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### **ELECTRONIC DEVICES INCLUDING A SIDEWALL STRUCTURE AND METHODS OF FORMATION THEREOF**

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#### **Abstract**

An electronic device including a substrate having a first surface, a second surface, and one or more sidewalls. The electronic device may include a base metallization coupled to the first surface, one or more circuit layers formed on the second surface, and a dielectric layer on the one or more sidewalls and on the one or more circuit layers. The electronic device may include a metal layer formed on the dielectric layer. In some embodiments, one or more of the metal layer or the dielectric layer may form an ionic-contamination barrier. In some implementations, the metal layer, the dielectric layer, and one or more of the substrate or the base metallization layer may form a capacitor that extends around the one or more sides.

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## Background/Summary

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority under 35 U.S.C. §119 of India Patent application No. 202441009249, filed on 12 Feb. 2024, the contents of which are incorporated by reference herein.

### FIELD OF USE

[0002] The present disclosure generally relates to electronic devices that include a sidewall structure and methods of formation thereof.

### BACKGROUND

[0003] Semiconductor circuits may benefit from having large-area decoupling capacitors. Such capacitors may help prevent voltage drops and voltage surges and can reduce or eliminate noise on the associated power rails. In some implementations, decoupling capacitors may prevent electrical energy from transferring to a circuit from another part of a larger system. Unfortunately, decoupling capacitors formed using front-end-of-the-line (FEOL) transistors may consume vital die area or may cause an increase in the chip size. Additionally, such transistors may cause high poly and active densities compared to other circuits.

[0004] Alternatively, a decoupling capacitor can be produced in the back-end-of-the-line (BEOL) metallization, for example, as a metal-insulator-metal (MIM) capacitor. However, such MIM capacitors may cause an increase in the die area to accommodate the spacing and routing requirements.

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## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The detailed description is set forth with reference to the accompanying figures. In the figures, the left-most digit of a reference number identifies the figure in which the reference number first appears. The use of the same reference numbers in different figures and in the detailed description indicates similar or identical items or features.

[0006] FIG. 1 depicts a top view of a portion of a semiconductor wafer having multiple dice, in accordance with one or more embodiments of the present disclosure.

[0007] FIG. 2 depicts a cross-sectional view of a portion of the semiconductor wafer of FIG. 1 along line 2-2, including two dice and including a scribe-lane area between the dice, in accordance with one or more embodiments of the present disclosure.

[0008] FIG. 3 depicts a cross-sectional view of the semiconductor wafer of FIG. 2 and including base metallization and a scribe-lane trench through the semiconductor substrate and into the base metallization, in accordance with one or more embodiments of the present disclosure.

[0009] FIG. 4 depicts a cross-sectional view of the semiconductor wafer of FIG. 3 and including a conformal dielectric layer on the top surfaces and sidewalls of the dice, in accordance with one or more embodiments of the present disclosure.

[0010] FIG. 5 depicts a cross-sectional view of the semiconductor wafer of FIG. 4 including a patterned dielectric and deposition of the metal-insulator-metal (MIM) top-plate metal layer, in accordance with one or more embodiments of the present disclosure.

[0011] FIG. 6 depicts a cross-sectional view of the semiconductor wafer of FIG. 5 after singulation by etching, sawing, or otherwise cutting through the MIM top-plate metal layer, the dielectric, and

the base metallization, in accordance with one or more embodiments of the present disclosure.

[0012] FIG. 7 depicts a cross-sectional view of a portion of one of the dice of the semiconductor wafer of FIG. 6 and including a scribe-lane extension having a selected width, in accordance with one or more embodiments of the present disclosure.

[0013] FIG. 8 depicts a top view of a plurality of separated circuit dice with die-sidewall and scribe-lane capacitors, in accordance with one or more embodiments of the present disclosure.

[0014] FIG. 9 depicts a flow diagram of a method of forming a semiconductor die including a die-sidewall capacitor, in accordance with one or more embodiments of the present disclosure.

[0015] While embodiments are described in this disclosure by way of example, those skilled in the art will recognize that the embodiments are not limited to the examples or figures described.

Rather, the figures and detailed description thereto are not intended to limit embodiments to the form disclosed, but instead the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope as defined by the appended claims. The headings used in this disclosure are for organizational purposes only and are not meant to limit the scope of the description or the claims. As used throughout this application, the word “may” is used in a permissive sense (in other words, the term “may” is intended to mean “having the potential to”) instead of in a mandatory sense (as in “must”). Similarly, the terms “include,” “including,” and “includes” mean “including, but not limited to.”

#### DETAILED DESCRIPTION

[0016] Embodiments of methods and circuits are described below that include a die (or “chip”) including a conformal surface dielectric layer extending around the sidewalls and optionally over the top surface of the die and including a conformal metal layer deposited on the dielectric layer. In some embodiments, the die may include an integrated “seal ring” with one or more of an internal crack-stop structure and an internal ionic-contamination barrier structure, wherein “internal” means that these structures are inset from the die sidewalls toward the center of the die. One or more of the conformal dielectric layers or the overlying metal layer on the sidewalls of the die may provide an ionic-contamination barrier layer, which may also be referred to as an ionic-contamination block structure or an ionic-contamination stopper structure. In such embodiments, the ionic-contamination barrier structure of the integrated seal ring may be omitted in lieu of the conformal surface dielectric and metal layers on the die sidewalls. In one or more embodiments, in addition or alternatively to omitting the ionic-contamination barrier structure, a crack-stop structure of the integrated seal ring may be omitted. Accordingly, the die area that would otherwise be used by the omitted structures of the integrated seal ring may be repurposed, for example, by extending the area of active circuitry of the die or the size of the die may be reduced.

[0017] In one or more embodiments, the conformal surface dielectric layer and the conformal metal layer deposited on the conformal surface dielectric layer may form portions of a metal-insulator-metal (MIM) capacitor in conjunction with one or more of the semiconductor substrate or a base metallization layer coupled to the semiconductor substrate. A MIM capacitor generally includes first and second overlapping conductive electrodes or plates that are separated by an insulator (e.g., a dielectric layer). In one or more embodiments, the MIM capacitor may extend peripherally, at least in part, around the sidewalls of the die. In some implementations, the metal layer may be coupled to a conductive pad of the die to receive an operating voltage (VDD), and the semiconductor substrate and the metallization layer may be coupled to ground or a negative voltage supply (VSS). The MIM capacitor may serve as a decoupling capacitor for a supply voltage, for various input/output interfaces, and for other purposes. In one or more embodiments, a portion of the scribe-lane (a scribe-lane extension) may remain after singulating the dice, providing a scribe-lane extension formed of the dielectric layer, the metal layer, and the base metallization layer at the bottom edge of the die. The scribe-lane extension may protrude from the sidewalls of the die and may contribute to the capacitance of the MIM capacitor.

[0018] One or more embodiments of circuits and methods are described below that use the

conformal dielectric layer and the metal layer on the chip sidewalls and portions of the bottom extent of the scribe lane between dice to form the MIM capacitor, which requires no extra die area, allowing a reduction of the internal area of the die. In an example, after partial sawing of the scribe-lane between dice, a dielectric may be applied conformally to the die sidewalls and optionally over other surfaces of the die. This dielectric may be selected based on its dielectric constant ( $k$ ). In one or more embodiments, a dielectric material having a dielectric constant ( $k$ ) may be selected that is high relative to the dielectric constant ( $k$ ) of the semiconductor substrate. In an example, the dielectric material may include one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>), or other dielectric material that may have a higher electrical resistance than the semiconductor substrate. In some embodiments, the dielectric material may be selected to enable a capacitance of approximately seventeen (17) femtofarad per micrometer squared (fF/μm<sup>2</sup>) or more.

[0019] In one or more embodiments, a method or process flow may begin with a processed semiconductor wafer, which may have received back-grinding processing. As used herein, the term “semiconductor wafer” refers to a semiconductor substrate with a first side upon which distinct active circuit areas are formed. Each distinct active circuit area may include an active circuit area, one or more conductive pads on a top surface, scribe-lane areas between the active circuit areas, and optionally a seal-ring structure. A base metallization layer may be applied to a second side of the semiconductor wafer. The semiconductor wafer may be partially cut through the scribe-lane areas between the active circuit areas to form scribe-lane trenches that extend between the distinct active circuit areas, through the semiconductor substrate, and partially into the base metallization layer. A dielectric material may be deposited conformally onto a top surface of each of the active circuit areas and on the sidewalls and bottom extent of the scribe-lane trenches to form a dielectric layer.

[0020] In some embodiments, the dielectric layer may be patterned to remove selected portions over the one or more conductive pads to facilitate bond-pad connections. In some embodiments, a patterned sacrificial mask may be applied over the bond pads prior to deposition of the dielectric layer. After applying the dielectric layer, the sacrificial mask may be removed to expose the conductive pads. After exposing the conductive pads, a metal layer (“top plate layer”) may be deposited onto the dielectric layer and into the openings through the dielectric layer to couple to the one or more conductive bond pads. After depositing the metal layer, the scribe-lane cuts may be completed to produce individual circuit dice by etching, sawing, or otherwise cutting at the center of the scribe-lane trenches.

[0021] One or more of the conformal metal layer or the conformal dielectric layer may provide an ionic-contamination barrier structure for each die, allowing for omission of an ionic contamination barrier structure from an integrated seal ring of the die. In some embodiments, the seal ring of the die may be omitted entirely, because the metal layer and the dielectric layer may provide both the ionic-contamination barrier and crack-stop functions. In some embodiments, the dielectric layer and the metal layer may couple with a combination of the substrate semiconductor material and the base metallization layer to form a metal-insulator-metal (MIM) capacitor.

[0022] By forming a MIM capacitor along the die sidewalls and portions of the scribe-lane, a MIM capacitor may be formed as a die-perimeter extension along the perimeter of the die that is approximately half the width of the scribe-lane and the thickness of the semiconductor wafer. In one or more instances, the MIM capacitor may allow for an area reduction of the die by as much as five to ten percent (5%-10%) since an otherwise internal decoupling capacitor can be omitted from the internal area of the die. Additionally, the added sidewall covering provided by the conformal surface dielectric layer and optionally the metal layer may act as an ionic-contamination barrier, allowing the seal ring design to be shrunk to only contain a sawing crack-stop structure, when applicable. In some embodiments, the sawing crack-stop structure may be omitted in addition to or in lieu of omission of the ionic-contamination barrier structure, and the dielectric layer and the

metal layer may provide sawing crack-stop functionality. In either case, the overall die size may be reduced, or this may alternatively allow for an increase in the active circuit area without increasing the size of the circuit die.

[0023] Referring now to FIG. 1, a top view of a portion a semiconductor wafer **100** is shown that includes multiple dice **102**, in accordance with one or more embodiments of the present disclosure. Each die **102** may include an integrated-circuit or active-circuit area **104** and scribe-lane areas (or saw-lane areas) **112(1)** and **112(2)** between adjacent dice **102**. The scribe-lane areas **112** may be areas of the semiconductor wafer **100** that do not include circuit structures or metal layers and that are reserved for cutting operations, such as by a saw, a laser, or other cutting process to singulate or separate the dice **102** from one another.

[0024] To prevent or reduce the likelihood of cracking of the dice **102** during the separation process, each die **102** may include a seal ring with a crack-stop structure **106**, which may be formed near the periphery of the die **102** and between the scribe-lane areas **112** and the active circuit area **104** of each die **102**. To prevent ionic contamination of the die **102**, the seal ring may also include an ionic-contamination barrier structure **108** formed between the crack-stop structure **106** and the active circuit area **104** of the die **102**. Both the crack-stop structure **106** and the ionic-contamination barrier structure **108** may contribute to the overall size of the die **102**.

[0025] The die **102** may include a first buffer area **110(1)** between and the scribe-lane areas **112** and the crack-stop structure **106**. The die **102** may include a second buffer area **110(2)** between the crack-stop structure **106** and the ionic-contamination barrier structure **108**. The die **102** may include a third buffer area **110(3)** between the ionic-contamination barrier structure **108** and the active circuit area **104**. The crack-stop structure **106**, the ionic-contamination barrier structure **108**, and the buffer areas **110** contribute to the overall size of the die **102**.

[0026] As mentioned above, embodiments of the circuits and methods described herein include a surface dielectric layer deposited conformally on the top surfaces and on the sidewalls of each die **102**, forming a portion of a perimeter structure (shown in FIGS. 4-8). Additionally, a metal layer may be deposited on the surface dielectric layer, forming the perimeter structure (shown and described with respect to FIGS. 5-8). The surface dielectric layer and the metal layer may be conformal to the top surfaces and sidewalls of the die **102**. The conformal metal layer and the conformal dielectric layer may operate to provide an ionic-contamination barrier function, allowing for omission of the ionic-contamination barrier structures **108**, which can enable an overall reduction in the size of the die **102**. In some embodiments, the dielectric layer and the metal layer may also provide a crack-stop function, allowing for omission of the crack-stop structure **106**, which can enable a further reduction in the size of the die **102**. Moreover, in one or more embodiments, the metal layer, the dielectric layer, and one or more of the semiconductor substrate or the base metallization layer may form a capacitor, which consumes no extra die area, allowing an internal capacitor (such as a decoupling capacitor) to be excluded and, thus, enabling internal die areas to be smaller (such as five to ten percent (5-10%) smaller).

[0027] In the following discussion of FIGS. 2-7, embodiments of a process for producing one or more dice **102** with a perimeter structure is shown and described. By applying metal and dielectric layers along the sidewalls of the die, the metal layer and the dielectric layer may couple with a bottom electrode that is formed by one or more of the semiconductor substrate and the base metallization layer attached to and configured to form the bottom surface of the semiconductor substrate. The semiconductor substrate and the base metallization layer may be grounded and may form a bottom plate of a capacitor (such as a decoupling capacitor that includes the bottom plate, the conformal dielectric layer, and the conformal metal layer). The semiconductor substrate and the base metallization layer may be coupled to electrical ground or to a negative supply voltage (VSS). For plasma-diced dice, it may be possible to completely forgo the area designated for the seal ring and to rely solely on the dielectric layer and the metal layer to provide the functionality of both a crack-stop structure and an ionic-contamination barrier structure, enabling a reduced die size, an

increased active circuit area, or both.

[0028] Referring now to FIG. 2, a cross-sectional view of an embodiment of a portion of a semiconductor wafer **200** is shown that may include a semiconductor substrate **202** and multiple layers **204** formed thereon that may include multiple active circuit areas **104** separated by scribe lane areas **112**. In this example, the semiconductor wafer **100** may be formed and fully processed. In one or more embodiments, the semiconductor wafer **200** may have received back-grinding to define a bottom surface of the semiconductor substrate **202** and the semiconductor wafer **200**. In addition, a build-up structure that includes a plurality of patterned metal layers **204** separated by dielectric layers (not numbered) is formed on the upper surface **222** of the semiconductor substrate **202**. An upper surface of the build-up structure may define a top surface of the semiconductor wafer **200**, and the semiconductor wafer **200** may or may not have electrical contact pads on the top surface. The semiconductor wafer **200** is provided for illustrative purposes only and is not necessarily drawn to scale.

[0029] Depending on the embodiment, the semiconductor substrate **202** may be thinner or thicker, and the build-up structure that includes the patterned metal layers **204** may be thicker or thinner and may include more or fewer layers. In some embodiments, the semiconductor substrate **202** may be formed from silicon, silicon carbide, gallium nitride, gallium arsenide, or another substrate material and may or may not include an insulative layer (e.g., silicon-on-insulator).

[0030] In the illustrated example, the semiconductor wafer **200** is provided that includes a plurality of distinct active circuit areas **104** separated by scribe-lane areas **112**. The semiconductor wafer **200** may be fully processed, but the active circuit areas **104** are not yet cut from the semiconductor wafer **200** by one or more cutting operations for forming the individual dice **102**. In this example, adjacent portions of only two dice **102(1)** and **102(2)** are shown, but it should be appreciated that the fully processed semiconductor wafer **200** may support any number of active circuit areas **104** formed in an array on the semiconductor substrate **202** prior to the cutting or singulation operations.

[0031] In the illustrated example, prior to singulation, the semiconductor wafer **200** may include a plurality of dice **102**, each of which may include a seal ring including a crack-stop structure **106** and an ionic-contamination barrier structure **108**. Each die **102** may be separated from adjacent dice **102** by saw-lane or scribe-lane areas **112** that extend around the crack-stop structures **106** and the ionic-contamination barrier structures **108**.

[0032] In the illustrated example, each of the crack-stop structure **106** and the ionic-contamination barrier structure **108** is generally indicated by a rectangle having dashed lines in FIGS. 2-7. The crack-stop structure **106** may be comprised of first portions of metal layers **208** and contact or via structures **206** that extend between and couple the first portions of the metal layers **208** to form a structure configured to prevent or reduce the likelihood of the die **102** cracking when the semiconductor wafer **200** is cut in the scribe-lane areas **112**. The ionic-contamination barrier structures **108** may be comprised of second portions of metal layers **212** and contact or via structures **210** that extend between and couple the second portions of the metal layers **212** to form a structure configured to protect the die from contamination. In the illustrated example, only the metal layers **208** and **212** and the metal structures **206** and **210** of the second die **102(2)** are provided with reference numbers, though the first die **102(1)** includes similar crack-stop structures **106** and ionic-contamination barrier structures **108**.

[0033] Each die **102** may include an active circuit area **104**, which may include various portions of metal layers **218**, vias **216**, and other circuit structures. In the illustrated example, the second die **102(2)** is cut off such that the associated active circuit area **104** is not visible in the drawing. Typically, each die **102** may include buffer areas **110** (in FIG. 1, for example) formed from dielectric material, and which do not include internal metal or circuit structures. Such buffer areas may be located between the scribe-lane areas **112** and the crack-stop structure **106**, between the crack-stop structure **106** and the ionic-contamination barrier structure **108**, and between the ionic-

contamination barrier structure **108** and the active circuit area **104**.

[0034] In the illustrated example, the semiconductor substrate **202** may include a first surface **220** and a second surface **222**. As discussed below with respect to FIG. **3**, a base metallization layer may be coupled to the first surface **220**. As shown, a build-up structure of multiple conductive layers (circuit layers) **204** and dielectric layers (not numbered) may be formed on or coupled to the second surface **222** of the semiconductor substrate **202**.

[0035] Referring now to FIG. **3**, a cross-sectional view **300** of the semiconductor wafer **200** of FIG. **2** is shown that includes a base metallization layer **302** and a scribe-lane trench **312** extending through the scribe-lane area **112**, including through the build-up structure and the semiconductor substrate **202**, and partially into the base metallization layer **302**, in accordance with one or more embodiments of the present disclosure. In one or more embodiments, the base metallization layer **302** may be formed from one or more of aluminum, copper, cobalt, nickel, tungsten, other conductive metals, or any combination thereof.

[0036] In this example, the base metallization layer **302** may be coupled to the first surface **220** of the semiconductor substrate **202** with conductive through-substrate vias (not illustrated). The base metallization layer **302** may be ohmic to the wafer and may therefore act as a negative voltage supply (VSS) or ground connection. This connection may be electrically and mechanically connected to the packaging, which may be grounded. The base metallization layer **302** together with the semiconductor substrate **202** may couple to form a bottom plate of a capacitor.

[0037] In the fabrication process, the active circuit areas **104** and the structures of the seal ring (if included) are formed, and the base metallization layer **302** may be applied to the semiconductor wafer **200**. The semiconductor wafer **200** may then be oriented with the base metallization layer **302** down, and the semiconductor wafer **200** may be partially cut through the scribe-lane areas **112** until a small portion of the base metallization layer **302** is exposed and cut, forming scribe-lane trenches **312**. In a manufacturing process that uses a saw blade for the singulation process, the saw blade may cut the semiconductor wafer **200** in the scribe-lane areas **112** through the build-up structure and the semiconductor substrate **202** and into the base metallization layer **302**, such that the saw blade slightly exposes and slightly cuts the base metallization layer **302** to produce scribe-lane trenches **312**. Saw blades used for cutting semiconductor wafers **200** may vary in width. In some embodiments, the saw blade may have a width of between twenty (20) and fifty (50) micrometers ( $\mu\text{m}$ ) but may be matched to the width of the scribe-lane area **112**. Alternatively, a plasma cutting tool may be used to cut through the build-up structure and the semiconductor substrate **202** within the scribe-lane areas **112**, and slightly into the base metallization layer **302** to produce the scribe-lane trench **312**.

[0038] The scribe-lane areas **112** may be cut, forming scribe-lane trenches **312**. Each scribe-lane trench **312** may extend from a top surface of the semiconductor wafer to and partially into the base metallization layer **302**. The sidewalls of the scribe-lane trenches **312** may form the die edges in the scribe-lane areas **112**. As discussed below with respect to FIG. **4**, the fabrication process may continue with depositing a selected dielectric onto the sidewalls of the scribe-lane trenches **312** and optionally over a top surface of the die **102** to provide a conformal dielectric layer.

[0039] Referring now to FIG. **4**, a cross-sectional view **400** of the semiconductor wafer **200** of FIG. **3** is depicted that includes a conformal dielectric layer **402** extending over the top of the chip and on the sidewalls (die edges within the scribe-lane trenches **312**) of the dice **102**, in accordance with one or more embodiments of the present disclosure. The dielectric material may be deposited onto the substantially vertical sidewalls of the scribe-lane trenches **312**, onto the horizontal surface of the partially cut base metallization layer **302** within the scribe-lane trenches **312**, and on top surfaces of the etched semiconductor wafer **200** to form the conformal dielectric layer **402**. The resulting semiconductor wafer is generally indicated at **406**, in part, because the thickness of the dielectric layer **402** alters the thickness of the semiconductor wafer **200**.

[0040] In one or more embodiments, the conformal dielectric layer **402** may be formed using

atomic layer deposition (ALD), which is well suited to forming thin conformal layers, and/or using a different deposition method (e.g., low pressure chemical vapor deposition (LPCVD), sputtering, physical vapor deposition (PVD), plasma-enhanced chemical vapor deposition (PECVD), metal organic CVD (MOCVD), molecular beam epitaxy (MBE), inductively coupled plasma (ICP) deposition, electron cyclotron resonance (ECR) deposition, plasma enhanced ALD (PEALD), or other suitable techniques). In some embodiments, the conformal dielectric layer **402** may have a thickness in a range of about **50** angstroms to about **300** angstroms, though layer **402** may be thick or thinner, as well. In one or more embodiments, the dielectric layer **402** may be formed from a dielectric material that is selected to have a relatively high dielectric constant ( $k$ ). In an example, the dielectric material may include one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>), silicon nitride (Si<sub>3</sub>N<sub>4</sub>, including silicon-rich or silicon-poor compositions thereof), or another dielectric material that may be configured to enable a capacitance of approximately seventeen (17) femtofarad per micrometer squared (fF/ $\mu\text{m}^2$ ) or more. As previously discussed, one or more of the metallization layer **302** and the semiconductor substrate **202** may form the bottom plate of a metal-insulator-metal (MIM) capacitor, while the dielectric layer **402** may form the insulator portion.

[0041] In one or more embodiments, the deposition of the dielectric layer **402** may provide an additional benefit. In particular, the dielectric layer **402** may operate to seal the die **102** from ionic and other contaminants. In some embodiments, the dielectric layer **402** may render the ionic-contamination barrier structures **108** redundant. In such a case, the ionic-contamination barrier structures **108** may be omitted, allowing room for increasing the active circuit area **104** without increasing the size of the die **102** or allowing for an overall reduction in the size of the die **102**. For example, the area of the die **102** that is currently occupied by the ionic-contamination barrier structures **108** and the buffer area **110(3)** (in FIG. 1) between the ionic-contamination barrier structures **108** and the active circuit area **104** may be reclaimed to either shrink the size of the die **102** or to expand the active circuit area **104** without increasing the size of the die **102**.

[0042] In one or more embodiments, the fabrication process may include applying a mask over horizontal portions of the dielectric layer **402** over the top surface of the die **102**, patterning the mask to include openings over selected portions of the dielectric layer **402** that cover electrical contacts or pads, removing the selected portions of the dielectric layer **402** (for example, to expose the electrical contacts or pads), and depositing a metal layer onto the dielectric layer **402** and onto the electrical contacts or pads that were exposed by patterning and etching of the dielectric layer **402**. An example depicting such patterning and deposition of the metal layer is described below with respect to FIG. 5.

[0043] FIG. 5 depicts a cross-sectional view **500** of the semiconductor wafer **406** of FIG. 4 including a patterned dielectric layer **402** and deposition of a metal-insulator-metal (MIM) top-plate metal layer **504**, in accordance with one or more embodiments of the present disclosure. In this example, the fabrication process may include patterning the dielectric layer **402**. For example, a mask may be applied to the dielectric layer **402** and unmasked portions of the dielectric layer **402** may be etched to remove selected portions of the dielectric layer **402**, such as in the contact areas **502**, which may correspond to areas that include metal contacts **508** (bond pads or other electrical interconnects) on the dice **102(1)** and **102(2)**. The patterning and etching of the dielectric layer **402** may expose one or more metal contacts or pads. Alternatively, a patterned sacrificial mask may be applied over the contact areas **502** prior to deposition of the dielectric layer **402**. After applying the dielectric layer **402**, the sacrificial mask may be removed to expose the conductive pads in the contact areas **502**.

[0044] After exposing the contact areas **502** (if any), a metal layer **504** may then be deposited over the horizontal and vertical portions of the dielectric layer **402**, within the scribe-lane trenches **312**, over the top surface of the die **102**, and within the contact areas **502**. The metal layer **504** may form



a top plate of capacitor and may be coupled to metal contacts on the die **102** at the contact area **502**. The resulting semiconductor wafer is generally indicated at **506**, in part, because the thickness of the metal layer **504** alters the thickness of the semiconductor wafer **406**.

[0045] In some embodiments, the metal layer **504** may be applied using atomic layer deposition (ALD), which is well suited to forming thin conformal layers, and/or using a different deposition method (e.g., low pressure chemical vapor deposition (LPCVD), sputtering, physical vapor deposition (PVD), plasma-enhanced chemical vapor deposition (PECVD), metal organic CVD (MOCVD), molecular beam epitaxy (MBE), inductively coupled plasma (ICP) deposition, electron cyclotron resonance (ECR) deposition, plasma enhanced ALD (PEALD), or other suitable techniques). In some embodiments, the metal layer **504** may have a thickness in a range of about 50 angstroms to about 300 angstroms, though the metal layer **504** may be thick or thinner, as well.

[0046] After the metal layer **504** is deposited, the fabrication process may include a singulation process, which may include completing the cut-through within the scribe-lane trenches **312** to separate the dice **102**. The singulation process may be performed by etching, sawing, or otherwise cutting the semiconductor wafer **506** beginning from a side corresponding to the base metallization layer **302**. The singulation process may cut through portions of the base metallization layer **302**, the dielectric layer **402**, and the metal layer **504** at the bottom extents of the scribe-lane trenches **312** to separate the dice **102**. When a width of the cut-through (cut-through **602** in FIG. **6**) is narrower than a width of the scribe-lane trench **312**, the singulation process may result in a capacitor with a perimeter extension around the die **102** (e.g., a scribe-lane extension or ledge that extends outward from a bottom surface of the die **102** around the die perimeter). The perimeter extensions (scribe-lane extensions **604** in FIG. **6**) may have horizontal dimensions that extend from the die sidewalls up to approximately half of the width of the scribe-lane trench **312** and that are approximately the thickness of the semiconductor wafer **202**.

[0047] In some embodiments, the saw blade used to cut the scribe-lane trench **312** may have a width of twenty (20) and fifty (50) micrometers ( $\mu\text{m}$ ) or could be sized according to a width of the scribe-lane areas **112**. In this example, the saw blade used to perform the singulation process could have a width of 20  $\mu\text{m}$ , which is smaller than the width of the scribe-lane trench **312**. The saw blade can be this small, in part, because the saw blade will not be cutting the back-end of the line (BEOL) metallization, there should be little variation in the content of the material to be cut that might cause chipping and peeling.

[0048] In an alternative process, the scribe-lane trench **312** may be formed by a laser grooving operation. In this alternative approach, laser ablation could be used to singulate the dice **102**. In still other embodiments, the scribe-lane trench **312** may be formed using a saw blade, and the singulation operation may be performed using a laser. Other implementations are also possible.

[0049] In one or more embodiments, the singulation operation may be completed by cutting at a center of a bottom extent of the scribe-lane trench **312**. In some embodiments, the scribe-lane trench **312** may have a width that is within a range of about fifty (50) to about one hundred (100) micrometers ( $\mu\text{m}$ ). In other embodiments, the scribe-lane trench **312** may have a width that is larger than one hundred micrometers (100  $\mu\text{m}$ ). In one or more embodiments, the cutting operation may be completed with a cut width that is less than a width of the scribe-lane trench **312**. In an example, the cut width may be twenty micrometers (20  $\mu\text{m}$ ). The cut operation may be performed at a center of a bottom extent of each scribe-lane trench **312**, leaving a remainder (a scribe lane extension **604** in FIG. **6**) on either side of the cut. This remainder may include a portion of the metal layer **504**, a portion of the dielectric layer **402**, and a portion of the base metallization layer **302**, thus extending the area of the capacitor.

[0050] FIG. **6** depicts a cross-sectional view **600** of the semiconductor wafer **506** of FIG. **5** after singulation by etching, sawing, or otherwise cutting through a portion of the metal layer **504**, a portion of the dielectric layer **402**, and portion of the base metallization layer **302** at a center of the bottom extent of the scribe-lane trench **312**, in accordance with one or more embodiments of the

present disclosure. The dice **102** may be separated by a sawing operation, a laser operation, or another cutting operation, providing a cut-through generally indicated at **602**, which may divide the bottom extent of the scribe-lane trench **312** approximately in half.

[0051] As indicated above, it may be desirable to provide as small a cut as possible, while dividing the scribe-lane trench **312** in half to leave a remainder (a scribe-lane extension **604**) on each side. The scribe-lane extension **604** may contribute to the surface area of the capacitor. The scribe-lane trench **312** (in FIG. **3**) may have a width that may vary from approximately sixty (60) to about two hundred (200) micrometers ( $\mu\text{m}$ ), depending on the embodiment. Depending on the width of the scribe-lane trench **312** and the width of the cut-through **602** at the center of the scribe-lane trench **312**, the scribe-lane extension **604** may have a width of about forty (40) to about one hundred (100) micrometers ( $\mu\text{m}$ ). The scribe-lane extensions **604** may be formed at a bottom of each sidewall of the die **102** and may contribute additional surface area for calculating the capacitance value of the capacitor.

[0052] Referring now to FIG. **7**, a cross-sectional view of a portion of the first die **102(1)** of the semiconductor wafer **506** of FIG. **6** is shown that includes a scribe-lane extension **604** having a selected size, in accordance with one or more embodiments of the present disclosure. In this example, the first die **102(1)** has been cut from the semiconductor wafer **506**, producing one or more sidewalls **702**. The sidewall **702** is covered with a conformal dielectric layer **402** and a conformal metal layer **504**, which may provide the functionality of a seal ring that may provide a crack-stop and an ionic-contamination barrier. Additionally, the conformal dielectric layer **402** and the conformal metal layer **504** may provide a metal-insulator perimeter extension that may couple with one or more of the semiconductor substrate **202** or the base metallization layer **302** to form the capacitor.

[0053] As mentioned above, the width of the scribe-lane extension **604** may contribute to the overall capacitance of a MIM capacitor. For a 1 millimeter (mm)×1 mm die **102** that has a square shape with a scribe-lane width of about sixty micrometers (60  $\mu\text{m}$ ) and a thickness of the semiconductor substrate **202** of approximately three hundred micrometers (300  $\mu\text{m}$ ), the MIM capacitor may have an area determined by subtracting the area of the 1 mm×1 mm die **102** from the total area of the chip as follows:

[00001]  $\text{CapacitorArea} = \text{ChipArea} - \text{DieArea} + \text{SidewallSurfaceArea}$  (1)

[0054] This equation may be rewritten numerically using the values provided above as follows in Equation 2 below:

[00002]  $((1.04\text{mm})^2 - (1\text{mm})^2) + 4 * (0.3\text{mm} * 1\text{mm}) = 1.2816\text{mm}^2$  (2)

[0055] In Equation 2, the example assumes that the width of the retained scribe-lane extension **604** is approximately twenty micrometers (20  $\mu\text{m}$ ) after cutting a 60  $\mu\text{m}$ -wide scribe-lane **312** and assuming that a center portion that is about twenty micrometers (20  $\mu\text{m}$ ) wide is removed during the cutting operation.

[0056] The capacitor area refers to the area in which the plates of the MIM capacitor overlap. The capacitance  $C$  associated with the MIM capacitor is a function of the capacitor area ( $A$ ) as follows:

[00003]  $C = \frac{k\epsilon_0 A}{d}$  (3)

where  $C$  is the capacitance measured in farads (F),  $\epsilon_{\text{sub.0}}$  is the permittivity of free space (a measure of resistance encountered when forming an electric field in a vacuum),  $k$  is the dielectric constant of the material of the dielectric layer **402**,  $A$  is the area where the plates overlap, and  $d$  is the separation distance between the plates (separation distance between the metal layer **504** and one of the semiconductor substrate **202** (the portion of the semiconductor substrate **202** including the sidewalls **702**) or the metallization layer **302** (portion including the scribe-lane extension **604**)).

[0057] It should be appreciated that the size of the MIM capacitor may vary with the size of the die **102**. In an example that includes a 5 mm×5 mm die **102** and using similar scribe-lane width and

die-saw consumption of scribe lane as in equation (2), the area of the MIM decoupling capacitor may be calculated as follows:

$$[00004] \ ((5.04\text{mm})^2 - (5\text{mm})^2) + 4 * (0.3\text{mm} * 5\text{mm}) = 6.4016\text{mm}^2 \quad (4)$$

[0058] The top plate formed by the metal layer **504** may contact exposed metal on the top of the die **102**, a through-hole or surface-mount pad on the top surface, or another designated connection for the MIM capacitor. In one or more embodiments, the metal layer **504** may be coupled to an operating voltage (VDD) of the die **102**.

[0059] In general, the sidewall and perimeter configuration of the MIM capacitor, using the sidewalls **702** adjacent to the semiconductor wafer **202** and the metallization layer **302** and the scribe-lane extension **604** adjacent to the metallization layer **302**, can be used to provide decoupling for input/output high-speed interfaces, reducing the overall die area typically reserved for such high-speed interfaces. In one or more embodiments, the MIM capacitor may be used for core power supply (0.8V, 1.1V, and so on) to reduce power-supply noise.

[0060] In one or more embodiments, the MIM capacitor may reduce the size of the die **102** by five to ten percent (5-10%) as compared to the size of a conventional die that includes a decoupling capacitor of similar capacitive density (on an order of seventeen (17) nano-farads per millimeter squared (nF/mm.sup.2.sub.) or seventeen (17) femtofarads per micrometer squared (fF/μm.sup.2)). Further, by moving the MIM capacitor to the sidewalls **702** and perimeter the die **102**, the structure of the MIM capacitor may render ionic-contamination barrier structures **108** redundant, since the metal layer **504** and the dielectric layer **402** may also prevent ionic contamination of the die **102**. Accordingly, ionic-contamination barrier structures **108** may be reduced in size or eliminated, and any buffer space (**110** in FIG. 1) between the ionic-contamination barrier structures **108** and the active circuit area **104** may be reclaimed by either reducing the size of the die **102**, expanding the active circuit area **104**, or both.

[0061] In some manufacturing processes, cracking of the chip may be reduced or eliminated by using lasers or other cutting processes that do not cause chipping or cracking of the chip edge during singulation. In such processes, the die **102** may be produced without either of the ionic-contamination barrier structure **108** or the crack-stop structure **106**, and the MIM capacitor may protect the chip both from cracking and from ionic contamination. By moving the MIM capacitor to the sidewalls **702** and perimeter the die **102**, one or more of the crack-stop structure **106** and the ionic-contamination barrier structure **108** may be reduced in size or eliminated and any buffer space (**110** in FIG. 1) may be reclaimed by either reducing the size of the die **102**, expanding the active circuit area **104**, or both.

[0062] FIG. 8 depicts a top view **800** of a plurality of separated circuit dice **802(1)** and **802(2)** that include a chip-edge and scribe-lane decoupling capacitor **804**, in accordance with one or more embodiments of the present disclosure. The dice **802(1)** and **802(2)** may be examples of the dice **102(1)** and **102(2)** in FIGS. 2-7 after the singulation process is completed. Each die **102** or **802** is an electronic device that may be incorporated into or electrically coupled to other circuits.

[0063] In this example, the dice **802(1)** and **802(2)** may each include a MIM capacitor **804** formed from the metal layer **504** (FIG. 5), the dielectric layer **402** (FIGS. 4 and 5), and one or more of the base metallization layer **302** and the semiconductor substrate **202** (FIGS. 4-7). Each die **802** may include a first buffer area **110(1)**, the crack-stop structure **106**, and a second buffer area **110(2)**. Unlike the dice **102(1)** and **102(2)** in FIG. 1, the dice **802(1)** and **802(2)** do not include the ionic-contamination barrier structure **108**. The MIM capacitors **804** may operate as ionic-contamination seals for the dice **802**. In this example, the MIM capacitors **804** may be formed as a die-perimeter extension around the sidewalls **806** and scribe-lane extensions **604** around the bottom extents of the sidewalls **806** of the dice **802(1)** and **802(2)**. In the illustrated example, the electronic device or die **802** includes sidewalls **806(1)**, **806(2)**, **806(3)**, and **806(4)**, each of which includes a conformal metal layer **504** and a conformal dielectric layer **402** that capacitively couple to one or more of the

semiconductor substrate **202** or the base metallization layer **302** to form the MIM capacitor **804**. In some implementations, one or more of the sidewalls **806** may include a scribe-lane extension **604** that extends from a base of the sidewall **806** and away from the sidewall **806**. The one or more scribe-lane extensions **604** may contribute to an overall capacitance of the MIM capacitor **804**. [0064] It should be appreciated that, since the ionic-contamination barrier structure **108** may be omitted (as shown in FIG. **8**), the overall size of the die **802** may be reduced by reclaiming (removing) the area previously reserved for the ionic-contamination barrier structure **108** and for the buffer **110(3)** (in FIG. **1**) between the ionic-contamination barrier structure **108** and the active circuit area **104**. Alternatively, the active circuit area **104** (shown in phantom) may be increased without adjusting the size of the die **802**.

[0065] In a manufacturing environment in which the scribe-lane trenches **312** are formed using lasers or other cutting techniques that don't cause cracking of the die **102**, the crack-stop structure **106** (shown in FIG. **8** as a dotted line) may also be omitted, and the metal layer **504** and the dielectric layer **402** may serve as both the crack-stop structure **106** and the ionic-contamination barrier structure **108**. In such an embodiment, the size of the die **802** may be reduced accordingly, or the area allocated for the active circuit area **104** may be increased without increasing the size of the die **802**.

[0066] FIG. **9** depicts a flow diagram of a method **900** of forming a semiconductor die including a MIM capacitor, in accordance with one or more embodiments of the present disclosure. At **902**, the method **900** may include providing a processed semiconductor wafer **200** having a first surface and a second surface. The semiconductor wafer **200** (in FIG. **2**) may include a plurality of pre-singulated dice **102** arranged in an array and separated from one another by scribe-lane areas. Each of the one or more dice **102** may include a plurality of layers **204** forming an active circuit area **104** and optionally one or more of a crack-stop structure **106** or an ionic-contamination barrier structure **108**. The processed semiconductor wafer **200** may have been processed using back-grinding. In one or more embodiments, the semiconductor wafer **200** may include conductive pads on a surface of each of the die **102**.

[0067] At **904**, the method **900** may include depositing a base metallization layer **302** on a semiconductor substrate **202** that comprises the first surface **220** of the semiconductor wafer **200**. The semiconductor substrate **202** may include a second surface **222** on which the active circuitry **104** may be formed. The base metallization layer **302** (in FIG. **3**) may be a base metallization. When each die **102** is subsequently packaged, the metallization layer **302** may be mechanically and electrically coupled to a packaging flange, which may be coupled to electrical ground. The base metallization layer **302** and the semiconductor substrate **202** may form a first conductive plate of a capacitor. The base metallization layer **302** is sometimes referred to as being deposited on a bottom of the die **102**.

[0068] At **906**, the method **900** may include cutting the semiconductor wafer **200** from the second surface in the scribe-lane areas **112** to form scribe-lane trenches **312** (in FIG. **3**) that extend through the layers **204**, through the semiconductor substrate **202**, and at least partially into the base metallization layer **302**. The cutting operation may be performed using a saw, a laser, or other cutting process.

[0069] At **908**, the method **900** may include depositing a conformal dielectric layer **402** onto horizontal and vertical surfaces of the semiconductor wafer **200** over each of the dice **102** and along the sidewalls **702** and bottom extent of the scribe-lane trenches **312**. The dielectric layer **402** (in FIG. **4**) may be conformal and may cover the interior surfaces (sidewalls **702** and bottom extents) of the scribe-lane trenches **312**. This dielectric layer **402** may be formed from a dielectric material that may include one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>), or other dielectric material that may be configured to enable a capacitance of approximately seventeen (17) femtofarad per micrometer squared (fF/μm<sup>2</sup>) or more. The dielectric layer **402** may form the

insulator of the MIM capacitor.

[0070] At **910**, the method **900** may optionally include patterning the dielectric layer **402** and processing the patterned dielectric layer **402** to remove portions of the dielectric layer **402** in contact areas **502** (in FIG. 5) to expose one or more conductive pads. In one or more embodiments, the dielectric layer **402** may be patterned and processed to expose conductive pads on a surface of the die **102**.

[0071] At **912**, the method **900** may include depositing a conformal metal layer **504** onto the conformal dielectric layer **402**. If the dielectric layer **402** was patterned at **910**, the metal layer **504** may extend into the contact areas **502** to contact the exposed metal contacts (conductive pad) **508**. The metal layer **504** may form a second metal layer of the MIM capacitor.

[0072] At **914**, the method **900** may include cutting, from a side of the base metallization layer **302**, through the base metallization layer **302**, through the dielectric layer **402**, and through the metal layer **504** from the base metallization layer **302** at a center of a bottom extent of the scribe-lane trenches **312** to separate the dice **102**. The cut-through **602** may have a width that is less than a width of the scribe-lane trench **312**. In one or more embodiments, the etching, sawing, or laser ablation may be performed at a center of the trench **312**. In some embodiments, the cutting operation may remove as little material as possible to leave a scribe-lane extension **604**, which may include portions of the metal layer **504**, the dielectric layer **402**, and the base metallization layer **302**.

[0073] In one or more embodiments, the metal layer **502**, the dielectric layer **402**, and one or more of the semiconductor substrate **202** and the base metallization layer **302** may form a MIM capacitor that may be configured to operate as a decoupling capacitor for the chip. The metal layer **504** may be coupled to an operating voltage (VDD) of the chip (for example, through a contact area **502** on a top surface of the die **102**), while the semiconductor substrate **202** and the metallization layer **302** may be coupled to ground or to a negative supply voltage (VSS). In some implementations, the metallization layer **302** may be coupled to a conductive feature of the packaging (e.g., to a flange), which may be coupled to ground.

[0074] The method **900** may produce a semiconductor die that includes active circuitry and a perimeter structure that may function as an ionic-contamination barrier structure **108**, a crack-stop structure **106**, or both. In some implementations, the perimeter structure may form a capacitor that can be used to provide decoupling for input/output (I/O) interfaces, power supplies, or other purposes.

[0075] In one or more embodiments, the perimeter structure may be used with one or more high-speed interfaces. In one or more embodiments, the perimeter structure manufactured along the sidewalls **806** and the scribe-lane extension **604** may provide a capacitor that may be used for core power supply (0.8V, 1.1V, or other voltage levels) and may remove power-supply noise by shorting high frequency voltage signals to ground.

[0076] In one or more embodiments, the perimeter structure may replace internal ionic-contamination barrier structures **108**, reducing the overall size of the die **102**, enabling a larger active circuit area **104**, or both. In some implementations, the perimeter structure may provide the functionality of, and thus enable elimination of one or more of a crack-stop structure **106** or an ionic-contamination barrier structure **108**, reducing the overall size of the die **102**, enabling a larger active circuit area **104**, or both. In some embodiments, the size of the active circuit area **104** may be increased without increasing the size of the die **102**. In some embodiments, the size of the active circuit area **104** may be increased while the overall size of the die **102** may be reduced.

[0077] In one or more embodiments, a circuit may be produced that may include a capacitor that includes a conformal dielectric layer **402** and a conformal metal layer **504** that are formed on the sidewalls **806** of the die **802**. The capacitor may extend around the sidewalls **806** of the die **802** and may include a scribe-lane extension **604**. The capacitor may be used as a decoupling capacitor, a power supply filter, or for other purposes.

[0078] In one or more embodiments, a method may include applying a base metallization layer **302** to a semiconductor substrate **202** of a semiconductor wafer **200** that includes an array of active circuit areas **104** formed on the semiconductor substrate **202** and separated from one another by scribe-lane areas **112**. The method may include cutting the scribe-lane areas **112** of the semiconductor wafer **200** through semiconductor substrate **202** and partially into the base metallization layer **302** to form scribe-lane trenches **312** including one or more sidewalls and depositing a dielectric material **402** onto at least a portion of the semiconductor wafer **200** including the one or more sidewalls within the scribe-lane trenches **312** to form a dielectric layer **402**. The method may include depositing a metal material onto the dielectric layer **402** and cutting through the base metallization layer **302** within the scribe-lane trenches **312** to separate the semiconductor wafer **200** into dice **102**.

[0079] In some embodiments, the metal layer and the dielectric layer may form a perimeter extension that may form a capacitor with one or more of the semiconductor substrate **202** or the base metallization layer **302**, where the capacitor extends around a perimeter of each die. In one or more embodiments, each die **102** may include a MIM capacitor extending around the perimeter of the die.

[0080] In one or more embodiments, cutting through the base metallization layer **302** may include cutting a center of a bottom extent of each of the scribe-lane trenches **312** to produce one or more scribe-lane extensions **604**.

[0081] In one or more embodiments, each scribe-lane extension **604** may have a width that is less than half of a width of one of the scribe-lane trenches **312**. In one or more embodiments, cutting the center of the bottom extent of each of the scribe-lane trenches **312** may include forming a scribe-lane extension **604** on one or more sidewalls **702** of each of the die **102** of the array of dice **102**. Each scribe-lane extension **604** may protrude from one of the one or more sidewalls **702** and may include the base metallization layer **302**, the dielectric layer **402**, and the metal layer **504**.

[0082] In one or more embodiments, depositing the dielectric material may include depositing one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), or doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>). In one or more embodiments, the dielectric material may be selected to enable a capacitance per unit area of seventeen (17) femtofarad per micrometer squared or more. In some embodiments, the dielectric material may be selected to have a resistance that is greater than the semiconductor wafer **202** or the base metallization layer **302**.

[0083] In one or more embodiments, applying the base metallization layer **302** to the semiconductor substrate **202** may include applying one or more of aluminum, copper, cobalt, nickel, or tungsten to the semiconductor substrate **202** to form the base metallization layer **302**. In one or more embodiments, one or more of the metal layer **504** and the dielectric layer **402** provides an ionic contamination barrier structure.

[0084] In one or more embodiments, an electronic device may include a semiconductor substrate **202** having a first surface and a second surface. The electronic device may include a base metallization layer formed on the first surface **220** of the semiconductor substrate **202** to form a bottom surface of the electronic device. The electronic device may include one or more circuit layers formed on the second surface **222** of the semiconductor substrate **202**, wherein one or more sidewalls extend between the bottom and top surfaces of the electronic device. The electronic device may include a dielectric layer on the one or more sidewalls and may include a metal layer on the dielectric layer.

[0085] In one or more embodiments, the one or more circuit layers may include a conductive pad on the top surface, the metal layer may be coupled to the conductive pad through the dielectric layer, and the base metallization layer **302** and the semiconductor substrate **202** may be coupled to one of a negative supply voltage (VSS) or ground and are capacitively coupled to the metal layer **504** through the dielectric layer **402**. In one or more embodiments, the metal layer **504** and the dielectric layer **402** may extend around the one or more sidewalls to form a capacitor with one or

more of the semiconductor substrate or the base metallization layer. In one or more embodiments, the capacitor is configured to be coupled to an input/output interface to provide a decoupling function. In one or more embodiments, the capacitor is configured to be coupled to a power supply to filter noise from a power supply signal.

[0086] In one or more embodiments, the dielectric layer **402** includes one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), or doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>). In one or more embodiments, the dielectric layer **402** includes a dielectric material selected to enable a capacitance per unit area of seventeen femtofarad per micrometer squared or more. In one or more embodiments, the base metallization layer comprises one or more of aluminum, copper, cobalt, nickel, or tungsten.

[0087] In one or more embodiments, the electronic device may include one or more scribe-lane extensions **604** extending from the one or more sidewalls **702**. The scribe-lane extension **604** may include the base metallization layer **302**, the dielectric layer **402**, and the metal layer **504**. In one or more embodiments, the scribe-lane extension **604** may have a width that is less than half of a width of a scribe-lane area **112** on a semiconductor wafer **200** from which the die was singulated. In one or more embodiments, one or more of the metal layer **504** or the dielectric layer **402** forms an ionic contamination barrier structure.

[0088] In one or more embodiments, an electronic device may include a semiconductor substrate **202** including a first surface **220** and a second surface **222**. The electronic device may include a base metallization layer **302** coupled to the first surface **220** of the semiconductor substrate **202**. The electronic device may include one or more circuit layers **204** formed on the second surface **222** of the semiconductor substrate to define a top surface of the electronic device, where one or more sidewalls of the electronic device extend between the bottom and top surfaces of the electronic device. The one or more circuit layers may include one or more metal structures forming an active circuit area and including at least one contact pad on a top surface. The electronic device may include a dielectric layer formed on at least a portion of the base metallization layer and on the one or more sidewalls. The dielectric layer may include an open area over the at least one contact pad. The electronic device may include a metal layer **504** formed on the dielectric layer **402** and coupled to the at least one contact pad **508**. In one or more embodiments, the metal layer **504**, the dielectric layer **402**, and one or more of the semiconductor substrate **202** or the base metallization layer **302** may form a capacitor that extends around the one or more sidewalls **702**, and the capacitor may include one or more scribe-lane extensions **604** protruding from the one or more sidewalls **702**, where each extension includes the metal layer **504**, the dielectric layer **402**, and the base metallization layer **302**. In one or more embodiments, the capacitor may include extensions protruding at an angle that is approximately perpendicular to the sidewalls **702**. In some embodiments, each of the scribe-lane extensions **604** may have a width that is less than a half of a width of a scribe-lane area **112** on a semiconductor wafer **200** from which the die **102** was singulated.

[0089] The preceding detailed description is merely illustrative in nature and is not intended to limit the embodiments of the subject matter or the application and uses of such embodiments. As used herein, the word “exemplary” means “serving as an example, instance, or illustration.” Any implementation described herein as exemplary is not necessarily to be construed as preferred or advantageous over other implementations. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, or detailed description.

[0090] The connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in an embodiment of the subject matter. In addition, certain terminology may also be used herein for the purpose of reference only, and thus are not intended to be limiting, and the

terms “first”, “second” and other such numerical terms referring to structures do not imply a sequence or order unless clearly indicated by the context.

[0091] The foregoing description refers to elements or features being “connected” or “coupled” together. As used herein, unless expressly stated otherwise, “connected” means that one element is directly joined to (or directly communicates with) another element, and not necessarily mechanically. Likewise, unless expressly stated otherwise, “coupled” means that one element is directly or indirectly joined to (or directly or indirectly communicates with, electrically or otherwise) another element, and not necessarily mechanically. Thus, although the schematic shown in the figures depict one exemplary arrangement of elements, additional intervening elements, devices, features, or components may be present in an embodiment of the depicted subject matter. [0092] While at least one exemplary embodiment has been presented in the foregoing detailed description, it should be appreciated that a vast number of variations exist. It should also be appreciated that the exemplary embodiment or embodiments described herein are not intended to limit the scope, applicability, or configuration of the claimed subject matter in any way. Rather, the foregoing detailed description will provide those skilled in the art with a convenient road map for implementing the described embodiment or embodiments. It should be understood that various changes can be made in the function and arrangement of elements without departing from the scope defined by the claims, which includes known equivalents and foreseeable equivalents at the time of filing this patent application.

## Claims

1. A method comprising: applying a base metallization layer to a semiconductor substrate of a semiconductor wafer that includes an array of active circuit areas formed on the semiconductor substrate and separated from one another by scribe-lane areas; cutting the scribe-lane areas of the semiconductor wafer through the semiconductor substrate and partially into the base metallization layer to form scribe-lane trenches including one or more sidewalls; depositing a dielectric material onto at least a portion of the semiconductor wafer including the one or more sidewalls within the scribe-lane trenches to form a dielectric layer; depositing a metal layer onto the dielectric layer; and cutting through the base metallization layer within the scribe-lane trenches to separate the semiconductor wafer into dice.
2. The method of claim 1, wherein the metal layer and the dielectric layer form a perimeter extension that forms a capacitor with one or more of the semiconductor substrate or the base metallization, wherein the capacitor extends around a perimeter of each die.
3. The method of claim 1, wherein cutting through the base metallization layer comprises cutting a center of a bottom extent of each of the scribe-lane trenches to produce one or more scribe-lane extensions.
4. The method of claim 3, wherein each of the one or more scribe-lane extensions has a width that is less than half of a width of one of the scribe-lane trenches.
5. The method of claim 3, wherein cutting the center of the bottom extent of each of the scribe-lane trenches comprises forming the one or more scribe-lane extensions on one or more sidewalls of each die of the array of dice, each scribe-lane extension protruding from one of the one or more sidewalls and including the base metallization layer, the dielectric layer, and the metal layer.
6. The method of claim 1, wherein depositing the dielectric material comprises depositing one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), or doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>).
7. The method of claim 1, wherein the dielectric material that is selected to enable a capacitance per unit area of seventeen femtofarad per micrometer squared or more.
8. The method of claim 1, wherein applying the base metallization layer to the semiconductor substrate comprises applying one or more of aluminum, copper, cobalt, nickel, or tungsten to the



semiconductor substrate to form the base metallization layer.

**9.** The method of claim 1, wherein one or more of the metal layer and the dielectric layer provides an ionic-contamination barrier structure.

**10.** An electronic device comprising: a semiconductor substrate having a first surface and a second surface; a base metallization layer formed on the first surface of the semiconductor substrate to form a bottom surface of the electronic device; one or more circuit layers formed on the second surface of the semiconductor substrate to define a top surface of the electronic device, wherein one or more sidewalls extend between the bottom and top surfaces of the electronic device; a dielectric layer on the one or more sidewalls; and a metal layer on the dielectric layer.

**11.** The electronic device of claim 10, wherein: the one or more circuit layers includes a conductive pad on the top surface; the metal layer is coupled to the conductive pad through the dielectric layer; and the base metallization layer and the semiconductor substrate are configured to be coupled to one of a negative supply voltage (VSS) or ground and are capacitively coupled to the metal layer through the dielectric layer.

**12.** The electronic device of claim 10, wherein the metal layer and the dielectric layer extend around the one or more sidewalls to form a capacitor with one or more of the semiconductor substrate or the base metallization layer.

**13.** The electronic device of claim 12, wherein the capacitor is configured to be coupled to an input/output interface to provide a decoupling function.

**14.** The electronic device of claim 12, wherein the capacitor is configured to be coupled to a power supply to filter noise from a power supply signal.

**15.** The electronic device of claim 10, wherein the dielectric layer includes one or more of tantalum nitride (TaN), hafnium oxide (HfO<sub>2</sub>), aluminum oxide (Al<sub>2</sub>O<sub>3</sub>), or doped tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>).

**16.** The electronic device of claim 10, wherein one or more of the metal layer or the dielectric layer forms an ionic-contamination barrier structure . . .

**17.** The electronic device of claim 10, wherein the base metallization layer comprises one or more of aluminum, copper, cobalt, nickel, or tungsten.

**18.** The electronic device of claim 10, further including one or more scribe-lane extensions extending from the one or more sidewalls, each of the one or more scribe-lane extensions including portions of the base metallization layer, the dielectric layer, and the metal layer.

**19.** An electronic device comprising: a semiconductor substrate including a first surface and a second surface; a base metallization layer coupled to the first surface of the semiconductor substrate to define a bottom surface of the electronic device; and one or more circuit layers formed on the second surface of the semiconductor substrate to define a top surface of the electronic device, wherein one or more sidewalls of the electronic device extend between the bottom and top surfaces of the electronic device, and wherein the one or more circuit layers including one or more metal structures forming an active circuit area and including at least one contact pad on the top surface; a dielectric layer formed on at least a portion of the base metallization layer and on the one or more sidewalls, the dielectric layer including an open area over the at least one contact pad; a metal layer on the dielectric layer over the sidewalls and coupled to the at least one contact pad.

**20.** The electronic device of claim 19, wherein: the metal layer, the dielectric layer, and one or more of the semiconductor substrate and the base metallization layer form a capacitor that extends around the one or more sidewalls of the semiconductor substrate; and the capacitor further includes scribe-lane extensions protruding from the one or more sidewalls, each of the scribe-lane extensions including the metal layer, the dielectric layer, and the base metallization layer.

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