

CLAIMS

What is claimed is:

1. A metrology system comprising:

a Soft X-Ray (SXR) illumination source configured to illuminate a first instance of a measurement target disposed on a substrate with a beam of SXR radiation having energy in a range between 10 and 5,000 electronvolts, wherein the measurement target includes a first structure disposed in a first layer fabricated at a first height above the substrate and a second structure disposed in a second layer fabricated at a second height above the substrate;

an x-ray detector configured to detect a plurality of intensities each associated with one or more nonzero diffraction orders of an amount of x-ray radiation scattered from the measurement target in response to the incident beam of x-ray radiation; and

a computing system configured to

estimate a value of overlay error associated with the measurement target or a corresponding in-die active device structure based on the plurality of detected intensities within each of the one or more nonzero diffraction orders.

2. The metrology system of Claim 1, the x-ray detector further configured to detect an intensity associated with a zero diffraction order of the amount of x-ray radiation scattered from the measurement target in response to the incident beam of x-ray radiation, and the computing system further configured to:

estimate a value of one or more parameters characterizing a shape of the measurement target based on the detected intensity within the zero diffraction order, the plurality of detected intensities within each of the one or more nonzero x-ray diffraction orders, or any combination thereof; and

estimate a value of an edge placement error of the measurement target based on the estimated value of overlay and the estimated value of the one or more parameters characterizing the shape of the measurement target.

3. The metrology system of Claim 1, the SXR illumination source further configured to illuminate a second instance of the measurement target disposed on the substrate with the beam of SXR radiation, wherein the first structure of the first instance of the measurement target is offset from the second structure of the first instance of the measurement target by an offset distance in a direction aligned with the first layer, wherein the first structure of the second instance of the measurement target is offset from the second structure of the second instance of the measurement target by the offset distance in a direction opposite the direction aligned with the first layer, the x-ray detector configured to detect a plurality of intensities each associated with one or more nonzero diffraction orders of an amount of x-ray radiation scattered from the second instance of the measurement target in response to the incident beam of x-ray radiation, and wherein the estimating of the value of overlay error associated with the measurement target is based on difference between the detected intensities within a +1 diffraction order and a -1 diffraction order associated

with the first instance of the measurement target and a difference between the detected intensities within the +1 diffraction order and the -1 diffraction order associated with the second instance of the measurement target.

4. The metrology system of Claim 1, wherein the estimating of the value of overlay error associated with the measurement target is based on a fitting analysis of the detected intensities within the one or more nonzero diffraction orders with a physically based measurement model.

5. The metrology system of Claim 1, wherein the beam of SXR radiation is incident on the measurement target at multiple measurement instances, each at a different nominal angle of incidence, a different nominal azimuth angle, or both.

6. The metrology system of Claim 5, wherein the estimating of the value of overlay error associated with the measurement target is based on modulations in the plurality of intensities within each of the one or more nonzero diffraction orders at each of the multiple measurement instances.

7. The metrology system of Claim 1, wherein the value of overlay error associated with the measurement target or the corresponding in-die target is directly determined from the detected intensities within the one or more nonzero diffraction orders by a trained machine learning based measurement model.

8. The metrology system of Claim 7, wherein the measurement target is not periodic.

9. The metrology system of Claim 7, the Soft X-Ray (SXR) illumination source further configured to illuminate a plurality of Design Of Experiments (DOE) measurement targets with the beam of SXR radiation having energy in a range between 10 and 5,000 electronvolts, the x-ray detector further configured to detect a plurality of intensities each associated with one or more nonzero diffraction orders of an amount of x-ray radiation scattered from each of the plurality of DOE measurement targets in response to the incident beam of x-ray radiation, the computing system further configured to train the machine learning based measurement model based on the detected plurality of intensities and known values of overlay error associated with each of the DOE measurement targets or corresponding in-die targets.

10. The metrology system of Claim 9, wherein the known values of overlay error are determined from measurements of the DOE measurement targets or corresponding in-die targets by a reference metrology system.

11. The metrology system of Claim 1, wherein the determining of the value of overlay error associated with the corresponding in-die active device structure involves a summation of the estimated value of overlay error associated with the measurement target based on the plurality of detected intensities within each of the one or more nonzero diffraction orders and a correction value.

12. The metrology system of Claim 1, wherein the first layer is a resist layer.

13. The metrology system of Claim 1, wherein the measurement target is a design rule target disposed within a scribe line or an in-die active device structure.

14. The metrology system of Claim 1, wherein the corresponding in-die active device structure is not periodic.

15. A method comprising:

illuminating a first instance of a design rule target disposed on a substrate with a beam of Soft X-Ray (SXR) radiation having energy in a range between 10 and 5,000 electronvolts, wherein the design rule target is a multiple layer target;

detecting a first plurality of intensities associated with the $+1/-1$ diffraction order of an amount of SXR radiation scattered from the first instance of the design rule target in response to the incident beam of SXR radiation;

estimating a first value of overlay error associated with the first instance of the design rule target based on the first plurality of detected intensities within the $+1/-1$ diffraction order;

estimating a value of overlay error associated with a first in-die active device structure based on a measurement of the first in-die active device structure by a scanning electron microscope, wherein the first instance of the design rule target and the first in-die active device

structure are fabricated in accordance with the same fabrication process rules; and

determining an overlay calibration value based on the value of overlay error associated with the first in-die active device structure and the first value of overlay error associated with the first instance of the design rule target.

16. The method of Claim 15, further comprising:

illuminating a second instance of the design rule target with a beam of SXR radiation having energy in a range between 10 and 5,000 electronvolts;

detecting a second plurality of intensities each associated with the +1/-1 diffraction order of an amount of SXR radiation scattered from the second instance of the design rule target in response to the incident beam of SXR radiation;

estimating a value of overlay error associated with the second instance of the design rule target based on the plurality of detected intensities within the +1/-1 diffraction order;

estimating a value of overlay error associated with a second in-die active device structure based on a summation of the value of overlay error associated with the second instance of the design rule target and the overlay calibration value.

17. The method of Claim 15, wherein the overlay calibration value is the difference between the value of overlay error associated with the first in-die active device structure and the first value of overlay error

associated with the first instance of the design rule target.

18. The method of Claim 15, further comprising:

estimating a second value of overlay error associated with the first instance of the design rule target based on a measurement of the first instance of the design rule target by the scanning electron microscope, wherein the determining of the overlay calibration value is based on a difference between the first and second values of overlay error associated with the first instance of the design rule target and a difference between the value of overlay error associated with the first in-die active device structure and the second value of overlay error associated with the first instance of the design rule target.

19. The method of Claim 16, further comprising:

detecting an intensity associated with a zero diffraction order of the amount of x-ray radiation scattered from the second instance of the design rule target in response to the incident beam of x-ray radiation;

estimating a value of one or more parameters characterizing a shape of the design rule target based on the detected intensity within the zero diffraction order, the plurality of detected intensities within the +1/-1 diffraction order, or any combination thereof; and

estimating a value of an edge placement error of the second instance of the design rule target based on the value of overlay error associated with the second instance of the design rule target and the value of the one or more parameters characterizing the shape of the second instance of the design rule target.

20. The method of Claim 15, wherein the design rule target is disposed within a scribe line or is an in-die active device structure.

21. The method of Claim 15, wherein the in-die active device structure is not periodic.

22. A metrology system comprising:

a Soft X-Ray (SXR) illumination source configured to illuminate a first instance of a measurement target disposed on a substrate with a beam of SXR radiation having energy in a range between 10 and 5,000 electronvolts, wherein the measurement target includes a first structure disposed in a first layer fabricated at a first height above the substrate and a second structure disposed in a second layer fabricated at a second height above the substrate;

an x-ray detector configured to detect a plurality of intensities each associated with one or more nonzero diffraction orders of an amount of x-ray radiation scattered from the measurement target in response to the incident beam of x-ray radiation; and

a non-transitory, computer-readable medium storing instructions that, when executed by one or more processors, causes the one or more processors to:

estimate a value of overlay error associated with the measurement target or a corresponding in-die active device structure based on the plurality of detected intensities within each of the one or more nonzero diffraction orders.