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SEMICONDUCTOR DEVICE WITH EMBEDDED BATTERY AND METHOD THEREFOR

Abstract

A method of manufacturing a packaged semiconductor device is provided. The method includes affixing a sensor system to a die pad portion of a leadframe. A battery is affixed to the lead frame including a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe. An encapsulant encapsulates the sensor system, battery, and leadframe.

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Background/Summary

BACKGROUND

Field

[0001] This disclosure relates generally to semiconductor devices, and more specifically, to semiconductor devices with an embedded battery and method of forming the same.

Related Art

[0002] Semiconductor devices are often found in a large spectrum of electronic products—from sewing machines to washing machines, from automobiles to cellular telephones, and so on. Many of these semiconductor devices may include sensitive systems and may be produced in high volumes to drive costs down. However, some factors such as manufacturing processes may be optimized for product costs but could adversely affect or constrain applications using these semiconductor devices. It is therefore desirable, as technology progresses, to accommodate flexible and less constrained applications of these semiconductor devices while keeping product costs in focus.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The present invention is illustrated by way of example and is not limited by the accompanying figures, in which like references indicate similar elements. Elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale.

[0004] FIG. 1 illustrates, in a simplified plan view, an example semiconductor device having an embedded battery at a stage of manufacture in accordance with an embodiment.

[0005] FIG. 2 and FIG. 3 illustrate, in simplified side-on cross-sectional views, the example semiconductor device at stages of manufacture in accordance with an embodiment.

DETAILED DESCRIPTION

[0006] Generally, there is provided, a semiconductor device having an embedded battery. The semiconductor device includes one or more semiconductor die mounted on a package leadframe along with a battery mounted on the leadframe. The one or more semiconductor die, battery, and leadframe are encapsulated with an encapsulant. In a self-contained manner, the semiconductor device is configured to operate using the battery as its power source. The semiconductor device is further configured to communicate wirelessly with an external device. The self-contained semiconductor device configured with wireless communication capability is especially useful for sensor systems, for example. In this manner, a self-contained, self-powered sensor system could be placed virtually anywhere.

[0007] FIG. 1 illustrates, in a simplified plan view, an example semiconductor device **100** having an embedded battery at a stage of manufacture in accordance with an embodiment. At this stage, the semiconductor device **100** includes a sensor system **130**, a battery **124**, and components **126**, **128** mounted on a package leadframe **108**. In this embodiment, the sensor system **130** is affixed to a die pad portion **116** of the leadframe **108** and the battery **124** is affixed to power legs **110**, **112** of the leadframe **108**. The term leg of the leadframe, as used herein, generally refers to a portion of the package leadframe suitable for connection of a bond wire and/or an internal component

terminal (e.g., battery **124** and components **126**, **128** terminals). Simplified side-on cross-sectional views of the example semiconductor device **100** taken are shown in stages of manufacture depicted in FIG. 2 and FIG. 3.

[0008] The sensor system **130** includes a controller subsystem **102**, a wireless communication subsystem **106**, and a sensor **104**. The sensor system **130** is configured to sense environmental conditions, changes, and/or events and wirelessly communicate information based on the sensed conditions, changes, and/or events. In this embodiment, the controller subsystem **102** includes circuitry configured to control functions of the sensor system **130** such as monitoring the sensor **104** and sending and/or receiving signals by way of the communication subsystem **106**. The sensor system **130** may be implemented as a single system-on-chip (SoC) semiconductor die or may be implemented as a plurality of semiconductor die (e.g., one die per subsystem).

[0009] In this embodiment, the controller subsystem **102** is formed as a semiconductor die **102** mounted on a die pad portion **116** of the leadframe **108**. The sensor **104** is formed as a micro-electromechanical system (MEMS) semiconductor die **104** mounted on the first semiconductor die **102** and the communication subsystem **106** is formed as a semiconductor die **106** mounted on the die pad portion **116** of the leadframe. In this embodiment, bond wires **118** interconnect the bond pads of the semiconductor die **102** with the leadframe **108**, bond wires **120** interconnect the bond pads of the semiconductor die **102** with the bond pads of the sensor **104**, and bond wires **122** interconnect bond pads of the semiconductor die **102** with the bond pads of the communication semiconductor die **106**. The number, location, and arrangement of bond pads and interconnectivity formed by bond wires **118-122** are examples chosen for illustration purposes. For discussion purposes herein, the term “controller die **102**” may be used interchangeably with the controller subsystem **102** and the semiconductor die **102**. Likewise, the term “sensor die **104**” may be used interchangeably with the sensor **104** and the MEMS semiconductor die **104**, and the term “communication die **106**” may be used interchangeably with the communication subsystem **106** and the semiconductor die **106**.

[0010] The controller subsystem **102** is coupled to the sensor **104** and the communication subsystem **106**. The controller subsystem **102** may include circuitry configured to monitor one or more output signals from the sensor **104** and based on the one or more output signals, send communication signals (e.g., alerts, status indications, data) by way of the communication subsystem **106**. The controller subsystem **102** may further include circuitry configured to receive communication signals (e.g., commands, information) by way of the communication subsystem **106**. The controller die **102** has an active side (e.g., major side having circuitry, bond pads) and a backside (e.g., major side opposite of the active side). The controller die **102** includes bond pads located at the active side of the semiconductor die. The controller die **102** may be formed from any suitable semiconductor material, such as silicon, germanium, gallium arsenide, gallium nitride, and the like. In addition to the controller subsystem, the controller die **102** may further include any digital circuits, analog circuits, RF circuits, memory, processor, the like, and combinations thereof at the active side.

[0011] The sensor **104** is coupled to the controller subsystem **102** and the communication subsystem **106**. The sensor **104** may include any suitable sensor such as an accelerometer, pressure sensor, temperature sensor, etc. The sensor die **104** has an active side (e.g., major side having circuitry, bond pads) and a backside (e.g., major side opposite of the active side). The sensor die **104** includes bond pads located at the active side of the die. The sensor of the sensor die **104** may include one or more micromachined devices. The sensor die **104** may be formed from any suitable semiconductor material, such as silicon, germanium, gallium arsenide, gallium nitride, and the like. In addition to the sensor, the sensor die **104** may further include any digital circuits, analog circuits, RF circuits, memory, processor, the like, and combinations thereof at the active side.

[0012] The communication subsystem **106** is coupled to the controller subsystem **102** and the sensor **104**. The communication subsystem **106** may include circuitry configured as a transmitter,

receiver, or transceiver sufficient to communicate wirelessly with an external device separate from the semiconductor device **100**. For example, the communication subsystem **106** may communicate information based on an output signal of the sensor **104** of the sensor system **130**. The communication subsystem **106** may further include an antenna. The communication subsystem **106** may be configured for one or more suitable wireless communication protocols (e.g., Bluetooth, Zigbee, Z-Wave, IoT, Wi-Fi, cellular). The communication die **106** has an active side (e.g., major side having circuitry, bond pads) and a backside (e.g., major side opposite of the active side). The communication die **106** includes bond pads located at the active side of the die. The communication die **106** may be formed from any suitable semiconductor material, such as silicon, germanium, gallium arsenide, gallium nitride, and the like. In addition to the communication subsystem, the communication die **106** may further include any digital circuits, analog circuits, RF circuits, memory, processor, the like, and combinations thereof at the active side. In some embodiments, the communication subsystem may be incorporated within the controller die **102** and the communication die **106** may serve as an antenna.

[0013] The leadframe **108** includes power legs **110** and **112**, signal leg **114**, and die pad portion **116**. The power legs **110** and **112** of the leadframe **108** are configured for connection of an internal power source (e.g., battery **124**). In this embodiment, the power leg **112** may be characterized as a ground power leg or ground leg **112** of the leadframe **108**. The leadframe **108** may be formed from any suitable metal materials, such as copper, nickel, aluminum, iron, or alloys thereof, for example. The leadframe **108** may be bare, partially plated, or plated with another metal or alloy. In this embodiment, the power legs **110** and **112**, signal leg **114**, and die pad portion **116** are all self-contained when encapsulated. Portions of the leadframe **108** such as tie bars and dam bars discarded during package singulation not shown for illustration purposes.

[0014] The battery **124** may be characterized as a surface mount battery including terminals configured for attachment to the power legs **110** and **112** of the leadframe **108**. In this embodiment, the negative terminal (−) of the battery **124** is connected to the power (e.g., ground) leg **112** and die pad portion **116** and the positive terminal (+) of the battery **124** is connected to the power leg **110**. The battery **124** may be formed as a single cell or plurality of cells configured to provide a predetermined nominal voltage and current capacity (e.g., 1.5 volts and 100 microampere-hours). In this embodiment, the battery **124** is configured to supply an operating voltage and current to the sensor system **130** sufficient for the semiconductor device **100** to operate in a self-contained manner over a predetermined period of time. The battery **124** may be formed from any suitable materials and chemistries.

[0015] The components **126** and **128** may be characterized as surface mount passive components (e.g., resistor, capacitor, inductor, diode) including terminals configured for attachment to the leadframe **108**. In this embodiment, the component **126** (e.g., bypass capacitor) is attached between the power legs **110** and **112** and the component **128** (e.g., signal termination resistor) is attached between the signal leg **114** and the power leg **112**. The number, type, and location of surface mount passive components are examples chosen for illustrative purposes.

[0016] FIG. 2 and FIG. 3 illustrate, in simplified side-on cross-sectional views, the example semiconductor device **100** at stages of manufacture in accordance with an embodiment.

[0017] FIG. 2 illustrates, in a simplified side-on cross-sectional view, the example semiconductor device **100** at a stage of manufacture in accordance with an embodiment. At this stage, the semiconductor device **100** includes the sensor system **130**, battery **124**, and components **126**, **128** mounted on the package leadframe **108**. In this embodiment, the semiconductor die **102** of the sensor system **130** is mounted on the die pad portion of the leadframe **108** in an active-side-up orientation. For example, the backside of the semiconductor die **102** is attached to top side of the die pad portion by way of a die attach material **202**. Likewise, the semiconductor die **106** of the sensor system **130** is mounted on the die pad portion of the leadframe **108** in an active-side-up orientation with the backside of the semiconductor die **106** attached to top side of the die pad

portion by way of a die attach material **206**. In this embodiment, the sensor die **104** is mounted on the active side of the semiconductor die **102** in an active-side-up orientation with the backside of the sensor die **104** attached to active side of the semiconductor die **102** by way of a die attach material **204**. In this embodiment, the die attach materials **202** and **206** may be characterized as a conductive die attach material and the die attach material **204** may be characterized as a non-conductive die attach material. For example, die attach materials **202** and **206** may be formed as a silver-filled epoxy, solder paste, or conductive DAF and the die attach material **204** may be formed as a non-conductive epoxy or DAF. In other embodiments, other die attach materials and methods may be utilized. The term conductive, as used herein, generally refers to the property of electrical conductivity.

[0018] In the embodiment of FIG. 2, the positive terminal (+) of the battery **124** is conductively attached to the power leg **110** of the leadframe **108** by way of a conductive attachment material **208**. Similarly, a first terminal of the component **128** is conductively attached to the power leg **112** of the leadframe **108** and a second terminal of the component **128** is conductively attached to the signal leg **114** of the leadframe **108** by way of conductive attachment material **210**. In this embodiment, the die attach materials **208** and **210** may be characterized as conductive die attach materials such as silver-filled epoxy, solder paste, conductive DAF, or the like. It may be desirable to utilize a common attachment material for affixing the semiconductor die, battery terminals, and component terminals to the leadframe. In this manner, the assembly process can be streamlined and thus, reduce costs.

[0019] After the sensor system **130**, battery **124**, and components **126**, **128** are mounted on the package leadframe **108**, the semiconductor die **102**, sensor **104**, and semiconductor die **106** of the sensor system **130** are interconnected with one another and the leadframe **108** by way of bond wires **118-122**. For example, a first set of bond pads (not shown) of the semiconductor die **102** are conductively connected to the leadframe **108** by way of bond wires **118**. Likewise, a second set of bond pads (not shown) of the semiconductor die **102** are conductively connected to the sensor **104** by way of bond wires **120**, and a third set of bond pads (not shown) of the semiconductor die **102** are conductively connected to the semiconductor die **106** by way of bond wires **122**. The bond wires **118-122** may be formed from a suitable metal material such as copper, silver, gold, or alloys thereof, for example. The number, location, and arrangement of bond wires **118-122** depicted in FIG. 2 are examples chosen for illustration purposes. bond wires **120** are configured to interconnect

[0020] FIG. 3 illustrates, in a simplified side-on cross-sectional view, the example semiconductor device **100** at a subsequent stage of manufacture in accordance with an embodiment. At this stage, the semiconductor device **100** is encapsulated and singulated. In this embodiment, the semiconductor device **100** includes an encapsulant **302** encapsulating the sensor system **130**, battery **124**, components **126**, **128**, and package leadframe **108**. The encapsulant **302** may be an epoxy molding compound dispensed during an injection molding encapsulation operation, for example. After the molding operation, the semiconductor device **100** is singulated (e.g., trimmed) from remaining portions of a leadframe strip (e.g., tie bars) which may extend through and outside of the encapsulant. In this embodiment, no portion of the leadframe **108** extends outside of the encapsulant for external connectivity.

[0021] In this embodiment, the semiconductor device **100** is configured to form a self-contained sensor system after encapsulation and singulation. For example, the self-contained sensor system of the semiconductor device **100** includes an embedded battery power source configured to supply an operating voltage and current to the sensor system. The embedded battery power source is sufficient for the sensor system **130** of the semiconductor device **100** to operate (e.g., sense, monitor, communicate) in a self-contained manner over a predetermined period of time.

[0022] In some embodiments, an external antenna may be coupled to the sensor system **130** to augment wireless communication. For example, an opening may be formed in the encapsulant **302** such that an external antenna may be affixed to the sensor system **130** in a manner sufficient to

extend the range and/or enhance the quality of the wireless communication capabilities of the sensor system **130**.

[0023] Generally, there is provided, a method of manufacturing a packaged semiconductor device including affixing a sensor system to a die pad portion of a leadframe; affixing a battery to the lead frame, a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe; and encapsulating with an encapsulant the sensor system, battery, and leadframe. The battery may be configured to supply an operating voltage and current to the sensor system. The sensor system may include a wireless communication subsystem configured for communication with an external device separate from the packaged semiconductor device, the communication including an output signal of the sensor system. The affixing the sensor system to the die pad portion may include affixing a semiconductor die to the die pad portion of the leadframe. The method may further include connecting a first bond pad of the semiconductor die to the first leg by way of a first bond wire and connecting a second bond pad of the semiconductor die to the second leg by way of a second bond wire. The sensor system may further include a MEMS sensor affixed to an active side of the semiconductor die. The method may further include, after encapsulating with the encapsulant, trimming to remove portions of the leadframe extending outside of the encapsulant. The second leg may be connected to the die pad portion of the leadframe. The method may further include, before encapsulating with the encapsulant, affixing a passive component to the lead frame, a first terminal of the passive component affixed to the first leg of the leadframe and a second terminal of the passive component affixed to the second leg of the leadframe, the passive component encapsulated by way of the encapsulating with the encapsulant.

[0024] In another embodiment, there is provided, a semiconductor device including a sensor system affixed to a die pad portion of a leadframe; a battery affixed to the lead frame, a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe; and an encapsulant encapsulating the sensor system, battery, and leadframe. The battery may be configured to supply an operating voltage and current to the sensor system. The sensor system may include a wireless communication subsystem configured for communication with an external device separate from the packaged semiconductor device, the communication based on an output signal of the sensor system. The sensor system affixed to the die pad portion may include a semiconductor die affixed to the die pad portion of the leadframe. The semiconductor device may further include a first bond pad of the semiconductor die connected to the first leg by way of a first bond wire and a second bond pad of the semiconductor die connected to the second leg by way of a second bond wire. The encapsulated sensor system, battery, and leadframe may be configured to form a self-contained sensor system.

[0025] In yet another embodiment, there is provided, a method of manufacturing a packaged semiconductor device including affixing a sensor system to a die pad portion of a leadframe; affixing a battery to the lead frame, a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe; and encapsulating with an encapsulant the sensor system, battery, and leadframe to form a self-contained sensor system. The battery may be configured to supply an operating voltage and current to the sensor system. The affixing the sensor system to the die pad portion may include affixing a semiconductor die to the die pad portion of the leadframe. The method may further include connecting a first bond pad of the semiconductor die to the first leg by way of a first bond wire and connecting a second bond pad of the semiconductor die to the second leg by way of a second bond wire. The sensor system may be configured to wirelessly transmit an output signal of the sensor system to an external device separate from the packaged semiconductor device.

[0026] By now it should be appreciated that there has been provided, a semiconductor device having an embedded battery. The semiconductor device includes one or more semiconductor die mounted on a package leadframe along with a battery mounted on the leadframe. The one or more

semiconductor die, battery, and leadframe are encapsulated with an encapsulant. In a self-contained manner, the semiconductor device is configured to operate using the battery as its power source. The semiconductor device is further configured to communicate wirelessly with an external device. The self-contained semiconductor device configured with wireless communication capability is especially useful for sensor systems, for example. In this manner, a self-contained, self-powered sensor system could be placed virtually anywhere.

[0027] Although the invention is described herein with reference to specific embodiments, various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of the present invention. Any benefits, advantages, or solutions to problems that are described herein with regard to specific embodiments are not intended to be construed as a critical, required, or essential feature or element of any or all the claims.

[0028] Furthermore, the terms “a” or “an,” as used herein, are defined as one or more than one. Also, the use of introductory phrases such as “at least one” and “one or more” in the claims should not be construed to imply that the introduction of another claim element by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim element to inventions containing only one such element, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an.” The same holds true for the use of definite articles.

[0029] Unless stated otherwise, terms such as “first” and “second” are used to arbitrarily distinguish between the elements such terms describe. Thus, these terms are not necessarily intended to indicate temporal or other prioritization of such elements.

Claims

1. A method of manufacturing a packaged semiconductor device, the method comprising: affixing a sensor system to a die pad portion of a leadframe; affixing a battery to the lead frame, a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe; and encapsulating with an encapsulant the sensor system, battery, and leadframe.
2. The method of claim 1, wherein the battery is configured to supply an operating voltage and current to the sensor system.
3. The method of claim 1, wherein the sensor system includes a wireless communication subsystem configured for communication with an external device separate from the packaged semiconductor device, the communication including an output signal of the sensor system.
4. The method of claim 1, wherein affixing the sensor system to the die pad portion includes affixing a semiconductor die to the die pad portion of the leadframe.
5. The method of claim 4, further comprising connecting a first bond pad of the semiconductor die to the first leg by way of a first bond wire and connecting a second bond pad of the semiconductor die to the second leg by way of a second bond wire.
6. The method of claim 4, wherein the sensor system further includes a MEM S sensor affixed to an active side of the semiconductor die.
7. The method of claim 1, further comprising, after encapsulating with the encapsulant, trimming to remove portions of the leadframe extending outside of the encapsulant.
8. The method of claim 1, wherein the second leg is connected to the die pad portion of the leadframe.
9. The method of claim 1, further comprising, before encapsulating with the encapsulant, affixing a passive component to the lead frame, a first terminal of the passive component affixed to the first leg of the leadframe and a second terminal of the passive component affixed to the second leg of

the leadframe, the passive component encapsulated by way of the encapsulating with the encapsulant.

10. (canceled)

11. (canceled)

12. (canceled)

13. (canceled)

14. (canceled)

15. (canceled)

16. A method of manufacturing a packaged semiconductor device, the method comprising: affixing a sensor system to a die pad portion of a leadframe; affixing a battery to the lead frame, a first terminal of the battery affixed to a first leg of the leadframe and a second terminal of the battery affixed to a second leg of the leadframe; and encapsulating with an encapsulant the sensor system, battery, and leadframe to form a self-contained sensor system.

17. The method of claim 16, wherein the battery is configured to supply an operating voltage and current to the sensor system.

18. The method of claim 16, wherein affixing the sensor system to the die pad portion includes affixing a semiconductor die to the die pad portion of the leadframe.

19. The method of claim 18, further comprising connecting a first bond pad of the semiconductor die to the first leg by way of a first bond wire and connecting a second bond pad of the semiconductor die to the second leg by way of a second bond wire.

20. The method of claim 16, wherein the sensor system is configured to wirelessly transmit an output signal of the sensor system to an external device separate from the packaged semiconductor device.
