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(54) **METHOD AND SYSTEM FOR MEASURING LASER INDUCED PHENOMENA CHANGES IN A SEMICONDUCTOR DEVICE**

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G01R 31/02 (2006.01)
G01R 31/302 (2006.01)

(52) **U.S. Cl.** **324/762.01**; 324/754.21; 324/762.09

(58) **Field of Classification Search** 324/158.1, 324/750–753, 763–765, 754.21–754.25, 324/762.01–762.1

See application file for complete search history.

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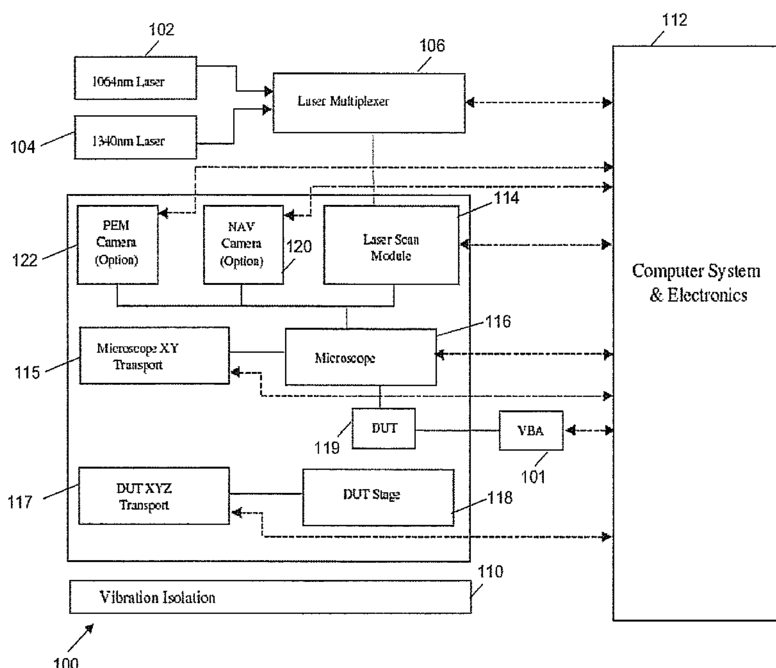
(57) **ABSTRACT**

A method and system for measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device. The method comprises applying a biasing voltage from an emitter-follower circuit to a device under test (DUT); inducing said changes in the DUT; and measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes.

15 Claims, 6 Drawing Sheets



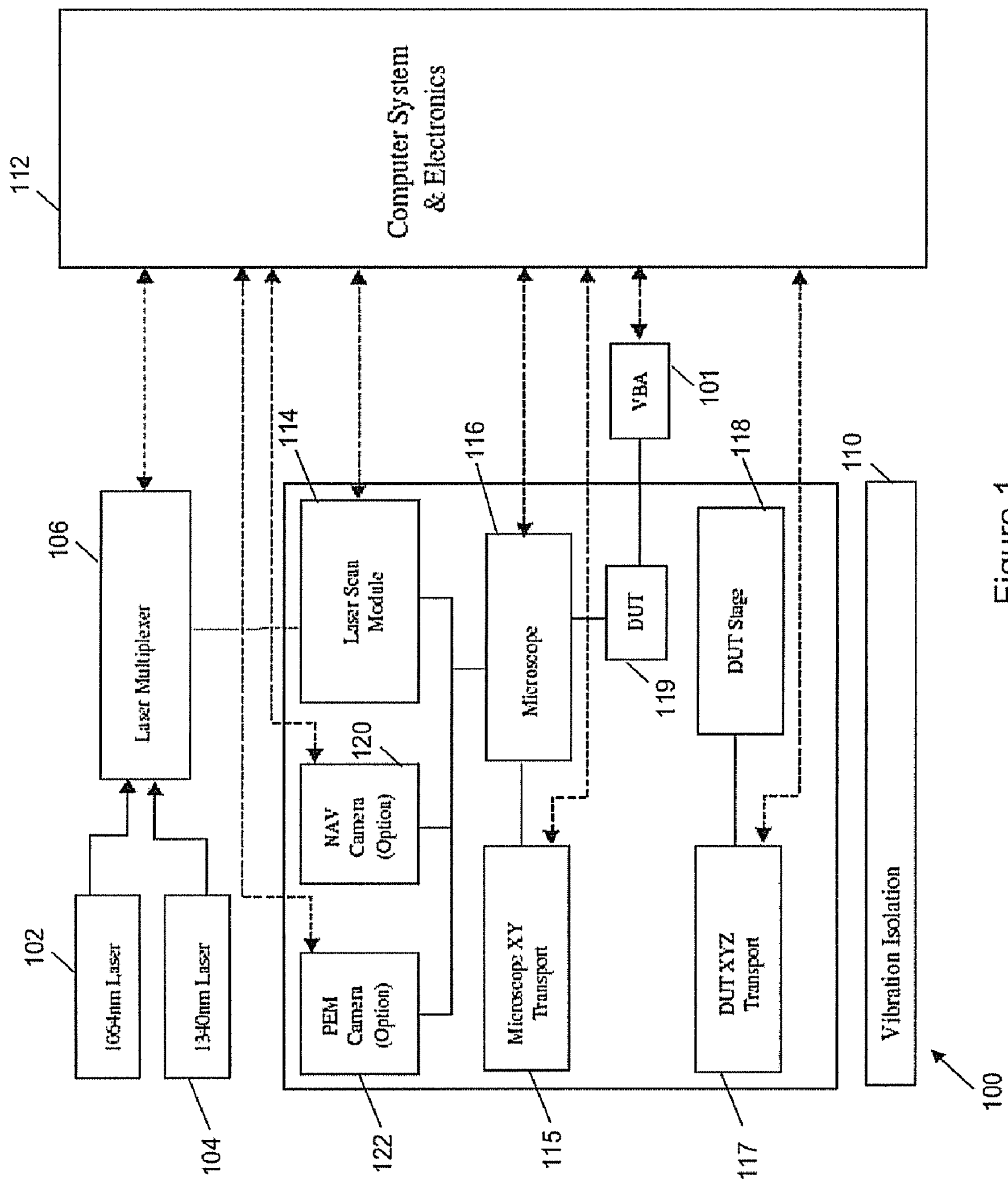


Figure 1

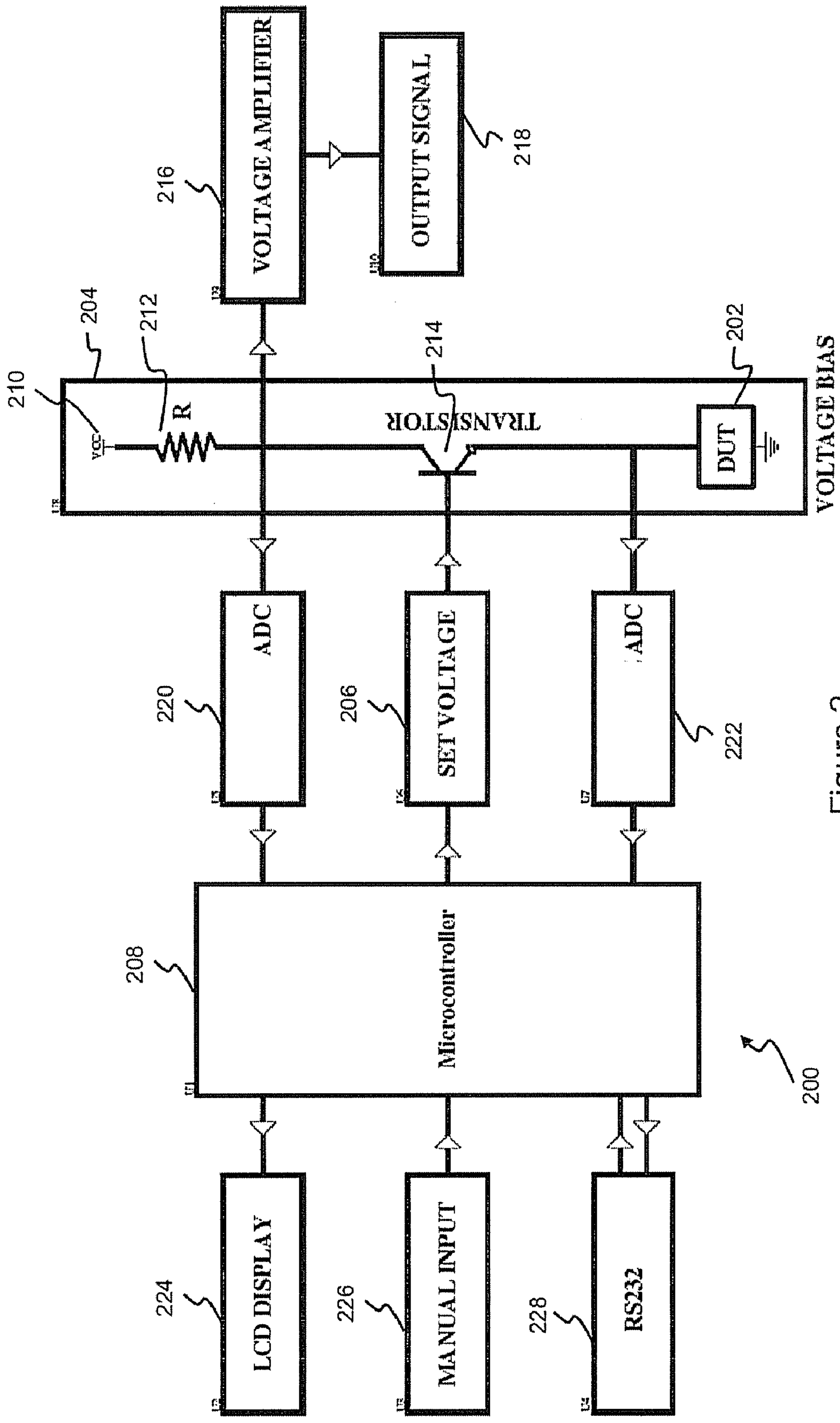


Figure 2

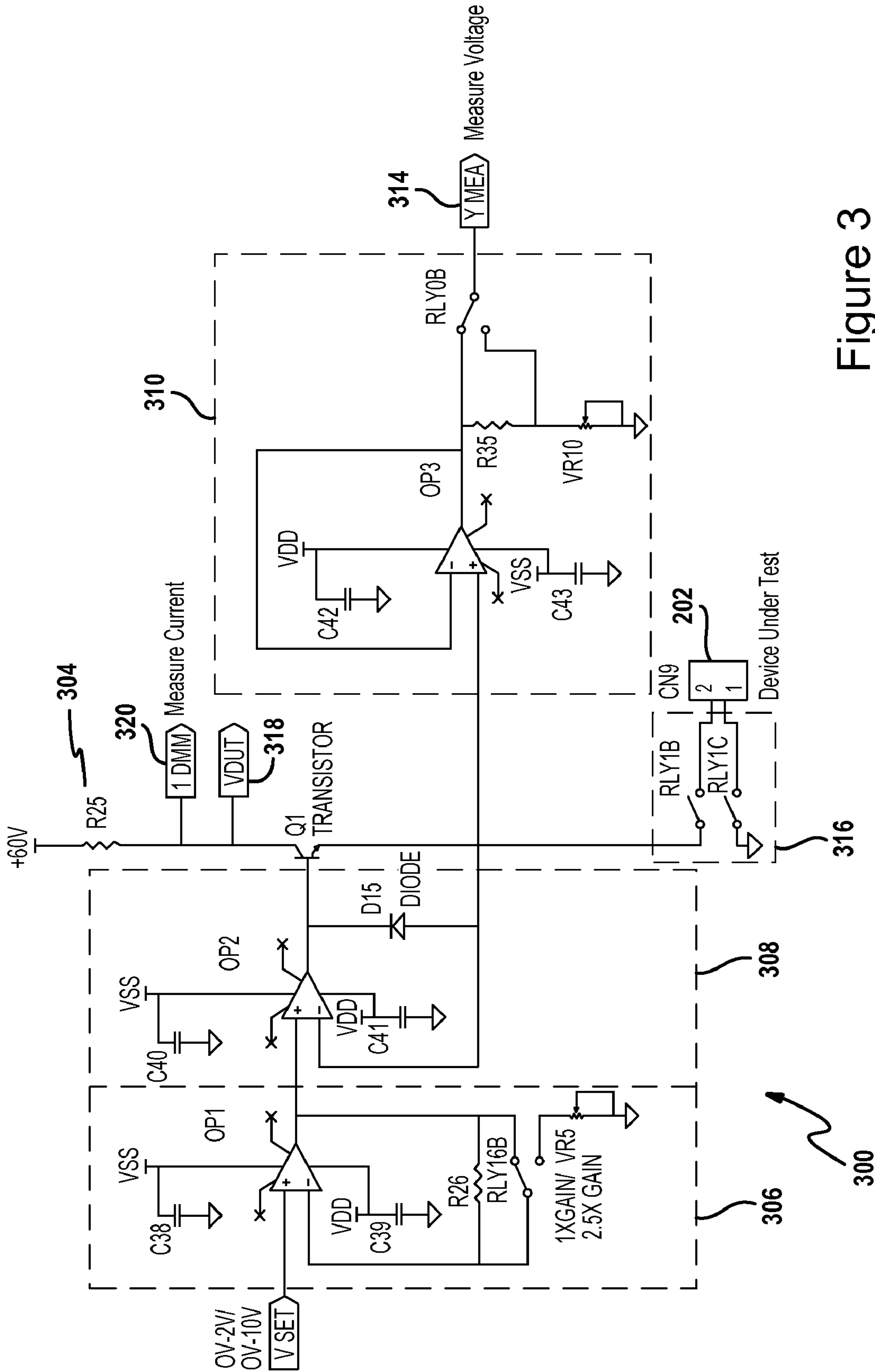


Figure 3

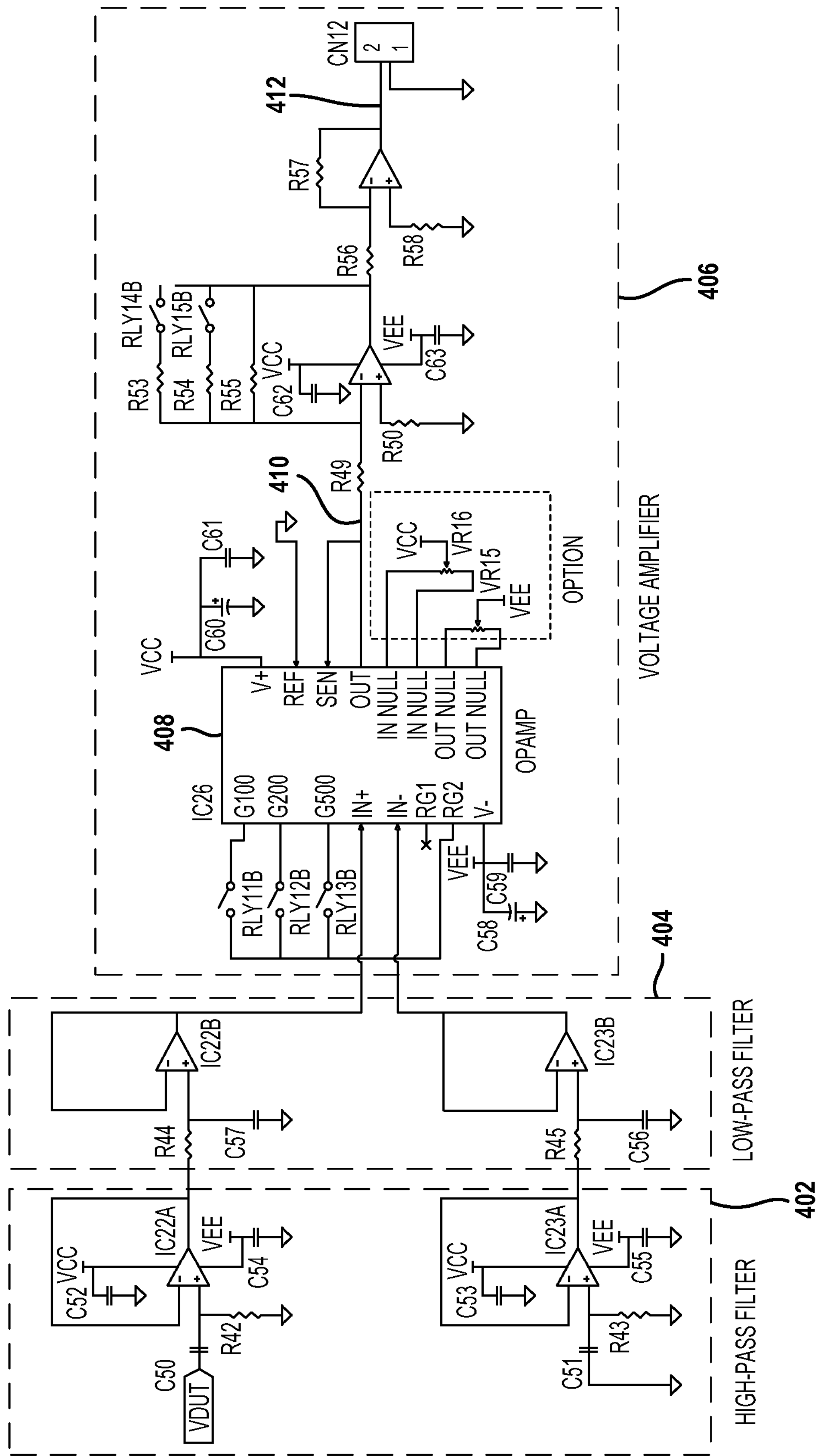


Figure 4

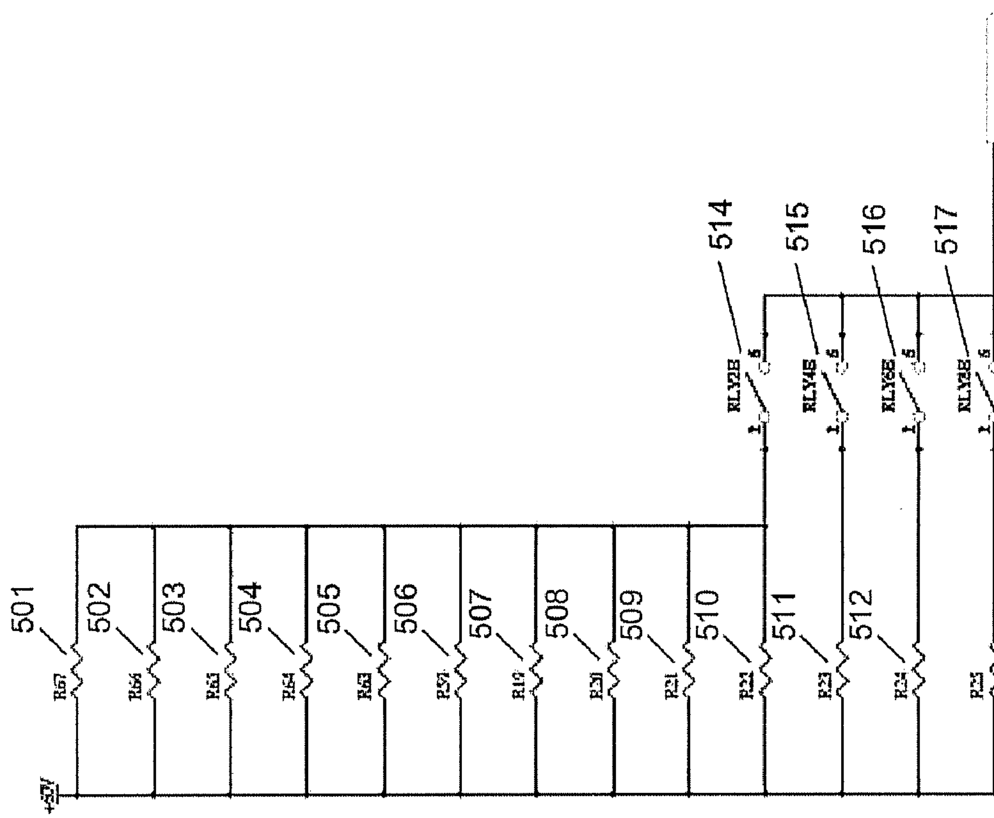


Figure 5

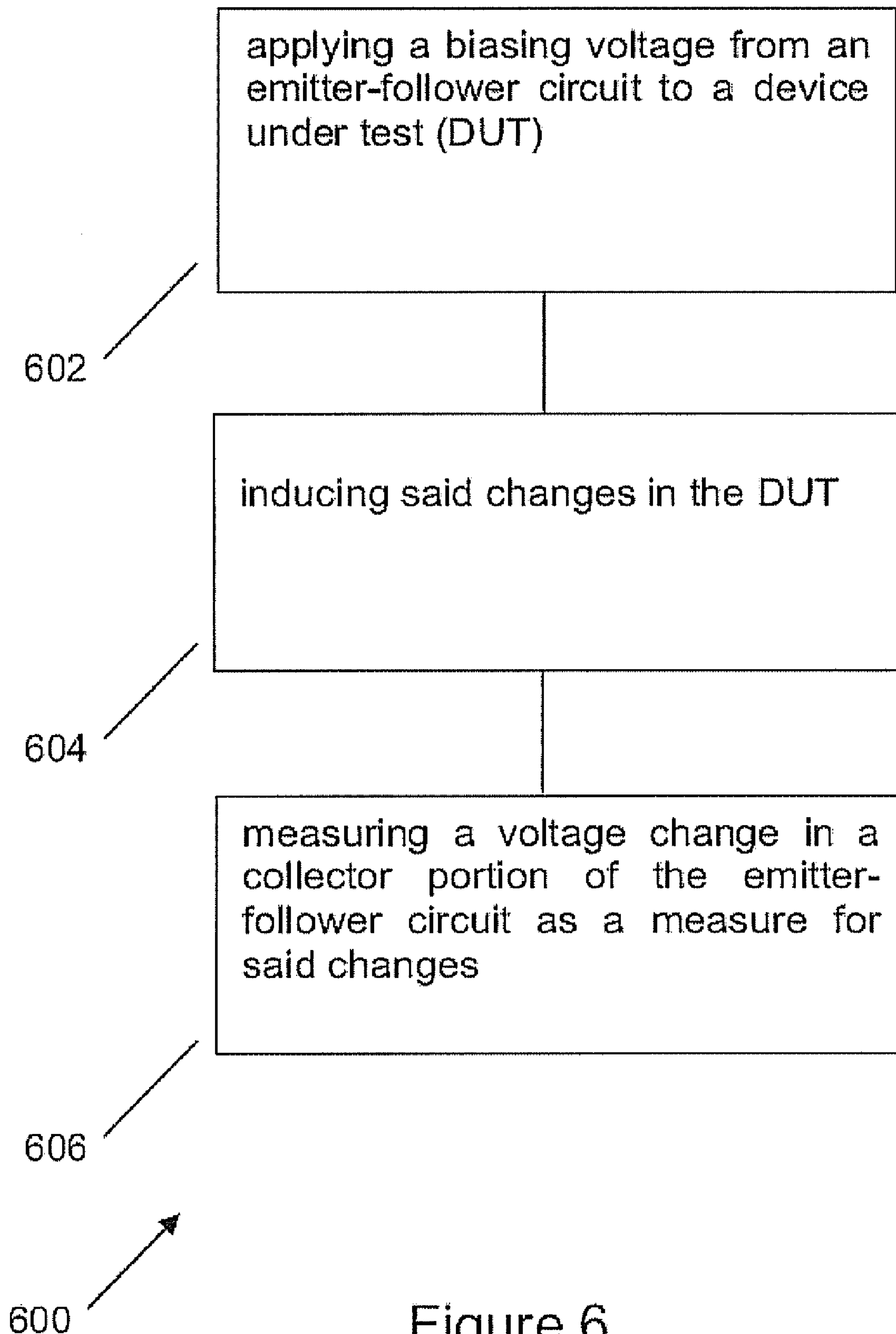


Figure 6

METHOD AND SYSTEM FOR MEASURING LASER INDUCED PHENOMENA CHANGES IN A SEMICONDUCTOR DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part Application of U.S. patent application Ser. No. 12/338,579 filed on Dec. 18, 2008. The entire disclosure of the above application is incorporated herein by reference.

FIELD OF INVENTION

The present invention relates broadly to a method and system for measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device.

BACKGROUND

Laser induced phenomena on semiconductor devices are used for example for failure analysis techniques for a variety of semiconductor devices. Examples of such failure analysis techniques include light induced voltage alteration (LIVA) techniques, thermally induced voltage alteration (TIVA) techniques, optical beam induced current (OBIC) techniques, and optical beam induced resistance change (OBIRCH) techniques.

Existing systems for implementing the above mentioned techniques have each been applied to failure analysis for particular purposes and conditions. However, existing systems do have certain limitations and disadvantages, which have hindered any one system from being suitable for a wide variety of analysis purposes and conditions.

For example, existing systems for TIVA and LIVA techniques use constant current biasing and an AC coupled amplifier. For an active device under test (DUT), due to voltage fluctuations such devices typically require a current surge during power-up, before reaching a stand-by state. The current surge can be several orders of magnitudes higher than the stand-by biasing current, and typical occurs over a very short period, for example in the order of μsec. Therefore, both TIVA and LIVA techniques, using constant current biasing, cannot provide the required current surge for proper power-up of an active DUT, and therefore existing TIVA and LIVA systems are typically limited to being applied to passive DUTs. In addition, using a constant current bias may lead to increase in DUT voltage during laser irradiation which may lead to DUT damage due to voltage over-stress.

As another example, existing OBIRCH systems, which are based on measuring changes in a current flow through the DUT, have been found to provide a lower sensitivity of the technique compared to TIVA and LIVA systems, for example. Furthermore, in OBIRCH systems, switching resistors in the measurement circuit to adjust sensitivity can effect a change of the DUT state as it changes the current that is being applied to the DUT.

As another example, a voltage bias and voltage change detection system uses an active reactive component in the measurement circuit. The use of the active reactive component may result in a back voltage which may cause damage to the measurement instrument or the DUT.

A need therefore exists for an alternative monitoring and measurement method and system for laser induced phenomena applications on semiconductor devices, which may address one or more of the above mentioned limitations and disadvantages.

SUMMARY

According to a first aspect of the present invention there is provided a method of measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, the method comprising applying a biasing voltage from an emitter-follower circuit to a device under test (DUT); inducing said changes in the DUT; and measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes.

The method may further comprise changing a resistance value in the collector portion of the emitter follower circuit for changing a sensitivity of the measurement.

The method may further comprise providing a digital signal representative of the biasing voltage applied to the DUT to a microcontroller for display of a value of the actual biasing voltage to a user.

The method may further comprise providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to the microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

The method may further comprise the microcontroller determining whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

According to a second aspect of the present invention there is provided a system for measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device; the system comprising an emitter-follower circuit for applying a biasing voltage to a device under test (DUT); and a laser source for inducing said changes in the DUT; and wherein the emitter-follower circuit comprises a measurement circuit for measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes.

The emitter-follower circuit may further comprise a switchable resistor network for changing a resistance value in the collector portion of the emitter follower circuit for changing a sensitivity of the system.

The system may further comprise a first analog to digital converter (ADC) coupled to the emitter-follower circuit for providing a digital signal representative of the biasing voltage applied to the DUT to a microcontroller of the system for display of a value of the actual biasing voltage to a user.

The system may further comprise a second ADC coupled to the emitter-follower circuit for providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to the microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

The microcontroller may determine whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the

following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. **1** shows a schematic diagram illustrating a scanning optical microscope system with a monitoring and measurement system according to an example embodiment of the present invention.

FIG. **2** shows a schematic circuit diagram of a monitoring and measurement circuit according to the example embodiment.

FIG. **3** shows a circuit diagram of a detail of the a monitoring and measurement circuit according to the example embodiment.

FIG. **4** shows a circuit diagram of a detail of the a monitoring and measurement circuit according to the example embodiment.

FIG. **5** shows a circuit diagram of a detail of the a monitoring and measurement circuit according to the example embodiment.

FIG. **6** shows a flowchart illustrating a method of measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, according to an example embodiment.

DETAILED DESCRIPTION

FIG. **1** shows a schematic diagram illustrating a scanning optical microscope system **100** with a monitoring and measurement system (**101**) according to an example embodiment of the present invention installed. The system **100** comprises a laser scan module **114** optically coupled to a microscope module **116**. Two laser sources, a 1064 nm laser source **102** and a 1340 nm laser source **104**, are optically coupled to the laser scan module **114** via a laser multiplexer **106**.

Microscope XYZ transport **115** and DUT XYZ transport **117** are provided on a vibration isolation table **110**, and mechanically coupled to the microscope module **116** and the DUT stage **118** respectively. The DUT (**119**) is mounted on the DUT stage **118**. The computer system and electronics module **112** are coupled to the laser multiplexer **106**, the laser scan module **114**, microscope module **116** microscope XYZ transport (**115**) and DUT XYZ transport **117**.

A TV-rate charge-coupled device (CCD) camera **120** and a photon emission microscope (PEM) camera **122** are mechanically coupled to the microscope module **116** and mounted on the vibration isolation table **110** in the example embodiment. The CCD camera **120** and PEM camera **122** are optically coupled to the microscope module **116** for capturing NAV and PEM images, respectively.

FIG. **2** shows a schematic circuit diagram of a monitoring and measurement circuit **200** as implemented in the monitoring and measurement system **100** (FIG. **1**) in the example embodiment. The circuit **200** is utilised to measure changes in the resistance of a semiconductor DUT **202** by measuring collector voltage changes in an emitter-follower voltage bias circuit **204**. The biasing voltage applied to the DUT **202** using the emitter follower voltage bias circuit **204** is set using a voltage setting circuit **206** under the control of a microcontroller **208**. It will be appreciated by a person skilled in the art that the voltage bias of the DUT **202** is thus maintained constant according to the set voltage. The collector portion of the emitter-follower voltage bias circuit **204** acts as a current source from the V_{CC} **210** connected to the emitter follower voltage biasing **204**.

A liquid crystal display (LCD) display unit **224** is coupled to the microcontroller **208** for providing visual output from the monitoring and measurement circuit **200** to a user. A manual input unit **226** is also coupled to the microcontroller **208**, as well as an RS **232** interface unit **228**.

In operation, changes in e.g. the resistance of the DUT will result in changes in the current flow through the emitter follower voltage bias circuit **204**, since the voltage bias of the DUT is maintained constant as described above. In-turn, the change in the current flow will result in a change in the voltage measured between the resistor **212** and the transistor **214**, using a voltage amplifier circuit **216** for generating an output signal **218**. The output signal **218** is thus a measure for the laser induced phenomena changes in the DUT **202**.

The resistor schematically indicated at numeral **212** in FIG. **2** represents a switchable resistor network for implementing different resistance values in the collector portion of the emitter follower voltage biasing circuit **204**, as will be described in more detail for an example implementation below. The monitoring and measurement circuit **200** advantageously allows make-before-break switching between different resistance values in the collector portion of the emitter follower voltage bias circuit **204** to change the sensitivity of the measurement without affecting the current flow through the DUT **202**. Because the biasing voltage across the DUT **202** is maintained constant, the current flow through the DUT **202** only changes with changes induced in the DUT, thus the transistor **214** effectively isolates the DUT **202** from changes caused by switching between different resistances in the collector portion of the emitter follower voltage bias circuit **204**.

In the monitoring and measurement circuit **200**, an analog to digital (ADC) converter unit **220** is also connected to the collector portion of the emitter-follower voltage bias circuit **204**, to provide a digital signal representative of the collector voltage. This collector voltage and the selected resistance are used by the microcontroller **208** to calculate the current flow in the collector portion of the emitter follower voltage bias circuit **204**. The microcontroller **208** displays the current value via the LCD display **224**. Another ADC converter unit **222** is connected at the emitter portion of the emitter follower voltage bias circuit **204** between the transistor **214** and the DUT **202**, to provide a digital signal representative of the voltage across the DUT **202** to the microcontroller **208**. The measured voltage across the DUT is also displayed on the LCD **224** and can be used as a confirmation to the user that the DUT voltage is correctly set.

The microcontroller **208** compares the collector voltage with the emitter voltage to determine whether the transistor **214** is saturated. The microcontroller **208** also displays a warning if transistor **214** is saturated on the LCD **224**. Preferably, optimum sensitivity is obtained by selecting the resistance/current range that does not saturate the transistor **214**.

FIG. **3** shows a circuit diagram of an example implementation of the emitter-follower voltage bias circuit **300** (compare **204** in FIG. **2**) in an example embodiment.

The emitter-follower voltage bias circuit **300** comprises a transistor **302** and a switchable resistor network, indicated for better clarity by resistor **304** in this diagram. The emitter-follower voltage biasing circuit **300** further comprises a voltage range selection circuit **306** connected to the V_{in+} input of a non inverting gain amplifier circuit **308** for setting the transistor base voltage. The emitter-follower voltage bias circuit **300** also comprises an unity gain buffer and potential divider circuit **310** for scaling the actual voltage applied across the DUT **202** in the emitter portion of the emitter-follower voltage bias circuit **300**, prior to providing the measured voltage signal **314** to the voltage ADC unit **222** (FIG. **2**).

The voltage output from the voltage setting unit **206** (FIG. **2**) is connected to the V_{in+} input of the voltage range selection circuit **306**, in which two voltage ranges can be set. A switch

circuit **316** is provided for selectively connecting and disconnecting an interconnection to the DUT **202**, for example for swapping between different DUTs.

The voltage measurement connection **318** in the collector portion of the emitter-follower voltage bias circuit **300** is provided to the voltage amplifier unit **216** (FIG. **2**), and a current measurement connection **320** is provided to the current ADC unit **220** (FIG. **2**).

During testing, a laser beam (not shown) for thermal simulation is rastered across the surface of the DUT **202** and changes in the resistance across the DUT **202** are induced due to temperature changes as a result of the thermal stimulation. The scanning of the laser is controlled by the computer system and electronics module **112** (FIG. **1**), and a map of the resistance change across the DUT **202** can be obtained based on the measured output signal **218** (FIG. **2**).

As will be appreciated by a person skilled in the art, while the laser beam is rastered across the surface of the DUT **202**, the generated heat is dissipated from the point of incidence of the laser beam on the DUT **202**. The heat dissipation is affected by a number of parameters or properties of the DUT **202**, including e.g. the presence of defects such as voids. Therefore, the resulting temperature increases at different points of incidence of the laser beam produces different changes in the resistance across the DUT **202**. The resulting map of the resistance changes as a function of the position of the point of incidence of the laser beam on the DUT **202** can be used to e.g. obtain a map indicative of location of defects such as voids in the DUT **202**.

Furthermore, while in the embodiment described above with reference to FIG. **3** the resistance changes are described as being thermally induced, it will be appreciated by the person skilled in the art that embodiments of the present invention are equally suitable for monitoring and measuring resistance changes in a DUT as a result of different laser-induced phenomena, including, but not limited to, electron-hole pair stimulation. Furthermore, it will be appreciated by the person skilled in the art that embodiments of the present invention are equally suitable for ion- and electron-beam stimulation monitoring and measuring.

In the example embodiment, the collector voltage change is being measured. The change is typically small relative to the steady state voltage. The collector voltage is ac coupled via **318** to the voltage amplifier unit **216** (FIG. **2**). The measured output signal **218** (FIG. **2**) is ac, and the resulting map from a raster scan of the DUT **202** is an ac map of the small voltage fluctuations. The collector voltage is also dc coupled via **320** to the ADC **220** (FIG. **2**) whose digitised output is used by the microcontroller unit **208** to calculate the current through the DUT and to display on the LCD as an indicator of the DUT bias condition.

FIG. **4** shows a circuit diagram of an example implementation of the voltage amplifier unit **216** (FIG. **2**), including a high pass filter circuit **402**, a low pass filter circuit **404**, and a voltage amplifier circuit **406**. The low pass filter circuit **404** removes the mains coupled 50 Hz/60 Hz noise from the collector voltage (manifested as bands on the signal (resistance) map. The high pass filter circuit **402** removes high frequency noise (manifested as small dots/salt and pepper noise on the signal (resistance) map). IC**26** at numeral **408** is a precision instrumentation amplifier with pin programmable gain. The output signal from IC**26** at numeral **410** is further amplified to provide more gain steps than can be obtained by IC**26**. The voltage measurement output at numeral **412** is output to the computer system & electronics module **112** (FIG. **1**) to generate the signal (resistance) map.

FIG. **5** shows a circuit diagram of an example implementation of the switchable resistor network schematically indicated at **212** at FIG. **2**. The example implementation of the switchable resistor network **500** shown in FIG. **5** includes a rank of resistors **501** to **513**, and switches **514** to **517**. It will be appreciated by a person skilled in the art that different resistance values can thus be selected based on the state of the switches **514** to **517**. In the example implementation, switches **514** to **517** are controlled by the microcontroller **208** (FIG. **2**) in response to either manual input received through the manual input unit **228** (FIG. **2**) and/or through control signals received via the RS **232** interface unit **228** (FIG. **2**). A make before break switching method prevents disturbance to the DUT bias voltage (emitter voltage) when switching resistor values (current range) in the example embodiment.

FIG. **6** shows a flowchart illustrating a method **600** of measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, according to an example embodiment. At step **602**, a biasing voltage from an emitter-follower circuit is applied to a device under test (DUT). At step **604**, said changes are induced in the DUT. At step **606**, a voltage change in a collector portion of the emitter-follower circuit is measured as a measure for said changes.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive.

The invention claimed is:

1. A method of measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, the method comprising:

applying a biasing voltage from an emitter-follower circuit to a device under test (DUT);

inducing said changes in the DUT;

measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes; and

providing a digital signal representative of the biasing voltage applied to the DUT to a microcontroller for display of a value of the actual biasing voltage to a user.

2. The method as claimed in claim **1**, further comprising changing a resistance value in the collector portion of the emitter-follower circuit for changing a sensitivity of the measurement.

3. The method as claimed in claim **1**, further comprising providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to the microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

4. The method as claimed in claim **3**, further comprising the microcontroller determining whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

5. A system for measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device; the system comprising:

an emitter-follower circuit for applying a biasing voltage to a device under test (DUT);

a laser source for inducing said changes in the DUT;

wherein the emitter-follower circuit comprises a measurement circuit for measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes; and

a first analog to digital converter (ADC) coupled to the emitter-follower circuit for providing a digital signal representative of the biasing voltage applied to the DUT to a microcontroller of the system for display of a value of the actual biasing voltage to a user.

6. The system as claimed in claim **5**, wherein the emitter-follower circuit further comprises a switchable resistor network for changing a resistance value in the collector portion of the emitter-follower circuit for changing a sensitivity of the system.

7. The system as claimed in claim **5**, further comprising a second ADC coupled to the emitter-follower circuit for providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to the microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

8. The system as claimed in claim **7**, wherein the microcontroller determines whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

9. A method of measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, the method comprising:

applying a biasing voltage from an emitter-follower circuit to a device under test (DUT);

inducing said changes in the DUT;

measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes; and

providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to a microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

10. The method as claimed in claim **9**, further comprising changing a resistance value in the collector portion of the emitter follower circuit for changing a sensitivity of the measurement.

11. The method as claimed in claim **9**, further comprising providing a digital signal representative of the biasing voltage applied to the DUT to a microcontroller for display of a value of the actual biasing voltage to a user.

12. The method as claimed in claim **11**, further comprising the microcontroller determining whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

13. A system for measuring laser induced phenomena changes of at least one of a resistance, a capacitance and an inductance in a semiconductor device, the system comprising:

an emitter-follower circuit for applying a biasing voltage to a device under test (DUT); and

a laser source for inducing said changes in the DUT;

wherein the emitter-follower circuit comprises a measurement circuit for measuring a voltage change in a collector portion of the emitter-follower circuit as a measure for said changes; and

an analog to digital converter (ADC) coupled to the emitter-follower circuit for providing a digital signal representative of a voltage in the collector portion of the emitter-follower circuit to a microcontroller for calculating a current flow in the collector portion of the emitter-follower circuit.

14. The system as claim in claim **13**, wherein the emitter-follower circuit further comprises a switchable resistor network for changing a resistance value in the collector portion of the emitter follower circuit for changing a sensitivity of the system.

15. The system as claimed in claim **13**, wherein the microcontroller determines whether a transistor of the emitter-follower circuit is in saturation based on the digital signal representative of the voltage in the collector portion of the emitter-follower circuit and the digital signal representative of the biasing voltage applied to the DUT.

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