US 20100001382A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2010/0001382 A1**

**Udompanyavit et al.** (43) **Pub. Date: Jan. 7, 2010**

(54) **MANUFACTURING METHOD FOR INTEGRATING A SHUNT RESISTOR INTO A SEMICONDUCTOR PACKAGE**

(75) Inventors: **Ubol Udompanyavit**, Plano, TX (US); **Sreenivasan K. Koduri**, Allen, TX (US); **Gerald William Steele**, Tucson, AZ (US); **Jason Marc Cole**, Sahuarita, AZ (US); **Steven Kummerl**, Carrollton, TX (US)

Correspondence Address:
**TEXAS INSTRUMENTS INCORPORATED**
**P O BOX 655474, M/S 3999**
**DALLAS, TX 75265**

(73) Assignee: **Texas Instruments Incorporated**, Dallas, TX (US)

(21) Appl. No.: **12/165,932**

(22) Filed: **Jul. 1, 2008**

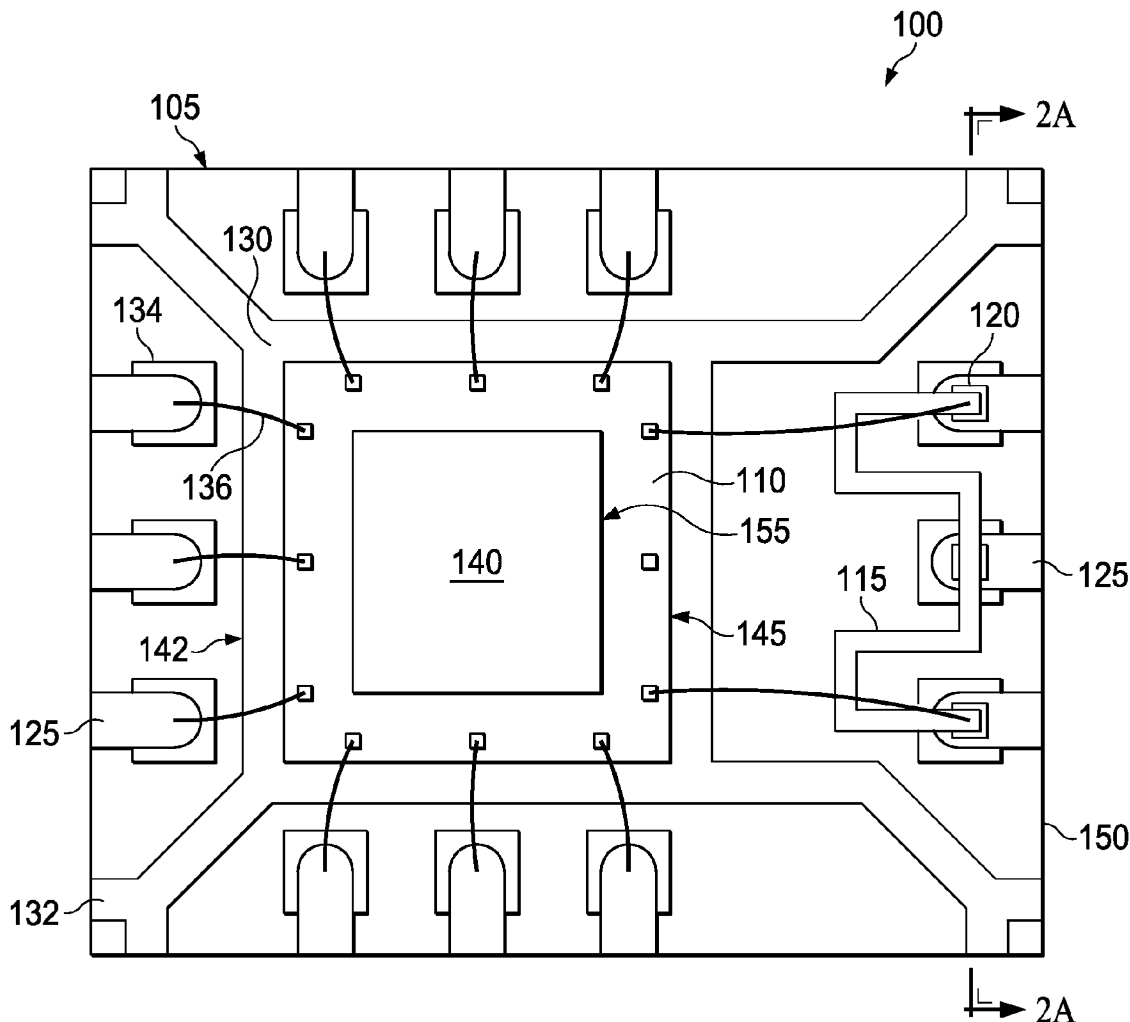
**Publication Classification**

(51) **Int. Cl.**
*H01L 23/495* (2006.01)
*H01L 21/60* (2006.01)

(52) **U.S. Cl.** .................. **257/666**; 438/123; 257/E21.51; 257/E23.031

(57) **ABSTRACT**

An integrated circuit package that comprises a lead frame, an integrated circuit located on the lead frame and a shunt resistor coupled to the lead frame and to the integrated circuit. The shunt resistor has a lower temperature coefficient of resistance than the lead frame, and the lead frame has a lower resistivity than the shunt resistor. The shunt resistor has a low-resistance coupling to external leads of the lead frame, or, the shunt resistor has its own integrated external leads.



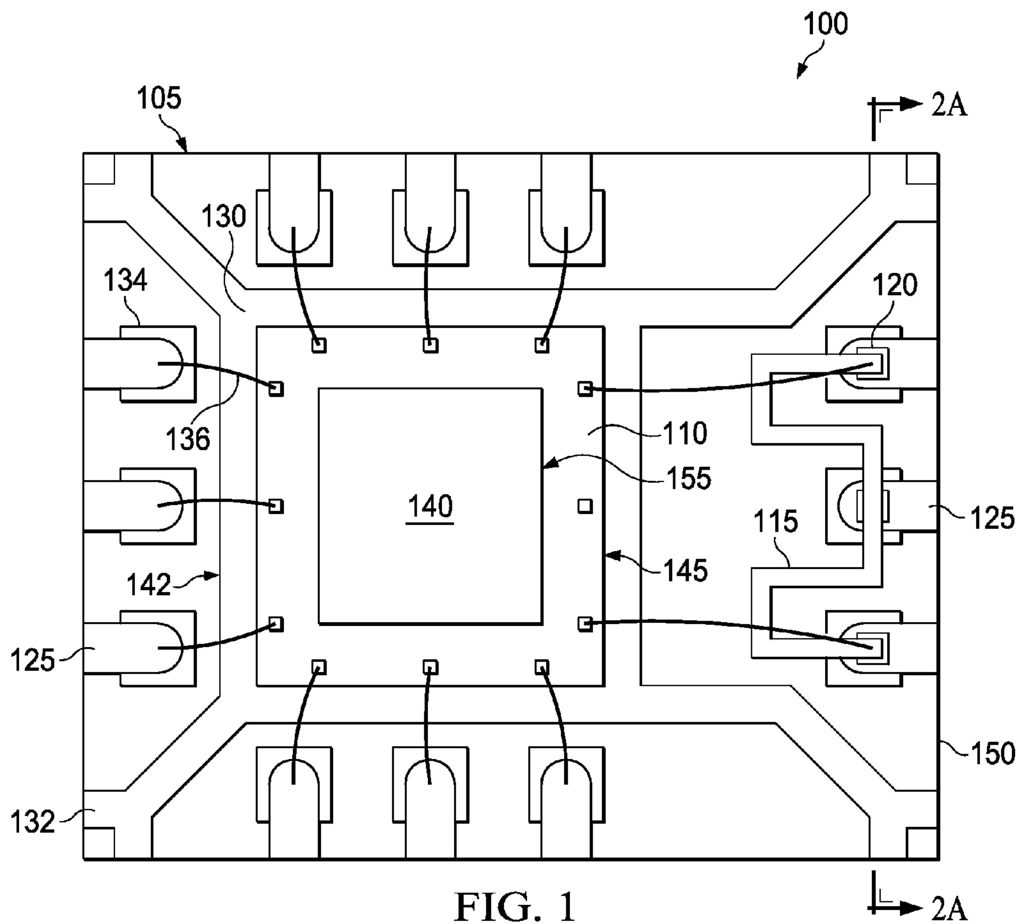



FIG. 1

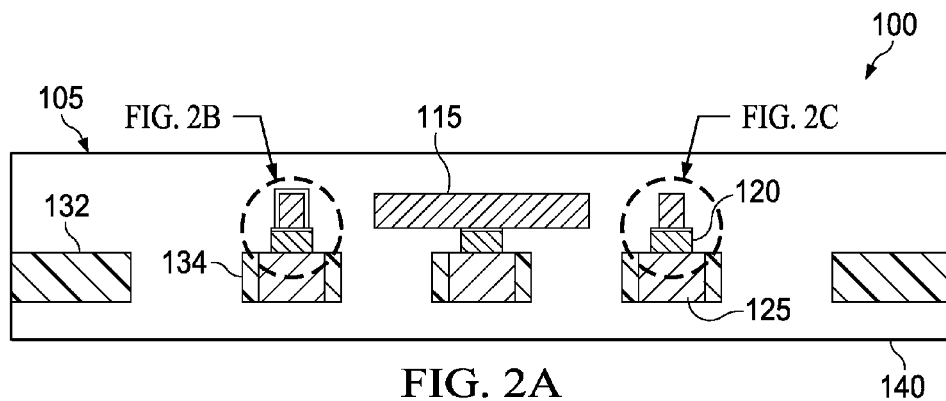



FIG. 2A

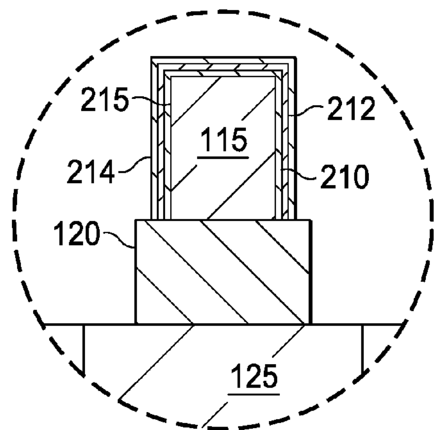


FIG. 2B

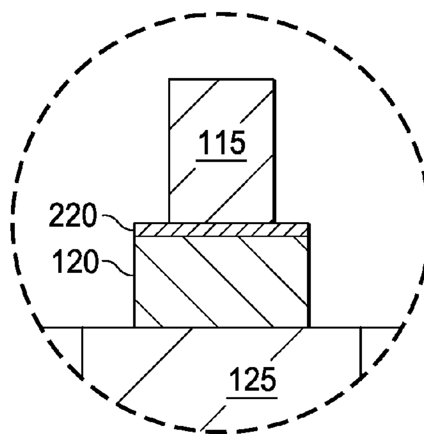


FIG. 2C

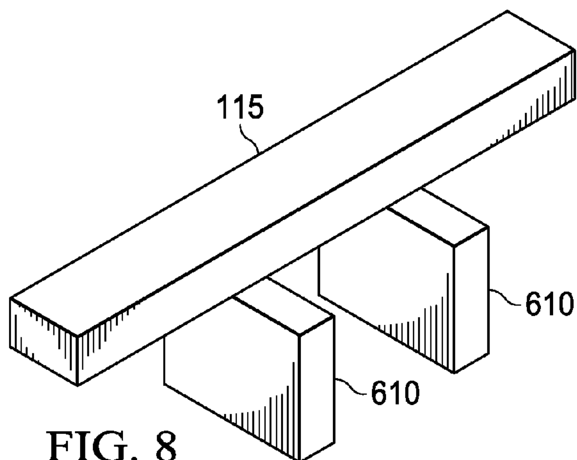


FIG. 8

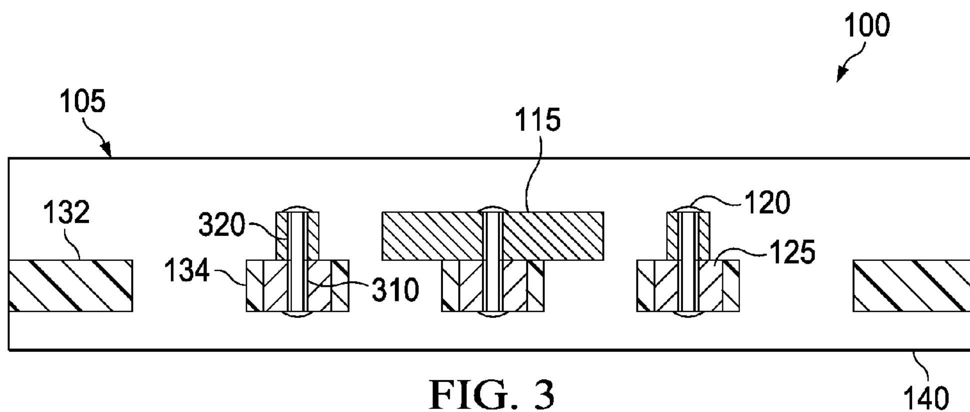



FIG. 3

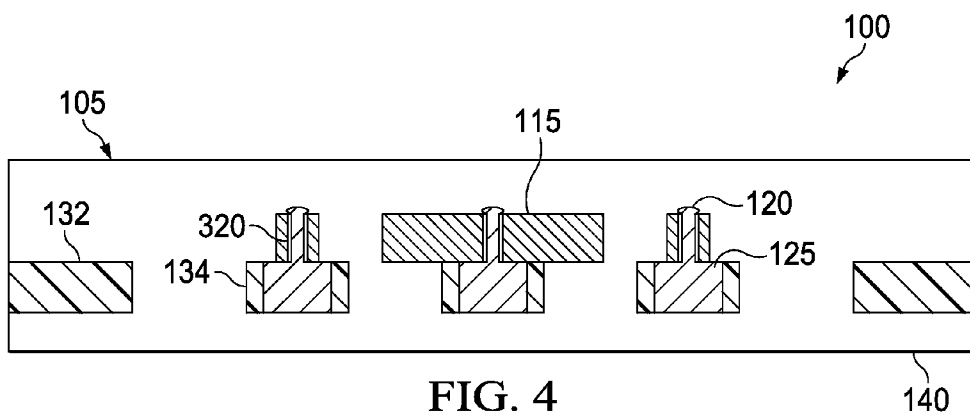



FIG. 4

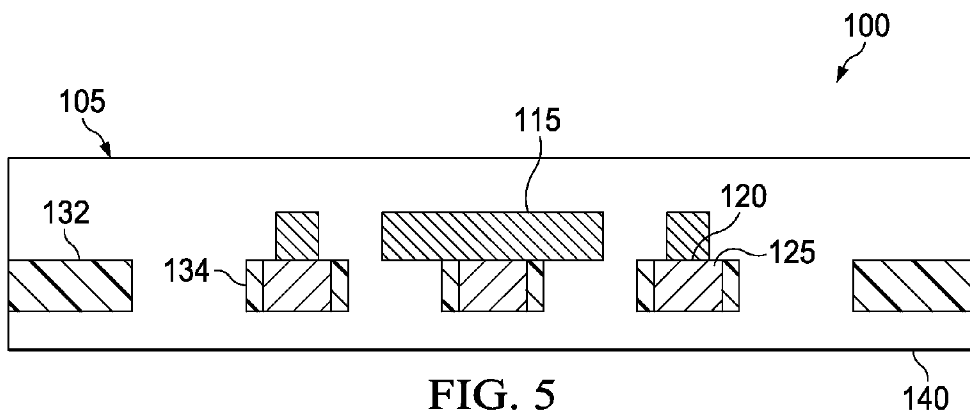



FIG. 5

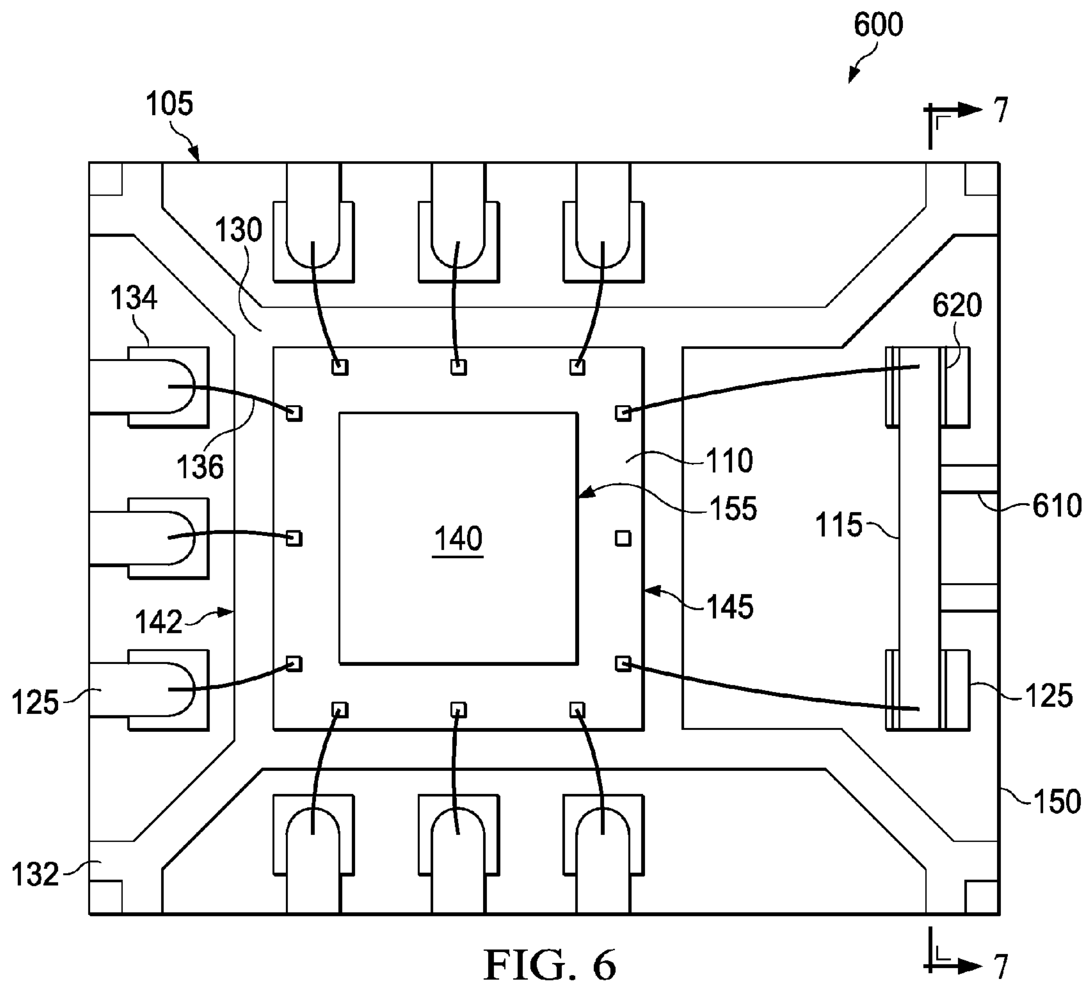



FIG. 6

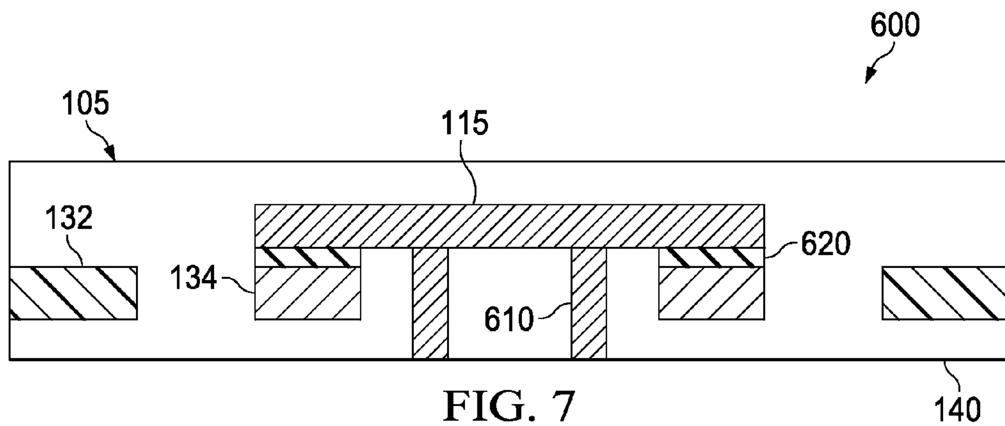



FIG. 7

FIG. 9A

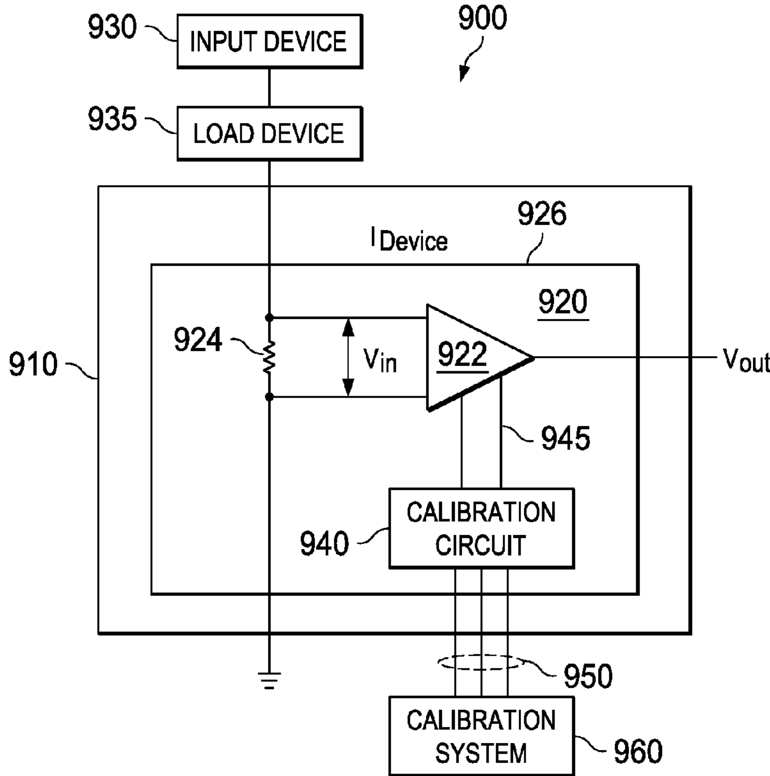



FIG. 9B

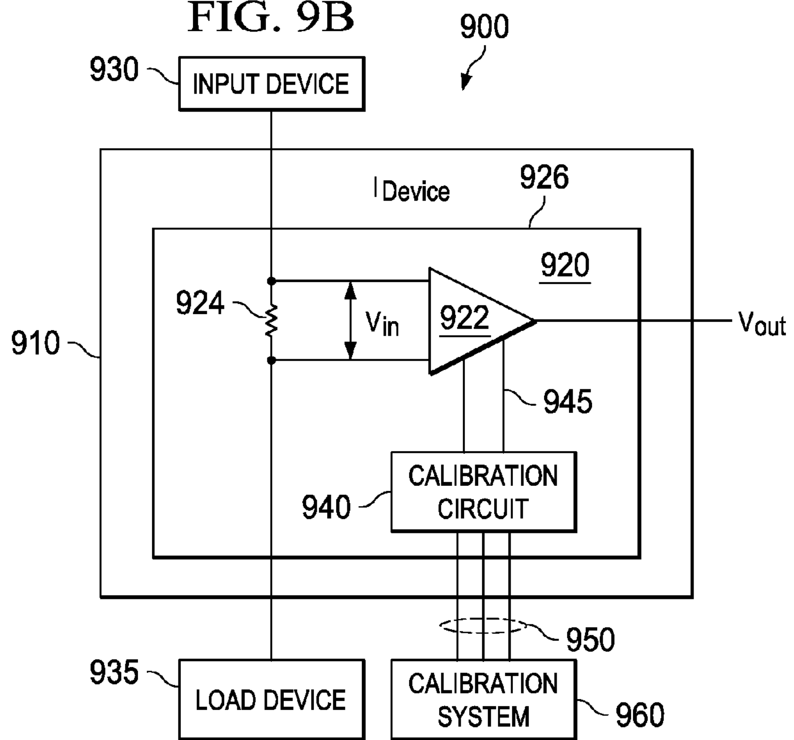
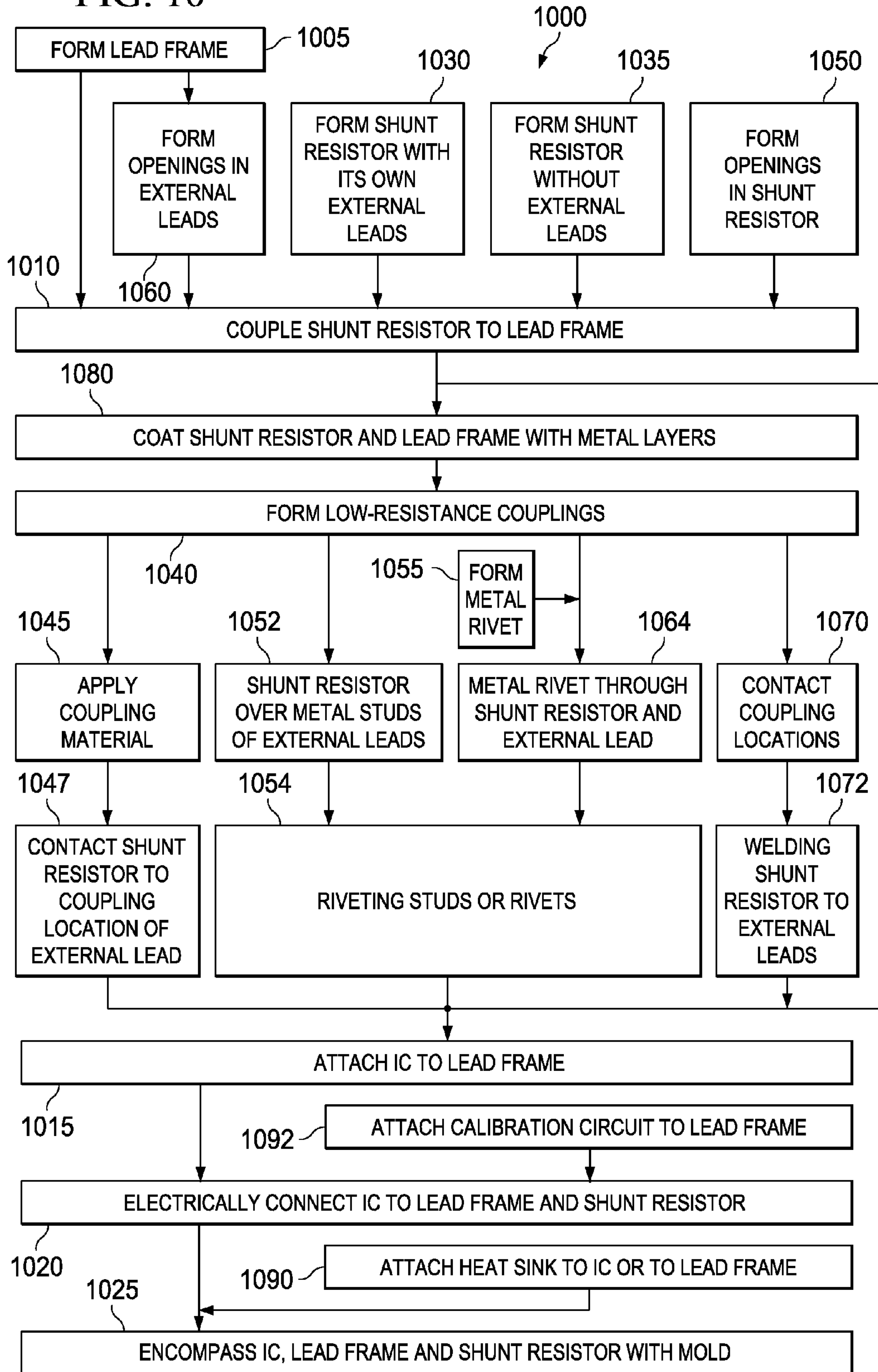


FIG. 10



# MANUFACTURING METHOD FOR INTEGRATING A SHUNT RESISTOR INTO A SEMICONDUCTOR PACKAGE

## TECHNICAL FIELD OF THE INVENTION

**[0001]** The present invention is directed to semiconductor packages and methods for manufacturing a semiconductor package.

## BACKGROUND OF THE INVENTION

**[0002]** Certain semiconductor devices are used as amplifiers dedicated to current or voltage sensing. Typically, the amplifier comprises an integrated circuit (IC) package, manufactured by one party, connected to a shunt resistor, manufactured by another party. The combination of separately manufactured IC packages and shunt resistors increases the area of the circuit board occupied by these elements. Attempts have been made to integrate a shunt resistor into the IC package, with parts of an IC lead frame being used as the shunt resistor.

## SUMMARY OF THE INVENTION

**[0003]** One aspect of the present disclosure provides an integrated circuit package. The package comprises a lead frame, an integrated circuit located on the lead frame and a shunt resistor coupled to the lead frame and to the integrated circuit. The shunt resistor has a lower temperature coefficient of resistance than the lead frame, and the lead frame has a lower resistivity than the shunt resistor. The shunt resistor has a low-resistance coupling to external leads of the lead frame. In an alternative embodiment of the package, the shunt resistor has its own integrated external leads.

**[0004]** Another aspect of the present disclosure is an amplifier for current or voltage measurements. The amplifier comprises the above-described package, wherein the shunt resistance has its own external leads, or, has a low-resistance coupling to external leads of the lead frame. A mold encompasses the lead frame, the shunt resistor, and the integrated circuit, except for the integrated external leads of the lead frame or the integrated external leads of the shunt resistor.

**[0005]** Another aspect of the present disclosure is method of manufacturing an integrated circuit package. The method comprises forming a lead frame, and coupling one of the above-described shunt resistors embodiments to the lead frame. The method further comprises attaching an integrated circuit to a surface of the lead frame and electrically connecting the integrated circuit to the shunt resistor and to the lead frame. The method further comprises encompassing the lead frame, the shunt resistor and the integrated circuit with a mold, except for external leads of the lead frame or of the shunt resistor.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0006]** The disclosure is described with reference to example embodiments and to the accompanying drawings:

**[0007]** FIG. **1** illustrates a plan view of an example integrated circuit package of the present disclosure;

**[0008]** FIGS. **2**A, **2**B, and **2**C present cross-sectional detail views of the integrated circuit package depicted in FIG. **1**;

**[0009]** FIGS. **3-5** present cross-sectional detail views of alternative embodiments of the integrated circuit package depicted in FIG. **1**;

**[0010]** FIG. **6** illustrates a plan view of an alternative integrated circuit package of the present disclosure;

**[0011]** FIG. **7** presents a cross-sectional detail view of the integrated circuit package depicted in FIG. **6**;

**[0012]** FIG. **8** presents a perspective view of the shunt resistor depicted in FIG. **6**;

**[0013]** FIGS. **9**A and **9**B present block diagrams of example embodiments of an amplifier of the present disclosure; and

**[0014]** FIG. **10** illustrates by flow diagram, selected steps in an example method for manufacturing an integrated circuit package according to the present disclosure.

## DETAILED DESCRIPTION

**[0015]** As part of the present disclosure, it was recognized that integrating a shunt resistor, as part of a lead frame, into an IC package is problematic for certain applications that require highly accurate current or voltage measurements and low resistive losses in and out of the IC package. Using part of a conventional lead frame material as the shunt resistor is not satisfactory, because the lead frame is typically made of a material having a high temperature co-efficient of resistivity (TCR). Consequently, the accuracy of current or voltage measurements suffers because of temperature-induced changes in the resistance of the shunt resistor.

**[0016]** In contrast, making the lead frame entirely out of a low TCR material is also unsatisfactory, because such materials have too high a resistivity. E.g., the high pin resistance of lead frames composed of low TCR materials results in an unacceptably high voltage loss when the IC and shunt resistor of the package are connected to an external device. Unfortunately, materials having both the desirably low TCR and low resistivity have not been discovered or recognized for today's required current and voltage sensing applications.

**[0017]** The present disclosure addresses the above-discussed problems by incorporating a shunt resistor made of a low TCR material into a package, not as part of the lead frame, but as a separate shunt resistor element of the package. The IC can be connected to external devices using external leads of the lead frame made of a low resistivity material. For its connection to external devices, the shunt resistor either has its own integrated external leads, or, has low resistance couplings to external leads of the low resistivity lead frame material. The resulting IC package has a new combination of properties that was not attainable in previous IC packages: a shunt resistor having a low TCR, and, minimal voltage losses from the package. Additionally, the IC package occupies less board space than separately-assembled IC packages and shunt resistors.

**[0018]** There are no existing process for manufacturing an IC package with this combination of low TCR and low resistivity materials. Indeed, the manufacture of a separate shunt resistor element made of low TCR material, and its attachment to a low resistivity lead frame material, presents new challenges that are not normally encountered by shunt resistor manufacturers.

**[0019]** For instance, it is difficult and expensive to manufacture a batch of shunt resistor elements with precisely the same dimensions for the entire batch. Variations in the dimensions of the shunt resistor element can give rise to large variations (e.g., about 30% variations) in its initial resistance. This difficulty was addressed by calibrating and compensating for such variations in resistance using the IC of the IC package. By measuring the resistance of each IC package after it is assembled, it is possible to use the IC to trim the output from the package to a desired value. As such, the total

accuracy of the package for making current or voltage measurements is brought under the control of the IC package manufacturer.

**[0020]** It is also difficult to attach the separate shunt resistor element made of low TCR material to the low resistivity lead frame material without increasing the shunt's resistivity. This follows because standard attachment materials have a high resistivity which in turn increases the overall resistivity of the shunt resistor, with consequent high voltage losses. This difficulty was addressed by selecting a low-resistance coupling to attach the shunt resistor to external leads of the lead frame, or, by configuring the shunt resistor to have its own integrated external leads. The selection of the low resistance couplings, or, the integrated external leads are important to the successful operation of the IC package. The use of low resistance couplings or integrated external leads facilitates having the desired accuracy of current or voltage measurements while not contributing to the high voltage losses such as found in packages having shunt resistors made entirely of low resistivity, but moderate-to-high TCR lead frame material, or, made entirely of low TCR, but high resistivity material.

**[0021]** FIG. **1** shows a plan view of an example IC package **100** of the present disclosure. FIG. **2**A shows a cross-sectional view of the same IC package **100** through view plan **2-2** (FIG. **1**). The example package **100** depicted in FIG. **1** is a quad flat no-lead package (QFN). The package **100**, however, can be any number of conventional type of lead-containing package, including plastic dual in-line integrated circuit packages (PDIP), small outline integrated circuits (SOICs), quad flat packages (QFP), thin QFPs (TQFPs), low profile QFPs (LPQFPs), Small Shrink Outline Plastic packages (SSOP), thin SSOPs (TSSOPs), thin very small-outline packages (TVSOPs), or other packages well known to those skilled in the art.

**[0022]** The example package **100** comprises a lead frame **105**, an integrated circuit **110** located on the lead frame **105**, and a shunt resistor **115** coupled to the lead frame **105** and to the IC **110**. The shunt resistor **115** has a lower TCR than the lead frame **105**, and the lead frame **105** has a lower resistivity than the shunt resistor **115**. The shunt resistor **115** also has a low-resistance coupling **120** to external leads **125** of the lead frame **105**.

**[0023]** In some embodiments, the TCR of the shunt resistor **115** is at least about 100 times lower than a TCR of the lead frame **105**. Having the shunt resistor **115** made of a low TCR material facilitates providing a precise resistance as part of making an accurate measurement of current or voltage. The term low TCR material as used herein refers to a TCR of about ±100 ppm/° C. or less. E.g., in some cases, the TCR of the shunt resistor **115** is about ±100 ppm/° C. or less, and more preferably, about ±50 ppm or less, and even more preferably, about ±20 ppm or less. This is contrast to the substantially higher TCR of conventional lead frame materials, such as copper (TCR about ±4300 ppm/° C.) or aluminum (TCR about ±4500 ppm/° C.).

**[0024]** Some preferred embodiments of the shunt resistor **115** are composed of a metal alloy that includes copper, nickel and manganese. In some preferred embodiments, the metal alloy of the shunt resistor **115** includes all three of copper, nickel, and manganese individually present in weight percentages of at least about 1 percent or higher. In some cases, the first metal comprises about 90 to 50 weight percent copper and balance nickel and manganese. Some embodiments of the first metal can include additional elements such as iron, silicon and carbon in amounts of about 1 percent or less. Non-limiting example commercial materials that can be used as the metal alloy include: Constantan® (Cu:Ni:Mn:Fe 53.8:44.2:1.5:0.5), Ferry® Alloy (Cu:Ni:Fe:Mn:Si:C 55:42.4:1:1:0.5:0.1; Special Metals Corporation,), Shunt Manganin (Cu:Mn:Ni 87:9.5:3.5; Hamilton Precision Metals), and Manganin® (Cu:Mn:Ni 86:12:2; Isabellenhutte). All of these example metal alloys have a TCR of about ±20 ppm/° C. or less.

**[0025]** Having the lead frame **105**, and its constituent leads **125**, made of a low resistivity material advantageously minimizes voltage losses into and out of the package **100**. The term low resistivity material refers to a material having a resistivity of about 3 μOhm·cm or less. By connecting the IC **110** and the shunt resistor **115** to external devices, through external leads **125** of the low resistivity lead frame material, voltage losses are minimized. Minimizing voltage losses are important in certain amplifier applications where, e.g., there is a 10 mV or less potential drop across the shunt resistor **115**, because power losses in the system are undesirable and costly for applications operating on high voltage supplies or battery operation. For instance, a drop of more than 100 mV could cause thermal heating issues for shunt resistors that are encapsulated in plastic packaging materials or other moldings.

**[0026]** In some embodiments, the resistivity of the lead frame **105** is at least about 10 times lower than a resistivity of the shunt resistor **115**. E.g., the lead frame **115** can comprise or in some cases, be substantially composed of, copper having a resistivity of about 1.5 μOhm·cm, or, aluminum having a resistivity of about 2.7 μOhm·cm). This is in contrast to the substantially higher resistivity of the above-described metal alloys of the shunt resistor. E.g., Manganin® can have a resistivity of about 45 μOhm·cm, and Constantan®, a resistivity of about 52 μOhm·cm. In addition to copper and aluminum, other example metals of the lead frame **115** include gold, silver and alloys thereof.

**[0027]** As noted above, it is important to the proper functioning of the package for the shunt resistor **115** to be connected to the external leads **125** by a low-resistance coupling **120**. Using a higher resistance coupling can result in unacceptably high voltage losses into and out of the package **100**. The low-resistance coupling **120** is defined as the interface between the shunt resistor **115** and the external leads **125** having a resistivity of about 2 mOhm·cm or less. More preferably, the resistivity of the low resistance coupling **120** is about 250 μOhm·cm or less.

**[0028]** In some cases, the low-resistance coupling **120** includes, or is, an additional material located in-between the shunt resistor **115** and the external leads **125**. For instance, in some embodiments of the package **100**, the low-resistance coupling **120** includes or is a solder, a conductive epoxy, or a thermal grease that has an electrical resistivity of about 2 mOhm·cm or less. Example materials that can serve as the low-resistance coupling **120** includes electrically conductive adhesives such as epoxy 8006 NS (Ablestik, Rancho Dominguez, Calif.), or thermal greases, or solder pastes with the appropriate low resistivity.

**[0029]** In other embodiments of the package **100**, the low-resistance coupling **120** includes, or is, one or more metal studs or rivets having an electrical resistivity of about 2 mOhm·cm or less. Example metal studs or rivets can be composed of substantially the same material as the lead frame **105**, or, a different low resistivity material.

**[0030]** FIG. **3** shows a cross-sectional view of an alternative IC package **100**, analogous to the view depicted in FIG. **2**A. The low-resistance coupling **120**, configured as metal rivets, spans openings **310** in the leads **125** and openings **320** in the shunt resistor **115**, to couple the shunt resistor **115** and leads **125** together.

**[0031]** FIG. **4** shows a cross-sectional view of another alternative IC package **100**, analogous to the view depicted in FIG. **2**A. The low-resistance coupling **120**, configured as metal studs, is a raised part of the lead frame **105** (FIG. **1**) and the openings **320** in the shunt resistor **115** fits over the metal stud to couple the shunt resistor **115** and leads **125** together.

**[0032]** FIG. **5** presents a cross-sectional view of another alternative IC package **100**. In this embodiment, there is no additional material between the shunt resistor **115** and the external leads **125**. That is, the shunt resistor **115** and the external leads **125** directly contact each other to form the low-resistance coupling **120**. E.g., the low-resistance coupling **120** includes, or is, a weld between the shunt resistor **115** and the external leads **125**. For instance, the weld could include an electron-beam weld, a laser weld, a pressure weld, or other forms of welding that do not require the placement of additional material between the shunt resistor **115** and the external leads **125**.

**[0033]** In such embodiments, the coupling **120** has an electrical resistivity that is substantially the same as the resistivity of the shunt resistor **115**, or, the external leads **125**, whichever is greater. E.g., the coupling **120** can have an electrical resistivity that is substantially equal to the resistivity of the low TCR material of the shunt resistor **115** (e.g., about 50 μOhm·cm, in some embodiments).

**[0034]** Electron-beam, laser and pressure welding are desirable because the dimensions embodiments of the shunt resistor **115** having this type of weld are better defined as compared to when there is an additional material (e.g., solder, conductive epoxy, or thermal grease) between the shunt resistor **115** and the external leads **125**. Because the dimensions of the shunt resistor **115** are better defined, a more accurate estimate of the expected resistance of the shunt resistor **115** can be made. Additionally, electron-beam, laser and pressure welding can eliminate the potential for increased voltage losses due to the use of an additional material with a higher resistivity than either the shunt resistor **115** or external leads **125**. Coupling the shunt resistor **115** and the external leads **125** by such forms of welding also has the advantage of being able to weld together dissimilar metals.

**[0035]** As shown in the cross-sectional view of FIG. **2**B, embodiments of the shunt resistor **115** can further include one or more metal layers **210**, **212**, **214**, located at least at the low resistance coupling **120**. The metal layers **210**, **212**, **214** can facilitate the bonding of additional materials (e.g., solder) of the low resistance coupling **120** to the shunt resistor **115**, or, to the external leads **125**. The metal layers **210**, **212**, **214** can also improve the adhesion of a pressure weld. In such cases, there is an additional material (e.g., the metal layer itself) between the shunt resistor **115** and external leads **125**.

**[0036]** The one or more metal layers **210**, **212**, **214** can promote sufficient coupling between the shunt resistor **115** and the external leads **125** without having to heat these components. Not heating these components saves energy and time in the package-manufacturing process, and helps avoid potential heat-induced damage to the IC **110** (FIG. **1**).

**[0037]** As also shown in FIG. **23**, the metal layers **210**, **212**, **214** can coat the entire exterior surface of the shunt resistor **115**. In some embodiments, the metal layers **210**, **212**, **214** are composed of nickel, palladium and gold, respectively. E.g., successive layers **210**, **212**, **214** of nickel, platinum and gold, can be plated onto the outer surface **215** of the shunt resistor **115** by well-known electro-deposition processes. The nickel layer **210** helps to prevent oxidation of a copper lead frame **105** or copper external lead **125**, the platinum layer **212** helps bond the nickel layer **210** to the gold layer **214**, and the gold layer **214** can bond strongly to certain low TCR materials (e.g. Manganin®) of the shunt resistor **115**.

**[0038]** As shown in the detailed cross-sectional view of FIG. **2**C, in other cases, there can be a single metal layer **220**. E.g., there can be a silver layer **220** configured as a bonding pad, located at the low resistance coupling **120**. Other example metals for the metal layers include tin, nickel, palladium or similar materials.

**[0039]** In some embodiments, the lead frame **115**, including the external leads **125**, can also have one or more metal layers (not shown, but analogous to that depicted in FIG. **2**B or **2**C) to facilitate forming the low resistance coupling **120** between the shunt resistor **115** and the external leads **125**.

**[0040]** As illustrated in FIG. **1**, to adjust the shunt resistor **115** to the appropriate length, and hence adjust its resistance, the shunt resistor **115** can have a serpentine shape. One skilled in the art would be familiar with other shapes and dimensions of the shunt resistor **115** that would be conducive to achieving a specific target resistance value.

**[0041]** As noted above, however, fabricating batches of shunt resistors **115** with precisely the same dimensions is difficult, and this can cause substantial variations in the resistance from one shunt resistor **115** to the next. Therefore in some embodiments, it is desirable for the resistance of each shunt resistor **115** in each IC package **100** to be calibrated, and for the IC **110** to be configured to compensate for a difference in the shunt resistor's **115** resistance from a specific target resistance value. For instance, in some cases, the IC **110** can be configured to adjust its gain to compensate for resistance variations due to variations in the dimension of the resistor **115**. Such an adjustment can facilitate the IC package's **100** use for making accurate current or voltage measurements, as further discussed below. For example, for an amplifier that includes the gain-compensated IC **110** and the shunt resistor **115**, the amplifier's output voltage can vary from a target value by about ±5 percent or less, or more preferably, about ±1 percent of less.

**[0042]** Variations in the dimensions of the shunt resistor element can give rise to large variations (e.g., about 30% variations) in its initial resistance. This difficulty was addressed by calibrating and compensating for such variations in resistance using the IC of the IC package. By measuring the resistance of each IC package after it is assembled, it is possible to use the IC to trim the output from the package to a desired value. As such, the total accuracy of the package for making current or voltage measurements is brought under the control of the IC package manufacturer.

**[0043]** As also shown in FIG. **1**, in addition to external leads **125**, the lead frame **105** can comprise a die mounting pad **130**, tie bar **132**, internal connections **134** (e.g., half etch leads), bonding wires **136** and other conventional lead frame components (e.g., shorting bars, dam bars, etc. . . . , not shown) to facilitate forming the integrated circuit package. All of these components of the lead frame **105** can be formed from the same material. The IC **110** can be coupled to the die mounting pad **130** using an adhesive material such as epoxy. The pack-

age **100** can further comprise a heat sink **140**. The heat sink **140** can be coupled to an exterior surface **142** of the lead frame (e.g., the opposite side that the IC **110** is mounted to), or as shown in FIG. **1**, to an exterior surface **145** of the IC **110**, using similar adhesive materials.

**[0044]** Another difficulty in the manufacture of the present IC package that is not encountered by shunt resistor manufactures is encompassing IC package components with a mold **150**. For clarity, the mold **150** in FIG. **1** is depicted as being transparent. The mold **150**, can encompass the IC **110**, shunt resistor **115**, and lead frame **105** (e.g., the die mounting pad **130**, tie bar **132**, internal connections **134**, and bonding wires **136**), except for the external leads **125**, and the exterior surface **155** of the heat sink **140**, when present. The mold **150** can made of an epoxy, ceramic, metal or other conventional packaging materials. In addition to protecting the IC **110** against harmful environmental conditions, the mold **150** securely holds the shunt resistor **115**, lead frame **105**, and heat sink **140** at appropriate locations relative to the IC **110**.

**[0045]** Both the IC **110** and shunt resistor **115** can generate substantial amounts of heat. Moreover, the shunt resistor **115** may not get the benefit of airflow cooling when it is encompassed by the mold **150**. The combination of heat from the IC **110** and shunt resistor **115** can be sufficient to melt or decompose certain types of molding **150** (e.g., plastic or epoxy moldings) or degrade the performance of the IC **110**.

**[0046]** Consequently, it is important to appropriately adjust the current rating of the shunt resistor **115** to avoid such effects. One skilled in the art would understand how to model heat generation from the IC **110** and the shunt resistor **115**, and to adjust the shunt resistor's **115** current rating such that the combined power output from the IC **110** and the shunt resistor **115** is below the power dissipation rating of the package **100**. For example in some embodiments the power dissipation rating of the package **100** is about −500 mWatts, and the combined power output from the IC **110** and the shunt resistor **115** is below this value.

**[0047]** FIG. **6** shows a plan view of another example IC package **600** of the present disclosure. FIG. **7** shows a cross-sectional view of the same IC package **600** through view **6-6** (FIG. **6**). FIG. **8** presents a perspective view of the shunt resistor **115** depicted in FIGS. **6** and **7**.

**[0048]** The package **600** is analogous to the QFN packages depicted in FIGS. **1-5**, and like reference numbers are used to depict like components. E.g., the package **600** comprises the analogous lead frame **105**, IC **110** located on the lead frame **105**, and shunt resistor **115** coupled to the lead frame **105** and IC **110**. Any of the materials of the lead frame **105** and shunt resistor **115** discussed above in the context of FIGS. **1-5** can be used in the package **600**. E.g., the shunt resistor **115** has a lower TCR than the lead frame **105**, and the lead frame **105** has a lower resistivity than the shunt resistor **115**. Unlike the packages **100** shown in FIGS. **1-5**, however, the shunt resistor **115** of the package **600** does not have the low-resistance coupling **120** to external leads **125** of the lead frame **105** (FIGS. **1-5**). Rather, the shunt resistor **115** has its own integrated external leads **610**. For instance, as shown in FIG. **8**, one continuous piece of low TCR material can be used to form both the shunt resistor **115** and the integrated external leads **610**. The shunt resistor **115** depicted in FIGS. **6-8** can be configured to have any of the above-described shapes (e.g., linear or serpentine) as needed to provide the desired resistance.

**[0049]** As shown in FIGS. **6** and **7**, an additional coupling material **620** may be used to attach the shunt resistor **115** to the lead frame **105**. Any of the materials and processes discussed in the context of FIGS. **1-5** to form the low resistivity coupling **120** used as the additional coupling material **620**. Unlike the low resistivity coupling **120**, however, the additional coupling material **620** need not have a low resistivity, and can even be an electrical insulator. Or, the additional coupling **620** can include welds (e.g., electron beam, laser or pressure welds) with no additional material.

**[0050]** A shunt resistor **115** with integrated external leads **610** has certain advantages over coupling the shunt resistor **115** to external leads **125** from the lead frame **105**. The shunt resistor **115** can be directly connected to an device external to the package **600** without having to interface with another material having a different TCR than the shunt resistor **115**, such as the external leads **125** from the lead frame **105**, or, the additional coupling material **120** (FIG. **1**). This, in turn, allows one to avoid the variable resistances associated with using different materials, having different TCRs, to interface the shunt resistor **115** to external elements. Providing a shunt resistor **115** with its own external leads **610** facilitates having a constant pin resistance and therefore having a constant voltage drop across the shunt resistor **115**. Additionally, the materials and processing steps to couple the shunt resistor **115** to the external lead **125** of the lead frame **105**, are eliminated, thereby making the manufacturing process more efficient.

**[0051]** FIGS. **9**A and **9**B show block diagrams of another aspect of the present disclosure, an amplifier **900** for current or voltage measurements. The amplifier comprises an IC package **910**. The package **910** can be any of the above-described embodiments of the IC packages discussed in the context of FIGS. **1-8**. The package **910** includes a lead frame **920**, IC **922** on the lead frame **920**, and shunt resistor **924**. The lead frame **920**, and shunt resistor **924** have the above-described TCR and resistivity properties. The shunt resistance **924** is coupled to the lead frame **920** and electrically connected to the IC **922**. As discussed above in the context of FIGS. **1-8**, the shunt resistor **924** can its own external leads, or, has a low-resistance coupling to external leads of the lead frame. Additionally, the package **910** includes a mold **926** that encompasses the lead frame **920**, shunt resistor **924**, and IC **922**, except for the external leads of lead frame **920** or shunt resistor **924**.

**[0052]** One of ordinary skill in the art would be familiar with various possible configurations the amplifier **900** could have to facilitate a current- or voltage-sensing function.

**[0053]** E.g., the shunt resistor **924** can be coupled via its own external leads, or, via external leads of the lead frame **920**, to an input device **930** and to a load device **935**. FIG. **9**A presents a low-side sensing configuration. FIG. **9**B presents a high-side sensing configuration. One skilled in the art would appreciate the other sensing configurations that could be used. In some embodiments, to measure the current ($I_{device}$) passing through the input device **930**, the voltage potential drop ($V_{in}$) across the shunt resistor **924**, is read as an input to the IC **922**, to produce an output voltage ($V_{out}$) from which $I_{device}$ can be calculated.

**[0054]** The amplifier **900** can further comprise additional components to facilitate the measurement of current or voltage. E.g., the amplifier **900** can also include a calibration circuit **940** that is electrically connected to the IC **922**. The calibration circuit **940** can also be encompassed by the mold **926**, or, can be external to the mold **926**. The calibration circuit **940** can be configured to facilitate adjustment of the gain of the amplifier IC **922**, using procedures well known to those skilled in the art. E.g., the calibration circuit **940** can include a network of parallel resistors, each resistor having a different value in a desired range governed by design considerations. In some embodiments, the parallel resistors of the

calibration circuit **940** comprise the same low TCR material used to form the shunt resistor **924**, or, in other cases is included in other topological configurations. The calibration circuit **940** can be connected via conventional input/output lead **945** to the IC **922**, and via a data bus **950**, to a conventional calibration system **960** that is external to the package **910**. Additional aspects of the amplifier **900**, including its operation and components, are further described in U.S. Pat. No. 6,225,684 to Stitt et al., which is incorporated by reference in its entirety.

**[0055]** Another aspect of the present invention is a method of manufacturing an integrated circuit package. The method of manufacturing an integrated circuit package can be used to produce any of the embodiments of the integrated circuit package presented in FIGS. **1-9**B and discussed above.

**[0056]** FIG. **10** illustrates by flow diagram, selected steps in an example method **1000** for manufacturing an integrated circuit package according to the principles of the present disclosure.

**[0057]** The method **1000** includes forming a lead frame (step **1005**), coupling a shunt resistor to the lead frame (step **1010**), attaching an IC to a surface of the lead frame (step **1015**), electrically connecting the IC to the shunt resistor and to the lead frame (step **1020**), and encompassing the shunt resistor and IC with a mold (step **1025**), except for external leads of the lead frame, or, of the shunt resistor.

**[0058]** As noted above, the shunt resistor and lead frame are composed of different materials such that the shunt resistor has a lower temperature coefficient of resistance than the lead frame, and the lead frame has a lower resistivity than the shunt resistor. In some embodiments, the shunt resistor is formed so as to have its own integrated external leads (step **1030**) while in other embodiments, the shunt resistor is formed without having its own external leads (step **1035**). In the latter case, low-resistance couplings to external leads is formed (step **1040**) as part of coupling the shunt resistor to the lead frame (step **1010**).

**[0059]** Some embodiments of the low-resistance coupling include solder, conductive epoxy, or thermal grease having an electrical resistivity of about 2 mOhm·cm or less. In such embodiments, coupling the shunt resistor to the lead frame in step **1010** includes a step **1045** of applying a low-resistance coupling material (e.g., the solder, conductive epoxy, or thermal grease) to one or both of coupling locations on the shunt resistor or on the external leads of the lead frame. Then in step **1047**, the shunt resistor is contacted to the external leads at the coupling locations.

**[0060]** Other embodiments of the low-resistance coupling include one or more metal studs or metal rivets having an electrical resistivity of about 2 mOhm·cm or less. In some instances, the metal stud can be formed as part the external lead during the formation of the lead frame in step **1005**. In such embodiments, coupling the shunt resistor to the lead frame in step **1010** and forming the low resistance coupling (step **1040**) can include a step **1050** of forming openings in the shunt resistor, a step **1052** of positioning the shunt resistor on the external leads such that the metal studs of the external leads fit through individual ones of the openings, and then riveting (step **1054**) an exposed end of each of the metal studs such that the exposed end expands to cover one of the openings.

**[0061]** In other instances, a metal rivet can be formed (step **1055**) separately from forming the lead frame in step **1005**. In such embodiments, coupling the shunt resistor to the lead frame in step **1010** and forming the low resistance coupling (step **1040**) can include forming openings in the shunt resistor (step **1050**) and/or in the external leads (step **1060**), a step **1064** of positioning metal rivets through individual ones of the openings, and then performing a riveting step **1054** such that exposed ends of each of the metal rivets expands to cover the openings.

**[0062]** In still other embodiments, the low-resistance coupling does not include additional material between the lead frame and the shunt resistor. In such embodiments, coupling the shunt resistor to the lead frame in step **1010** can include a step **1070** of making contact of the shunt resistor to coupling locations of the external leads of the lead frame, and then a step **1072** of directly welding the shunt resistor (e.g., electron beam, laser or pressure welding) to the external leads at the coupling locations.

**[0063]** In some embodiments, before coupling the shunt resistor to the lead frame in step **1010**, there is an additional step **1080** of coating at least the coupling locations of the shunt resistor to the lead frame (e.g., the external leads) with one or more metal layers of Ni, Pd, Au or Ag. In some embodiments, the entire shunt resistor, entire lead frame or both the shunt resistor and the lead frame are coated in step **1080**.

**[0064]** One skilled in the art would be familiar with the various embodiments that could be applied to accomplish steps **1005**, **1015**, **1020** and **1025**. E.g., forming the lead frame in step **1005** can include forming a layout pattern for the lead frame on a metal sheet, stamping or etching the metal sheet to form the lead frame pattern, and trimming the lead frame pattern to form the lead frame's component structures (e.g., leads, die mounting pad, tie bar etc. . . . ). E.g., attaching the IC to a surface of the lead frame in step **1015** can include bonding the IC to the die mounting pad of the lead frame using a resin or other conventional adhesive. E.g., electrically connecting the IC to the shunt resistor and to the lead frame in step **1020** can be accomplished by forming bonding wires between the IC and the external leads and between the shunt resistor and IC. E.g., encompassing the shunt resistor and IC with a mold in step **1025** can include surrounding these components with an injection mold or a coating of epoxy resin, ceramic, or other conventional insulating material. Lead frame structures, such as dam bars, can facilitate preventing the external leads of the lead frame or shunt resistor from being encompassed by the mold.

**[0065]** Additional steps to complete the package's manufacture can include attaching a heat sink (step **1090**) to an exterior surface of the integrated circuit or the lead frame (e.g., to the underside of the die mounting pad), coupling a calibration circuit to the lead frame (step **1092**), and making electrical connections between the IC and calibration circuit and between the calibration circuit and input/output pins (e.g., as part of making other electrical connections in step **1020**).

**[0066]** Although the present invention has been described in detail, those skilled in the art should understand that they could make various changes, substitutions and alterations herein without departing from the scope of the invention in its broadest form.

What is claimed is:

**1**. An integrated circuit package, comprising:

a lead frame;

an integrated circuit located on said lead frame; and

a shunt resistor coupled to said lead frame and to said integrated circuit, wherein:

said shunt resistor has a lower temperature coefficient of resistance than said lead frame,

said lead frame has a lower resistivity than said shunt resistor, and

said shunt resistor has a low-resistance coupling to external leads of said lead frame.

**2**. The IC package as recited in claim **1**, wherein said temperature coefficient of resistance of said shunt resistor is at least about 100 times lower than a temperature coefficient of resistance of said lead frame.

**3**. The IC package as recited in claim **1**, wherein said resistivity of said lead frame is at least about 10 times lower than a resistivity of said shunt resistor.

**4**. The IC package as recited in claim **1**, wherein said temperature coefficient of resistance of said shunt resistor is about ±100 ppm/° C. or less.

**5**. The IC package as recited in claim **1**, wherein said shunt resistor is composed of a metal alloy that includes copper, nickel and manganese.

**6**. The IC package as recited in claim **1**, wherein said low-resistance coupling includes a solder, a conductive epoxy, or a thermal grease, that have an electrical resistivity of about 2 mOhm·cm or less.

**7**. The IC package as recited in claim **1**, wherein said low-resistance coupling includes metal studs or rivets having an electrical resistivity of about 2 mOhm·cm or less.

**8**. The IC package as recited in claim **1**, wherein said low-resistance coupling includes an electron-beam, laser or pressure weld between said shunt resistor and said external leads.

**9**. The IC package as recited in claim **1**, wherein said shunt resistor further includes one or more metal layers, said metal layers being located at least at said low resistance coupling.

**10**. The IC package as recited in claim **1**, wherein a gain of said IC is configured to compensate for a different in a resistance of said shunt resistor from a target resistance value.

**11**. The IC package as recited in claim **1**, further including a mold encompassing said integrated circuit, said shunt resistor and said lead frame, except for said external leads of said lead frame or of said shunt resistor.

**12**. An integrated circuit package, comprising:
- a lead frame;
- an integrated circuit located on said lead frame; and
- a shunt resistor coupled to said lead frame and said integrated circuit, wherein:
  - said shunt resistor has a lower temperature coefficient of resistance than said lead frame,
  - said lead frame has a lower resistivity than said shunt resistor, and
  - said shunt resistor has its own integrated external leads.

**13**. An amplifier for current or voltage measurements, comprising:
- an integrated circuit package, including:
  - a lead frame;
  - an integrated circuit located on said lead frame;
  - a shunt resistor coupled to said lead frame and electrically connected to said integrated circuit, wherein:
    - said shunt resistor has a lower temperature coefficient of resistance than said lead frame,
    - said lead frame has a lower resistivity than said shunt resistor, and
    - said shunt resistance has its own external leads, or, has a low-resistance coupling to external leads of said lead frame; and
  - a mold encompassing said lead frame, said shunt resistor, and said integrated circuit, except for external leads of said lead frame or of said shunt resistor.

**14**. A method of manufacturing an integrated circuit package, comprising:
- forming a lead frame;
- coupling a shunt resistor to said lead frame, wherein
  - said shunt resistor has a lower temperature coefficient of resistance than said lead frame,
  - said lead frame has a lower resistivity than said shunt resistor, and
  - said shunt resistance has its own integrated external leads, or, has a low-resistance coupling to external leads of said lead frame;
- attaching an integrated circuit to a surface of said lead frame;
- electrically connecting said integrated circuit to said shunt resistor and to said lead frame; and
- encompassing said lead frame, said shunt resistor and said integrated circuit with a mold, except for said external leads of said lead frame or said integrated external leads of said shunt resistor.

**15**. The method as recited in claim **14**, wherein coupling said shunt resistor to said lead frame includes applying said low-resistance coupling to one or both of coupling locations on said shunt resistor or on said external leads of said lead frame, and then contacting said shunt resistor to said external leads at said coupling locations, wherein said low-resistance coupling includes a solder, conductive epoxy, or thermal grease that has an electrical resistivity of about 2 milliOhm·cm or less.

**16**. The method as recited in claim **14**, wherein said low-resistance coupling includes one or more metal studs or rivets having an electrical resistivity of about 2 milliOhm·cm or less.

**17**. The method as recited in claim **16**, wherein coupling said shunt resistor to said lead frame includes forming openings in said shunt resistor, positioning said shunt resistor on said external leads of said lead frame such that said metal studs of said external leads fit through individual ones of said openings, and then riveting an exposed end of each of said metal studs such that said exposed end expands to cover one of said openings.

**18**. The method as recited in claim **16**, wherein coupling said shunt resistor to said lead frame includes forming openings in said shunt resistor and in said external leads, positioning said metal rivets through individual ones of said openings, and then riveting exposed ends of each of said metal rivets such that said exposed ends expand to cover said openings.

**19**. The method as recited in claim **14**, wherein coupling said shunt resistor to said lead frame includes contacting said shunt resistor to coupling locations of said external leads of said lead frame, and then welding said shunt resistor to said external leads at said coupling locations.

**20**. The method as recited in claim **14**, further including coating at least coupling locations of said shunt resistor with one or more metal layers of Ni, Pd, Au or Ag, before coupling said shunt resistor to said lead frame.

* * * * *