensor **406**E fixed to PNP base plate **222** allows detection of the position of PNP nozzle head **122** along the Z-axis. Note that in the figure, although it may appear that proximity sensor **406**E is attached to slider **402**J, such is not the case and is merely an artefact of the view shown. Proximity sensor **406**E is attached to another plate **1010** that is stationary relative to PNP base plate **222**. A limit positioning sensor (not shown) may also be included without departing from the scope of the embodiments. In some embodiments, the limit position (i.e., maximum travel) may be determined by sensors integrated with actuator **140**E; such sensors may identify the number of steps, turns and angles of partial turns or steps by stepper motor **206**E and compute the linear travel therefrom.

[0090] Actuator **140**F is fixed to PNP nozzle head **122** so that actuator **140**F slides with PNP nozzle head **122** along the Z-axis. Actuator **140**F enables PNP nozzle **1006** to rotate around the Z-axis. When PNP nozzle **1006** rotates, hollow shaft **1008** that is coupled to PNP nozzle **1006** also rotates. Hollow shaft **1008** passes through actuator **140**F, which is a hollow-shaft motor in the embodiment shown. In some other embodiments, hollow shaft **1008** and actuator **140**F may be independently connected to PNP nozzle head **122**; in such embodiments, actuator **140**F may be a theta-motor with a non-hollow shaft. In various embodiments, actuator **140**F may also include one or more sensors for determining the angle of rotation of PNP nozzle head **122** and controlling the rotation of the theta-motor based on the determination.

[0091] Support plate **1002** includes a cutout **1012** in which elbow coupler **1004** is positioned. Cutout **1012** prevents elbow coupler **1004** from rotating. Hollow shaft **1008** is connected to elbow coupler **1004**. Rotation of hollow shaft **1008** with PNP nozzle **1006** would cause elbow coupler **1004** also to rotate, which would lead to entanglement of the vacuum hose (not shown) connected to elbow coupler **1004**. However, cutout **1012** prevents such entangling by preventing elbow coupler **1004** from rotating when PNP nozzle **1006** rotates.

[0092] FIG. **12** is a simplified perspective bottom view of PNP head **120** according to an example embodiment. PNP nozzle head **122** comprises PNP nozzle **1006** and a vision head **1202** having a camera **1204** above one or more flash LED **1206**. Vision head **1202** is coupled to PNP nozzle head **122** so that it slides along the Z-axis along with PNP nozzle head **122**. Vision head **1202** is decoupled from PNP nozzle **1006** so that vision head **1202** does not rotate when PNP nozzle **1006** rotates around the Z-axis. Vision head **1202** is at an offset **1208** from PNP nozzle **1006** in the X-Y plane. In some embodiments, offset **1208** may be solely along the X-axis; in some other embodiments, offset **1208** may be solely along the Y-axis; in yet other embodiments, offset **1208** may be along both the X-axis and the Y-axis. Camera **1204** may be offset along the Z-axis from the tip of PNP nozzle **1006** as well. In some embodiments, camera **1204** may be replaced with other similarly sized cameras having different resolutions based on the range of sizes of semiconductor device **104** to be tested. Note that the illustration does not show plate **1010** in order to render rails **204**H visible.

[0093] In various embodiments, vision head **1202** is configured to recognize (e.g., distinguish, identify, etc.) semiconductor device **104** from its surroundings. Such recognizing may be by any suitable image processing algorithms beyond the scope of the present disclosure. During operation, vision head **1202** may be used to calibrate the motions of PNP subsystem **118**. In a particular embodiment, vision head **1202** is brought approximately close to the vicinity of active position **50** and is configured to identify semiconductor device **104** in tray **106**, including its alignment in tray **106**. One or more flash LED **1206** enables shining light on the field of vision of camera **1204** during such identification operations. Camera **1204** may determine any linear misalignment of semiconductor device **104** inside tray **106**. Since offset **1208** is known beforehand, after semiconductor device **104** is identified, PNP head **120** may be moved by offset **1208** and any linear misalignment identified by camera **1204** to bring PNP nozzle **1006** over center of semiconductor device **104** in tray **106**. Actuator **140**E is activated to move PNP nozzle head **122** down by the Z-offset to pick up semiconductor device **104** from tray **106**. Camera **1204** further enables determining any angular misalignment of semiconductor device **104** with respect to socket **108**. Actuator **140**F is activated to rotate PNP nozzle **1006** suitably so that the angular misalignment is removed between semiconductor device **104** and socket **108**.

[0094] Thereafter, PNP head **120** is moved approximately close to the vicinity of active position **156** and adjusted to align vision head **1202** over socket **108**. After active position **56** is identified, including the Z-offset (e.g., depth) of socket **108** from PNP nozzle head **122**, PNP head **120** is moved to place PNP nozzle head **122** over socket **108**. Actuator **140**E is activated to move PNP nozzle head **122** down by the appropriate distance determined by vision head **1202** previously to place semiconductor device **104** in socket **108** appropriately.

[0095] Thereafter, vision head **1202** is used to identify various sites for active position **154**. After testing is completed on semiconductor device **104**, the specific site of active position **154** is provided to handler **102** by tester **160**, for example, based on the sorting bin of semiconductor device **104** according to test results so that vision head **1202** is next moved approximately to the vicinity of active position **154**. After identifying the exact position in tray **106** to which semiconductor device **104** is to be returned, PNP nozzle head **122** is moved suitably to place semiconductor device **104** in tray **106** according to the test bin/sorting results. In various embodiments, vision head **1202** is used during setup operations, to determine distances to be traversed by PNP head **120** before semiconductor device **104** is tested. After setup operations are completed, and active positions **150-156** are identified, testing operations commence, during which time vision head **1202** is not used further unless necessary.

[0096] FIG. **13** is a simplified perspective view of handler **102** in an engineering configuration according to an example embodiment. A housing **1302** covers the mechanisms described in preceding FIGS. **1-12** within an enclosure **1304** that is provided with a plurality of windows for a human operator to see the operations. Additional enclosures **1304** are also provided in housing **1302**, for example, to accommodate thermal systems, vacuum systems, testing instruments, and other ancillary subsystems that enable suitable operation by handler **102**. Note that the configuration shown in the figure is merely an example and is not to be construed as a limitation. Various other configurations housing the mechanisms described herein are included within the broad scope of the embodiments herein.

[0097] In some embodiments, handler bottom plate **112** may rest on a shelf in enclosure **1304** of housing **1302**. The shelf may have an opening corresponding to test opening **144**. Printed circuit board **110** may be mounted underneath the shelf in test opening **144** so that socket **108** is exposed through test opening **144**. In some such embodiments, printed circuit board **110** may be screwed or otherwise fastened to the shelf suitably.

[0098] FIG. **14** is a simplified perspective view of handler **102** in a production configuration according to an example embodiment. A housing **1402** covers the mechanisms described in preceding FIGS. **1-12** within an enclosure **1404** that is provided with a plurality of windows for a human operator to see the operations. A space **1406** is provided underneath enclosure **1404** to accommodate tester **160**. Tester **160** docks to handler **102** in space **1406**. Printed circuit board **110** is attached to tester **160** mechanically and electrically. In the docked position, tester **160** is suitably aligned to expose printed circuit board **110** on tester **160** through test opening **144** of handler **102**. In some such embodiments, the docking enables mechanical and electrical coupling of tester **160** and handler **102**.

[0099] During production, a human operator (or robotic machine) may place one or more trays **106** from a conveyor belt into tray recess **142** within enclosure **1404**. Tester **160** may be docked in space **1406** during the duration of the production line operations. After testing is completed, and tester **160** is no longer needed, tester **160** may be de-docked from space **1406** suitably. Note that the configuration shown in the figure is merely an example and is not to be construed as a limitation. Various other configurations housing the mechanisms described herein are included within the broad scope of the embodiments herein.

[0100] FIG. **15** is a simplified block diagram illustrating control system **162** in system **100** according to an example embodiment. Control system **162** comprises a controller **1500** coupled in a wiring scheme **1502** to a plurality of RTUs **136**, for example, RTUs **136**A-**136**F. Each RTU **136**A-**136**F controls a separate one of actuator **140** in the embodiment shown. In other embodiments, one RTU **136** may control more than one actuator **140**. In the example embodiment shown, wiring scheme **1502** comprises two separate daisy chains **1502**A and **1502**B. In other embodiments, RTUs **136** may be connected to controller **1500** by wiring scheme **1502** comprising a single daisy chain. In yet other embodiments, RTUs **136** may be connected to controller **1500** by wiring scheme **1502** comprising a star configuration. The daisy chain may simplify wiring in handler **102** but may add additional complexity to the embedded control algorithms. The star configuration may be simple in terms of the embedded control algorithms but may present a challenge in wiring within handler **102**. The choice of wiring scheme **1502** used to connect RTUs **136** with controller **1500** may be based on various needs beyond the scope of the present disclosure. In yet other embodiments, the functionalities of all RTUs **136** may be included in controller **1500** with wiring scheme **1502** being internal to controller **1500** without departing from the scope of the disclosure.

[0101] Controller **1500** may include a processor **1504**, a memory **1506**, a sensor module **1508**, a feedback module **1510**, an instructions module **1512** and a MODBUS interface **1514** (among other components). Processor **1504** may execute any type of instructions associated with data stored in memory **1506** to achieve the operations detailed herein. In one example, processor **1504** may transform data from one state or thing to another state or thing. In another example, the activities outlined herein may be implemented with fixed logic or programmable logic (e.g., software/computer instructions executed by a processor) and the elements identified herein could be some type of a programmable processor, programmable digital logic (e.g., field programmable gate array (FPGA), an erasable programmable read only memory (EPROM), an application specific integrated circuit (ASIC)) that includes digital logic, software, code, electronic instructions, flash memory, optical disks, magnetic or optical cards, other types of machine-readable mediums suitable for storing electronic instructions, or any suitable combination thereof.

[0102] In some of example embodiments, memory **1506** may store data used for the operations described herein. This includes memory **1506** storing instructions (e.g., software, logic, code, etc.) in non-transitory media (e.g., random access memory (RAM), read only memory (ROM), FPGA, EPROM, etc.) such that the instructions are executed to carry out the activities described in this disclosure based on particular needs. In some embodiments, memory **1506** may comprise non-transitory computer-readable media, including one or more memory devices such as volatile memory such as dynamic RAM (DRAM), nonvolatile memory (e.g., ROM), flash memory, solid-state memory, and/or a hard drive. In some embodiments, memory **1506** may share a die with processor **1504**. Memory **1506** may include algorithms, code, software modules, and applications, which may be executed by processor **1504**. The data being tracked, sent, received, or stored in system **100** may be provided in any database, register, table, cache, queue, control list, or storage structure, based on particular needs and implementations, all of which could be referenced in any suitable timeframe.

[0103] The example network may be configured over a physical infrastructure that may include one or more networks and, further, may be configured in any form including, but not limited to, local area networks (LANs), wireless local area networks (WLANs), virtual local area networks (VLANs), metropolitan area networks (MANs), wide area networks (WANs), virtual private networks (VPNs), Intranet, Extranet, any other appropriate architecture or system, or any combination thereof that facilitates communications in a network. In some embodiments, a communication link may represent any electronic link supporting a LAN environment such as, for example, cable, Ethernet, wireless technologies (e.g., IEEE 802.11x), ATM, fiber optics, etc. or any suitable combination thereof. In other embodiments, communication links may represent a remote connection through any appropriate medium (e.g., digital subscriber lines (DSL), telephone lines, T1 lines, T3 lines, wireless, satellite, fiber optics, cable, Ethernet, etc. or any combination thereof) and/or through any additional networks such as a WANs (e.g., the Internet). To this end, each of controller **1500** and RTUs **136** may be configured with the appropriate communication interfaces and circuitry for the appropriate functionalities.

[0104] Sensor module **1508** may receive electrical signals from sensors in one or more actuator **140**, proximity sensor **406**, vision head **1202**, and other sensors in system **100**. In some embodiments, the electrical signals may be received directly from the sensors; in other embodiments, the electrical signals from the sensors may be routed through one or more RTUs **136**. The electrical signals may comprise current and/or voltage representing the position, speed and direction of rotating motor **206**, position of one or more nuts **404**, orientation and position of PNP nozzle **1006**, etc. For example, in some embodiments, motors **206** of actuators **140** may be equipped with sensors that detect the number of turns and angle of rotation of the motor; electrical signals from these sensors may be received at sensor module **1508**. Feedback module **1510** analyzes the received electrical signals and determines various courses of action, such as stop, move, rotate, etc. for actuators **140**. Instructions module **1512** may receive instructions from tester **160**, and/or generate instructions for RTUs **136** suitably based on the analysis results by feedback module **1510**.

[0105] MODBUS interface **1514** comprises circuitry to enable communication using MODBUS protocol. MODBUS protocol is a client/server data communications protocol in the application layer of the Open Systems Interconnection model (OSI model). MODBUS protocol uses serial communication lines, Ethernet, or Internet Protocol (IP) suite as a transport layer. MODBUS protocol supports communication to and from multiple devices connected to the same communication network. In embodiments herein, RTUs **136** are connected to the same communication network managed by controller **1500** over MODBUS interface **1514**. The various RTUs **136** comprise clients in the client/server paradigm, while controller **1500** functions as the server. MODBUS interface **1514** comprises the various communication layers, modules and circuitry to enable the MODBUS protocol. Note that MODBUS protocol is merely one example communication protocol that may be used in system **100**. Other communication protocols may also be used without departing from the scope of the embodiments. MODBUS interface **1514** may be modified according to the specific communication protocol used in the network.

[0106] Each one of RTUs **136** may comprise various components, including processor **1504**, memory **1506**, feedback module **1510**, and MODBUS interface **1514**. In addition, other components include a motor module **1516** and a travel module **1518**. Motor module **1516** may control all aspects of motors **206** to which the respective RTU **136** is coupled, including powering the motor, controlling its speed and acceleration, and identifying its base position. Travel module **1518** may determine the distance traveled as enabled by the motor's rotation, including counting the number of rotations of the motor, identifying the angle of partial rotation, etc. Note that RTUs **136** may each comprise modules similar to the other RTUs **136** in functionalities according to some embodiments. In other embodiments, RTUs **136** may comprise modules different from other RTUs in structure and functionalities. For example, RTUs **136** may be off-the-shelf, with some RTUs **136** by one manufacturer, and other RTUs **136** by other manufacturers. In some such embodiments, each module within any one RTU **136** may have a different electrical circuit structure compared to corresponding modules in other RTUs **136** without departing from the scope of the embodiments. Further, in some embodiments, some RTUs **136** may have more or less modules/components than other RTUs **136** in system **100** without departing from the scope of the embodiments.

[0107] In an example operation, sensor module **1508** receives electrical signals from proximity sensors **406**. Based on the electrical signals, feedback module **1510** determines that PNP subsystem **118** and TM subsystem **128** are at respective home positions **150** and **158** with all respective movable components (e.g., PNP head **120**, PNP nozzle head **122**, TM carriage **130**, and TM head **132**) at base positions. Thereafter, instructions module **1512** in controller **1500** receives instructions from tester **160** to commence testing. Instructions module **1512** in controller **1500** generates instructions to RTUs **136**A, **136**B, **136**E, and **136**F to move to active position **152**, pick up semiconductor device **104**, rotate semiconductor device **104** suitably, move to active position **156**, and place semiconductor device **104** in socket **108**.

[0108] The instructions to RTUs **136**A, **136**B, **136**E, and **136**F are sent over MODBUS interface **1514** in controller **1500** suitably and received at respective RTUs **136** over corresponding MODBUS interface **1514** in the individual RTUs **136**. Each RTU **136** may direct the respective actuator **140** under its control to carry out the received instructions. The movements of PNP subsystem **118** are monitored by the appropriate sensors in respective actuators **140**A, **140**B, **140**E, and **140**F and controlled independently by corresponding RTUs **136**A, **136**B, **136**E, and **136**F. Thereafter, instructions module **1512** in controller **1500** may direct PNP subsystem **118** to return to PNP home position **150**. Subsequently, instructions module **1512** in controller **1500** may generate corresponding instructions to RTUs **136**, which may activate respective actuators **140** and facilitate returning PNP subsystem **118** to PNP home position **150**. Similar operations may enable moving TM subsystem **128** between TM home position **158** and active position **156**, for example, by suitably activating actuators **140**C and **140**D by RTU **136**C and **136**D, respectively.

[0109] Note that the above example is merely one of many examples and is not to be construed as a limitation. Various other such operations to adjust positions of one or more components of handler **102** may be controlled by controller **1500** and various ones of RTUs **136** and all such operations are contemplated and included within the broad scope of the embodiments herein. Further control system **162** may comprise other modules, data, circuits, and components not illustrated in FIG. **15** for lack of relevancy to the explanation herein. Some such components not illustrated in FIG. **15** may be illustrated and described in other figures in this disclosure without departing from the scope of the embodiments.

[0110] FIG. **16** is a simplified top view of a tray template **1600** representative of tray **106** according to an example embodiment. Tray template **1600** is a virtual representation of tray **106**, or a type of tray **106**. Note that tray **106** shown and illustrated is merely as containing a plurality of receptacles for one or more of semiconductor device **104** and is not to be construed as a limitation. Any suitable configuration for holding semiconductor device **104** may be mapped to tray template **1600** in system **100** without departing from the scope of the various embodiments. In the example shown, tray **106** is a waffle JEDEC tray configured to place several semiconductor devices **104** in a matrix arrangement, i.e., in rows and columns. The intersections of rows and columns represent receptacles to hold semiconductor device **104**. In other words, a specific receptacle in template **1600** may be represented by the intersection of a specific row and a specific column. In some embodiments, each receptacle is represented by its respective center points, shown as crosses in the illustration. Each such center point thus represents a possible location for semiconductor device **104**.

[0111] In some other embodiments, one or more coordinates may represent a specific location in tray template **1600**. In some such embodiments, the coordinates may be rows and columns; in other such embodiments, the coordinates may be X-coordinates and Y-coordinates, measured from an origin (e.g., represented by a corner of tray template **1600**). According to various embodiments, controller **1500** may classify subsets of the rows and columns into different zones **1602**. In some such embodiments, tray **106** may be mapped into tray template **1600** as one or more zones **1602**, for example, **1602**A, **1602**B, and **1602**C. Each zone **1602** may be identified as having a specific number of center points (i.e., receptacles) or rows and columns. In various embodiments, zones **1602** may be mutually exclusive and may not overlap.

[0112] In some embodiments, semiconductor device **104** may be represented as a device template **1610** (shown with continuous lines) having a specified boundary of known dimensions, leads, etc. Device template **1610** is a virtual representation of semiconductor device **104**, or a type of semiconductor device **104**. For example, the package type, the number of leads, thickness, length and width, and other salient characteristics of semiconductor device **104** may be represented by device template **1610** suitably. In some embodiments, separate templates may be generated to represent tray **106** with semiconductor device **104** therein, and tray **106** without semiconductor device **104** therein. In the illustration, template **1610** is shows as filling completely the receptacle it is in; however, in some cases, semiconductor device **104** may be smaller than its respective receptacle and may only partially fill the space thereof. As a consequence, the center point representing the receptacle may not coincide with the center point of semiconductor device **104** in a physical embodiment. Nevertheless, the center point of a particular receptacle may be closer to the center point of semiconductor device **104** therein than to the center points of other semiconductor devices **104** in adjacent receptacles.

[0113] Each center point of semiconductor device **104** may represent one of active positions **152** or **154**. In some embodiments, active positions **152** and **154** may be in separate zones **1602** in common tray template **1600**; for example, active position **152** may be in zone **1602**A and active position **154** may be in zone **1602**B. In some other embodiments, active positions **152** and **154** may be in the same zone **1602**. In yet other embodiments, active position **152** and **154** may be the same (i.e., semiconductor device **104** is returned to the same receptacle after testing). In some embodiments, there may be only a single zone **1602** (i.e., the entire tray may be represented as single zone **1602**).

[0114] In some embodiments, during operation, vision head **1202** may be used to initialize the actual tray position, for example, by identifying two salient locations, such as top right corner **1604** and bottom left corner **1606** of tray **106**. Having identified these two salient points, tray template **1600** may be positioned between them so as to represent the actual position of tray **106** virtually in controller **1500**. Any active position **152** (i.e., center of semiconductor device **104** of interest) may be approximately represented by the closest center point of the corresponding receptacle as identified by a specific row and specific column.

[0115] Mapping of tray **106** to tray template **1600** may be a manual process in some embodiments, with the mapping operations performed when handler **102** is deployed in system **100** or configured at the factory before any engineering or production run. In some embodiments, mapping may be performed automatically by image processing algorithms. For example, tray **106** may be placed in tray recess **142** and vision head **1202** positioned over tray **106**. Camera **1204** may take a photo of tray **106** and identify the length, width, corners, etc. as needed to generate tray template **1600**. Suitable image processing algorithms may be executed to identify various edges and boundaries, for example, to determine the various center points of each receptacle in a waffle type tray. In some embodiments, the image may be cropped suitably to generate tray template **1600**. The same image may be used to generate device template **1610** in cases where tray **106** has one or more semiconductor device **104** placed therein. Multiple images may be taken of tray **106** and a subset of them used to validate against another subset, for example, in a train/test mode.

[0116] One or more tray templates **1600** may represent the same type of tray **106**, for example, to account for variations in dimensions between different samples of tray **106**. Likewise, one or more device templates **1610** may represent the same type of semiconductor device **104**, for example, to account for variations in dimensions between different samples of semiconductor device **104**. Each such tray template **1600** and device template **1610** may be stored in system **100**, for example, in controller **1500**.

[0117] FIG. **17** is a simplified top view of a socket template **1700** representative of socket **108** according to an example embodiment. Socket template **1700** is a virtual representation of socket **108**, or a type of socket **108**. Note that socket **108** shown and illustrated is merely as an example of a receptacle for semiconductor device **104** and is not to be construed as a limitation. Any suitable receptacle for semiconductor device **104** may be mapped to socket template **1700** in system **100** without departing from the scope of the various embodiments. In the example shown, socket **108** is a double sited socket configured to receive two semiconductor devices **104**. According to various embodiments, controller **1500** may map socket **108** into socket template **1700** as one or more sites **1702**, for example, **1702**A and **1702**B corresponding to the sites in socket **108**. Each site **1702** may be identified by its boundaries (shown in continuous line) and as having a center point (shown as a cross). The boundaries and center point may provide the geometry and alignment information needed to accurately identify active position **156**. In some embodiments, during operation, vision head **1202** may be used to initialize the actual socket position, for example, by identifying two salient locations, such as top right corner **1704** and bottom left corner **1706** of the receptacle in socket **108**. Having identified these two salient points, socket template **1700** may be positioned between them so as to represent the actual position of socket **108** in system **100**.

[0118] Mapping of socket **108** to socket template **1700** may be a manual process in some embodiments, with the mapping operations performed when handler **102** is deployed in system **100** or configured at the factory before any engineering or production run. One or more socket template **1700** may represent the same type of socket **108**, for example, to account for variations in dimensions between different samples of socket **108**. Each such socket template **1700** may be stored in system **100**, for example, in controller **1500**.

[0119] FIG. **18** is a simplified block diagram illustrating example operations to generate tray template **1600**, device template **1610**, and/or socket template **1700** according to an example embodiment. PNP head **120** may be positioned above tray **106** (or socket **108**). Initially, vision head **1202** may verify placement of tray **106** (or socket **108**), after which PNP nozzle head **122** may be moved thereto. PNP nozzle head **122** may be moved down by depth **1802** until PNP nozzle **1006** touches bottom of tray **106** (or socket **108**) and another depth **1804** until PNP nozzle **1006** touches top of semiconductor device **104**. Depths **1802** and **1804** may be converted to rotations of relevant actuators **140**E that controls the Z-motion of PNP nozzle head **122**. Depths **1802** and **1804** may be stored suitably as part of tray template **1600**, device template **1610**, and socket template **1700**, for example, in controller **1500** of control system **162**.

[0120] In many embodiments, depths **1802** and **1804** may be determined during setup of handler **102** to prevent PNP nozzle **1006** from moving too much along the Z-axis and hitting the bottom of tray **106** (or socket **108**) or the top of semiconductor device **104**. In some embodiments, PNP nozzle **1006** may not touch the surfaces of tray **106** (or socket **108**) or semiconductor device **104** but may be brought close enough that vacuum suction is sufficient to pick up semiconductor device **104** from tray **106** (or socket **108**). During operation, the distance traversed by PNP nozzle head **122** along the Z-axis may be determined in reference to depths **1802** and **1804**.

[0121] FIGS. **19**A and **19**B are simplified schematic diagrams illustrating example operations to identify semiconductor device **104** in tray **106** and determine paths **124** and **126** of PNP subsystem **118** using vision head **1202**. As shown in FIG. **19**A, in various embodiments, vision head **1202** may identify active position **152**, for example, as X, Y, Z co-ordinates (X_a, Y_a, Z_a) in the X-Y-Z orthogonal space. In some embodiments, (X_a, Y_a, Z_a) may represent the respective travel along the X-axis of PNP head **120**, along the Y-axis of PNP carriage **220**, and along the Z-axis of PNP nozzle head **122** from their respective base configuration and PNP home position **150**. (X_a, Y_a, Z_a) may be stored as part of tray template **1600** in some embodiments, for example, in controller **1500**.

[0122] In various embodiments, vision head **1202** may traverse PNP path **124** to reach active position **156**, and identify active position **156** by X, Y, Z co-ordinates (X_b, Y_b, Z_b) in the X-Y-Z orthogonal space. In some embodiments, (X_b, Y_b, Z_b) may represent the respective travel along the X-axis of PNP head **120**, along the Y-axis of PNP carriage **220**, and along the Z-axis of PNP nozzle head **122** from their respective base configuration and PNP home position **150**. X-travel **1902** between active positions **152** and **156** may be calculated as X_b-X_a; Y-travel **1904** between active positions **152** and **156** may be calculated as Y_b-Y_a; and Z-travel (not labeled) between active positions **152** and **156** may be calculated as Z_b-Z_a. (X_b, Y_b, Z_b) and/or the various other distances may be stored as part of tray template **1600** in some embodiments, for example, in controller **1500**.

[0123] In various embodiments, vision head **1202** may traverse PNP path **126** from active position **156** to reach active position **154**, and identify active position **156** by X, Y, Z co-ordinates (X_c, Y_c, Z_c) in the X-Y-Z orthogonal space. In some embodiments, (X_c, Y_c, Z_c) may represent the respective travel along the X-axis of PNP head **120**, along the Y-axis of PNP carriage **220**, and along the Z-axis of PNP nozzle head **122** from their respective base configuration and PNP home position **150**. X-travel **1906** between active positions **156** and **154** may be calculated as X_c-X_b; Y-travel **1908** between active positions **156** and **154** may be calculated as Y_c-Y_b; and Z-travel (not labeled) between active positions **156** and **154** may be calculated as Z_c-Z_b. (X_c, Y_c, Z_c) and/or the various other distances may be stored as part of tray template **1600** in some embodiments, for example, in controller **1500**.

[0124] During operation, vision head **1202** may identify misalignment of semiconductor device **104** in tray **106**. Misalignment may include angular misalignment **1910** by which semiconductor device **104** is rotated in tray **106**. Misalignment may also include linear misalignment **1912** along X-axis and/or Y-axis from the center of the respective receptacle in tray **106**. Misalignments, including angular misalignment **1910** and linear misalignment **1912** may be detected by vision head **1202** as described in FIG. **19**B and using suitable edge detection algorithms beyond the scope of the present disclosure. PNP nozzle head **122** may be adjusted suitably to remove the misalignment, for example, PNP nozzle head **122** may be moved along the X-axis or Y-axis, as the case may be, to center on semiconductor device **104** before semiconductor device **104** is picked up and rotated by an to offset angular misalignment **1910** after semiconductor device **104** is picked up.

[0125] FIG. **19**B is a simplified diagram schematically illustrating a top view of a field of view **1920** of camera **1204**. Center **1922** of field of view **1920** is where crosshairs **1924** of camera **1204** intersect. During operation, vision head **1202** may be moved so that center **1922** is approximately close to active position **152**, corresponding to the center of semiconductor device **104**. The exact location of semiconductor device **104** may not be known apriori, because semiconductor device **104** may have moved inside its receptacle in tray **106** by the time tray **106** is loaded into handler **102**. In many situations, semiconductor device **104** is much smaller than the receptacle of tray **106** that holds it, and semiconductor device **104** in any one receptacle may not be in the exact same location or orientation as any other semiconductor device **104** in other receptacles in tray **106**. Thus, at the outset, only the approximate location of active position **152** may be known as being somewhere in the vicinity of the center of the receptacle of tray **106** holding semiconductor device **104**.

[0126] The center of the receptacle of tray **106** may be initially identified by its (row, column) co-ordinates in tray template **1600**. Center **1922** of camera **1204** may be moved approximately close to, but need not be exactly at, the center of the receptacle which holds semiconductor device **104** to be picked up; further, center **1922** may be approximately close to, but need not be exactly aligned with, center of actual semiconductor device **104**. After vision head **1202** comes to a halt in the vicinity of active position **152** over the specific receptacle of interest, camera **1204** captures an image of field of view **1920**. The captured image is compared with device template **1610** corresponding to semiconductor device **104**. The comparison may be performed using any suitable image processing algorithm beyond the scope of the present disclosure. In the image, a shape having closest match with device template **1610** and closest to center **1922** may be identified as semiconductor device **104** to be picked up. Comparison with device template **1610** may also enable identifying any angular misalignment **1910** and linear misalignment **1912**.

[0127] Use of camera **1204** for identifying semiconductor device **104**, including its misalignment, in tray **106** enables operations without using a precisor. As described previously, the precisor is a gravity fed precisely machined receptacle that can hold semiconductor device **104** in a predetermined orientation. In systems that do not use vision head **1202** to identify semiconductor device **104**, the nozzle may approach a location approximately close to semiconductor device **104**, not necessarily at its center, and then picks it up. Such pick-up operation may result in semiconductor device **104** being picked up off-center, for example, by its corner. In such systems, the next operation is to drop semiconductor device **104** in the precisor. The precisor reorients semiconductor device **104** to a predetermined orientation by force of gravity. Thereafter, the location and orientation of semiconductor device **104** is precisely known and the nozzle can again pick up semiconductor device **104** from the precisor without additional alignment operations. However, the precisor is not only cumbersome to add to the equipment, but it also increases the overall cost due to its precise manufacturing requirements and it adds additional steps to the pick-and-place operations. Further, a separate precisor is needed for every different type of semiconductor device **104** to be tested. Embodiments of system **100**, on the other hand, use vision head **1202**, including camera **1204** along with prestored templates **1600** and **1610** to identify semiconductor device **104** precisely avoiding the use of any precisor.

[0128] FIG. **20** is a simplified block diagram illustration calibration operations **2000** associated with converting pixel information of camera **1204** to distance information (e.g., in millimeters) according to an example embodiment. A calibrated optical marker **2002** may be placed under camera **1204**. Calibrated optical marker **2002** may have precisely measured optical shapes. Camera **1204** may take an image of optical marker **2002**. The precisely measured optical shapes may be correlated with the pixel information of the image captured by camera **1204** by pixel to mm converter **2004**. In other words, pixel to mm converter **2004** converts pixels in the captured image to linear dimensions (e.g., in mm). The conversion information may be stored suitably, for example, in controller **1500**.

[0129] FIG. **21** is a simplified block diagram illustration calibration operations **2100** associated with converting rotation information of actuators **140** to distance information (e.g., in millimeters) according to an example embodiment. A calibration plate **2102** may be placed under PNP head **120**. Calibration plate **2102** may have markers at precisely measured locations **2104**A and **2104**B. In various embodiments, location **2104**A may be suitably identified by camera **1204** by moving PNP head **120** such that camera **1204** is directly over location **2104**A. Thereafter, PNP nozzle head **122** may be moved to location **2104**A. The distance traveled by PNP nozzle head **122** to reach the same location as camera **1204** represents offset **1208**. Thereafter, PNP head **120** may be moved to location **2104**B and the distances traveled **2106** and **2108** along the X-axis and the Y-axis respectively by PNP nozzle head **122** between locations **2104**A and **2104**B may be corresponded with the rotations of respective actuators **140** (e.g., **140**A, **140**B) by rotation to mm converter **2110**. In other words, rotation to mm converter **2110** converts rotations of the actuator to linear dimensions (e.g., distance traveled in mm). The conversion information may be stored suitably, for example, in controller **1500**.

[0130] FIG. **22** is a simplified block diagram illustrating example details of a template module **2200** of controller **1500** in control system **162** according to an example embodiment. In some embodiments, template module **2200** may be provisioned in feedback module **1510**. In other embodiments, template module **2200** may be stored in memory **1506** suitably and accessed by other modules, for example feedback module **1510**. In yet other embodiments, template module **2200** may be distributed across various components of control system **162**.

[0131] Template module **2200** may comprise various templates **1600**, **1610**, and **1700**; paths **124**, **126**, depths **1802**, **1804**, offset **1208**, test recipes **2202**, TM paths **2204**, pixel-mm conversions **2206**, and rotation-mm conversions **2208** from various calibration and setup operations. Each tray template **1600**, device template **1610** and socket template **1700** may include a plurality of corresponding templates of tray **106**, semiconductor device **104**, and socket **108**, respectively. Likewise, each PNP path **124** may correspond to different paths between various ones of active positions **152**, for example, corresponding to the different centers of a waffle tray configured to receive a plurality of semiconductor device **104** and different sites on socket **108**. Likewise, each PNP path **126** may correspond to different paths between various ones of active positions **154**, for example, corresponding to the different centers of a waffle tray configured to receive a plurality of semiconductor device **104** and different sites on socket **108**.

[0132] Test recipe **2202** may include various test settings commonly used for testing. Test recipe **2202** may include, as examples and not as limitations, temperature settings and soak times. In some embodiments, a few such test recipes **2202** may be stored during configuration of handler **102** and others may be manually input by an operator prior to testing. In some other embodiments, all test recipes **2202** may be manually input by an operator prior to testing. In yet other embodiments, tester **160** may provide test recipe **2202** to handler **102** prior to testing. Each TM path **2204** may correspond to different paths between various ones of active positions **156**, for example, corresponding to the different sites on socket **108**, and TM home position **158** of TM subsystem **128**. Pixel-mm conversions **2206** may include information for different ones of camera **1204** preconfigured in handler **102**. Rotation-mm conversions **2208** may include information for each of actuators **140**A-**140**F.

[0133] Feedback module **1510** may be provisioned with a comparator **2210**. Comparator **2210** may use information from template module **2200** to compute and identify various elements such as dimensions, positions, distances, boundaries, etc. For example, comparator **2210** may compare images captured by camera **1204** with tray template **1600**, and device template **1610** in template module **2200** to identify the center of semiconductor device **104** in tray **106**, and angular misalignment **1910** and linear misalignment **1912** of semiconductor device **104**. The comparison may be performed using any suitable image processing algorithms beyond the scope of the present disclosure. Other functions of comparator **2210** include template matching, distance computation, path identification, rotation angles, actuator turns, etc.

[0134] FIG. **23** is a simplified flow diagram illustrating example configuration operations **2300** that may be associated with some embodiments of system **100**. At **2302**, camera **1204** may be calibrated suitably as described in reference to FIG. **20**, and the pixel-mm conversions **2206** may be stored suitably in system **100**. At **2304**, actuators **140** may be calibrated suitably as described in reference to FIG. **21**, and the rotation-mm conversions **2208** may be stored suitably in system **100**. At **2306**, one or more of tray template **1600**, device template **1610**, and socket template **1700** may be suitably generated as described in reference to FIGS. **16**, **17** and **18**, and stored appropriately. At **2308**, the test recipe for testing semiconductor device **104** may be generated, for example, by entering the temperature and soak times for testing. At **2310**, PNP paths **124** and **126** may be generated, for example, as described in reference to FIG. **19**A, and stored appropriately. At **2312**, TM paths **2204** may be generated substantially similarly to generating PNP paths **124** and **126**, except using TM subsystem **128** and actuators **140** thereof. Generated TM paths **2204** may be stored suitably in system **100**.

[0135] FIG. **24** is a simplified flow diagram illustrating example pickup operations **2400** that may be associated with some embodiments of system **100**. At **2402**, PNP nozzle head **122** may be moved to align camera **1204** over approximate location of semiconductor device **104**. At **2404**, an image of field of view **1920** may be captured by vision head **1202**. At **2406**, the captured image may be compared with stored template(s) **1610** of semiconductor device **104**. The center of semiconductor device **104** and any angular misalignment **1910** may be identified from the comparison at **2408**. At **2410**, PNP nozzle head **122** may be moved to align PNP nozzle **1006** with the center of semiconductor device **104** (e.g., moved by linear misalignment **1912** and offset **1208** between camera **1204** and PNP nozzle **1006**). PNP nozzle head **122** may be lowered along the Z-axis until PNP nozzle **1006** is almost touching (or touching) the surface of semiconductor device **104**. Vacuum may be activated to pick up semiconductor device **104**. At **2412**, PNP nozzle **1006** may be rotated to offset any angular misalignment **1910**.

[0136] FIG. **25** is a simplified flow diagram illustrating example handling operations **2500** that may be associated with some embodiments of system **100**. At **2502**, handler **102** may receive instructions from tester **160** to start operations. At **2504**, PNP subsystem **118** may be moved appropriately to the vicinity of semiconductor device **104** in tray **106**. At **2506**, a determination may be made whether there is misalignment of semiconductor device **104** with respect to socket **108**. If misalignment is detected, at **2508**, PNP nozzle head **122** may be adjusted by appropriate movements to offset any angular misalignment **1910** and linear misalignment **1912** to align semiconductor device **104** suitably. At **2510**, semiconductor device **104** may be picked up from tray **106** and placed in socket **108**. At **2512**, PNP subsystem **118** is moved away from socket **108**. At **2514**, TM subsystem **128** is moved to vicinity of socket **108**. At **2516**, a determination may be made whether temperature testing is to be conducted. In some embodiments, the determination comprises looking up appropriate test recipe **2202**. If temperature testing is to be conducted, at **2518**, semiconductor device **104** is soaked at the specified temperature (e.g., hot or cold) per test recipe **2202**. If no temperature testing is to be performed, the operations may step from **2516** to **2520** directly. At **2520**, tester **160** may be informed that semiconductor device **104** is ready and testing may commence. At **2522**, tester **160** may complete testing and handler **102** may receive instructions from tester **160** that testing is completed. At **2524**, TM subsystem **128** is moved away from socket **108**. At **2526**, semiconductor device **104** is picked up from socket **108** by PNP subsystem **118**. At **2528**, semiconductor device **104** is placed in tray **106** according to the sort/bin criteria provided by tester **160**.

[0137] Although the present disclosure has been described in detail with reference to particular arrangements and configurations, these example configurations and arrangements may be changed significantly without departing from the scope of the present disclosure. For example, although the present disclosure has been described with reference to particular types of components, handler **102** may be implemented using other components that perform substantially the same functions in similar ways. For example, servo motors **206** may be replaced with stepper motors and vice versa; rails may be replaced with wheels and grooves; etc. Moreover, although system **100** has been illustrated with reference to particular elements and operations that facilitate various control system process, these elements, and operations may be replaced by any suitable architecture or process that achieves the intended functionality of system **100**.

[0138] In various embodiments, the operations described in FIGS. **19-25** are performed automatically without human intervention. Although FIGS. **19-25** illustrate various operations performed in a particular order, this is simply illustrative, and the operations discussed herein may be reordered and/or repeated as suitable. Further, additional operations which are not illustrated may also be performed without departing from the scope of the present disclosure. Also, various ones of the operations discussed herein with respect to FIGS. **19-25** may be modified in accordance with the present disclosure to facilitate operations of handler **102** in system **100** as disclosed herein. Although various operations are illustrated in FIGS. **23-25** once each, the operations may be repeated as often as desired.

[0139] It is important to note that the operations described with reference to the preceding figures illustrate only some of the possible scenarios that may be executed by, or within, system **100**. Some of these operations may be deleted or removed where appropriate, or these steps may be modified or changed considerably without departing from the scope of the discussed concepts. In addition, the timing of these operations may be altered considerably and still achieve the results taught in this disclosure. The preceding operational flows have been offered for purposes of example and discussion.

SELECT EXAMPLES

[0140] Example 1 provides a system, comprising: a first plate in a plane of an X-axis and a Y-axis, the X-axis and the Y-axis being mutually orthogonal; a second plate parallel to and offset from the first plate along a Z-axis, the Z-axis being mutually orthogonal to the X-axis and the Y-axis; a first subsystem slidably coupled to the first plate, the first subsystem comprising a pick-and-place (PNP) carriage to slide along the Y-axis, the PNP carriage comprising a PNP head to slide along the X-axis, the PNP head comprising a PNP nozzle head to slide along the Z-axis; and a second subsystem slidably coupled to the second plate, the second subsystem comprising a thermo-mechanical (TM) carriage to slide along the X-axis and a TM head slidably coupled to the carriage to slide along the Z-axis, wherein: the PNP nozzle head includes a PNP nozzle to pick a semiconductor device from a first location and place the semiconductor device at a second location on a printed circuit board, and the TM head is to facilitate exertion of a predetermined pressure on the semiconductor device at the second location.

[0141] Example 2 provides the system of example 1, wherein the first plate comprises: at least one recess for a tray configured for placing semiconductor devices; and an opening for the printed circuit board.

[0142] Example 3 provides the system of example 2, wherein the tray is a matrix tray having dimensions approximately according to JEDEC standards.

[0143] Example 4 provides the system of any of examples 1-3, wherein: the printed circuit board has a first side and an opposing second side, the first side is exposed to the PNP head and the TM head, and the second side is exposed to a tester.

[0144] Example 5 provides the system of any of examples 1-4, further comprising: separate sets of rails affixed to the first plate to facilitate sliding of the first subsystem along the X-axis and the Y-axis; and another set of rails affixed to the second plate to facilitate sliding of the second subsystem along the X-axis.

[0145] Example 6 provides the system of any of examples 1-5, wherein: the first subsystem is to slide between a home position and a plurality of active positions, and the plurality of active positions of the first subsystem comprises at least: a first active position proximate to the first location; a second active position proximate to the second location; and a third active position proximate to a third location.

[0146] Example 7 provides the system of example 6, wherein: the first location is proximate to a first zone in a tray, the second location is proximate to a socket in the printed circuit board, and the third location is proximate to a second zone in the tray or another tray.

[0147] Example 8 provides the system of example 7, wherein: the socket comprises a plurality of sites for a corresponding plurality of semiconductor dies, and the second location is one of the plurality of sites.

[0148] Example 9 provides the system of any of examples 6-8, wherein: the PNP head further comprises a vision head at a fixed offset from the PNP nozzle head, and the vision head is to identify the plurality of active positions of the first subsystem.

[0149] Example 10 provides the system of example 9, wherein the vision head comprises an optical camera.

[0150] Example 11 provides the system of any of examples 1-10, wherein the second subsystem is to slide between a home position and an active position.

[0151] Example 12 provides the system of example 11, wherein the home position and the active position are identified by a proximity sensor.

[0152] Example 13 provides the system of any of examples 11-12, wherein the active position of the second subsystem is proximate to the second location.

[0153] Example 14 provides the system of any of examples 11-13, wherein the second subsystem is at the home position when the first subsystem is at the second location.

[0154] Example 15 provides the system of any of examples 1-14, wherein a top of the first subsystem is between the second plate and the first plate along the Z-axis.

[0155] Example 16 provides the system of any of examples 1-15, wherein the first subsystem and the second subsystem are not simultaneously at the second location during operation of the system.

[0156] Example 17 provides the system of any of examples 1-16, wherein the TM carriage comprises: a TM carriage first plate including a plurality of sliders to facilitate sliding on rails, the rails being attached to the second plate of the system; and a TM carriage second plate parallel to and coupled at a fixed offset from the TM carriage first plate along the Z-axis.

[0157] Example 18 provides the system of example 17, wherein the TM head comprises: a TM head first plate between the TM carriage first plate and the TM carriage second plate; a TM head second plate parallel to and coupled at a fixed offset from the TM first plate, the TM head second plate positioned between the TM carriage second plate and the first plate of the system, the TM head second plate having a first side proximate to the TM head first plate and an opposing second side proximate to the first plate of the system; and a casing coupled by spring-loaded fasteners to the second side of the TM head second plate, wherein: the TM head first plate is to slide along the Z-axis, the casing is to envelope the semiconductor device on the printed circuit board, and the spring-loaded fasteners are to enable the casing to maintain contact on the printed circuit board.

[0158] Example 19 provides the system of example 18, wherein the second subsystem further includes a fixture removably coupled to the TM head second plate by spring-loaded fasteners, wherein the fixture is to exert the predetermined pressure on the semiconductor device.

[0159] Example 20 provides the system of any of examples 1-19, wherein the predetermined pressure is sufficient to enable electrical connectivity between the semiconductor device and the printed circuit board.

[0160] Example 21 provides the system of any of examples 1-18 or 20, wherein: the TM head is further to facilitate heat transfer to the semiconductor device at the second location, the second subsystem further comprises a fixture to facilitate the heat transfer, the fixture is to further exert the predetermined pressure on the semiconductor device, and the fixture is mounted to the TM head by spring-loaded fasteners.

[0161] Example 22 provides the system of any of examples 1-21, further comprising a pair of third plates in a plane of the Z-axis and the X-axis, the third plates directly coupled to the first plate and the second plate.

[0162] Example 23 provides the system of any of examples 1-22, further comprising: a first actuator to slide the PNP carriage along the Y-axis; a second actuator to slide the PNP head along the X-axis; a third actuator to slide the PNP nozzle head along the Z-axis; a fourth actuator to rotate the PNP nozzle around the Z-axis; a fifth actuator to slide the TM carriage along the X-axis; and a sixth actuator to slide the TM head along the Z-axis.

[0163] Example 24 provides the system of example 23, wherein: the first actuator comprises a first servo motor coupled with a Y-axis lead screw fixed to the first plate, the second actuator comprises a second servo motor coupled with an X-axis lead screw fixed to the PNP carriage, the third actuator comprises a stepper motor coupled with a Z-axis lead screw fixed to PNP head, the fourth actuator comprises a theta-motor mounted to the PNP nozzle head, the fifth actuator comprises a third servo motor coupled with another X-axis lead screw fixed to the second plate, and the sixth actuator comprise a fourth servo motor coupled with another Z-axis lead screw fixed to the TM carriage.

[0164] Example 25 provides the system of example 24, wherein each of the first actuator, the second actuator, the third actuator, the fourth actuator, the fifth actuator and the sixth actuator is separately controlled by a corresponding remote terminal unit.

[0165] Example 26 provides the system of example 25, wherein: the remote terminal units are controlled by a central controller, and the remote terminal units are coupled together in a daisy chain to the central controller.

[0166] Example 27 provides the system of example 26, wherein: the daisy chain comprises a plurality of daisy chains, the daisy chains in the plurality of daisy chains are independently and separately coupled with the central controller, and different subsets of the remote terminal units are coupled together to different ones in the plurality of daisy chains.

[0167] Example 28 provides the system of any of examples 1-27, further comprising a housing enclosing the first plate, the second plate, the first subsystem and the second subsystem.

[0168] Example 29 provides the system of example 28, wherein the housing is configured to dock with a tester on which the printed circuit board is mounted.

[0169] Example 30 provides the system of any of examples 28-29, wherein the housing facilitates coupling the printed circuit board to the first plate.

[0170] Example 31 provides an apparatus, comprising: a frame having a bottom plate and a top plate in a three-dimensional space of mutually orthogonal X-axis, Y-axis and Z-axis, the top plate offset from the bottom plate along the Z-axis; a thermo-mechanical (TM) subsystem slidably coupled to the top plate, the TM subsystem comprising: a TM carriage to slide along the X-axis; and a TM head to slide on the carriage along the Z-axis, the TM head configured to position a fixture to exert pressure on a semiconductor device in a socket of a printed circuit board; and a pick-and-place (PNP) subsystem slidably coupled to the bottom plate, the PNP subsystem comprising: a PNP carriage to slide along the Y-axis; a PNP head to slide on the PNP carriage along the X-axis; and a PNP nozzle head to slide on the PNP head along the Z-axis, the PNP nozzle head comprising: a PNP nozzle to rotate around the Z-axis and to removably couple to the semiconductor device; and a vision head to recognize the semiconductor device from surroundings of the semiconductor device.

[0171] Example 32 provides the apparatus of example 31, wherein the PNP head comprises: a hollow shaft coupled to the PNP nozzle, the hollow shaft to provide vacuum at the PNP nozzle, the hollow shaft coupled to an elbow coupler; and a support plate having a cutout in which the elbow coupler is positioned.

[0172] Example 33 provides the apparatus of any of examples 31-32, wherein: the PNP head comprises a PNP base plate slidably mounted on rails fixed to the PNP carriage, and the PNP nozzle head slides along the Z-axis on rails fixed to the PNP base plate.

[0173] Example 34 provides the apparatus of any of examples 31-33, wherein the TM head slides along the Z-axis on pillars fixed to the TM carriage.

[0174] Example 35 provides the apparatus of any of examples 31-34, wherein: the TM carriage slides along the X-axis on rails fixed to the top plate, and the PNP carriage slides along the Y-axis on rails fixed to the bottom plate.

[0175] Example 36 provides the apparatus of any of examples 31-35, wherein the fixture is further to heat or cool the semiconductor device in the socket.

[0176] Example 37 provides the apparatus of any of examples 31-36, wherein: the apparatus is electrically coupled to a control system to control movements of the PNP carriage, the PNP head, the PNP nozzle head, the TM carriage, and the TM head, and the control system comprises: a plurality of actuators to control movements of the PNP carriage, the PNP head, the PNP nozzle head, the TM carriage, and the TM head separately, a plurality of remote terminal units (RTUs) controlling corresponding ones in the plurality of actuators; and a controller communicable with the plurality of RTUs on a MODBUS interface.

[0177] Example 38 provides the apparatus of example 37, wherein the plurality of RTUs is electrically coupled to the controlled in a daisy chain.

[0178] Example 39 provides the apparatus of any of examples 37-38, wherein the plurality of actuators comprises: a first actuator to control sliding of the PNP carriage along the Y-axis; a second actuator to control sliding of the PNP head on the PNP carriage along the X-axis; a third actuator to control sliding of the TM carriage on the top plate along the X-axis; a fourth actuator to control sliding of the TM head on the TM carriage along the Z-axis; a fifth actuator to control sliding of the PNP nozzle head on the PNP head along the Z-axis; and a sixth actuator to control rotation of the PNP nozzle head around the Z-axis.

[0179] Example 40 provides the apparatus of any of examples 37-39, wherein: the plurality of actuators comprises a first subset, a second subset, and a third subset, each actuator in the first subset comprises a servo motor coupled to a lead screw, the lead screw coupled to a nut that converts rotation of the lead screw to translation along the lead screw, each actuator in the second subset comprises a stepper motor coupled to a lead screw, the lead screw coupled to a nut that converts rotation of the lead screw to translation along the lead screw, and each actuator in the third subset comprises a hollow-shaft theta motor.

[0180] Example 41 provides a system, comprising: a handler configured to: (i) pick up a semiconductor device from a tray, (ii) place the semiconductor device in a socket of a printed circuit board, (iii) exert a predetermined pressure on the semiconductor device in the socket, and (iv) return the semiconductor device to the tray; a tester configured to test the semiconductor device in the socket; and a control system configured to: (i) automate operations of the handler, and (ii) coordinate between the handler and the tester, wherein: the handler comprises a pick-and-place (PNP) subsystem and a thermo-mechanical (TM) subsystem, the PNP subsystem and the TM subsystem are to move independent of each other on separate rails, the PNP subsystem is to (i) pick up a semiconductor device from the tray, (ii) place the semiconductor device in the socket, and (iii) return the semiconductor device to the tray, and the TM subsystem is to exert the predetermined pressure on the semiconductor device in the socket.

[0181] Example 42 provides the system of example 41, wherein: the PNP subsystem is to move between a PNP home position, a first active position, a second active position and a third active position, the TM subsystem is to move between a TM home position and the third active position, and the PNP home position is different from the TM home position.

[0182] Example 43 provides the system of any of examples 41-42, wherein movements of the PNP subsystem and the TM subsystem are controlled by the control system without human intervention.

[0183] Example 44 provides the system of any of examples 41-43, wherein the control system controls movements of the PNP subsystem based on information from the tester.

[0184] Example 45 provides the system of any of examples 41-44, wherein: the PNP subsystem comprises a vision head to recognize the semiconductor device in the tray, the vision head is further to identify a center and orientation of the semiconductor device, and based on the identifying, the control system enables the PNP subsystem to pick up the semiconductor device from the tray.

[0185] Example 46 provides a method executed by a controller in a system for handling a semiconductor device, the method comprising: moving a pick-and-place (PNP) head in the system to an approximate location of the semiconductor device in a tray, the approximate location determined from a tray template stored in the system, the tray template comprising a virtual representation of the tray; automatically capturing an image of the semiconductor device in the tray using a camera in the PNP head; comparing the image to a device template stored in the system, the device template comprising a virtual representation of the semiconductor device; identifying a center of the semiconductor device based on the comparing; and moving a PNP nozzle in the PNP head to the identified center of the semiconductor device.

[0186] Example 47 provides the method of example 46, further comprising: identifying an angular misalignment of the semiconductor device in the tray based on the comparing, the angular misalignment relative to a socket of a printed circuit board; and rotating the PNP nozzle to remove the angular misalignment after picking up the semiconductor device from the tray with the PNP nozzle.

[0187] Example 48 provides the method of any of examples 46-47, further comprising generating the tray template, wherein: the tray template comprises a plurality of rows and columns, and the approximate location of the semiconductor device is determined by an intersection of a specific row and a specific column in the tray template.

[0188] Example 49 provides the method of example 48, wherein generating the tray template further comprises classifying subsets of the rows and the columns into different zones.

[0189] Example 50 provides the method of any of examples 46-49, wherein: the center of the semiconductor device at the approximate location represents a first active position of the PNP head, a second active position of the PNP head is at a socket on a printed circuit board, the socket is represented virtually by a socket template stored in the system, with the second active position being represented as a center of the socket template, and the method further comprises picking up the semiconductor device and moving the PNP head with the semiconductor device to the center of the socket template.

[0190] Example 51 provides the method of any of examples 46-50, further comprising converting pixels in the captured image to linear dimensions using a calibrated optical marker.

[0191] Example 52 provides the method of example 51, wherein the calibrated optical marker comprises shapes having known dimensions.

[0192] Example 53 provides the method of any of examples 46-52, wherein: the PNP head moves by action of an actuator in the system, and the method further comprises converting linear distance traveled by the PNP head to rotations of the actuator using a calibration plate.

[0193] Example 54 provides the method of example 53, wherein the calibration plate comprises precisely measured locations at known distances from each other.

[0194] Example 55 provides the method of any of examples 46-54, wherein the tray template is correlated with the tray using a plurality of reference points on the tray.

[0195] Example 56 provides an apparatus, comprising: a pick-and-place (PNP) nozzle coupled to a hollow shaft configured to provide vacuum suction at the PNP nozzle; a camera adjacent to and offset from the PNP nozzle; and a control system to coordinate the PNP nozzle and the camera, the control system including a memory for storing at least one tray template representing a tray for holding semiconductor devices and one device template representing a semiconductor device, wherein the control system, the PNP nozzle and the camera perform operations comprising: moving the PNP nozzle to an approximate location of the semiconductor device in the tray, the approximate location determined in relation to the tray template; capturing an image of the semiconductor device in the tray using the camera; comparing the image to the device template; identifying a center of the semiconductor device based on the comparing; moving the PNP nozzle to the identified center of the semiconductor device; and picking up the semiconductor device using vacuum at the PNP nozzle.

[0196] Example 57 provides the apparatus of example 56, wherein the operations further comprise: identifying an angular misalignment of the semiconductor device in the tray based on the comparing, the angular misalignment relative to a socket of a printed circuit board; and rotating the PNP nozzle to remove the angular misalignment after picking up the semiconductor device from the tray with the PNP nozzle.

[0197] Example 58 provides the apparatus of any of examples 56-57, wherein the operations further comprise generating the tray template, wherein: the tray template comprises a plurality of rows and columns, and the approximate location of the semiconductor device is determined by an intersection of a specific row and a specific column in the tray template.

[0198] Example 59 provides the apparatus of any of examples 56-58, wherein the operations further comprise moving the PNP nozzle with the semiconductor device attached thereto to a socket on a printed circuit board.

[0199] Example 60 provides the apparatus of example 59, wherein the operations further comprise moving the PNP nozzle with the semiconductor device attached thereto from the socket to another tray in the apparatus, the another tray represented by another tray template.

[0200] Example 61 provides a method executed by a control system coupled to a handler for handling semiconductor devices for testing, the method comprising: moving a pick-and-place (PNP) subsystem in the handler to a vicinity of a semiconductor device in a tray; identifying the semiconductor device in the tray using a camera in the PNP subsystem; picking up the semiconductor device using a PNP nozzle in the PNP subsystem; placing the semiconductor device in a socket of a printed circuit board connected electrically to a tester; moving the PNP subsystem away from the socket; moving a thermo-mechanical (TM) subsystem to the socket; exerting pressure on the semiconductor device by the TM subsystem; informing the tester that the semiconductor device is ready for testing; receiving instructions from the tester that the testing is completed; moving the TM subsystem away from the socket; picking up the semiconductor device from the socket using the PNP nozzle; and placing the semiconductor device in a sorted bin according to the instructions.

[0201] Example 62 provides the method of example 61, further comprising: aligning the camera over the semiconductor device in the tray; capturing an image of a field of view of the camera; comparing the image with a device template stored in the control system; identifying a center of the semiconductor device and any misalignment of the semiconductor device from the comparing; and moving the PNP nozzle to the center of the semiconductor device before picking up the semiconductor device.

[0202] Example 63 provides the method of any of examples 61-62, further comprising: calibrating the camera, the calibrating comprising generating a correlation of pixels to linear dimensions; calibrating actuators in the handler, the calibrating comprising generating a correlation of motion of the actuator to linear dimensions; generating a tray template, a device template, and a socket template; generating a test recipe; generating a first PNP path from the tray to the socket and another PNP path from the socket to the tray; and generating a TM path from a TM home position to the socket.

[0203] Example 64 provides the method of example 63, wherein: the test recipe specifies a temperature and soak time, and the method further comprises soaking the semiconductor device at the temperature for the soak time before informing the tester.

[0204] Example 65 provides the method of any of examples 63-64, further comprising: identifying misalignment of the semiconductor device in the tray based on the tray template, the device template and the socket template; and adjusting the PNP nozzle to remove the misalignment.

[0205] The above description of illustrated implementations of the disclosure, including what is described in the abstract, is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. While specific implementations of, and examples for, the disclosure are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the disclosure, as those skilled in the relevant art will recognize.

1. A method executed by a controller in a system for handling a semiconductor device, the method comprising:

moving a pick-and-place (PNP) head in the system to an approximate location of the semiconductor device in a tray, the approximate location determined from a tray template stored in the system, the tray template comprising a virtual representation of the tray;

automatically capturing an image of the semiconductor device in the tray using a camera in the PNP head;

comparing the image to a device template stored in the system, the device template comprising a virtual representation of the semiconductor device;

identifying a center of the semiconductor device based on the comparing; and

moving a PNP nozzle in the PNP head to the identified center of the semiconductor device.

2. The method of claim **1**, further comprising:

identifying an angular misalignment of the semiconductor device in the tray based on the comparing, the angular misalignment relative to a socket of a printed circuit board; and

rotating the PNP nozzle to remove the angular misalignment after picking up the semiconductor device from the tray with the PNP nozzle.

3. The method of claim **1**, further comprising generating the tray template, wherein:

the tray template comprises a plurality of rows and columns, and

the approximate location of the semiconductor device is determined by an intersection of a specific row and a specific column in the tray template.

4. The method of claim **3**, wherein generating the tray template further comprises classifying subsets of the rows and the columns into different zones.

5. The method of claim **1**, wherein:

the center of the semiconductor device at the approximate location represents a first active position of the PNP head,

a second active position of the PNP head is at a socket on a printed circuit board,

the socket is represented virtually by a socket template stored in the system, with the second active position being represented as a center of the socket template, and

the method further comprises picking up the semiconductor device and moving the PNP head with the semiconductor device to the center of the socket template.

6. The method of claim **1**, further comprising converting pixels in the captured image to linear dimensions using a calibrated optical marker.

7. The method of claim **6**, wherein the calibrated optical marker comprises shapes having known dimensions.

8. The method of claim **1**, wherein:

the PNP head moves by action of an actuator in the system, and the method further comprises converting linear distance traveled by the PNP head to rotations of the actuator using a calibration plate.

9. The method of claim **8**, wherein the calibration plate comprises precisely measured locations at known distances from each other.

10. The method of claim **1**, wherein the tray template is correlated with the tray using a plurality of reference points on the tray.

11. An apparatus, comprising:

a pick-and-place (PNP) nozzle coupled to a hollow shaft configured to provide vacuum suction at the PNP nozzle;

a camera adjacent to and offset from the PNP nozzle; and

a control system to coordinate the PNP nozzle and the camera, the control system including a memory for storing at least one tray template representing a tray for holding semiconductor devices and one device template representing a semiconductor device,

wherein the control system, the PNP nozzle and the camera perform operations comprising:

moving the PNP nozzle to an approximate location of the semiconductor device in the tray, the approximate location determined in relation to the tray template;

capturing an image of the semiconductor device in the tray using the camera;

comparing the image to the device template;

identifying a center of the semiconductor device based on the comparing;

moving the PNP nozzle to the identified center of the semiconductor device; and

picking up the semiconductor device using vacuum at the PNP nozzle.

12. The apparatus of claim **11**, wherein the operations further comprise:

identifying an angular misalignment of the semiconductor device in the tray based on the comparing, the angular misalignment relative to a socket of a printed circuit board; and

rotating the PNP nozzle to remove the angular misalignment after picking up the semiconductor device from the tray with the PNP nozzle.

13. The apparatus of claim **11**, wherein the operations further comprise generating the tray template, wherein:

the tray template comprises a plurality of rows and columns, and

the approximate location of the semiconductor device is determined by an intersection of a specific row and a specific column in the tray template.

14. The apparatus of claim **11**, wherein the operations further comprise moving the PNP nozzle with the semiconductor device attached thereto to a socket on a printed circuit board.

15. The apparatus of claim **14**, wherein the operations further comprise moving the PNP nozzle with the semiconductor device attached thereto from the socket to another tray in the apparatus, the another tray represented by another tray template.

16. A method executed by a control system coupled to a handler for handling semiconductor devices for testing, the method comprising:

moving a pick-and-place (PNP) subsystem in the handler to a vicinity of a semiconductor device in a tray;

identifying the semiconductor device in the tray using a camera in the PNP subsystem;

picking up the semiconductor device using a PNP nozzle in the PNP subsystem;

placing the semiconductor device in a socket of a printed circuit board connected electrically to a tester;

moving the PNP subsystem away from the socket;

moving a thermo-mechanical (TM) subsystem to the socket;

exerting pressure on the semiconductor device by the TM subsystem;

informing the tester that the semiconductor device is ready for testing;

receiving instructions from the tester that the testing is completed;

moving the TM subsystem away from the socket;

picking up the semiconductor device from the socket using the PNP nozzle; and

placing the semiconductor device in a sorted bin according to the instructions.

17. The method of claim **16**, further comprising:

aligning the camera over the semiconductor device in the tray;

capturing an image of a field of view of the camera;

comparing the image with a device template stored in the control system;

identifying a center of the semiconductor device and any misalignment of the semiconductor device from the comparing; and

moving the PNP nozzle to the center of the semiconductor device before picking up the semiconductor device.

18. The method of claim **16**, further comprising:

calibrating the camera, the calibrating comprising generating a correlation of pixels to linear dimensions;

calibrating actuators in the handler, the calibrating comprising generating a correlation of motion of the actuator to linear dimensions;

generating a tray template, a device template, and a socket template;

generating a test recipe;

generating a first PNP path from the tray to the socket and another PNP path from the socket to the tray; and

generating a TM path from a TM home position to the socket.

19. The method of claim **18**, wherein:

the test recipe specifies a temperature and soak time, and

the method further comprises soaking the semiconductor device at the temperature for the soak time before informing the tester.

20. The method of claim **18**, further comprising:

identifying misalignment of the semiconductor device in the tray based on the tray template, the device template and the socket template; and

adjusting the PNP nozzle to remove the misalignment.

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