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(10) **Patent No.: US 12,389,551 B2**
(45) **Date of Patent: Aug. 12, 2025**

(54) **ROLL-TO-ROLL ADDITIVE MANUFACTURING METHOD AND DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 502 days.

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(60) Provisional application No. 62/900,333, filed on Sep. 13, 2019.

(51) **Int. Cl.**

H05K 3/28	(2006.01)
H05K 1/02	(2006.01)
H05K 1/03	(2006.01)

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

CPC ***H05K 3/28*** (2013.01); ***H05K 1/028*** (2013.01); ***H05K 1/0373*** (2013.01)

(58) **Field of Classification Search**

CPC H05K 3/28

USPC 361/749

See application file for complete search history.

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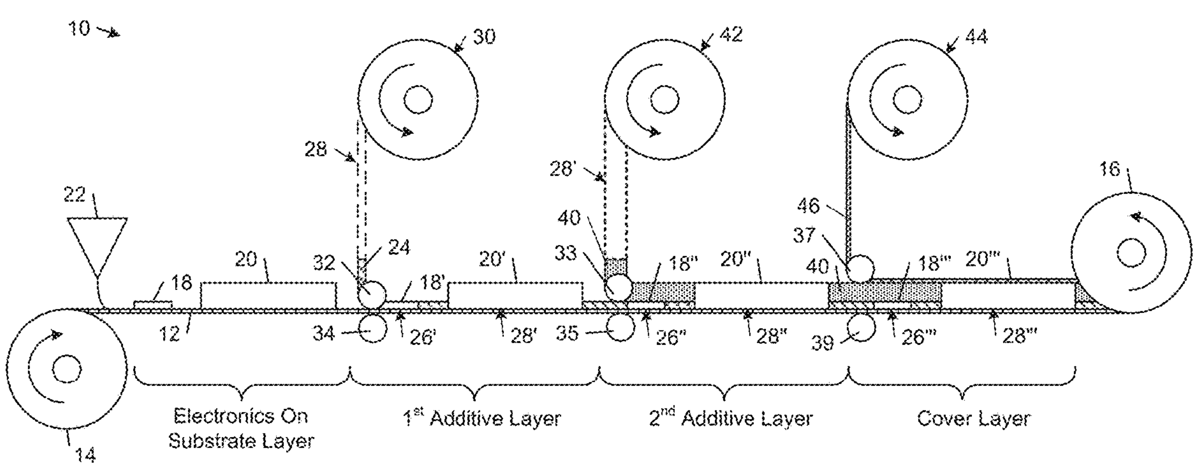
Primary Examiner — Stanley Tso

(57) **ABSTRACT**

A flexible laminate electronic device includes a flexible substrate that includes electrical connections between electronic components attached to the flexible substrate. A first flexible additive layer includes apertures, wherein at least one of the one or more electronic components is aligned in one of the apertures. A subsequent flexible additive layer is disposed over the first flexible additive layer and aligned around respective portions of the electronic components protruding above the first flexible additive layer. A flexible cover layer is placed over the subsequent flexible additive layer.

21 Claims, 8 Drawing Sheets



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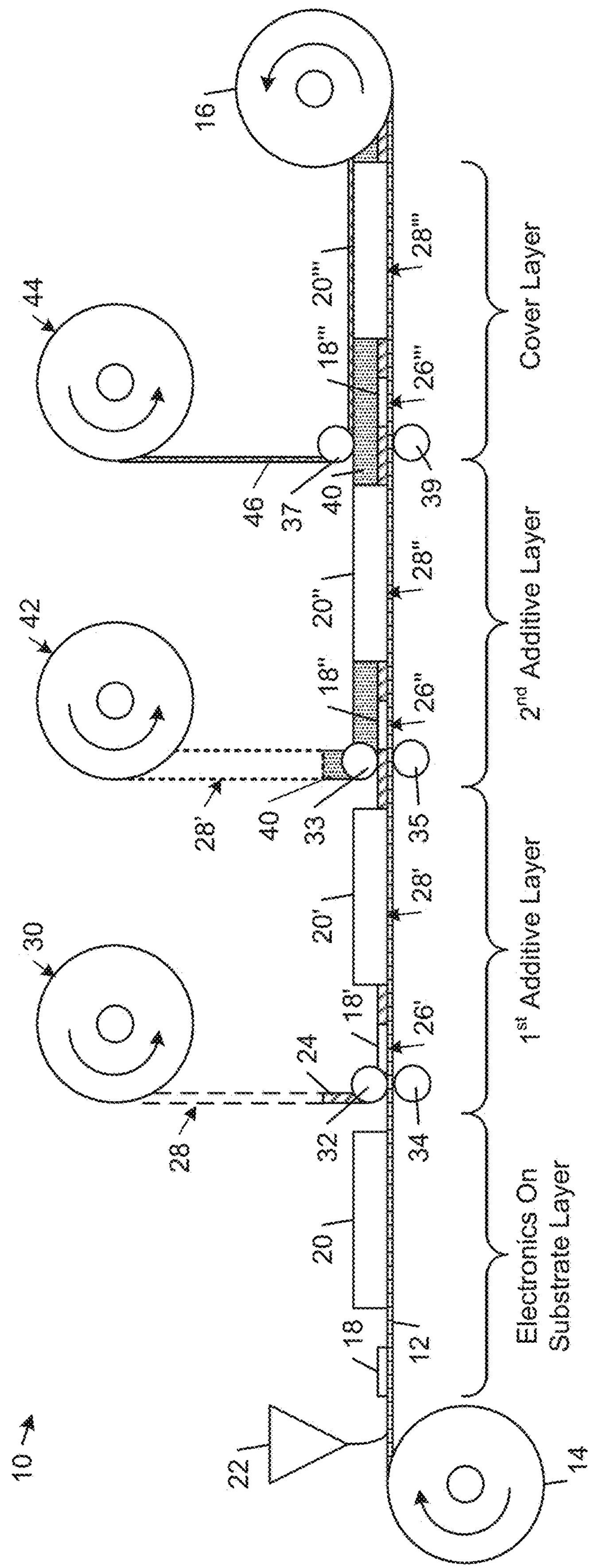

10
22
14
18
12
20
Electronics On Substrate Layer
28
24
32
34
30
18'
26'
20'
28'
1st Additive Layer
28'
40
33
35
42
18"
26"
20"
28"
2nd Additive Layer
46
37
40
39
44
18'''
26'''
20'''
28'''
Cover Layer
16

FIG. 1

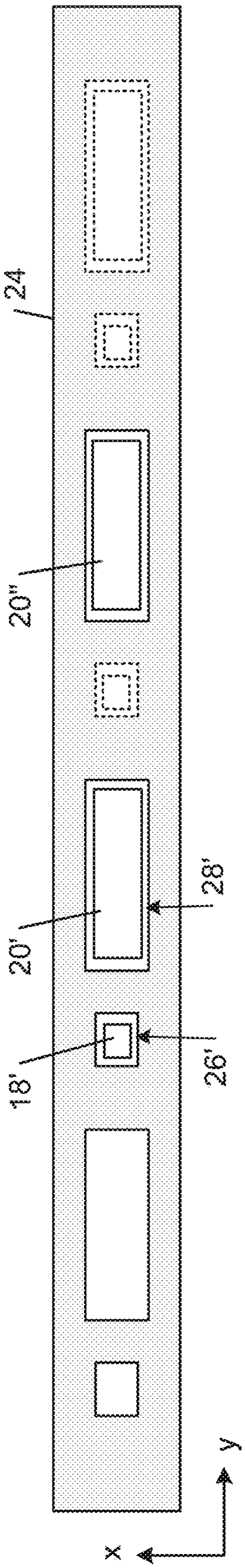


FIG. 2A

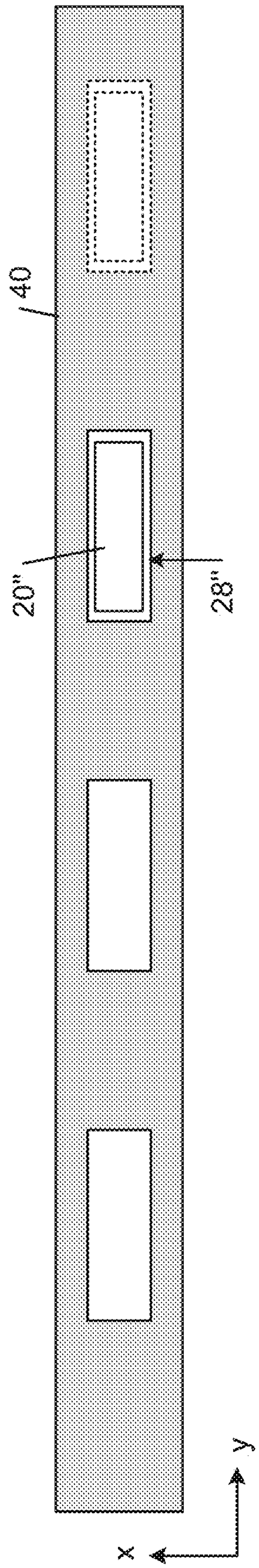


FIG. 2B

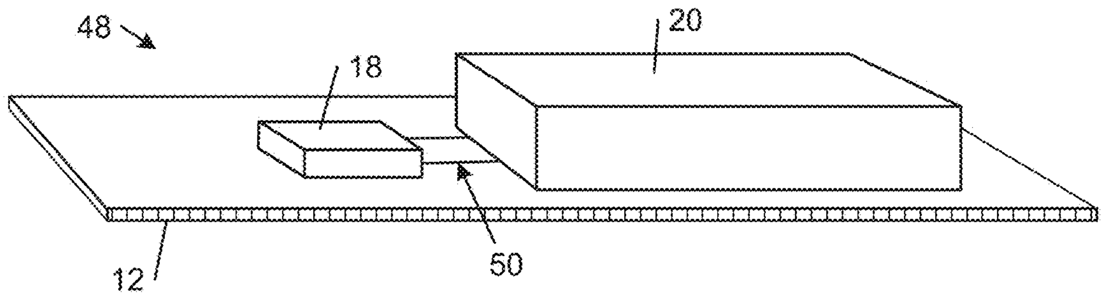


FIG. 3

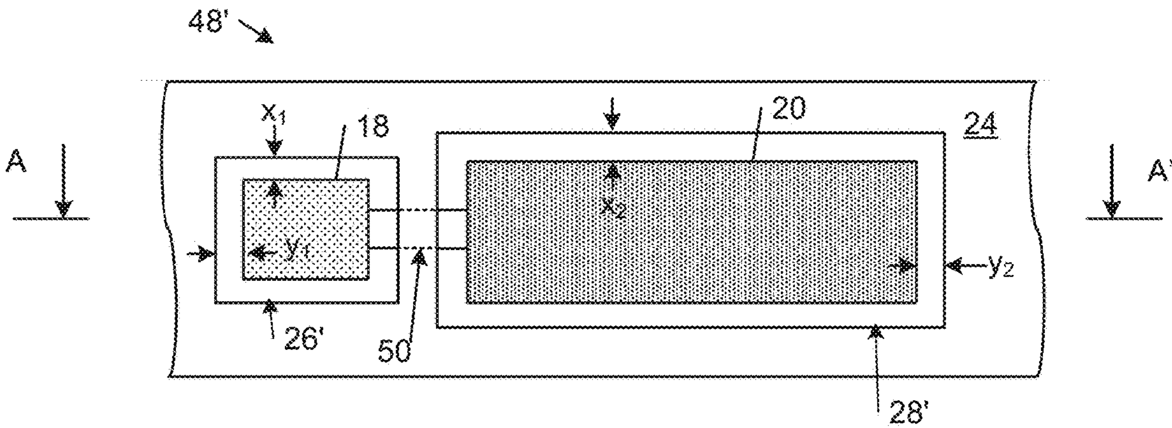


FIG. 4A

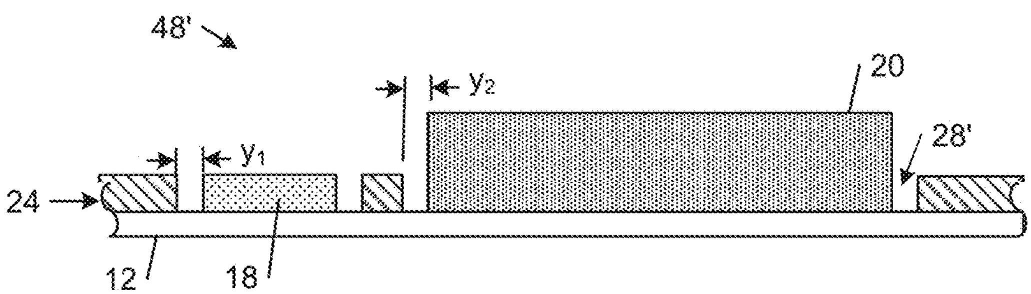


FIG. 4B

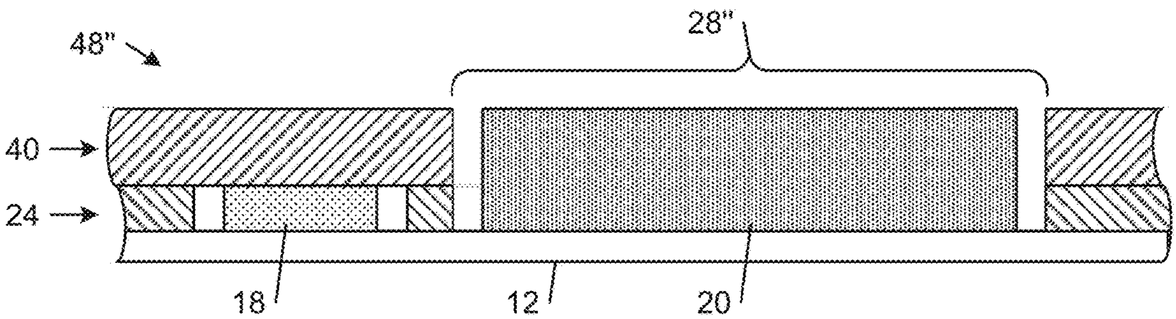


FIG. 5

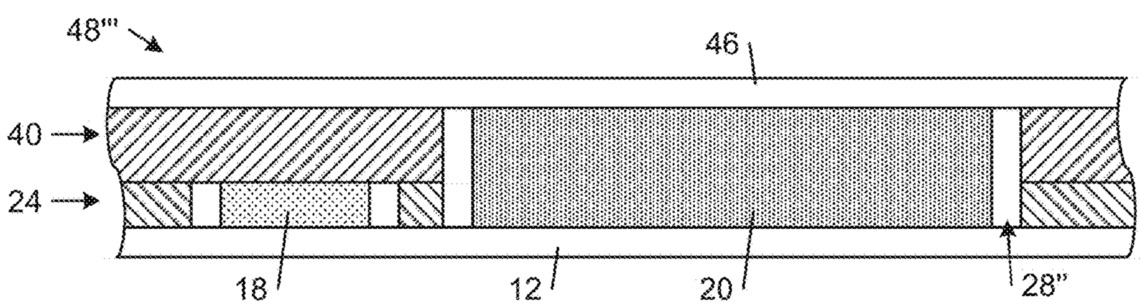


FIG. 6

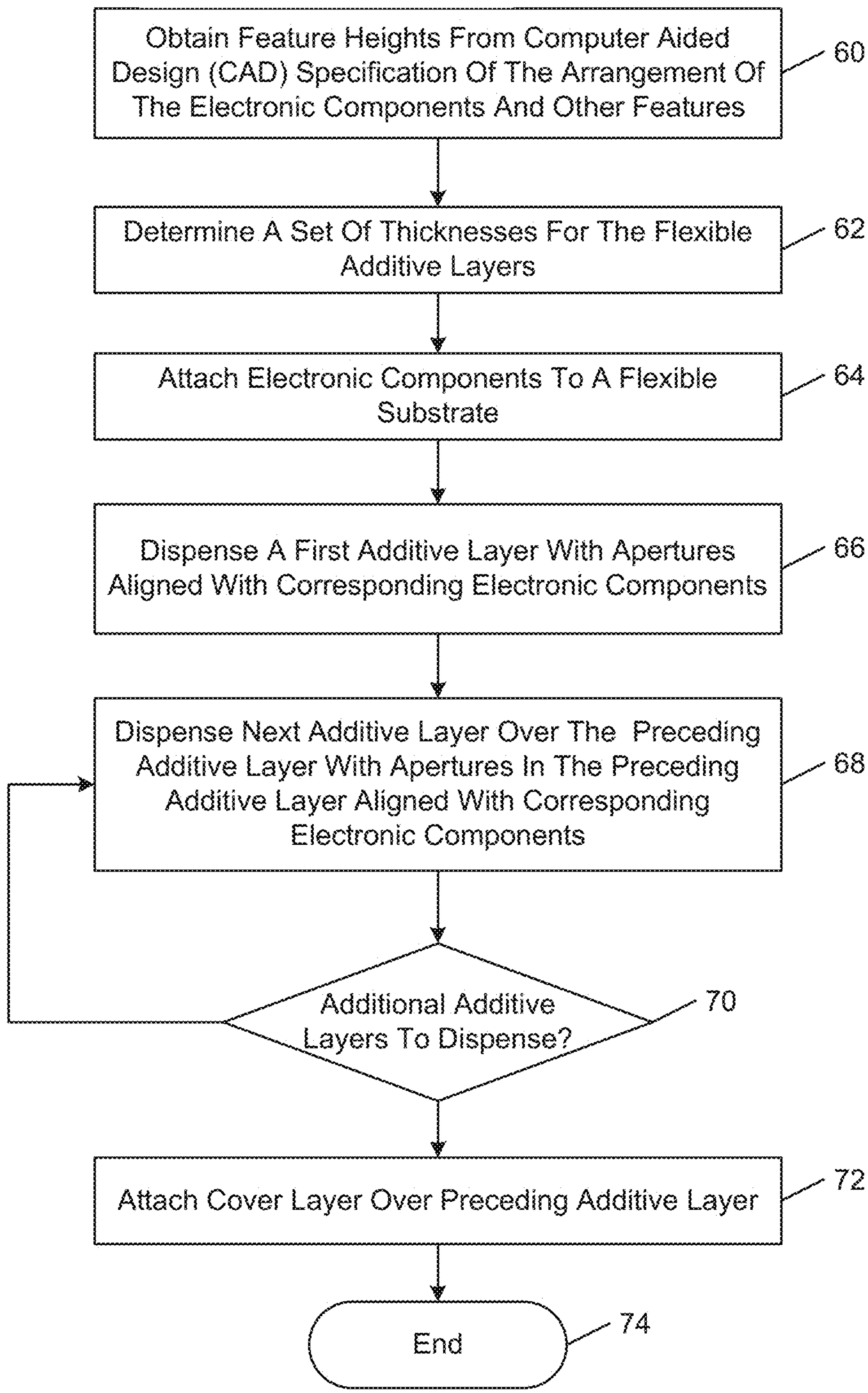
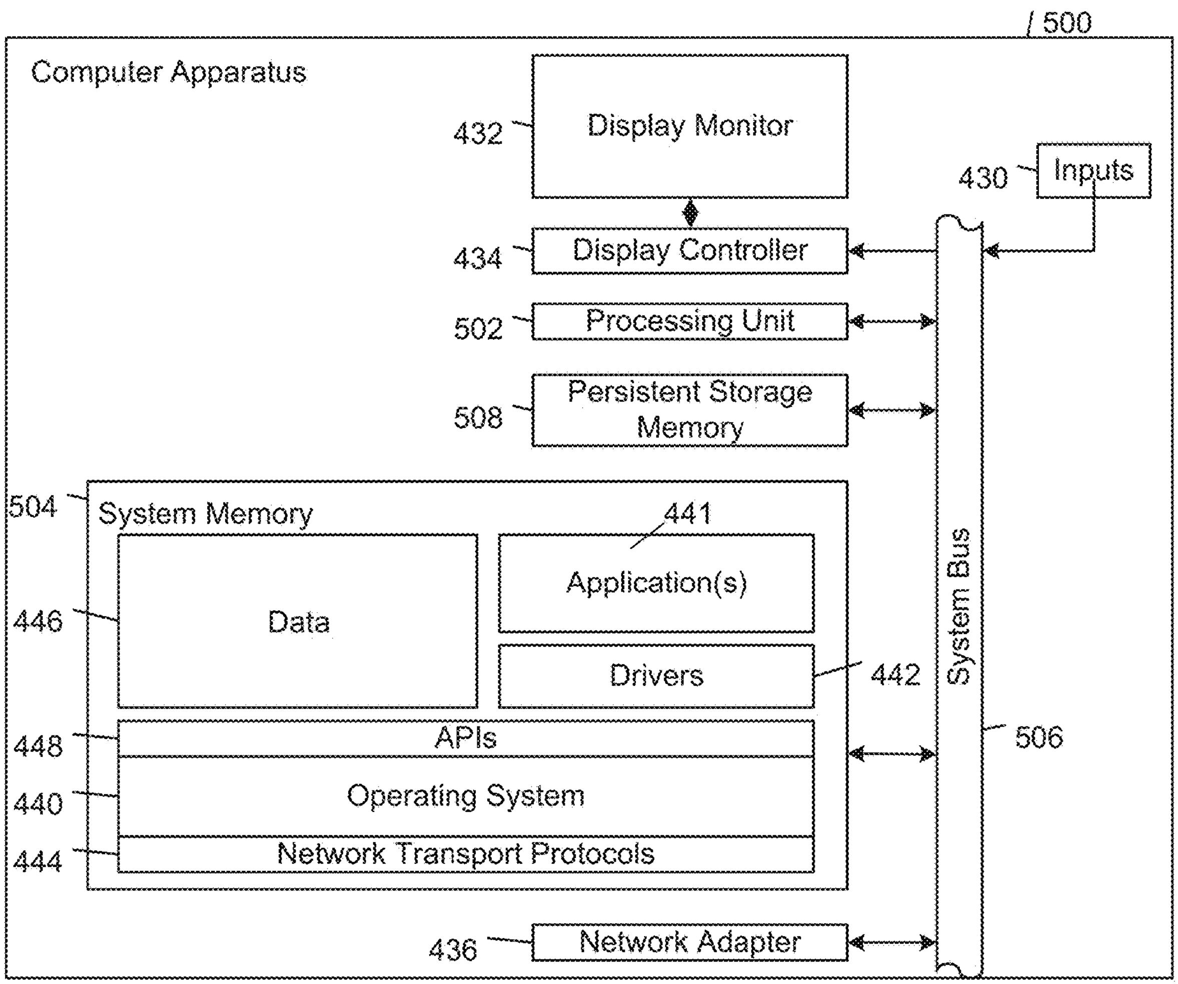

Obtain Feature Heights From Computer Aided Design (CAD) Specification Of The Arrangement Of The Electronic Components And Other Features
60
Determine A Set Of Thicknesses For The Flexible Additive Layers
62
Attach Electronic Components To A Flexible Substrate
64
Dispense A First Additive Layer With Apertures Aligned With Corresponding Electronic Components
66
Dispense Next Additive Layer Over The Preceding Additive Layer With Apertures In The Preceding Additive Layer Aligned With Corresponding Electronic Components
68
Additional Additive Layers To Dispense?
70
Attach Cover Layer Over Preceding Additive Layer
72
End
74

FIG. 7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Computer Apparatus
432
Display Monitor
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Inputs
434
Display Controller
502
Processing Unit
508
Persistent Storage Memory
504
System Memory
441
446
Data
Application(s)
Drivers
442
System Bus
448
APIs
506
440
Operating System
444
Network Transport Protocols
436
Network Adapter

FIG. 8

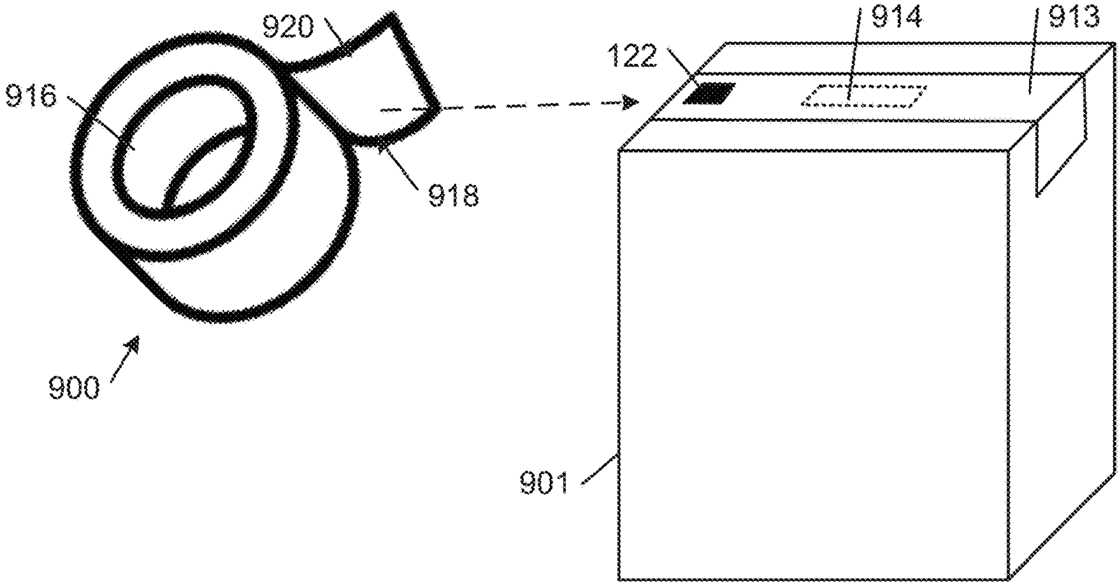
920
916
918
900
122
914
913
901

FIG. 9A

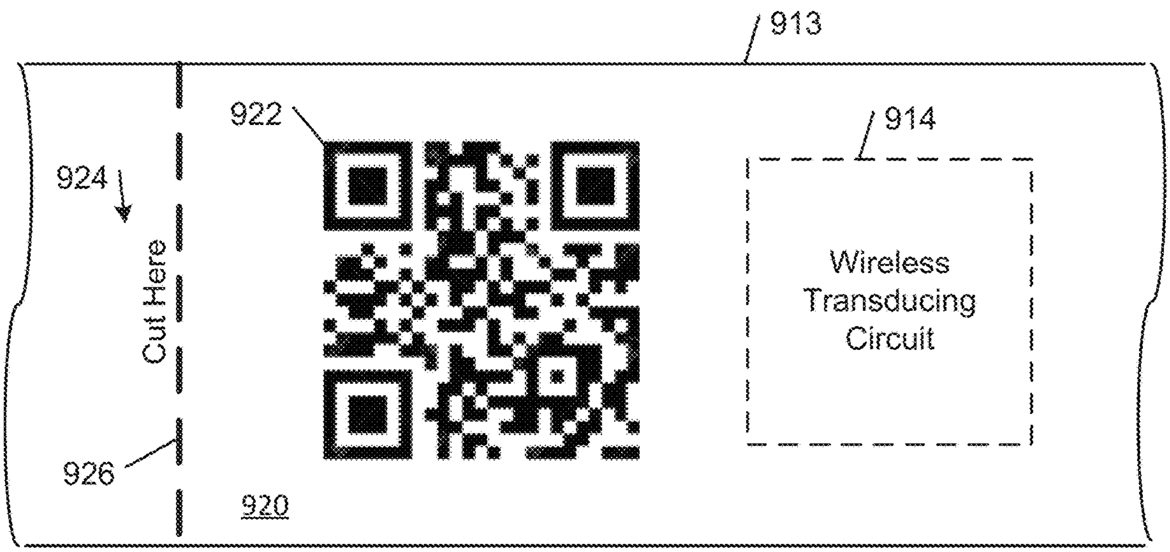
913
922
914
924
Cut Here
Wireless
Transducing
Circuit
926
920

FIG. 9B

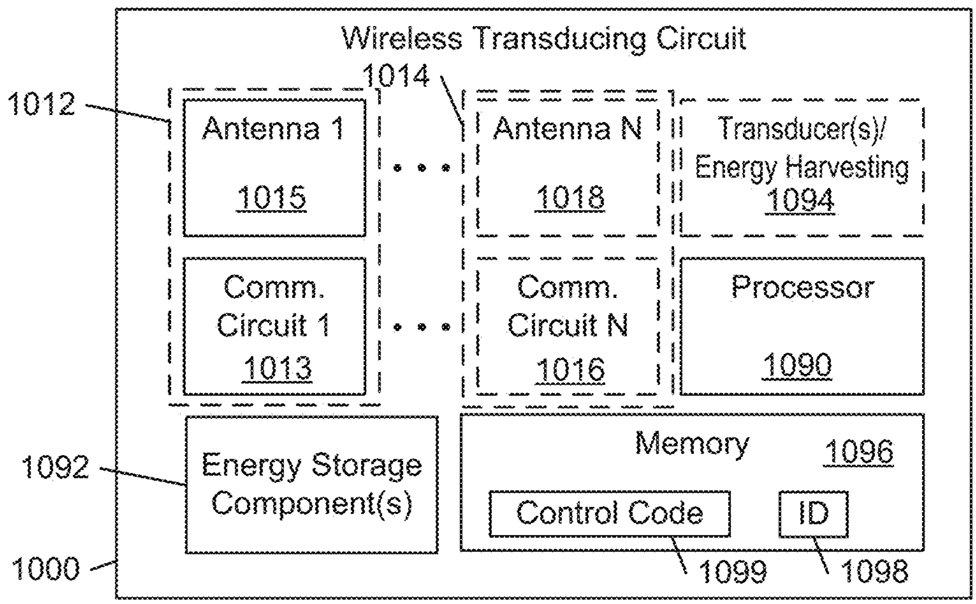
Wireless Transducing Circuit
1012
1014
Antenna 1
1015
Antenna N
1018
Transducer(s)/
Energy Harvesting
1094
Comm.
Circuit 1
1013
Comm.
Circuit N
1016
Processor
1090
1092
Energy Storage
Component(s)
Memory
1096
Control Code
ID
1000
1099
1098

FIG. 10

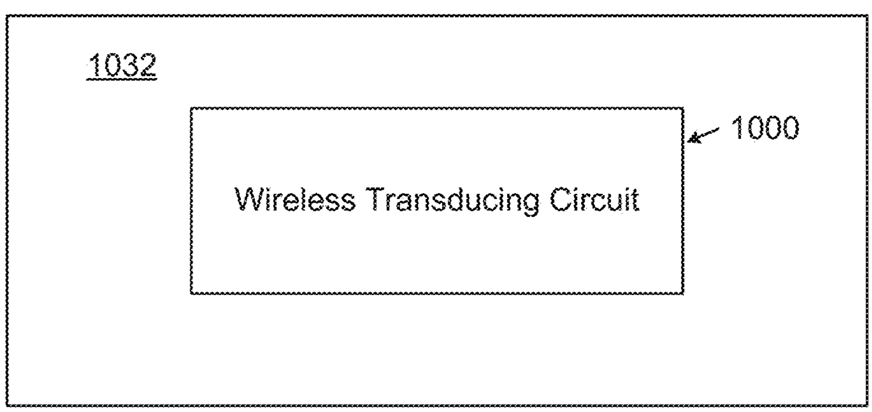
1032
Wireless Transducing Circuit
1000

FIG. 11

ROLL-TO-ROLL ADDITIVE MANUFACTURING METHOD AND DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a division of U.S. patent application Ser. No. 17/019,833, filed on Sep. 14, 2020, which claims priority to U.S. Provisional Patent Application No. 62/900,333, filed on Sep. 13, 2019, both of which are incorporated herein in their entirety.

FIELD OF THE DISCLOSURE

The disclosure generally relates to manufacturing processes for electronic devices.

BACKGROUND

Additive manufacturing typically involves forming a three-dimensional object by adding layers of material (e.g., plastic and metal). Designing such three-dimensional objects is a time-consuming process, despite the availability of powerful computer aided design (CAD) tools. For this reason, conventional additive manufacturing techniques, such as stereo lithography, selective laser sintering, and fused deposition modeling, typically are reserved for use in manufacturing complex, low volume, and high cost parts.

SUMMARY

In an embodiment, a process of manufacturing a flexible laminate electronic device is disclosed. The process includes placing electronic components over a flexible substrate layer that includes electrical connections between the electronic components. A first flexible additive layer that includes apertures is positioned to align each of the electronic components in a respective aperture. A subsequent flexible additive layer is arranged over the first flexible additive layer and the apertures are aligned around respective portions of the electronic components protruding above the first flexible additive layer. A flexible cover layer is placed over the subsequent flexible additive layer.

In another embodiment, a flexible laminate electronic device includes a flexible substrate that includes electrical connections between electronic components attached to the flexible substrate. A first flexible additive layer includes apertures, wherein at least one of the one or more electronic components is aligned in one of the apertures. A subsequent flexible additive layer is disposed over the first flexible additive layer and aligned around respective portions of the electronic components protruding above the first flexible additive layer. A flexible cover layer is placed over the subsequent flexible additive layer.

Additional descriptions of features and details of the present invention are described in the following specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** illustrates an embodiment of an apparatus for implementing a roll-to-roll process of manufacturing a series of contiguous flexible electronic devices.

FIG. **2**A illustrates an embodiment of a first flexible additive layer with two apertures for each flexible electronic device segment.

FIG. **2**B illustrates an embodiment of a subsequent flexible additive layer with one aperture for each flexible electronic device segment.

FIG. **3** is perspective view of an embodiment of two electronic components mounted to a flexible substrate segment.

FIG. **4**A is a top view of an embodiment of the flexible substrate segment shown in FIG. **3** with a first overlaying flexible additive layer that has two apertures encircling respective electronic component

FIG. **4**B is a cross-sectional side view from A to A' of an embodiment of the flexible substrate segment shown in FIG. **3** with a first overlaying flexible additive layer that has two apertures encircling respective electronic components.

FIG. **5** is a cross-sectional side view corresponding to the cross-sectional side view shown in FIG. **4**B of the flexible substrate segment with an embodiment of a second overlaying flexible additive layer that has one aperture encircling a respective electronic component.

FIG. **6** is a cross-sectional side view corresponding to the cross-sectional side view shown in FIG. **5** of the flexible substrate segment with an embodiment of a top overlaying flexible cover layer.

FIG. **7** is a flow chart illustrating steps of a method of fabricating a flexible electronic device, according to some embodiments.

FIG. **8** is a block diagram of a computer apparatus, according to some embodiments.

FIG. **9**A is a diagrammatic view of a package that has been sealed for shipment using a segment of an example tracking adhesive product dispensed from a roll, according to some embodiments.

FIG. **9**B is a diagrammatic top view of a portion of the segment of the example tracking adhesive product shown in FIG. **9**A, according to some embodiments.

FIG. **10** is a schematic view of an example wireless transducer circuit, according to some embodiments.

FIG. **11** is a diagrammatic top view of a length of an example autonomous agent platform containing an embedded wireless transducing circuit, according to some embodiments.

DETAILED DESCRIPTION

In the following description, like reference numbers are used to identify like elements. Furthermore, the drawings are intended to illustrate major features of exemplary embodiments in a diagrammatic manner. The drawings are not intended to depict every feature of actual embodiments nor relative dimensions of the depicted elements. The drawings are not drawn to scale.

The present invention is not limited in any way to the illustrated embodiments. Instead, the illustrated embodiments described below are merely examples of the invention. Therefore, the structural and functional details disclosed herein are not to be construed as limiting the claims. The disclosure merely provides bases for the claims and representative examples that enable one skilled in the art to make and use the claimed inventions. Furthermore, the terms and phrases used herein are intended to provide a comprehensible description of the invention without being limiting.

As used herein, the term "or" refers an inclusive "or" rather than an exclusive "or." In addition, the articles "a" and "an" as used in the specification and claims mean "one or more" unless specified otherwise or clear from the context to refer the singular form.

The terms "module," "manager," and "unit" refer to hardware, software, or firmware, or a combination thereof.

Exemplary Embodiments

Disclosed herein is a low-cost, multi-function flexible platform (also referred to herein as a "tape platform") with a form factor that integrates the components useful for implementing a combination of different functions and also is able to perform a useful ancillary function that otherwise would have to be performed with the attendant need for additional materials, labor, and expense. In an aspect, the flexible platform is implemented as a collection of flexible products that integrate wireless communications and sensing components within a flexible structure in a way that not only provides a cost-effective platform for interconnecting, optimizing, and protecting the components of the system but also maintains the flexibility needed to function as a flexible product that can be deployed seamlessly into various applications and workflows. The various applications and workflows may include person and object tracking applications, asset management workflows such as manufacturing, storage, shipping, delivery, and other tasks associated with moving products and other physical objects, including logistics, sensing, tracking, locationing, warehousing, parking, safety, construction, event detection, road management and infrastructure, security, and healthcare. The multi-function flexible platform may have an adhesive tape platform and have a dual function of an adhesive tape that can adhere to an object or seal an object, in addition to being a wireless communications and sensing device. In some examples, the adhesive tape platforms (also referred to herein as "tape nodes") are used in various aspects of asset tracking and management, including sealing assets, transporting assets, tracking assets, monitoring the conditions of assets, inventorying assets, and verifying security of assets. In some examples, a parcel sealed with the adhesive tape platform typically is transported from one location to another by truck, train, ship, or aircraft, or within premises, e.g., warehouses, by forklift, trolleys etc.

In some embodiments, the tape platform includes a plurality of segments that can be separated from the adhesive product (e.g., by cutting, tearing, peeling, or the like) and adhesively attached to a variety of different surfaces to inconspicuously implement any of a wide variety of different wireless communications based network communications and transducing (e.g., sensing, actuating, etc.) applications. Examples of such applications include: event detection applications, monitoring applications, security applications, notification applications, and tracking applications, including inventory tracking, asset tracking, person tracking, animal (e.g., pet) tracking, manufactured parts tracking, and vehicle tracking. In example embodiments, each segment of an adhesive tape platform is equipped with an energy source, wireless communication functionality, transducing functionality, and processing functionality that enable the segment to perform one or more transducing functions and report the results to a remote server or other computer system directly or through a network of tapes. The components of the tape platform are encapsulated within a flexible structure that protects the components from damage while maintaining the flexibility needed to function as an adhesive tape (e.g., duct tape or a label) for use in various applications and workflows. In addition to single function applications, some embodiments also include multiple transducers (e.g., sensing and/or actuating transducers) that extend the utility of the platform by, for example, providing supplemental information and functionality relating characteristics of the state and or environment of, for example, an article, object, vehicle, or person, over time.

Systems and processes for fabricating flexible multifunction adhesive tape platforms in efficient and low-cost ways also are described. In addition to using roll-to-roll and/or sheet-to-sheet manufacturing techniques, the fabrication systems and processes are configured to optimize the placement and integration of components within the flexible adhesive structure to achieve high flexibility and durability. These fabrication systems and processes are able to create useful and reliable tape platforms that can provide local sensing, wireless transmitting, locationing functionalities, other functionalities, or some combination thereof. Such functionality together with the low cost of production is advantageous for the ubiquitous deployment of adhesive tape platform segments for various applications and thereby alleviate at least some of the problems arising from gaps in conventional infrastructure coverage that prevent continuous monitoring, event detection, security, tracking, and other logistics applications across heterogeneous environments.

In particular embodiments described herein, examples of a low-cost, roll-to-roll additive manufacturing method of fabricating flexible electronic devices are provided. Roll-to-roll additive layer-based manufacturing methods and devices formed by these methods are described. The manufacturing methods include use of low-cost electronic components embedded within low-cost, flexible, multi-layered, encapsulating structures that protect the embedded electronic components and associated wiring components. In general, the flexible electronic devices may incorporate a wide variety of electronic components, such as microcontrollers, wireless communications systems, antennas, sensors, other components, or some combination thereof. In addition to the various functionalities of the embedded electronic components, embodiments of the flexible electronic devices also can function as adhesive tapes, labels, stickers, or any other type of flexible tape and/or flexible adhesive tape product.

FIG. **1** shows a diagrammatic side view of an embodiment of an apparatus **10** for implementing a roll-to-roll process for manufacturing a series of contiguous segments corresponding to respective flexible electronic devices. In this process, a flexible substrate layer **12** is dispensed from a roll **14**, processed through a number of additive layer stages and a cover **46** application stage, and the composite structure is taken-up by a roll **16**.

In the first stage of the illustrated automated manufacturing embodiment, the manufacturing apparatus **10** includes an adhesive dispenser **22** that deposits a layer of adhesive on the top surface of the substrate layer **12** to fix electronic components **18**, **20** in place on the substrate layer **12**. In some examples, the substrate layer **12** carries a pre-applied adhesive on the top surface of the substrate layer **12**. In some embodiments, the pre-applied adhesive is uniformly distributed across the top surface of the substrate layer **12**. In other embodiments, the adhesive is located only in regions of the top surface of the substrate layer **12** corresponding to the specified locations of the electronic components. In the above-mentioned embodiments, the adhesive may be a pressure sensitive adhesive or a liquid adhesive.

In some examples, the electronic components are placed on the substrate layer **12** by automated equipment. For example, in some embodiments, a precision pick-and-place robotic arm and camera is used to pick up electronic components **18**, **20** and precisely place the electronic components **18**, **20** at specified locations on the substrate layer

12. The electronic components **18**, **20** typically are interconnected by one or more electrical connections. In some embodiments, the electrical connections are direct wire connections between the electronic components **18**, **20**. In other embodiments, the substrate layer **12** includes one or more wiring layers that electrically interconnect the electronic components **18**, **20** either on the top surface of the flexible substrate layer **12** or embedded in the flexible substrate layer **12**. In some embodiments, the electronic components **18**, **20** are soldered to portions of one or more wiring layers on the top surface of the flexible substrate layer **12** or embedded in the flexible substrate layer to electrically connect the electronic components **18**, **20** to the one or more wiring layers. In other embodiments, the electronic components **18**, **20** are electrically connected to one or more wiring layers by other techniques. For example, the electronic components **18**, **20** may be electrically connected to one or more wiring layers by surface mounting techniques, pick-and-place techniques, die bonding techniques, reflow soldering, other techniques, or some combination thereof, according to some embodiments.

A wide variety of electronic components may be incorporated into the segments of flexible electronic devices. Example electronic components include batteries, microcontrollers, wireless communications systems, antennas, and sensor circuits. The microcontrollers typically include one or more CPUs (e.g., processor cores), a memory, and programmable input and output peripherals. The wireless communications systems typically are implemented by one or more network interface controllers that include one or more wireless network communications interfaces. For example, the wireless communications systems may include a cellular communication system (e.g., GSM/GPRS), a Wi-Fi communication system, an RF communication system (e.g., LoRa), a Bluetooth communication system (e.g., a Bluetooth Low Energy system), a Z-wave communication system, a ZigBee communication system, other communication systems, or some combination thereof.

In the second stage of the illustrated manufacturing embodiment, a first flexible additive layer **24** is unrolled from a roll **30** and positioned over the substrate layer **12** with the electronic components **18'**, **20'** spatially aligned with respective apertures **26'**, **28'** in the first flexible additive layer **24**. FIG. **2**A shows a top view of a segment of the first additive layer **24** including the apertures **26'**, **28'**. The apertures **26'**, **28'** are aligned spatially with the corresponding electronic components **18'**, **20'**. As shown in FIG. **2**A, the x-y dimensions of the apertures **26'**, **28'** in the first flexible additive layer **24** are larger than the corresponding x-y dimensions of the electronic components **18'**, **20'** so that the apertures **26'**, **28'** can accommodate the electronic components **18'**, **20'** and thereby create a substantially uniform thickness along the length of the flexible adhesive product. As shown in FIG. **2**A, in some examples, the differences in the x-y dimensions of the apertures **26'**, **28'** and the corresponding x-y dimensions of the electronic components are 0.1 mm or less.

In some embodiments, referring to FIG. **1**, as the first flexible additive layer **24** is dispensed from a supply roll **30**, a pair of laminating rollers **32**, **34** apply a compressive force between the first flexible additive layer **24** and the underlying substrate layer **12** to assist in aligning the apertures **26'**, **28'** in the first flexible additive layer **24** with the corresponding features of the electronic components **18'**, **20'** adhered to the surface of the substrate layer **12** by urging the apertures **26'**, **28'** formed in first flexible additive layer **24** into alignment over the protruding portions of the electronic components **18'**, **20'**. In some examples, the bottom surface of the first flexible additive layer **24** includes an adhesive layer, which may be, for example, a pressure sensitive adhesive, a non-pressure sensitive adhesive, other suitable adhesive, or some combination thereof.

In a third stage of the illustrated manufacturing embodiment, a second flexible additive layer **40** is unrolled from a roll **42** and arranged over the first flexible additive layer **24** and the electronic components **18"**, **20"** with the electronic component **20"** spatially aligned in the aperture **28"** formed in the second flexible additive layer **40**. FIG. **2**B shows a top view of a segment of the second flexible additive layer **40** including the aperture **28"**. As shown in FIG. **2**B, the x-y dimensions of the aperture **28"** in the second flexible additive layer **40** is larger than the corresponding x-y dimensions of the electronic component **20"** so that the aperture **28"** can accommodate the size of the electronic component **20"** and thereby create a substantially uniform thickness along the length of the flexible product. In some embodiments, the differences in the x-y dimensions of the aperture **28"** and the corresponding x-y dimensions of the electronic component **20"** are 0.1 mm or less.

In some embodiments, referring to FIG. **1**, as the second flexible additive layer **40** is dispensed from a supply roll **42**, a pair of laminating rollers **33**, **35** apply a compressive force between the second flexible additive layer **40** and the underlying first flexible additive layer **24** to assist in aligning the apertures **26"** in the second flexible additive layer **40** with the corresponding features of the electronic component **20"** adhered to the surface of the substrate layer **12** by urging the aperture **28"** formed in the second flexible additive layer **40** into alignment over the protruding portions of the electronic component **20"**. In some examples, the bottom surface of the second flexible additive layer **40** includes an adhesive layer, which may be, for example, a pressure sensitive adhesive, a non-pressure sensitive adhesive, other suitable adhesive, or some combination thereof.

As shown in FIG. **1**, the first flexible additive layer **24** may have a thickness that corresponds to a thickness of the electronic component **18'**. Thus, when the first flexible additive layer **24** is dispensed with the apertures **26'**, **28'** aligned with the corresponding electronic components **18'**, **20'**, a top surface of the first flexible additive layer **24** may be flush with a top surface of the electronic component **18'**. Similarly, second flexible additive layer **40** may have a thickness that corresponds to a thickness of the electronic component **20"**. In some embodiments, the second flexible additive layer **40** may have a thickness corresponding to the difference between the thickness of the electronic component **20"** and the first flexible additive layer **24**. Thus, when the second flexible additive layer **40** is dispensed with the aperture **28"** aligned with the corresponding electronic component **20"**, a top surface of the second flexible additive layer **40** may be flush with a top surface of the electronic component **20"**.

In a fourth stage of the illustrated manufacturing embodiment, a flexible cover layer **46** is unrolled from a supply roll **44** of a cover material and arranged over the electronic component **20'"** and the second flexible additive layer **40**.

In some embodiments, as the flexible cover layer **46** is dispensed from a supply roll **44**, a pair of laminating rollers **37**, **39** apply a compressive force between the flexible cover layer **46** and the underlying second flexible additive layer **40**. In some examples, the bottom surface of the flexible cover layer **46** includes an adhesive layer, which may be, for example, a pressure sensitive adhesive, a non-pressure sensitive adhesive, other suitable adhesive, or some combination thereof.

In some examples, the flexible cover layer **46** and the flexible substrate **12** may have the same or different compositions depending on the intended application. In some examples, one or both of the flexible cover **46** and the flexible substrate **12** include flexible film layers and/or paper substrates, where the film layers may have reflective surfaces or reflective surface coatings. Example compositions for the flexible film layers include polymer films, such as polyester, polyimide, polyethylene terephthalate (PET), other plastics, or some combination thereof. Optional adhesive layers may be applied on the bottom surface of the flexible cover layer **46** and on the top and bottom surfaces of the flexible substrate **12**. In some embodiments, these adhesive layers typically include a pressure-sensitive adhesive (e.g., a silicon-based adhesive). In some examples, the adhesive layers are applied to the flexible cover **46** and the flexible substrate **12** during manufacture (e.g., during a roll-to-roll or sheet-to-sheet fabrication process). In other examples, the flexible cover **46** may be implemented by a prefabricated single-sided pressure-sensitive adhesive tape and the flexible substrate **12** may be implemented by a prefabricated double-sided pressure-sensitive adhesive tape; both kinds of tape may be readily incorporated into a roll-to-roll or sheet-to-sheet fabrication process. In some embodiments, a flexible polymer layer is included between the flexible substrate **12** and the flexible cover layer **46**. In further embodiments, the flexible polymer layer is included beneath the flexible cover layer **46** and assists in adhering the flexible cover layer **46** to the second flexible additive layer **40** and the electronic component **20'''**. In some embodiments, the flexible polymer layer planarizes the section of the flexible electronics device including the electronic component **20'''** and the second flexible additive layer **40**. The flexible polymer layer may be composed of a flexible epoxy (e.g., silicone), according to some embodiments.

In some embodiments, an optional adhesive layer is on a top surface of the flexible cover layer **46**. In further embodiments, both an adhesive layer is on the bottom surface of the flexible substrate **12** and another adhesive layer is on the top surface of the flexible cover layer **46**, resulting in a double-sided adhesive tape platform, where the top side of the flexible electronics device and the bottom side of the flexible electronics device can be adhered to a surface.

In other embodiments, the flexible electronics device fabricated on the flexible substrate **12** according to the automated manufacturing process illustrated in FIG. **1** are cut into segments after completing the automated manufacturing process instead of being taken up by the roll **16**, after the flexible cover layer is added. The flexible electronics device may be cut in portions where no electronic components **18**, **20** or wiring layers are present, resulting in a plurality of flexible electronics device segments where each segment is an individual device.

In some embodiments, the apertures **26'**, **28'**, **26"**, **28"**, **26'''**, **28'''** are formed by stamping out a portion of the respective flexible additive layer. In other embodiments, the apertures **26'**, **28'**, **26"**, **28"**, **26'''**, **28'''** are formed by cutting out portions of the respective flexible additive layer by other methods.

FIG. **3** shows a perspective view of a flexible electronic device **48** in the first stage of process of fabrication in accordance with the manufacturing process described above, with respect to FIG. **1**, according to some embodiments. In the illustrated embodiment, the electronic device **48** includes two electronic components **18**, **20** mounted on a surface of a segment of a flexible substrate **12** in the first stage of the automated manufacturing process shown in FIG. **1**. The electronic components **18**, **20** are adhesively mounted to a surface of the flexible substrate segment **12**. In the illustrated embodiment, the electronic components **18**, **20** are interconnected by a wiring layer **50** on the surface of the flexible substrate segment **12**. As explained above, in other embodiments, the wiring layer **50** may be embedded within the flexible substrate segment **12**.

FIG. **4**A is a top view of an embodiment of the flexible electronic device **48'**, after the second stage of the automated manufacturing process shown in FIG. **1**. The flexible electronic device **48'** is the same as the flexible electronic device **48**, but with the addition of the first flexible additive layer **24** added in the second stage of the automated manufacturing process. FIG. **4**B is a cross-sectional side view from A to A' of the flexible electronic device **48'** shown in FIG. **4**A. FIGS. **4**A and **4**B respectively show top and cross-sectional side views of the flexible electronic device **48'** after the first additive layer **24** is unrolled from a roll **30** and positioned over the substrate layer **12**. In this process, the apertures **26'**, **28'** in the first additive layer **24** are aligned with the respective components **18**, **20**. As shown in FIGS. **4**A and **4**B, the planar cross-sections of the components **18**, **20** are smaller than the respective apertures **26'**, **28'**. As a result, there are gaps between the electronic components **18**, **20** and the sidewalls of the apertures **26'**, **28'**, as denoted by the parameters x_1, y_1, x_2, y_2 in FIGS. **4**A and **4**B. As explained above, the gaps between the components **18**, **20** and the sidewalls of the apertures **26'**, **28'** assist in sliding the first additive layer **24** over the electronic components **18**, **20** to create a laminate structure between the substrate and the first additive layer **24**. In some embodiments, both the parameters x_1 and y_1 are less than or equal to 0.1 mm (i.e. the gap between a respective sidewalls of the aperture **26'** and a respective edge of the electronic component **18** is less than 0.1 mm). In some embodiments, both the parameters x_2 and y_2 are less than or equal to 0.1 mm (i.e. the gap between a respective sidewall of the aperture **28'** and a respective edge of the electronic component **20** is less than 0.1 mm).

In some embodiments, as shown in FIG. **4**B, the thickness of the first flexible additive layer **24** corresponds to a thickness of the electronic component **18**. This results in a top surface of the flexible additive layer **24** being flush with a top surface of the electronic component **18**. This may be done so that a majority of the flexible electronic device **48'** has a relatively same thickness. For example, as shown in FIG. **4**B, portions of the flexible electronic device **48'** that overlap with the first flexible additive layer **24** has a same thickness of portions of the flexible electronic device **48'** that overlap with the electronic component **18**.

FIG. **5** shows a cross-sectional side view of the flexible electronic device **48"** after the third stage of the automated manufacturing process shown in FIG. **1** in which the second flexible additive layer **40** is unrolled from a roll **42** and positioned over the first additive layer **24**. The flexible electronic device **48** is the same as the flexible electronic device **48'** shown in FIG. **4**B but with the addition of the second flexible additive layer **40**. In this process, the aperture **28"** in the second additive layer **40** is aligned with the component **20**. As shown in FIG. **5**, the planar cross-section of the electronic component **20** is smaller than the respective aperture **28"**. As a result, there are gaps between the electronic component **20** and the sidewalls of the aperture **28"**. As explained above, the gaps between the component **20** and the sidewalls of the aperture **28"** assist in sliding the second additive layer **40** over the electronic component **20** to create a laminate structure between the first additive layer **24** and the second additive layer **40**. In some embodiments, a gap between an edge of the component **20** and a respective sidewall of the aperture **28"** is less than or equal to 0.1 mm.

In some embodiments, as shown in FIG. **5**, the thickness of the second flexible additive layer **40** corresponds to a thickness of the electronic component **20** and a thickness of the first flexible additive layer **24**. In one example, as illustrated in FIG. **5**, the sum of the thicknesses of the first flexible additive layer **24** and the second flexible additive layer **40** correspond to a thickness of the electronic component **20**. This results in a top surface of the second flexible additive layer **40** being flush with a top surface of the electronic component **20**. This may be done so that a majority of the flexible electronic device **48"** has a relatively same thickness. For example, as shown in FIG. **5**, portions of the flexible electronic device **48"** that overlap with the second flexible additive layer **40** has a same thickness of portions of the flexible electronic device **48"** that overlap with the electronic component **20**.

FIG. **6** shows a cross-sectional side view of the flexible electronic device **48'''** after the fourth stage of the automated manufacturing process shown in FIG. **1** in which the flexible cover layer **46** is unrolled from a roll **44** and positioned over the second additive layer **40** to complete the flexible electronic devices. The flexible electronic device **48'''** is the same as the flexible electronic device **48"** shown in FIG. **5** but with the addition of the flexible cover layer **46**. In the illustrated embodiment, the resulting continuous flexible laminate electronic device segments are completed sequentially and taken up on the roll **16** (see FIG. **1**).

The embodiments described above are examples of a low-cost, roll-to-roll, additive and layer-based method of fabricating an elongated flexible structure having segments with embedded electronic devices. In particular, the roll-to-roll additive layer-based manufacturing method involves layering a series of material layers (typically plastic) to build up a thickness that matches height profiles of the embedded electronic components to produce an elongated flexible tape-like laminate structure of substantially uniform thickness with segments containing embedded electronics.

One aspect of achieving a low-cost flexible device is to minimize the number of layers needed to construct a planar tape-like laminate structure. In some low complexity embodiments (e.g., embodiments with a relatively small set of feature heights), it may be possible to empirically derive a set of feature heights that corresponds to a low-cost solution. For example, with a small set of feature heights, one can empirically determine a set of height differences that achieves the fewest number of additive layers that results in a substantially uniform tape-like laminate structure. For more complex embodiments, an optimization algorithm typically is needed to determine a low-cost solution.

FIG. **7** shows an embodiment of a computer-implemented method of fabricating a specification of a flexible electronic device. In accordance with this method, feature heights are obtained from a received computer aided design (CAD) specification of the arrangement of the electronic components and other features to be incorporated in the flexible tape-like laminate structure (FIG. **7**, block **60**). In some embodiments, the feature heights are received alongside the CAD specification. In other embodiments, the feature heights are determined based on the received CAD specification.

A number of flexible additive layers and a respective set of thicknesses for the flexible additive layers is determined (FIG. **7**, block **62**) based on the obtained feature heights. In some embodiments, the flexible additive layer thicknesses are determined by calculating height differences between each pair of feature heights obtained from the CAD specification. A preliminary set of the flexible additive layer thickness includes all of the feature heights and all of the feature height differences. An optimization program is run on the preliminary set of the flexible additive layer thicknesses, which is a nonlinear combinatorial problem. In some embodiments, the optimization program runs an exhaustive or brute-force search algorithm for the smallest set of the flexible additive layer thicknesses subject to a specified tolerance level (e.g., 0.1 mm). In other embodiments, an evolutionary algorithm is used to solve the nonlinear combinatorial optimization problem. For example, a genetic evolutionary algorithm may be used for layer stacking sequence optimization. A differential evolution algorithm also may be used to determine an optimized stack-up sequence of laminate composite structures, according to some embodiments.

After the set of thicknesses for the flexible additive layers has been determined, the electronic components are attached to a flexible substrate (FIG. **7**, block **64**). A first additive layer with apertures is dispensed with the apertures aligned with respective electronic components attached to the flexible substrate (FIG. **7**, block **66**). A next additive layer is dispensed over the preceding additive layer with the apertures in the next additive layer aligned with respective electronic components attached to the flexible substrate that protrude past the preceding additive layer (FIG. **7**, block **68**). If there are addition additive layers to dispense (FIG. **7**, block **70**), the process returns to block **68** to dispense a next additive layer over the preceding additive layer (FIG. **7**, block **68**). Otherwise, the process advances to the step of attaching a cover layer over the preceding additive layer (FIG. **7**, block **72**). After the cover layer is attached over the preceding additive layer, the process ends (FIG. **7**, block **74**). In some embodiments, the flexible electronic device is gathered into a roll after the cover layer is attached (FIG. **7**, block **74**). In other embodiments, the flexible electronic device is cut into segments, resulting in a plurality of flexible electronic device segments.

Exemplary Computer Apparatus

FIG. **8** shows an example embodiment of a computer apparatus **500** that is configured to implement one or more of the systems described in this specification. In some embodiments, an embodiment of the computer apparatus **500** executes steps of the automatic manufacturing process described above, with respect to FIGS. **1** and **7**. The computer apparatus **500** includes a processing unit **502**, a system memory **504**, and a system bus **506** that couples the processing unit **502** to the various components of the computer apparatus **500**. The processing unit **502** may include one or more data processors, each of which may be in the form of any one of various commercially available computer processors. The system memory **504** includes one or more computer-readable media that typically are associated with a software application addressing space that defines the addresses that are available to software applications. The system memory **504** may include a read only memory (ROM) that stores a basic input/output system (BIOS) that contains start-up routines for the computer apparatus **500**, and a random access memory (RAM). The system bus **506** may be a memory bus, a peripheral bus or a local bus, and may be compatible with any of a variety of bus protocols, including PCI, VESA, Microchannel, ISA, and EISA. The computer apparatus **500** also includes a persistent storage memory **508** (e.g., a hard drive, a floppy drive, a CD ROM drive, magnetic tape drives, flash memory devices, and digital video disks) that is connected to the system bus **506** and contains one or more computer-readable media disks that provide non-volatile or persistent storage for data, data structures and computer-executable instructions.

A user may interact (e.g., input commands or data) with the computer apparatus **500** using one or more input devices **430** (e.g. one or more keyboards, computer mice, microphones, cameras, joysticks, physical motion sensors, and touch pads). Information may be presented through a graphical user interface (GUI) that is presented to the user on a display monitor **432**, which is controlled by a display controller **434**. The computer apparatus **500** also may include other input/output hardware (e.g., peripheral output devices, such as speakers and a printer). The computer apparatus **500** connects to other network nodes through a network adapter **436** (also referred to as a "network interface card" or NIC).

A number of program modules may be stored in the system memory **504**, including application programming interfaces **448** (APIs), an operating system (OS) **440** (e.g., the Windows® operating system available from Microsoft Corporation of Redmond, Washigton U.S.A.), software applications **441** including one or more software applications programming the computer apparatus **500** to perform one or more of the steps, tasks, operations, or processes of the hierarchical classification systems described herein, drivers **442** (e.g., a GUI driver), network transport protocols **444**, and data **446** (e.g., input data, output data, program data, a registry, and configuration settings).

Examples of the subject matter described herein, including the disclosed systems, process, processes, functional operations, and logic flows, can be implemented in data processing apparatus (e.g., computer hardware and digital electronic circuitry) operable to perform functions by operating on input and generating output. Examples of the subject matter described herein also can be tangibly embodied in software or firmware, as one or more sets of computer instructions encoded on one or more tangible non-transitory carrier media (e.g., a machine readable storage device, substrate, or sequential access memory device) for execution by data processing apparatus.

Exemplary Adhesive Tape Platform

FIGS. **9**A and **9**B show an example adhesive tape platform **900** that is fabricated according to the automated manufacturing processes described above, with respect to FIGS. **1-7**. The example of the adhesive tape platform **900** is a wireless communication and sensing device that also has the functionality and form factor of an adhesive tape which can seal items and adhere to items. As illustrated in FIG. **9**A, the adhesive tape platform is a flexible electronic device which has been gathered into a roll **916** according to the process shown in FIG. **1**.

FIG. **9**A shows an example asset **901** that is sealed for shipment using an example adhesive tape platform **900** that includes embedded components of a wireless transducing circuit **914** (collectively referred to herein as a "tape node"). In this example, a segment **913** of the adhesive tape platform **900** is dispensed from a roll **916** and affixed to the asset **901**. The adhesive tape platform **900** includes an adhesive side **918** and a non-adhesive side **920**. The adhesive tape platform **900** can be dispensed from the roll **916** in the same way as any conventional packing tape, shipping tape, or duct tape. For example, the adhesive tape platform **900** may be dispensed from the roll **916** by hand, laid across the seam where the two top flaps of the asset **901** meet, and cut to a suitable length either by hand or using a cutting instrument (e.g., scissors or an automated or manual tape dispenser). Examples of such tapes include tapes having non-adhesive sides **920** that carry one or more coatings or layers (e.g., colored, light reflective, light absorbing, and/or light emitting coatings or layers).

Referring to FIG. **9**B, in some examples, the non-adhesive side **920** of the segment **913** of the adhesive tape platform **900** includes writing or other markings that convey instructions, warnings, or other information to a person or machine (e.g., a bar code reader), or may simply be decorative and/or entertaining. For example, different types of adhesive tape platforms may be marked with distinctive colorations to distinguish one type of adhesive tape platform from another. In the illustrated example, the segment **913** of the adhesive tape platform **900** includes a two-dimensional bar code (e.g., a QR Code) **922**, written instructions **924** (i.e., "Cut Here") and an associated cut line **926** that indicates where the user should cut the adhesive tape platform **900**. The written instructions **924** and the cut line **926** typically are printed or otherwise marked on the top non-adhesive side **920** of the adhesive tape platform **900** during manufacture, for example, after the step of adding the flexible cover layer (FIG. **7**, block **72**). The two-dimensional bar code **922**, on the other hand, may be marked on the non-adhesive side **920** of the adhesive tape platform **900** during the manufacture of the adhesive layer **918** or, alternatively, may be marked on the non-adhesive side **920** of the adhesive tape platform **900** as needed using, for example, a printer or other marking device.

In order to avoid damage to the functionality of the segments of the adhesive tape platform **900**, the cut lines **926** typically demarcate the boundaries between adjacent segments at locations that are free of any active components of the wireless transducing circuit **914**. The spacing between components of the wireless transducing circuit **914** and the cut lines **926** may vary depending on the intended communication, transducing, and/or adhesive taping application. In the example illustrated in FIG. **9**A, the length of the adhesive tape platform **900** that is dispensed to seal the asset **901** corresponds to a single segment **913** of the adhesive tape platform **900**. In other examples, the length of the adhesive tape platform **900** needed to seal an asset or otherwise serve the adhesive function for which the adhesive tape platform **900** is being applied may include multiple segments **913** of the adhesive tape platform **900**, one or more of which segments **913** may be activated upon cutting the length of the adhesive tape platform **900** from the roll **916** and/or applying the length of the adhesive tape platform to the asset **901**.

In some examples, components of the wireless transducing circuit **914** that are embedded in one or more segments **913** of the adhesive tape platform **900** are activated when the adhesive tape platform **900** is cut along the cut line **926**. In these examples, the adhesive tape platform **900** includes one or more embedded energy sources (e.g., thin film batteries, which may be printed, or conventional cell batteries, such as conventional watch style batteries, rechargeable batteries, or other energy storage devices, such as a super capacitor or charge pump) that supply power to components of the wireless transducing circuit **914** in one or more segments of the adhesive tape platform **900** in response to being separated from the adhesive tape platform **900** (e.g., along the cut line **926**).

In some examples, each segment **913** of the adhesive tape platform **900** includes its own respective energy source including energy harvesting elements that can harvest energy from the environment. In some of these examples, each energy source is configured to only supply power to the components in its respective adhesive tape platform segment regardless of the number of contiguous segments **913** that are in a given length of the adhesive tape platform **900**. In other examples, when a given length of the adhesive tape platform **900** includes multiple segments **913**, the energy sources in the respective segments **913** are configured to supply power to components of the wireless transducing circuit **914** in all of the segments **913** in the given length of the adhesive tape platform **900**. In some of these examples, the energy sources are connected in parallel and concurrently activated to power components of the wireless transducing circuit **914** in all of the segments **913** at the same time. In other examples, the energy sources are connected in parallel and alternately activated to power components of the wireless transducing circuit **914** in respective ones of the adhesive tape platform segments **913** at different time periods, which may or may not overlap.

FIG. **10** shows a block diagram of the components of an example wireless transducing circuit **1000** that includes a number of communication systems **1012**, **1014**. Wireless transducing circuit **1000** is an example of wireless transducing circuit **914**, discussed above. Components of the wireless transducing circuit **1000** may be embodiments of the electronic components **18**, **20** discussed above with respect to FIGS. **1-7**. Example communication systems **1012**, **1014** include a GPS system that includes a GPS receiver circuit **1013** (e.g., a receiver integrated circuit) and a GPS antenna **1015**, and one or more wireless communication systems each of which includes a respective transceiver circuit **1016** (e.g., a transceiver integrated circuit) and a respective antenna **108**. Example wireless communication systems include a cellular communication system (e.g., GSM/GPRS), a Wi-Fi communication system, an RF communication system (e.g., LoRa), a Bluetooth communication system (e.g., a Bluetooth Low Energy system), a Z-wave communication system, and a ZigBee communication system. The wireless transducing circuit **1000** also includes a processor **1090** (e.g., a microcontroller or microprocessor), one or more energy storage devices **1092** (e.g., non-rechargeable or rechargeable printed flexible battery, conventional single or multiple cell battery, and/or a supercapacitor or charge pump), one or more transducers **1094** (e.g., sensors and/or actuators, and, optionally, one or more energy harvesting transducer components). The one or more transducers **1094** includes at least one sensing transducer, according to some embodiment. In some examples, the conventional single or multiple cell battery may be a watch style disk or button cell battery that is associated electrical connection apparatus (e.g., a metal clip) that electrically connects the electrodes of the battery to contact pads on a flexible circuit. In some embodiments the energy storage **1092** is in the form of a flexible battery layer.

Examples of sensing transducers **1094** (also referred to herein as "sensors") include a capacitive sensor, an altimeter, a gyroscope, an accelerometer, a temperature sensor, a strain sensor, a pressure sensor, a piezoelectric sensor, a weight sensor, an optical or light sensor (e.g., a photodiode or a camera), an acoustic or sound sensor (e.g., a microphone), a smoke detector, a radioactivity sensor, a chemical sensor (e.g., an explosives detector), a biosensor (e.g., a blood glucose biosensor, odor detectors, antibody based pathogen, food, and water contaminant and toxin detectors, DNA detectors, microbial detectors, pregnancy detectors, and ozone detectors), a magnetic sensor, an electromagnetic field sensor, and a humidity sensor. Examples of actuating (e.g., energy emitting) transducers **1094** include light emitting components (e.g., light emitting diodes and displays), electro-acoustic transducers (e.g. audio speakers), electric motors, and thermal radiators (e.g., an electrical resistor or a thermoelectric cooler).

In some examples, the wireless transducing circuit **1000** includes a memory **1096** for storing data, including, e.g., profile data, state data, event data, sensor data, localization data, security data, and one or more unique identifiers (ID) **1098** associated with the wireless transducing circuit **1000**, such as a product ID, a type ID, and a media access control (MAC) ID, and control code **1099**. In some examples, the memory **1096** may be incorporated into one or more of the processor **1090** or transducers **1094**, or may be a separate component that is integrated in the wireless transducing circuit **1000** as shown in FIG. **11**. The control code typically is implemented as programmatic functions or program modules that control the operation of the wireless transducing circuit **1000**, including a tape node communication manager that manages the manner and timing of tape node communications, a tape node power manager that manages power consumption, and a tape node connection manager that controls whether connections with other nodes are secure connections or unsecure connections, and a tape node storage manager that securely manages the local data storage on the node. The tape node connection manager ensures the level of security required by the end application and supports various encryption mechanisms. The tape node power manager and tape communication manager work together to optimize the battery consumption for data communication. In some examples, execution of the control code by the different types of tape nodes described herein may result in the performance of similar or different functions.

FIG. **11** is a top view of a generic platform **1032** for the wireless transducing circuit **1000**, according to some embodiments. The platform (also referred to as a "tape node," herein) includes a respective set of the components of the wireless transducing circuit **100**. The tape node **1032** may be fabricated according to the automated manufacturing process described above, with respect to FIGS. **1-6**. In some embodiments, the tape node **1032** is a single segment of a flexible electronic device that has been cut from a roll gathering a larger length of the flexible electronic device (see FIG. **1**). In some embodiments, multiple platforms contain respective sets of components that are identical and configured in the same way. In some other embodiments, however, multiple platforms contain respective sets of components that are different and/or configured in different ways. For example, different ones of the platforms **1032** have different sets or configurations of tracking and/or transducing components that are designed and/or optimized for different applications. Alternatively, different sets of segments of the platform **1032** may have different ornamentations (e.g., markings on the exterior surface of the platform) and/or different dimensions.

The details of specific implementations described herein may be specific to particular embodiments of particular inventions and should not be construed as limitations on the scope of any claimed invention. For example, features that are described in connection with separate embodiments may also be incorporated into a single embodiment, and features that are described in connection with a single embodiment may also be implemented in multiple separate embodiments. In addition, the disclosure of steps, tasks, operations, or processes being performed in a particular order does not necessarily require that those steps, tasks, operations, or processes be performed in the particular order; instead, in some cases, one or more of the disclosed steps, tasks, operations, and processes may be performed in a different order or in accordance with a multi-tasking schedule or in parallel.

Other embodiments are within the scope of the claims.

Additional Configuration Information

The foregoing description of the embodiments of the disclosure have been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

Some portions of this description describe the embodiments of the disclosure in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In one embodiment, a software module is implemented with a computer program product comprising a computer-readable medium containing computer program code, which can be executed by a computer processor for performing any or all of the steps, operations, or processes described.

Embodiments of the disclosure may also relate to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, and/or it may comprise a general-purpose computing device selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a non-transitory, tangible computer readable storage medium, or any type of media suitable for storing electronic instructions, which may be coupled to a computer system bus. Furthermore, any computing systems referred to in the specification may include a single processor or may be architectures employing multiple processor designs for increased computing capability.

Embodiments of the disclosure may also relate to a product that is produced by a computing process described herein. Such a product may comprise information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the disclosure be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments is intended to be illustrative, but not limiting, of the scope of the disclosure, which is set forth in the following claims.

What is claimed is:

1. A flexible laminate electronic device comprising:

a flexible substrate comprising a flexible circuit electrically connecting a plurality of electronic components attached to the flexible substrate;

a first flexible additive layer on the flexible substrate and comprising apertures, wherein each of the plurality of electronic components are aligned in a respective aperture of the apertures and wherein a top surface of the first flexible additive layer is flush with a top surface of each electronic component of a first set of the plurality of electronic components;

a subsequent flexible additive layer on the first flexible additive layer and covering the first set of the plurality of electronic components, the subsequent flexible additive layer comprising apertures aligned around respective portions of a second set of the plurality of electronic components protruding above the first flexible additive layer from the flexible substrate, wherein a thickness of the subsequent flexible additive layer corresponds to a difference between a thickness of a second set of the plurality of electronic components and a thickness of the first flexible additive layer; and

a flexible cover layer on the subsequent flexible additive layer and covering the plurality of electronic components.

2. The flexible laminate electronic device of claim **1**, further comprising one or more other successive flexible additive layers on the subsequent flexible additive layer and under the flexible cover layer, the other successive flexible additive layers comprising one or more apertures aligned around respective portions of ones of the electric components protruding above preceding ones of the flexible additive layers.

3. The flexible laminate electronic device of claim **1**, the plurality of electronic components comprising:

a processor;

a memory or storage device; and

a battery.

4. The flexible laminate electronic device of claim **3**, wherein the battery comprises a flexible battery.

5. The flexible laminate electronic device of claim **1**, wherein a first thickness of the first flexible additive layer corresponds to a height of at least one electronic component of the plurality of electronic components.

6. The flexible laminate electronic device of claim **5**, wherein the subsequent flexible additive layer covers the at least one electronic component and covers an aperture of the first flexible additive layer aligned with the at least one electronic component.

7. The flexible laminate electronic device of the claim **1**, wherein a top surface of the subsequent flexible additive layer is flush with a top surface of each electronic component of the second set of the plurality of electronic components.

8. The flexible laminate electronic device of claim **1**, wherein a first thickness of the first flexible additive layer equals a first height of a first electronic component of the plurality of electronics components.

9. The flexible laminate electronic device of claim **1**, wherein a first thickness of the first flexible additive layer is greater than or equal to the heights of multiple electronic components of the plurality of electronic components.

10. The flexible laminate electronic device of claim **1**, wherein a first width of a first aperture of the first flexible additive layer is greater than a first width of a first electronic component of the plurality of electronic components.

11. The flexible laminate electronic device of claim **1**, further comprising a flexible polymer layer on the subsequent flexible additive layer, the flexible polymer layer adhering the flexible cover layer to the subsequent flexible additive layer.

12. The flexible laminate electronic device of claim **11**, wherein the flexible polymer layer planarizes a section of the flexible laminate electronic device comprising a region where one of the electronic components of the plurality of electronic components is positioned.

13. The flexible laminate electronic device of claim **1**, further comprising at least one of an adhesive layer on a bottom surface of the flexible substrate or on a top surface of the flexible cover layer.

14. The flexible laminate electronic device of claim **1**, wherein the apertures of the subsequent flexible additive layer are aligned to overlap with a subset of the apertures of the first flexible additive layer.

15. A flexible electronic device, comprising:

a flexible substrate comprising a flexible circuit electrically connecting a plurality of electronic components;

a first flexible additive layer on the flexible substrate and comprising apertures, the first flexible additive layer comprising a first thickness, wherein a first electronic component of the plurality of electronic components is aligned with a first aperture of the apertures and wherein a top surface of the first flexible additive layer is flush with a top surface of a second electronic component of the plurality of the electronic components;

a second flexible additive layer on the flexible substrate comprising apertures, the second flexible additive layer having a second thickness, wherein the first electronic component and the first aperture are both aligned with a second aperture of the second flexible additive layer's apertures; and

a flexible cover layer on the second flexible additive layer, wherein

a sum of the first thickness and the second thickness corresponds to a height of the first electronic component of the plurality of electronic components, and

a thickness of the flexible electronic device at a location overlapping the first electronic component equals a thickness of the flexible electronic device at a location overlapping the second electronic component.

16. The flexible electronic device of claim **15**,

wherein the second electronic component is on the flexible substrate and aligned with a third aperture of the first flexible additive layer, and the second electronic component and the third aperture are not aligned with any of the apertures of the second flexible additive layer.

17. The flexible electronic device of claim **16**, wherein the first thickness corresponds to a height of the second electronic component.

18. The flexible electronic device of claim **16**, wherein a height of the second electronic component is less than a height of the first component.

19. The flexible electronic device of claim **16**, wherein the second flexible additive layer covers the second electronic component and covers the third aperture of the first flexible additive layer.

20. The flexible electronic device of claim **15**, wherein the second thickness is greater than the first thickness.

21. The flexible electronic device of claim **15**, wherein the second thickness is less than the first thickness.

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