requirements of registration procedures; automate (semi or fully) registration procedures; alleviate the minimum knowledge and experience requirements to perform registration procedures; or some combination thereof.

## SUMMARY

**[0015]** Consistent with one aspect of the present disclosure, a system includes a material processing system, a coherence imaging (CI) measurement system, and at least one controller. The material processing system includes a processing beam source for generating a processing beam and a processing beam head for delivering the processing beam to a target. The coherence imaging (CI) measurement system includes a coherence imaging (CI) core unit for generating a measurement beam and a CI scan module for delivering the measurement beam to the target, wherein the CI measurement system produces a CI measurement output. The at least one controller is configured to receive the CI measurement output from the CI core unit for monitoring and/or controlling the material processing system. The at least one controller is also configured to receive a calibration measurement output and to control the CI measurement system based, at least in part, on the calibration measurement output. The at least one controller is also configured to control the CI measurement system to modify future measurements made by the CI measurement system for alignment of the CI measurement system and the processing beam. Further, the CI measurement system produces the calibration measurement output. Furthermore, process radiation produced by the processing beam is used as the contrast mechanism to produce the calibration output from the CI measurement system.

**[0016]** Consistent with another aspect of the present disclosure, a method is provided for calibrating a coherence imaging (CI) measurement system. The method includes: providing a material processing system configured to generate and deliver a processing beam to a target; providing a coherence imaging (CI) measurement system configured to generate and deliver a measurement beam to the target and configured to provide a CI measurement system output for controlling and/or monitoring the material processing system; obtaining a calibration measurement output from the CI measurement system and/or from an auxiliary sensor; and automatically controlling the CI measurement system based on, at least in part, the calibration measurement output, wherein the CI measurement system is controlled to modify future

measurements made by the CI measurement system for alignment of the CI measurement system and the processing beam. Further, the calibration measurement output is provided by the CI measurement system using a process emission produced by the processing beam as a contrast mechanism.

**[0016A]** Modifying future measurements made by the CI measurement system may include performing system level calibrations, performing process level corrections, and/or performing intra-process level corrections.

**[0017]** In some examples of this method, the CI measurement system is automatically controlled to modify future measurements made by the CI measurement system such that static calibrations are performed for alignment of the CI measurement system and the processing beam. In other examples of this method, the CI measurement system is automatically controlled to modify future measurements made by the CI measurement system such that dynamic calibrations are performed for alignment of the CI measurement system and the processing beam.

**[0018]** There is disclosed a system includes a material processing system, at least one material processing system controller, a coherence imaging (CI) measurement system, and at least one CI system controller. The material processing system includes a laser for generating a laser processing beam and a processing beam head for delivering the laser processing beam to a target. The laser is configured to generate an output substantially of a single spatial mode with an M-squared value of less than 2.0. The material processing system controller(s) is(are) configured to cause the material processing system to generate and direct the laser processing beam to the target for a calibration measurement.

**[0019]** In some examples of this system, the material processing system controller may be configured to cause the material processing system to generate and direct the laser processing beam to the target to produce a physical modification on the target. In these examples, the calibration measurement output may be based on the physical modification, and the CI system controller may be configured to control the CI measurement system to align the CI measurement system relative to the physical modification. In other examples, the material processing system controller may be configured to cause the material processing system to generate and direct the laser processing beam to the target to generate localized process radiation on the target. In these examples, the calibration measurement output may be based on the localized process radiation, and the CI system controller may be configured to control the CI measurement system to align the CI measurement system relative to the localized process radiation.

**[0020]** The CI measurement system includes a coherence imaging (CI) core unit for generating a measurement beam and a CI scan module for delivering the measurement beam to the target, wherein the CI measurement system produces a CI measurement output. The CI system controller(s) is(are) configured to receive the CI measurement output from the CI core

unit for monitoring and/or controlling the material processing system. The CI system controller(s) is(are) also configured to receive a calibration measurement output and to control the CI measurement system based, at least in part, on the calibration measurement output. The CI system controller(s) is(are) configured to control the CI measurement system to modify future measurements made by

the CI measurement system for alignment of the CI measurement system and the processing beam. In some examples of this system, the CI measurement system may include an inline coherent imaging (ICI) measurement system and the CI measurement system may be configured to produce the calibration measurement output. In other examples, an auxiliary sensor may be configured to produce the calibration measurement output.

**[0021]** There is disclosed a method for calibrating a coherence imaging (CI) measurement system. The method includes: providing a material processing system including a laser configured to generate and deliver a laser processing beam to a target; providing a coherence imaging (CI) measurement system configured to generate and deliver a measurement beam to the target and configured to provide a CI measurement system output for controlling and/or monitoring the material processing system; generating and directing the laser processing beam to the target for a calibration measurement; obtaining a calibration measurement output from the CI measurement system and/or from an auxiliary sensor; and automatically controlling the CI measurement system based on, at least in part, the calibration measurement output, wherein the CI measurement system is controlled to modify future measurements made by the CI measurement system for alignment of the CI measurement system and the processing beam. In some examples of this method, the laser may be configured to generate an output substantially of a single spatial mode with an M-squared value of less than 2.0.

**[0022]** In some examples of this method, the laser processing beam produces a physical modification on the target, which corresponds to a position of the processing beam. In these examples, the calibration measurement output may be based on the physical modification, and the CI measurement system may be controlled to align the CI measurement system relative to the physical modification. Obtaining the calibration measurement output may include, for example, measuring the physical modification with the CI measurement system. In other examples, the laser processing beam generates localized process radiation on the target, which represents a position of the processing beam. In these examples, the calibration measurement output may be based on the localized process radiation, and the CI measurement system may be controlled to align the CI measurement system relative to the localized process radiation. Obtaining the calibration measurement output may include, for example, detecting the localized process radiation with the CI measurement system.

CLAIMS

What is claimed is:

1. A system (100, 100’, 100”, 100’”) comprising:

a material processing system including a processing beam source (110) for generating a processing beam (111) and a processing beam head (112) for delivering the processing beam (111) to a target;

a coherence imaging (CI) measurement system including a coherence imaging (CI) core unit (120) for generating a measurement beam (121) and a CI scan module for delivering the measurement beam (121) to the target, wherein the CI measurement system produces a CI measurement output; and

at least one controller (156) configured to receive the CI measurement output from the CI core unit (120) for monitoring and/or controlling the material processing system, wherein the controller (156) is also configured to receive a calibration measurement output and to control the CI measurement system based, at least in part, on the calibration measurement output, wherein the controller (156) is configured to control the CI measurement system to modify future measurements made by the CI measurement system for alignment of the CI measurement system and the processing beam (111); and

wherein the CI measurement system produces the calibration measurement output, and wherein process radiation produced by the processing beam (111) is used as the contrast mechanism to produce the calibration output from the CI measurement system.

2. The system (100, 100’, 100”, 100’”) of claim 1 further including a 2D inline camera coupled to the processing head, and wherein the 2D inline camera generates image data used to produce the calibration measurement output.

3. The system (100, 100’, 100”, 100’”) of claim 2 wherein the 2D inline camera shares an optical path with the CI measurement system, and wherein back reflected light is split between the 2D inline camera and the CI measurement system.

4. The system (100, 100’, 100”, 100’”) of claim 1 further including a double clad fiber coupled to the CI core unit (120) and to a photodetector, wherein the double clad fiber is configured to transmit process radiation to the photodetector and to transmit light from the measurement beam (121) to the CI core unit (120).

5. The system (100, 100’, 100”, 100’”) of claim 4 wherein the calibration measurement output is produced by the photodetector.

6. The system (100, 100’, 100”, 100’”) of claim 1 further including a 2D camera positioned proximate the target, and wherein the 2D camera generates image data used to produce the calibration measurement output.

7. The system (100, 100’, 100”, 100’”) of claim 1 wherein the material processing system includes a laser processing system.

8. The system (100, 100’, 100”, 100’”) of claim 7 wherein the laser processing system includes a laser with an output substantially of a single spatial mode with an M-squared value of less than 2.0.

9. The system (100, 100’, 100”, 100’”) of claim 1 wherein the CI measurement system includes an inline coherent imaging (ICI) system.

10. A method for calibrating a coherence imaging (CI) measurement system, comprising:
providing a material processing system configured to generate and deliver a processing beam (111) to a target;
providing a coherence imaging (CI) measurement system configured to generate and deliver a measurement beam (121) to the target and configured to provide a CI measurement system output for controlling and/or monitoring the material processing system;
obtaining a calibration measurement output from the CI measurement system and/or from an auxiliary sensor; and
automatically controlling the CI measurement system based on, at least in part, the calibration measurement output, wherein the CI measurement system is controlled to modify future measurements made by the CI measurement system for alignment of the CI measurement system and the processing beam (111); and
wherein
the calibration measurement output is provided by the CI measurement system using a process emission produced by the processing beam (111) as a contrast mechanism.

11. The method of claim 10 wherein obtaining the calibration measurement output comprises:
reducing a CI system light source to at least a negligible level;
directing the processing beam (111) to the target;
receiving process radiation from the target into the CI measurement system when the processing beam (111) is directed at the target; and
obtaining the calibration measurement output from the CI measurement system detecting the process radiation.

12. The method of claim 10 wherein the calibration measurement output is provided based on image data from a 2D inline camera coupled to the material processing system,
wherein obtaining the calibration measurement output comprises:
directing at least one of the processing beam (111) and the measurement beam (121) to the target;
detecting, using the 2D inline camera, at least one of process radiation caused by the processing beam (111) and back-reflected light from the measurement beam (121); and
obtaining the calibration measurement output from image data generated by the 2D inline camera detecting at least one of the process radiation and the back-reflected light from the measurement beam (121).

13. The method of claim 10 wherein modifying future measurements made by the CI measurement system includes at least one of modifying spatial positioning during measurement acquisition, modifying temporal synchronization during measurement acquisition, and modifying measurement algorithms.

14. The method of claim 10 wherein modifying future measurements made by the CI measurement system includes modifications to correct for optical distortions introduced by a beam delivery system in the material processing system and/or in the CI measurement system.

15. The method of claim 10 wherein modifying future measurements made by the CI measurement system includes modifications to correct for process synchronization

issues selected from the group consisting of process synchronization issues include at least one of: motion control path synchronization, processing laser energy profile synchronization, workpiece distortions, process inputs, shielding gas, cover gas, process environment, process feed material, process sacrificial material, and process fixturing.