

RADIATION HARDENED E-FUSE MACRO

FIELD OF THE DISCLOSURE

[0001] The following disclosure relates generally to fuses and, more specifically, to radiation hardened electronic fuses (E-FUSE).

BACKGROUND

[0002] As a preliminary matter, an electronic fuse, or e-fuse, while sometimes acting as an active circuit protection device with an integrated Field Effect Transistor (FET) that is used to limit currents and voltages to safe levels during fault conditions, can also be used as a non-volatile, programmable memory element. Such an e-fuse can be inexpensively incorporated into an Integrated Circuit (IC), such as a Very Large Scale Integration (VLSI) IC, relative to charge storage based non-volatile memory, such as Flash.

[0003] These fuses function as resistive links that can be permanently programmed in either a conductive or highly resistive state, which is typically sensed at device power on and latched in memory. Notably, this allows for reconfiguration of chip function, such as disabling or enabling portions thereof to achieve design goals or work around issues, such as manufacturing defects, affecting portions of the chip in the field.

[0004] Static Random-Access Memory (static RAM or SRAM) is a type of random-access memory (RAM) that uses latching circuitry (e.g. flip-flops) to store each bit. SRAM is volatile memory, meaning data is lost when power is removed. The term static differentiates SRAM from DRAM (Dynamic Random-Access Memory), which must be periodically refreshed.

[0005] Electronic fuses are now finding use in SRAM circuits, which operate asynchronously and do not inherently require an external clock. Synchronous operation and an external clock are, however, required by current e-fuse implementations, requiring such circuits to be redesigned to support asynchronous operation when incorporating e-fuse technology.

[0006] Furthermore, an e-fuse that supports asynchronous operation and operation without an external clock that could also be used in high radiation environments would be beneficial in expanding the potential usage of such an e-fuse to environments where resistance to such conditions is needed.

[0007] What is needed, therefore, is an electronic fuse that can operate asynchronously and be integrated into radiation hardened products that do not require a clock while minimizing the addition of additional circuitry and components.

SUMMARY

[0008] Embodiments of the present disclosure provide radiation hardened e-fuse technology appropriate for integration into asynchronous memory designs for memory repair, which was previously accomplished using laser programmable metal fuses.

[0009] In embodiments, asynchronous read/write circuitry is controlled by a combination of shared functional I/O signals and test signals.

[0010] Further embodiments provide a fuse sensing capability that only requires a power on reset signal and that is internally self-timed.

[0011] The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the drawings, specification, and claims. Moreover, it should be noted that the language used in the specification has been selected principally for readability and instructional purposes and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a schematic describing a multi-bit, asynchronous e-fuse macro, in accordance with embodiments of the present disclosure;

[0013] Figure 2 is a schematic describing a single e-fuse bit, in accordance with embodiments of the present disclosure;

[0014] Figure 3 is a schematic describing self-timing and control circuitry, in accordance with embodiments of the present disclosure;

[0015] Figure 4 is a timing diagram describing the signaling sequence for reading the multi-bit, asynchronous e-fuse macro, in accordance with embodiments of the present disclosure;

[0016] Figure 5 is a timing diagram describing the signaling sequence for reading a single e-fuse bit, in accordance with embodiments of the present disclosure;

[0017] Figure 6 is a timing diagram describing the signaling sequence for writing a multi-bit, asynchronous e-fuse macro, in accordance with embodiments of the present disclosure;

[0018] Figure 7 is a timing diagram describing the signaling sequence for writing a single e-fuse bit, in accordance with embodiments of the present disclosure; and

[0019] Figure 8 is a flowchart describing the read method of Figure 4, in accordance with embodiments of the present disclosure;

[0020] Figure 9 is a flowchart describing the write method of Figure 6, in accordance with embodiments of the present disclosure;

[0021] Figure 10 is a flowchart describing the signaling sequence for reading a single e-fuse bit of Figure 5, in accordance with embodiments of the present disclosure; and

[0022] Figure 11 is a flowchart describing the signaling sequence for writing a single e-fuse bit of Figure 7, in accordance with embodiments of the present disclosure.

[0023] These and other features of the present embodiments will be understood better by reading the following detailed description, taken together with the figures herein described. The accompanying drawings are not intended to be drawn to scale. For purposes of clarity, not every component may be labeled in every drawing.

DETAILED DESCRIPTION

[0024] As a preliminary matter, Verilog notation, such as [X:x] is used herein and in the figures. Where present, this should be understood to refer to a bus containing multiple bits, numbered from X down to x. For example, [2:0] would indicate a three bit bus (i.e. 2, 1, 0).

[0025] Now regarding Figure 1, a schematic describing a multi-bit, asynchronous e-fuse macro **100**, in accordance with embodiments of the present disclosure is depicted. In embodiments, the e-fuse macro contains a plurality of e-fuse bits **200**, which may also be referred to as e-fuse circuits **200**, and which are depicted individually and in greater detail in Figure 2.

[0026] Now referring again to Figure 1, the e-fuse macro **100** of embodiments comprises the following inputs: an input output enable **106** (active high in embodiments), a power on reset **108** (active low in embodiments), a write address **110**, an input write enable **112** (active high in embodiments), a write clock **114** (active high in embodiments), and a ground clamp enable **116** (active low in embodiments). A supply voltage **102** (i.e. V_{PROGRAM}) input is also included, in embodiments, for programming purposes. Finally, the e-fuse macro **100** comprises a fuse output ($[2^{X+1}-1:0]$) **104**.

[0027] In embodiments, the write address **110** is a variable width bus (e.g. [X:0]). The value of the most significant bit of the write address **110** bus, X, in embodiments, is selected

based on the desired number of fuse output ($[2^{X+1}-1:0]$) **104** bits, where the number of fuse output ($[2^{X+1}-1:0]$) **104** bits is equal to two raised to the power of $X+1$.

[0028] In embodiments, the e-fuse macro **100** supports two operating modes, an application mode, which is used to read the e-fuse macro **100**, and a programming mode, which is used to write the e-fuse macro **100**.

[0029] In embodiments, the e-fuse macro **100** is configured such that only one e-fuse **200** can be written at a time. Write operations are further described in Figure 6, Figure 7, Figure 9, and Figure 11.

[0030] In embodiments, the e-fuse macro **100** is configured such that all e-fuses **200** are read simultaneously. Read operations are further described in Figure 4, Figure 5, Figure 8, and Figure 10.

[0031] In embodiments, all e-fuse macro **100** functions are externally controlled.

[0032] In embodiments, any signaling required to read the state of each e-fuse memory element **228** is generated via self-timing and control circuitry **118** included within the e-fuse macro **100**. The inclusion of the self-timing and control circuitry **118** enables the multi-bit, asynchronous e-fuse macro **100** to operate in asynchronous designs as no periodic clock signal is required to perform read operations.

[0033] Now regarding Figure 2, a schematic describing a single e-fuse bit **200**, in accordance with embodiments of the present disclosure, is depicted. More specifically, the e-fuse bit **200** of such embodiments comprises the following inputs: a reset **214**, a read reference current **204**, a precharge **202** (active low in embodiments), a read enable **206**, a hold (also referred to herein as a latch clock) **218**, an output enable **220**, a ground clamp **232**, and a write enable **234**. A voltage supply input **102**, the same as described in Figure 1, is also included for programming purposes. Finally, the e-fuse circuit **200** comprises a fuse output **104**.

[0034] Again referring to Figure 2, the e-fuse circuit **200** of embodiments comprises the following components: a first p-channel MOSFET (P1) **208**, a second p-channel MOSFET (P2) **212**, a first n-channel MOSFET (N1) **210**, a second n-channel MOSFET (N2) **226**, a third n-channel MOSFET (N3) **230**, an e-fuse memory element **228**, a radiation hardened latch circuit **216**, and a logical AND gate **236**. The functionality of each component within the e-fuse circuit **200** is further described in Figure 5, Figure 7, Figure 10, and Figure 11.

[0035] Now referring to Figure 3, the self-timing and control circuitry **118** included within the e-fuse macro **100** of embodiments is depicted in greater detail. More specifically, in Figure 3 the logical inverter **814**, logical AND gate **816**, and delay circuits **818/820**, in

embodiments, form a positive (active high) pulse generation circuit, which is activated by the rising edge of input power on reset **108** (active low in embodiments); delay circuit **818** determines the rising edge delay of the pulse generated on outputs read enable **206** (active high in embodiments) and precharge **202** (active low in embodiments). Furthermore, the time difference between delay circuit **818** and delay circuit **820** determines the pulse width of the pulse generated on outputs read enable **206** (active high in embodiments) and precharge **202** (active low in embodiments).

[0036] Also, in such embodiments, logical inverter **822**, logical NAND gate **824**, and delay circuits **826/828** form a negative (active low) pulse generation circuit activated by the rising edge of input power on reset **108** (active low in embodiments); delay circuit **826** determines the falling edge delay of the pulse generated on output hold **218**. Furthermore, the time difference between delay circuit **826** and delay circuit **828** determines the pulse width of the pulse generated on output hold **218**.

[0037] Again regarding Figure 3, logical AND gate **830** and delay circuit **832** form a positive (active high) pulse generation circuit activated by the rising edge of input power on reset **108** (active low in embodiments). Delay circuit **832** determines the pulse width of the enable signal used by the bias generation circuit **834**, which creates the read reference current **204** used by the e-fuse circuit **200**. Finally, logical inverter **812** converts the power on reset **108** input (active low in embodiments) to the reset **214** (active high in embodiments) input used by the e-fuse circuit **200**.

[0038] Lastly regarding Figure 3, decoder **802** (also referred to herein as a 1-Hot Decoder) converts the write address **110** input bus into a 1-hot write decode $[2^{X+1}-1:0]$ bus **836**. A plurality of logical AND gates **804** provide additional gating of the 1-hot write decode $[2^{X+1}-1:0]$ bus **836** to allow the write clock **114** input (active high in embodiments) to control the pulse width of output write enable $[2^{X+1}-1:0]$ **234** (active high in embodiments). Logical AND gate **806** provides clock gating control of the write clock **114** input (active high in embodiments) via the input write enable **112** input (active high in embodiments). Logical inverter **808** converts the ground clamp enable **116** input (active low in embodiments) to the ground clamp **232** (active high in embodiments) input used by the e-fuse circuit **200**. Finally, logical buffer **810** redrives input output enable **106** (active high in embodiments) to output enable **220** (active high in embodiments).

[0039] Notably, while Figure 3 describes one particular way of constructing such a circuit, other ways of constructing a circuit having similar functionality would be known to one of ordinary skill in the art; Figure 3 is intended to be merely exemplary and non-limiting. For

instance, designations of active high and active low should be considered merely exemplary. Similarly, designations of logic1 and logic0 should be considered merely exemplary and non-limiting.

[0040] In embodiments, a reset initialization sequence is used to place the e-fuse macro **100** of embodiments into application mode for reading each e-fuse memory element **228** and storing the state in a radiation hardened latch circuit **216** immediately following device power up. This procedure is graphically depicted in Figure 4, from a top-level perspective, and in Figure 5 from the perspective of a single e-fuse circuit **200**. This is also described in a flowchart in Figure 8 and Figure 10.

[0041] Now regarding Figure 4, specifically, a timing diagram describing the signaling sequence for reading the multi-bit, asynchronous e-fuse macro **100**, in accordance with embodiments of the present disclosure is depicted. Even more specifically, Figure 4 illustrates the process for placing the multi-bit, asynchronous e-fuse macro **100** into an application (read) mode by either floating or grounding the supply voltage input **102**, setting write clock **114** (active high in embodiments) to logic0, setting ground clamp enable **116** (active low in embodiments) to logic0, and setting input output enable **106** (active high in embodiments) to logic1. The write address **110** and input write enable **112** (active high in embodiments) inputs are not used and may be set to either logic0 or logic1.

[0042] Again referring to Figure 4, the multi-bit, asynchronous e-fuse macro **100** is held in the reset state during device power up by holding power on reset **108** (active low in embodiments) at logic0. A read of all e-fuse circuits **200** is initiated when power on reset **108** (active low in embodiments) transitions from logic0 to logic1. In embodiments, the signaling required to read the state of each e-fuse memory element **228** is generated via self-timing and control circuitry **118** included within the e-fuse macro **100**. The inclusion of the self-timing and control circuitry **118** enables the multi-bit, asynchronous e-fuse macro **100** to operate in asynchronous designs as no periodic clock signal is required to perform read operations.

[0043] Now regarding Figure 5, a timing diagram describing the signaling sequence for reading a single e-fuse bit **200**, in accordance with embodiments of the present disclosure is depicted.

[0044] Now referring again to Figure 5, the e-fuse circuit **200** is placed into application (read) mode by either floating or grounding the supply voltage input **102**, setting output enable **220** (active high in embodiments) to logic1, setting ground clamp **232** (active high in embodiments) to logic1, and setting write enable **234** (active high in embodiments) to logic0.

The previously described signal settings ensure that the circuitry used during write operations does not affect read operations.

[0045] Now referring to Figures 4 and 5, taken together, the e-fuse circuit **200** is held in the reset state during device power up by holding power on reset **108** (active low in embodiments) at logic0. In this state reset **214** (active high in embodiments) is set to logic1 thus resetting the radiation hardened latch **216**, the read reference current **204** is set to logic1 turning off p-channel MOSFET **208**, precharge **202** (active low in embodiments) is set to logic0 turning on second p-channel MOSFET (P2) **212** pulling up Net 1 **224**, read enable **206** (active high in embodiments) is set to logic0 turning off first n-channel MOSFET **210**, and latch clock (hold) **218** is set to logic1, forcing the radiation hardened latch **216** into a hold state. A read of the e-fuse circuit **200** is initiated when power on reset **108** (active low in embodiments) transitions from logic0 to logic1. The logic0 to logic1 input transition of power on reset **108** (active low in embodiments) creates a sequence of self-timed control signals and results in the value of the e-fuse memory element **228** being stored in the radiation hardened latch **216**.

[0046] The first event of the read sequence sets reset **214** (active high in embodiments) to logic0, de-asserting reset to the radiation hardened latch **216** and enables the read reference current **204** turning on first p-channel MOSFET (P1) **208**.

[0047] The second event of the read sequence sets precharge **202** (active low in embodiments) to logic1 turning off second p-channel MOSFET (P2) **212** and sets read enable **206** (active high in embodiments) to logic1 turning on first n-channel MOSFET (N1) **210**. During this step, the read reference current **204** is forced through the e-fuse memory element **228**. The use of a current reference for read operations reduces read current variability and improves read endurance. If the e-fuse memory element **228** is un-programmed, the resistance is low and therefore the voltage at Net 1 **224** is near ground and treated as logic0. If the e-fuse memory element **228** is programmed, the resistance is high and therefore the voltage at Net 1 **224** is near the supply and treated as logic1.

[0048] The third event of the read sequence pulses the latch clock (hold) **218** to sample and then hold the logic value at Net 1 **224**, which represents the state of the e-fuse memory element **228**, into the radiation hardened latch **216**.

[0049] The fourth event of the read sequence sets precharge **202** (active low in embodiments) to logic0 turning on p-channel MOSFET **212** pulling up Net 1 **224** and sets read enable **206** (active high in embodiments) to logic0, turning off first n-channel MOSFET **210**.

[0050] The fifth and final event of the read sequence sets the read reference current **204** to logic1 turning off p-channel MOSFET **208**. All signals except reset **214** (active high in embodiments) are returned to their initial state at the end of the read sequence. The reset **214** (active high in embodiments) signal is returned to its initial state when power on reset **108** (active low in embodiments) returns to logic0.

[0051] Now regarding Figure 6, a timing diagram describing the signaling sequence for writing the multi-bit, asynchronous e-fuse macro **100**, in accordance with embodiments of the present disclosure is depicted.

[0052] Now referring again to Figure 6, the multi-bit, asynchronous e-fuse macro **100** is placed into programming (write) mode by initially grounding the supply voltage input **102**, setting input output enable **106** (active high in embodiments) to logic0, setting power on reset **108** (active low in embodiments) to logic0, and setting ground clamp enable **116** (active low in embodiments) to logic1. The supply voltage input **102** is enabled once all inputs to the multi-bit, asynchronous e-fuse macro **100** are stable and valid.

[0053] Again referring to Figure 6, a write operation to a single e-fuse bit **200** is preceded by setting the write address **110** to the targeted e-fuse bit **200** and setting input write enable **112** (active high in embodiments) to logic1. A pulse is then applied to the write clock **114** (active high in embodiments) to control programming of the e-fuse memory element **228**. The write address **110** inputs ensure that only one e-fuse bit **200** is programmed at a time for the multi-bit, asynchronous e-fuse macro **100**. The input write enable **112** input (active high in embodiments) is included to extend decoding for designs that use multiple multi-bit, asynchronous e-fuse macros **100**.

[0054] Now regarding Figure 7, a timing diagram describing the signaling sequence for writing a single e-fuse bit **200**, in accordance with embodiments of the present disclosure is depicted.

[0055] Now referring again to Figure 7, the e-fuse circuit **200** is placed into programming (write) mode by setting reset **214** (active high in embodiments) to logic1, setting the read reference current **204** to logic1, setting precharge **202** (active low in embodiments) to logic0, setting read enable **206** (active high in embodiments) to logic0, setting latch clock (hold) **218** to logic1, setting output enable **220** (active high in embodiments) to logic0, and setting ground clamp **232** (active high in embodiments) to logic0. The previously described signal settings ensure that the circuitry used during read operations does not affect write operations.

[0056] Again referring to Figure 7, a write operation to the e-fuse memory element **228** is preceded by enabling the supply voltage input **102**. A pulse is then applied to write enable

234 (active high in embodiments) to control programming of the e-fuse memory element **228**. When write enable **234** (active high in embodiments) is logic1, current flows from the supply voltage input **102** through the e-fuse memory element **228**, and then through second n-channel MOSFET **226** to ground, thus programming the e-fuse memory element **228**.

[0057] Now referring to Figure 8, Figure 8 provides a flowchart describing the read method of Figure 4 **800**. More specifically, the method comprises: applying power to the e-fuse macro **100** while grounding or floating supply voltage **102 - 805**; asserting power on reset **108**, ground clamp enable **116**, and input output enable **106** and de-asserting write clock **114 - 810**; de-asserting power on reset **108 - 815**; reading e-fuse bits **200** via self-timing and control circuitry **118 - 820**; storing e-fuse memory element **228** values in radiation hardened latches **216 - 825**; and outputting values stored in radiation hardened latches **216** to e-fuse macro **100** outputs **104 - 830**.

[0058] Now referring to Figure 9, Figure 9 provides a flowchart describing the write method of Figure 6 **900**. More specifically, the method comprises: applying power to an e-fuse macro **100** while grounding or floating the supply voltage **102 - 905**; asserting power on reset **108** and de-asserting ground clamp enable **116**, input output enable **106**, write clock **114**, input write enable **112 - 910**; set write address **110** and assert input write enable **112 - 915**; apply supply voltage **102 - 920**; pulsing write clock **114** to program a single e-fuse memory element **228 - 925**; grounding or floating supply voltage **102 - 930**; and de-asserting input write enable **112 - 935**.

[0059] Now referring to Figure 10, Figure 10 provides a flowchart describing the signaling sequence for reading a single e-fuse bit of Figure 5 **1000**. More specifically, the method comprises: applying power to the e-fuse macro **100** while grounding or floating supply voltage **102 - 1005**; asserting reset **214**, precharge **202**, output enable **220**, and ground clamp **232** as well as de-asserting read enable **206**, hold **218**, and write enable **234** as well as disabling read reference current **204 - 1010**; de-asserting reset **214** and enabling read reference current **204 - 1015**; de-asserting precharge **202** and asserting read enable **206 - 1020**; pulsing hold **218**, causing e-fuse memory element **228** values to be stored in radiation hardened latch **216 - 1025**; asserting precharge **202** and de-asserting read enable **206 - 1030**; and disabling read reference current **204 - 1035**.

[0060] Now referring to Figure 11, Figure 11 provides a flowchart describing the signaling sequence for writing a single e-fuse bit of Figure 7 **1100**. More specifically, the method comprises: applying power to an e-fuse macro **100** while grounding the supply voltage **102 - 1105**; asserting reset **214** and precharge **202** and de-asserting read enable **206**, hold **218**,

output enable **220**, ground clamp **232**, and write enable **234**, while disabling read reference current **204 - 1110**; Applying supply voltage **102 - 1115**; pulsing write enable **234**, thereby programming the e-fuse memory element **228 - 1120**; and grounding or floating supply voltage **102 - 1125**.

[0061] Now referring to the disclosure, generally, embodiments of the present disclosure are described throughout as comprising circuits and elements thereof that are described as being “active low”, “active high”, or similar. Such language is intended to describe the relationship between elements of embodiments and not to limit the disclosure to such embodiments, specifically. For instance, the polarity of circuit elements of embodiments could be entirely flipped while maintaining the functionality described herein. For the avoidance of doubt, it is the relationship between the polarity of one circuit and/or circuit element to another that is important, not the specific polarity used herein to describe specific embodiments, as would be known to one of ordinary skill in the art.

[0062] Furthermore, alternative circuits could be used, in embodiments, to achieve the functions described herein without departing from the scope of the present disclosure.

[0063] Also, while embodiments of the present disclosure are ideally suited for applications such as Integrated Circuit (IC) memory repair, device identifiers, or crypto keys, the teachings of the present disclosure relating to asynchronous operation would also apply to other types of synchronous and asynchronous integrated circuits.

[0064] Lastly, active high, active low, logic0, and logic 1 are relative terms used only to denote the polarity and required logic, respectively, between circuit elements. A person of ordinary skill in the art would be able to design such circuits using different polarities and logic levels without departing from the teachings of the present disclosure.

[0065] The foregoing description of the embodiments of the present disclosure has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the present disclosure to the precise form disclosed. Many modifications and variations are possible in light of this disclosure. It is intended that the scope of the present disclosure be limited not by this detailed description, but rather by the claims appended hereto.

[0066] A number of implementations have been described. Nevertheless, it will be understood that various modifications may be made without departing from the scope of the disclosure. Although operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order

shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results.

CLAIMS

What is claimed is:

1. A multi-bit, asynchronous e-fuse macro, the macro comprising:
the following inputs: an input output enable, a power on reset, a write address, an input write enable, a ground clamp enable, and a write clock;
a plurality of e-fuse bits;
a supply voltage configured to allow programming at least one of the e-fuse bits;
at least one fuse output; and
self-timing and control circuitry configured to perform signaling,
wherein each of the inputs is in electrical communication with said e-fuse macro.
2. The multi-bit, asynchronous e-fuse macro of claim 1 wherein each e-fuse bit comprises at least one radiation hardened latch.
3. The multi-bit, asynchronous e-fuse macro of claim 2 wherein the supply voltage is configured to be grounded and/or ground clamp enable is configured to be asserted when writing to the e-fuse macro is not desired.
4. The multi-bit, asynchronous e-fuse macro of claim 1 wherein the write address is a variable width bus configured to provide a plurality of write address bits.
5. The multi-bit, asynchronous e-fuse macro of claim 1 wherein the fuse output comprises a number of fuse output bits that is equal to two raised to the power of X, where X represents the number of write address bits.
6. The multi-bit, asynchronous e-fuse macro of claim 1 wherein the macro is configured to support two operating modes, an application mode configured to allow reading from the e-fuse macro and a programming mode configured to allow writing to the e-fuse macro.
7. The multi-bit, asynchronous e-fuse macro of claim 1 wherein the e-fuse macro is configured such that all e-fuse bits are read simultaneously.
8. The multi-bit, asynchronous e-fuse macro of claim 1 wherein all e-fuse macro functions are externally controlled.

9. The multi-bit, asynchronous e-fuse macro of claim 1 wherein the macro is configured to operate in asynchronous designs without requiring a periodic clock signal.

10. The multi-bit, asynchronous e-fuse macro of claim 1 further comprising a supply voltage configured to allow programming at least one of the e-fuse bits and wherein the write address is a variable width bus configured to provide a plurality of write address bits.

11. The multi-bit, asynchronous e-fuse macro of claim 10 wherein each e-fuse bit comprises a reset, a precharge, an output enable, a ground clamp, a read enable, a hold, a write enable, at least one latch, an e-fuse memory element, a fuse output, and a read reference current.

12. A method of reading a single e-fuse bit from an asynchronous e-fuse macro, the method comprising:

- providing a multi-bit, asynchronous e-fuse macro in accordance with claim 11;
- applying power to the e-fuse macro while grounding or floating the supply voltage;
- asserting reset, precharge, output enable, and ground clamp while de-asserting read enable, hold, and write enable and disabling read reference current;
- de-asserting reset while enabling read reference current;
- de-asserting precharge while asserting read enable;
- pulsing hold, thereby storing e-fuse memory element values in the at least one latch;
- asserting precharge while de-asserting read enable; and
- disabling read reference current.

13. A method of writing a single e-fuse bit from an asynchronous e-fuse macro, the method comprising:

- providing a multi-bit, asynchronous e-fuse macro in accordance with claim 11;
- applying power to the e-fuse macro while grounding or floating the supply voltage;
- asserting reset and precharge while de-asserting read enable, hold, output enable, ground clamp, and write enable and disabling read reference current;
- applying supply voltage;

pulsing write enable, thereby programming an e-fuse memory element; and grounding supply voltage.

14. A method of reading a multi-bit, asynchronous e-fuse macro, the method comprising:

providing a multi-bit asynchronous e-fuse macro comprising:

the following inputs: a power on reset, a write address, an input write enable, a ground clamp enable, a supply voltage, an input output enable, and a write clock;

a plurality of e-fuse bits, each of the plurality of e-fuse bits comprising a reset, a precharge, an output enable, a ground clamp, a read enable, a hold, a write enable, at least one latch, an e-fuse memory element, and a read reference current;

a write address bus in operative communication with the plurality of e-fuse bits, providing a write address for each of the plurality of e-fuse bits;

at least one fuse output; and

self-timing and control circuitry configured to perform signaling,

wherein each of the inputs is in electrical communication with said e-fuse macro,

applying power to the e-fuse macro while grounding or floating the supply voltage;

asserting power on reset, ground clamp enable, and output enable while de-asserting write clock;

de-asserting power on reset;

reading e-fuse bits upon de-assertion of power on reset via the self-timing and control circuitry, producing e-fuse memory element logic values;

storing the e-fuse memory element logic values in the at least one latch; and

outputting the e-fuse memory element logic values stored in the at least one latch to the fuse output.

15. The method of reading a multi-bit, asynchronous e-fuse macro of claim 14 wherein the at least one latch comprises at least one radiation hardened latch.

16. The method of reading a multi-bit, asynchronous e-fuse macro of claim 14 wherein reading e-fuse bits upon de-assertion of power on reset is done asynchronously.

17. A method of writing a multi-bit, asynchronous e-fuse macro, the method comprising:

providing a multi-bit asynchronous e-fuse macro comprising:

- the following inputs: a power on reset, a write address, an input write enable, a ground clamp enable, a supply voltage, an input output enable, and a write clock;
- a plurality of e-fuse bits, each of the plurality of e-fuse bits comprising a reset, a precharge, an output enable, a ground clamp, a read enable, a hold, a write enable, at least one latch, an e-fuse memory element, and a read reference current;
- a write address bus in operative communication with the plurality of e-fuse bits, providing a write address for each of the plurality of e-fuse bits;
- at least one fuse output; and
- self-timing and control circuitry configured to perform signaling,

wherein each of the inputs is in electrical communication with said e-fuse macro,

applying power to the e-fuse macro while grounding the supply voltage;

asserting power on reset while de-asserting ground clamp enable, input output enable, write clock, and write enable;

setting the write address and asserting the write enable;

applying supply voltage to the e-fuse macro;

pulsing the write clock to program a single e-fuse memory element;

grounding the supply voltage; and

de-asserting write enable.

18. The method of writing a multi-bit, asynchronous e-fuse macro of claim 17 wherein the at least one latch comprises at least one radiation hardened latch.