CLAIMS

1. A real-time measurement system in a crystal puller for determining a distance between a silicon melt in a crucible and a reflector while a crystal is being pulled from the silicon melt, the system comprising:

the reflector defining a central passage through which the crystal is pulled and an opening;

a measurement assembly comprising:

a run pin having a head that is visible through the opening;

a camera to capture images through the opening in the reflector, each captured image including a surface of the silicon melt in the crystal puller; and

a laser to selectively transmit coherent light through the opening to the head of the run pin to produce a reflection of the run pin on the surface of the silicon melt; and

a controller connected to the camera and the laser, the controller programmed to:

control the laser to direct coherent light from the laser to the run pin,

control the camera to capture first captured images through the opening in the reflector while the coherent light is directed at the run pin, the first captured images including at least a part of the surface of the silicon melt on which the reflection of the run pin is visible, and

determine a distance between the surface of the silicon melt and a bottom surface of the reflector based on a location of the reflection of the run pin in the first captured images,

the system further comprising an anchor pin mounted to the reflector, the anchor pin including a head and an end opposite the head, the anchor pin being sized to extend past a bottom surface of the reflector,

wherein the controller is programmed to calibrate the system using the anchor pin without touching the anchor pin to the silicon melt, and the calibration occurs before determining the distance between the surface of the silicon melt and the bottom surface of the reflector while the crystal is being pulled from the silicon melt, and

wherein the controller is programmed to calibrate the system by:

controlling the laser to direct coherent light from the laser to the head of the anchor pin,

control the camera to capture second captured images through the opening in the reflector while the coherent light is directed at the anchor pin, the second captured images including at least a part of the anchor pin and at least a part of the surface of the silicon melt on which a reflection of the end of the anchor pin is visible, and

determine a distance between the surface of the silicon melt and a bottom surface of the reflector based at least in part on a location of the reflection of the end of the anchor pin in the second captured images, known dimensions of the anchor pin, and an amount by which the anchor pin extends past the bottom surface of the reflector.

2. The measurement system of claim 1, wherein the run pin is mounted in the reflector.

3. The measurement system of claim 1 or claim 2, wherein the run pin includes an end opposite the head of the pin, the reflection of the run pin is a reflection of the end of the run pin, and the end of the run pin is not visible to the camera through the opening.

4. The measurement system of any one of claims 1-3, wherein the run pin comprises a quartz run pin.

5. The measurement system of any one of claims 1-4, wherein the end of the run pin is sized and positioned to prevent the run pin from touching the surface of the silicon melt when the crystal is being pulled from the silicon melt.

6. The measurement system of any one of claims 1-5, wherein the controller is programmed to:

control the camera to capture images while calibrating the system by:

controlling the camera to capture a first image through the opening in the reflector while the coherent light is directed at the head of the anchor pin and the surface of the melt is at a first distance from the bottom of the reflector;

controlling the camera to capture a second image through the opening in the reflector while the coherent light is directed at the head of the anchor pin when the surface of the melt is at a second distance from the bottom of the reflector; and

determine the distance between the surface of the silicon melt and the bottom surface of the reflector while calibrating the system based at least in part on the first and second images.

7. The measurement system of claim 6, wherein the controller is programmed to control a crucible lift to move the crucible to change the distance between the surface of the silicon melt and the bottom surface of the reflector by known amounts.

8. The measurement system of claim 6 or claim 10, wherein the controller is further programmed to calibrate the system by:

controlling the laser to direct coherent light from the laser to the head of the run pin when the surface of the melt is at the second distance from the bottom of the reflector;

controlling the camera to capture run calibration images through the opening in the reflector while the coherent light is directed at the run pin, the run calibration images including at least a part of the surface of the silicon melt on which the reflection of the end of the run pin is visible;

correlate the location of the reflection of the end of the run pin in the run calibration images to a reflection of the end of the anchor pin in the second image.

9. A system for producing a silicon ingot, the system including:

a crucible for holding a silicon melt; and

the measurement system of any one of claims 1-8.

10. A method of determining a distance between a silicon melt in a crucible and a reflector in a crystal puller while a crystal is being pulled from the silicon melt using a measurement system including a camera, a laser, a run pin, and a controller, the method comprising:

directing coherent light from the laser to the run pin mounted on the reflector and visible through an opening in the reflector;

capturing first captured images through the opening in the reflector using the camera while the coherent light is directed at the run pin, the first captured images including at least a part of a surface of the silicon melt on which the reflection of the run pin is visible; and

determining, by the controller, a distance between the surface of the silicon melt and a bottom surface of the reflector based on a location of the reflection of the run pin in the first captured images,

wherein the measurement system includes an anchor pin mounted to the reflector and having a head and an end opposite the head, the anchor pin being sized to extend past a bottom surface of the reflector, and wherein the method further comprises: calibrating the measurement system using the anchor pin without touching the anchor pin to the silicon melt before determining the distance between the surface of the silicon melt and the bottom surface of the reflector while the crystal is being pulled from the silicon melt, wherein calibrating the measurement system further comprises:

directing coherent light from the laser to the head of the anchor pin;

capturing second captured images through the opening in the reflector while the coherent light is directed at the anchor pin using the camera, the second captured images including at least a part of the anchor pin and at least a part of the surface of the silicon melt on which a reflection of the end of the anchor pin is visible; and

determining a distance between the surface of the silicon melt and a bottom surface of the reflector based at least in part on a location of the reflection of the end of the anchor pin in the second captured images, known dimensions of the anchor pin, and an amount by which the anchor pin extends past the bottom surface of the reflector.

11. The method of claim 10, wherein capturing images through the opening in the reflector while the coherent light is directed at the anchor pin using the camera comprises:

capturing a first image through the opening in the reflector while the coherent light is directed at the head of the anchor pin and the surface of the melt is at a first distance from the bottom of the reflector; and

capturing a second image through the opening in the reflector while the coherent light is directed at the head of the anchor pin when the surface of the melt is at a second distance from the bottom of the reflector, and wherein determining the distance between the surface of the silicon melt and the bottom surface of the reflector while calibrating the measurement system is based at least in part on the first and second images.

12. The method of claim 11, further comprising controlling a crucible lift to move the crucible to change the distance between the surface of the silicon melt and the bottom surface of the reflector by known amounts.

13. A system for producing a silicon ingot, the system including:

a crucible for holding a silicon melt; and

the measurement system configured to perform the method of any one of claims 10-12.