CLAIMS

1. An apparatus for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

an illumination unit including an illumination source for illuminating an illumination area of a substrate including a light emitting diode structure with light of a selected intensity amplitude, the light including at least one of intensity modulated light or pulsed light, the light suitable for stimulating photoluminescence within at least a first area of the light emitting diode structure of the illumination area;

a luminescence measurement unit including at least one optical sensor configured to measure a luminescence signal from the first area of the LED structure within the illumination area;

a junction photovoltage measurement unit including at least a first transparent electrode positioned proximate to the light emitting diode structure and configured to transmit light from the illumination source to the first area of the LED structure, wherein the first transparent electrode is configured to measure a junction photovoltage signal of the light emitting diode structure corresponding with the first area within the illuminated

area, wherein the area of the first electrode is smaller than the illumination area illuminated by the illumination unit; and

a controller communicatively coupled to at least the luminescence measurement unit, the junction photovoltage measurement unit and the illumination unit, the controller configured to:

control one or more characteristics of the light from the illumination source;

receive one or more measurements of the luminescence signal from the luminescence measurement unit;

receive one or more measurements of the junction photovoltage signal from the junction photovoltage measurement unit; and

determine at least one of an internal quantum efficiency or an internal injection efficiency of the light emitting diode structure based on one or more characteristics of the received one or more measurements of the luminescence signal and one or more characteristics of the received one or more measurements of the junction photovoltage signal.

2. The apparatus of claim **1**, wherein the controller is further configured to:

determine at least one of an internal quantum efficiency or an internal injection efficiency of the light emitting diode structure with at least one of a determined junction photovoltage forward voltage of the light emitting diode structure from the luminescence area, a photocurrent density of the light emitting diode structure or an intensity of the electroluminescence component of the luminescence signal.

3. The apparatus of claim **1**, wherein the illumination source comprises:

an illumination source configured to emit light modulated at a selected modulation frequency.

4. The apparatus of claim **1**, wherein the illumination source comprises:

an illumination source configured to emit pulsed light of a selected magnitude and pulse duration.

5. The apparatus of claim **1**, wherein the illumination source comprises:

at least one of a light emitting diode, a laser or a filtered flash lamp.

6. The apparatus of claim **1**, wherein the junction photovoltage measurement unit further includes:

one or more signal processing elements.

7. The apparatus of claim **6**, wherein the one or more signal processing elements comprise:

at least one of a preamplifier or detector.

8. The apparatus of claim **1**, wherein the luminescence measurement unit further includes:

one or more signal processing elements.

9. The apparatus of claim **8**, wherein the one or more signal processing elements comprise:

at least one of a preamplifier or detector.

10. The apparatus of claim **1**, wherein the substrate including a light emitting diode structure is disposed on a chuck.

11. The apparatus of claim **10**, further comprising:

a signal generator electrically coupled to the chuck via a switch.

12. The apparatus of claim **1**, wherein the one or more characteristics of the luminescence signal comprise:

at least one of a transient of the luminescence signal or an amplitude of the luminescence signal.

13. The apparatus of claim **1**, wherein the one or more characteristics of the junction photovoltage signal comprise:

at least one of a transient of the junction photovoltage signal or an amplitude of the junction photovoltage signal.

14. The apparatus of claim **1**, further comprising:

a transparent element configured to secure at least the first transparent electrode.

15. The apparatus of claim **1**, further comprising:

at least one conducting pad electrically coupling a p-layer of the light emitting diode structure to an n-layer of the light emitting diode structure.

16. The apparatus of claim **1**, further comprising:

an additional electrode disposed on a vertical stage and positioned proximate to the light emitting diode structure.

17. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating an illumination area of a surface of a light emitting diode structure with one or more light pulses;

measuring a transient of a luminescence signal from a luminescence area within the illumination area with a luminescence sensor;

measuring a transient of a junction photovoltage signal from the luminescence area within the illumination area with a transparent electrode positioned within the illumination area and proximate to the surface of the light emitting diode structure;

determining a junction photovoltage forward voltage of the light emitting diode structure from the luminescence area;

determining a photocurrent density of the light emitting diode structure;

determining an intensity of an electroluminescence component of the luminescence signal; and

determining at least one of an internal quantum efficiency or an internal injection efficiency of the light emitting diode structure with at least one of the determined junction photovoltage forward voltage of the light emitting diode structure from the luminescence area, the photocurrent density of the light emitting diode structure or the intensity of the electroluminescence component of the luminescence signal.

18. The method of claim **17**, wherein the junction photovoltage forward voltage of the luminescence area is determined based on the amplitude of the junction photovoltage signal measured from the luminescence area with the transparent electrode.

19. The method of claim **17**, wherein the determining a photocurrent density of the LED structure comprises:

determining a derivative of the transient of the JPV signal at a front edge of the JPV signal;

acquiring a capacitance of a p-n junction of the LED structure; and

calculating the photocurrent density of the LED structure with the derivative of the transient of the JPV signal at a front edge of the JPV signal and the capacitance of the p-n junction of the LED structure.

20. The method of claim **17**, wherein the determining an intensity of an electroluminescence component of the luminescence signal comprises:

applying pulsed illumination to the light emitting diode structure having a first time interval corresponding with the junction photovoltage forward voltage being lower than a turn on voltage of the electroluminescence signal based on the transient of the junction photovoltage;

applying pulsed illumination to the light emitting diode structure having a second time interval corresponding

with the junction photovoltage forward voltage being higher than the turn on voltage of the electroluminescence signal based on the transient of the junction photovoltage; and

determining the intensity of the electroluminescence component of the luminescence signal by calculating a difference between a first luminescence signal acquired during the second time interval and a second luminescence signal acquired during the first time interval.

21. The method of claim **17**, wherein the determining an intensity of an electroluminescence component of the luminescence signal comprises:

upon terminating the illumination of the light emitting diode structure, identifying a value of the luminescence signal following a selected time of decay of the luminescence signal.

22. The method of claim **17**, wherein the determining an intensity of an electroluminescence component of the luminescence signal comprises:

establishing a duration time of the one or more light pulses so as to illuminate the illumination area with a first one or more light pulses having a first duration sufficient to establish a steady-state condition when forward voltage is higher than electroluminescence turn-on voltage;

establishing a duration time of the one or more light pulses so as to illuminate the illumination area with a second one or more light pulses having a second duration shorter than the first duration and sufficient to establish a non-steady state condition when the forward voltage is lower than electroluminescence turn-on voltage; and

determining the intensity of the electroluminescence signal component by calculating the difference between a first luminescence intensity acquired during illumination with the first one or more light pulses and a second luminescence intensity acquired during illumination with the second one or more light pulses.

23. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating an illumination area of a surface of a light emitting diode structure with one or more light pulses;

measuring a transient of a luminescence signal from a luminescence area within the illumination area of the light emitting diode structure with a luminescence sensor;

determining a first luminescence intensity at a first time of the measured transient of the luminescence signal from the light emitting diode structure;

determining a second luminescence intensity at a second time different from the first time of the measured transient of the luminescence signal from the light emitting diode structure; and

determining an intensity of the electroluminescence component of the luminescence signal from the light emitting diode structure with the first luminescence intensity and the second luminescence intensity.

24. The method of claim **23**, further comprising:

illuminating an illumination area of a surface of a calibration wafer having a known internal quantum efficiency with one or more light pulses;

measuring a transient of a luminescence signal from a luminescence area within the illumination area of the calibration wafer with a luminescence sensor;

determining a first luminescence intensity at a first time of the measured transient of the luminescence signal from the calibration wafer;

determining a second luminescence intensity at a second time different from the first time of the measured transient of the luminescence signal from the calibration wafer;

determining an intensity of the electroluminescence component of the luminescence signal from the calibration wafer based on the first luminescence intensity and the second luminescence intensity; and

determining an internal quantum efficiency of the light emitting diode structure with the intensity of electroluminescence component from the light emitting diode structure, the intensity of the electroluminescence component from the calibration wafer and the known internal quantum efficiency of the calibration wafer.

25. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating an illumination area of a surface of a light emitting diode structure with one or more first light pulses of a first pulse duration;

illuminating the illumination area of the surface of the light emitting diode structure with one or more second light pulses of a second pulse duration;

measuring a first luminescence intensity from the light emitting diode structure stimulated by the one or more first light pulses;

measuring a second luminescence intensity from the light emitting diode structure stimulated by the one or more second light pulses; and

determining an intensity of the electroluminescence component of the luminescence signal from the light emitting diode structure based on the first luminescence intensity and the second luminescence intensity.

26. The method of claim **25**, further comprising:

illuminating an illumination area of a surface of a calibration wafer with a known internal quantum efficiency with one or more first light pulses of a first pulse duration;

illuminating the illumination area of the surface of the calibration wafer with one or more second light pulses of a second pulse duration;

measuring a first luminescence intensity from the calibration wafer stimulated by the one or more first light pulses;

measuring a second luminescence intensity from the calibration wafer stimulated by the one or more second light pulses;

determining an intensity of the electroluminescence component of the luminescence signal from the calibration wafer based on the first luminescence intensity and the second luminescence intensity; and

determining an internal quantum efficiency of the light emitting diode structure with the intensity of electroluminescence component from the light emitting diode structure, the intensity of the electroluminescence component from the calibration wafer and the known internal quantum efficiency of the calibration wafer.

27. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating a illumination area of a surface of a light emitting diode structure with intensity modulated light;

measuring an electroluminescence intensity induced by photocarrier drift from an area of the light emitting diode unexposed to the intensity modulated light with a luminescence sensor;

measuring an unexposed junction photovoltage signal from the unexposed area of the light emitting diode structure with a first transparent electrode positioned within the unexposed area and proximate to the surface of the light emitting diode structure;

measuring an exposed junction photovoltage signal from the illumination area of the light emitting diode structure with a second transparent electrode external to the first transparent electrode, positioned within the illumination area and proximate to the surface of the light emitting diode structure;

determining a photocurrent density of the light emitting diode structure with the measured unexposed junction photovoltage and the measured exposed junction photovoltage;

measuring a forward voltage of the light emitting diode structure; and

determining an internal quantum efficiency of the light emitting diode structure with at least one of the measured electroluminescence intensity from the unexposed area of the light emitting diode structure, the determined photocurrent density of the light emitting diode structure or the measured forward voltage of the diode structure.

28. The method of claim **27**, wherein the measuring a forward voltage of the light emitting diode structure comprises:

illuminating the surface of the light emitting diode structure with one or more light pulses;

measuring a first junction photovoltage signal with the first transparent electrode;

measuring a second junction photovoltage signal with the second transparent electrode; and

determining the forward voltage of the light emitting diode structure with the first junction photovoltage signal and the second junction photovoltage signal.

29. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating an illumination area of a surface of a light emitting diode structure with intensity modulated light;

measuring an electroluminescence intensity induced by photocarrier drift from an area of the light emitting diode unexposed to the intensity modulated light with a luminescence sensor;

measuring an exposed junction photovoltage signal from the exposed area of the light emitting diode structure with a first transparent electrode positioned within the exposed area and proximate to the surface of the light emitting diode structure;

measuring an unexposed junction photovoltage signal from the illumination area of the light emitting diode structure with a second transparent electrode encompassing the first transparent electrode and proximate to the surface of the light emitting diode structure;

determining a photocurrent density of the light emitting diode structure with the measured unexposed junction photovoltage and the measured exposed junction photovoltage;

measuring a forward voltage of the light emitting diode structure; and

determining an internal quantum efficiency of the light emitting diode structure with at least one of the measured electroluminescence intensity from the unexposed area of the light emitting diode structure, the determined photocurrent density of the light emitting diode structure or the measured forward voltage of the diode structure.

30. A method for contactless measurement of one or more characteristics of a light emitting diode structure comprising:

illuminating a illumination area of a surface of a light emitting diode structure with intensity modulated light;

measuring an intensity of the intensity modulated light;

measuring an electroluminescence intensity induced by photocarrier drift from an area of the light emitting diode structure unexposed to the intensity modulated light with a luminescence sensor; and

determining an electroluminescence efficiency by comparing the electroluminescence intensity to the intensity of the modulated light.