SUMMARY OF THE INVENTION

~~Embodiments of the present invention include~~ There is disclosed a projection system and corresponding method for estimating a position of an image relative to a substrate. Examples of the projection system include projection optics, which may include one or more objectives, configured to project image(s) of one or more objects. A metrology plate disposed between the projection optics and the substrate supports first and second sensors that are configured to sense the positions of the metrology plate relative to the substrate and the image, respectively. Together, the sensors and the metrology plate form a system metrology core that can be used to locate and match the image to the substrate surface. Example methods and apparatus for estimating image plane position may be used to fabricate semiconductor devices, such as computer chips and thin-film transistor displays, for use in electronics, including, but not limited to, cell phones, personal digital assistants, computers, solar cells, and other electronic devices.

Because the metrology plate is mechanically decoupled from the projection optics (and may be mechanically decoupled from the substrate as well), the metrology plate, surface plane, and image plane can move relative to each other. The sensors provide indications of this movement to a processor, which estimates a position of the image relative to the surface based on the positions of the metrology plate relative to the surface and the image.

Mechanically decoupling the metrology plate (system metrology core) from the projection optics allows simultaneous formation and accurate coordination of multiple images on a single substrate. For example, decoupled metrology plates can be used to estimate the positions of images associated with two or more projection optics relative to the surface of a single substrate. In addition, mechanically decoupling the metrology plate from the projection optics provides added design flexibility, including space for additional sensors, and relaxes constraints on expansion/contraction of components due to heating, etc.

Fundamentally, a decoupled metrology plate (system metrology core) allows greater design flexibility to make a super-stable, robust reference base for all the

important coordinate systems in the system. It eases stability tolerances on other subsystems and structures, such as the camera/lens. Also, the mass and weight distribution needed to create a suitably stable metrology plate could have a detrimental effect if mounted to the camera or objective; the decoupled metrology plate according to this embodiment of the invention enables stability without negatively impacting other system components.

~~Further embodiments include~~There is also disclosed an apparatus and corresponding method for estimating field curvature of an image that can be used with or without a mechanically decoupled metrology plate. One or more sensors detect the sagittal and tangential foci of the image associated with a substrate, possibly during exposure of the substrate. The sensors may be disposed on a decoupled metrology plate, like the ones described herein. A processor coupled to the sensors uses information about the sagittal and tangential foci to estimate the field curvature of the image. The processor may also use calibration data acquired before exposure to compute or refine the estimate of field curvature. Servos compensate for the estimated field curvature and astigmatism by matching an upper surface of the substrate to a best-fit plane associated with the actual image surface. As above, example methods and apparatus for estimating field curvature may be used to fabricate semiconductor devices, such as computer chips and thin-film transistor displays, for use in electronics, including, but not limited to, cell phones, personal digital assistants, computers, solar cells, and other electronic devices.

A first aspect of the present invention provides a method for estimating a field curvature of a projected image projected by projection optics, the method comprising the steps of:

detecting sagittal and tangential foci of at least a portion of an aerial image corresponding to the projected image, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

estimating a field curvature of the aerial image based at least in part on the sagittal and tangential foci; and

estimating the field curvature of the projected image based at least in part on the estimated field curvature of the aerial image.

A second aspect of the present invention provides an apparatus comprising:

an aerial image sensor configured to:

receive at least a portion of an aerial image corresponding to a projected image projected by projection optics, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

detect sagittal and tangential foci of at least a portion of the aerial image; and

transmit first data based at least in part on the sagittal and tangential foci; and

a processor operably coupled to the aerial image sensor, wherein the processor is configured to:

receive the first data;

estimate a field curvature of the aerial image based at least in part on the first data; and

estimate a field curvature of the projected image based in least in part on the estimated field curvature of the aerial image.

A third aspect of the present invention provides a method for controlling a focus of a projected image, the method comprising the steps of:

detecting, at a first time instant, first sagittal and tangential foci of at least a portion of an aerial image corresponding to the projected image, wherein the aerial image is disposed between projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

estimating a first field curvature of the aerial image based at least in part on the first sagittal and tangential foci;

determining a first best fit image plane based at least in part on the first field curvature; and

adjusting a position of the first best fit image plane with respect to the reference surface.

A fourth aspect of the present invention provides an apparatus comprising:

an aerial image sensor configured to:

receive at least a portion of an aerial image corresponding to a projected image projected by projection optics, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

detect, at a first time instant, first sagittal and tangential foci of at least a portion of the aerial image; and

transmit first data based at least in part on the first sagittal and tangential foci; and

a processor operably coupled to the aerial image sensor, wherein the processor is configured to:

receive the first data;

estimate a first field curvature of the aerial image based at least in part on the first data; and

estimate a first field curvature of the projected image based at least in part on the first estimated field curvature of the aerial image.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing will be apparent from the following more particular description of example embodiments of the invention, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating embodiments of the present invention.

FIGS. 1A and 1B are elevation views of a projection system according to embodiments of the present invention.

CLAIMS:

1. An apparatus for estimating field curvature of an image, the apparatus comprising:

an aerial image sensor configured to detect sagittal and tangential foci of the image and to provide information about the sagittal and tangential foci; and

a processor operably coupled to the aerial image sensor and configured to estimate field curvature based on the information about the sagittal and tangential foci.

2. An apparatus as in claim 1, wherein the aerial image sensor is disposed on a metrology plate.

3. An apparatus as in claim 1, further including:

a height sensor configured to detect a distance from the aerial image sensor to a surface.

4. An apparatus as in claim 1, further including;

a servo configured to adjust optics in response to actuation from the processor based on the information about the sagittal and tangential foci.

5. An apparatus as in claim 1, wherein the processor is further configured to estimate a shape of the image.

6. An apparatus as in claim 1, wherein the processor is further configured to estimate a best-fit plane that corresponds to an optimum fit between the image and a substrate.

7. A method for estimating field curvature of an image, the method comprising:

detecting sagittal and tangential foci of the image; and

estimating field curvature of the image based on information about the sagittal and tangential foci.

8. A method as in claim 7, wherein detecting the sagittal and tangential foci and estimating field curvature occur during exposure of a substrate positioned at or near an image plane associated with the image.

9. A method as in claim 7, further including:

mapping an image plane associated with the image to provide a baseline field curvature before detecting the sagittal and tangential foci.

10. A method as in claim 7, further including;

detecting a distance from the aerial image sensor to a substrate.

11. A method as in claim 7, further including:

adjusting at least one of a lens and a stage based on information about the sagittal and tangential foci.

12. A method as in claim 7, further including:

estimating a shape of the image based on information about the sagittal and tangential foci.

13. A method as in claim 7, further including:

estimating a best-fit plane that corresponds to an optimum fit between the image and a substrate.

14. An apparatus for estimating field curvature of an image, the apparatus comprising:

means for detecting sagittal and tangential foci of the image and for providing information about the sagittal and tangential foci; and

means for estimating field curvature based on the information about the sagittal and tangential foci.

15. A method of making a semiconductor or thin-film transistor device, the method comprising:

detecting sagittal and tangential foci of an image associated with the semiconductor or thin-film transistor device;

estimating field curvature of the image based on information about the sagittal and tangential foci;

if necessary, adjusting the image based on estimated field curvature; and

illuminating a substrate with the image associated with the semiconductor or thin-film transistor device.

CLAIMS:

1. A method for estimating a field curvature of a projected image projected by projection optics, the method comprising the steps of:

detecting sagittal and tangential foci of at least a portion of an aerial image corresponding to the projected image, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

estimating a field curvature of the aerial image based at least in part on the sagittal and tangential foci; and

estimating the field curvature of the projected image based at least in part on the estimated field curvature of the aerial image.

2. The method of claim 1, further comprising the step of:

determining a best fit image plane based at least in part on the sagittal and tangential foci.

3. The method of claim 2, further comprising the step of:

adjusting a position of the best fit image plane with respect to the reference surface.

4. The method of claim 3, wherein the step of adjusting a position of the best fit image plane with respect to the reference surface comprises the step of moving at least one of the best fit image plane or the substrate.

5. The method of claim 1, wherein:

the reference surface is the surface of the coating on the substrate; and

the step of detecting sagittal and tangential foci occurs during exposure of the surface of the coating on the substrate in a photolithographic process.

6. An apparatus comprising:

an aerial image sensor configured to:

receive at least a portion of an aerial image corresponding to a projected image projected by projection optics, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

detect sagittal and tangential foci of at least a portion of the aerial image; and

transmit first data based at least in part on the sagittal and tangential foci; and

a processor operably coupled to the aerial image sensor, wherein the processor is configured to:

receive the first data;

estimate a field curvature of the aerial image based at least in part on the first data; and

estimate a field curvature of the projected image based in least in part on the estimated field curvature of the aerial image.

7. The apparatus of claim 6, further comprising:

a metrology plate, wherein the aerial image sensor is disposed on the metrology plate;

a substrate stage disposed such that the metrology plate is disposed between the projection optics and the substrate stage, wherein the substrate stage is configured to hold the substrate; and

a servo operably coupled to the processor.

8. The apparatus of claim 7, wherein:

the processor is further configured to:

determine a best fit image plane based at least in part on the first data; and

transmit second data based at least in part on the best fit image plane; and

the servo is configured to:

receive the second data; and

based at least in part on the second data, adjust a position of the best fit image plane with respect to the reference surface.

9. The apparatus of claim 8, wherein the servo is further configured to:

based at least in part on the second data, adjust the position of the best fit image plane with respect to the reference surface by moving at least one of the best fit image plane or the substrate stage.

10. The apparatus of claim 21, wherein:

the reference surface is the surface of the coating on the substrate; and

the aerial image sensor is configured to detect sagittal and tangential foci during exposure of the surface of the coating on the substrate in a photolithographic process.

11. A method for controlling a focus of a projected image, the method comprising the steps of:

detecting, at a first time instant, first sagittal and tangential foci of at least a portion of an aerial image corresponding to the projected image, wherein the aerial image is disposed between projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

estimating a first field curvature of the aerial image based at least in part on the first sagittal and tangential foci;

determining a first best fit image plane based at least in part on the first field curvature; and

adjusting a position of the first best fit image plane with respect to the reference surface.

12. The method of claim 11, wherein the step of adjusting a position of the first best fit image plane with respect to the reference surface comprises the step of moving at least one of the first best fit image plane or the substrate.

13. The method of claim 11, wherein:

the reference surface is the surface of the coating on the substrate; and

the step of detecting, at a first time instant, first sagittal and tangential foci occurs during exposure of the surface of the coating on the substrate in a photolithographic process.

14. The method of claim 11, further comprising the steps of:

detecting, at a second time instant, second sagittal and tangential foci of at least a portion of the aerial image;

determining whether a change in sagittal and tangential foci has occurred, wherein the change in sagittal and tangential foci is based at least in part on the second sagittal and tangential foci and the first sagittal and tangential foci;

upon determining that a change in sagittal and tangential foci has occurred, determining whether the change in sagittal and tangential foci corresponds to a change in pure focus or to a change in astigmatism;

upon determining that the change in sagittal and tangential foci corresponds to a change in pure focus, re-adjusting the position of the first best fit image plane with respect to the reference surface; and

upon determining that the change in sagittal and tangential foci corresponds to a change in astigmatism:

estimating a second field curvature of the aerial image based at least in part on the second sagittal and tangential foci;

determining a second best fit image plane based at least in part on the second field curvature; and

adjusting a position of the second best fit image plane with respect to the reference surface.

15. An apparatus comprising:

an aerial image sensor configured to:

receive at least a portion of an aerial image corresponding to a projected image projected by projection optics, wherein the aerial image is disposed between the projection optics and a reference surface selected from the group consisting of a surface of a substrate and a surface of a coating on the substrate;

detect, at a first time instant, first sagittal and tangential foci of at least a portion of the aerial image; and

transmit first data based at least in part on the first sagittal and tangential foci; and

a processor operably coupled to the aerial image sensor, wherein the processor is configured to:

receive the first data;

estimate a first field curvature of the aerial image based at least in part on the first data; and

estimate a first field curvature of the projected image based at least in part on the first estimated field curvature of the aerial image.

16. The apparatus of claim 15, further comprising:

a metrology plate, wherein the aerial sensor is disposed on the metrology plate;

a substrate stage disposed such that the metrology plate is disposed between the projection optics and the substrate stage, wherein the substrate stage is configured to hold the substrate; and

a servo operably coupled to the processor.

17. The apparatus of claim 16, wherein:

the processor is further configured to:

determine a first best fit image plane based at least in part on the first data; and

transmit second data based at least in part on the first best fit image plane; and

the servo is configured to:

receive the second data; and

based at least in part on the second data, adjust a position of the first best fit image plane with respect to the reference surface.

18. The apparatus of claim 17, wherein the servo is further configured to:

based at least in part on the second data, adjust the position of the first best fit image plane with respect to the reference surface by moving at least one of the first best fit image plane or the substrate stage.

19. The apparatus of claim 17, wherein:

the aerial image sensor is further configured to:

detect, at a second time instant, second sagittal and tangential foci of at least a portion of the aerial image; and

transmit third data based at least in part on the second sagittal and tangential foci;

the processor is further configured to:

receive the third data;

based at least in part on the first data and the third data, determine whether a change in sagittal and tangential foci has occurred;

upon determining that a change in sagittal and tangential foci has occurred, determine whether the change in sagittal and tangential foci corresponds to a change in pure focus or to a change in astigmatism;

upon determining that the change in sagittal and tangential foci corresponds to a change in pure focus, transmit fourth data based at least in part on the change in pure focus; and

upon determining that the change in sagittal and tangential foci corresponds to a change in astigmatism:

estimate a second field curvature of the aerial image based at least in part on the third data;

determine a second best fit image plane based at least in part on the second field curvature; and

transmit fifth data based at least in part on the second best fit image plane; and

the servo is further configured to:

receive the fourth data from the processor;

based at least in part on the fourth data, re-adjust the position of the first best fit image plane with respect to the reference surface;

receive the fifth data from the processor; and

based at least in part on the fifth data, adjust the position of the second best fit image plane with respect to the reference surface.

20. The apparatus of claim 19, wherein the servo is further configured to:

based at least in part on the fifth data, adjust the position of the second best fit image plane with respect to the reference surface by moving at least one of the second best fit image plane or the substrate stage.

21. The apparatus of claim 15, wherein:

the reference surface is the surface of the coating on the substrate; and

the aerial image sensor is configured to detect first sagittal and tangential foci during exposure of the surface of the coating on the substrate in a photolithographic process.