drive unit may rotate the pulling cable 118 in the same direction in which crucible drive unit 107 rotates the crucible 102. In addition, the crystal drive unit raises and lowers the ingot 113 relative to the melt surface 111 as desired during the growth process.

[0038] The ingot puller apparatus 101 may include an inert gas system to introduce and withdraw an inert gas such as argon from the growth chamber 152. The ingot puller apparatus 101 may also include a dopant feed system (not shown) for introducing dopant into the melt 104.

[0039] According to the Czochralski single crystal growth process, a quantity of polycrystalline silicon, or polysilicon, is charged to the crucible 102. The initial semiconductor or solar-grade material that is introduced into the crucible is melted by heat provided from one or more heating elements to form a silicon melt in the crucible. The ingot puller apparatus 101 includes bottom insulation 115 and side insulation 124 to retain heat in the ingot puller apparatus. In the illustrated embodiment, the ingot puller apparatus 101 includes a bottom heater 126 disposed below the crucible floor 129. The crucible 102 may be moved to be in relatively close proximity to the bottom heater 126 to melt the polycrystalline charged to the crucible 102.

[0040] To form the ingot, the seed crystal 122 is contacted with the surface 111 of the melt 104. The pulling mechanism 114 is operated to pull the seed crystal 122 from the melt 104. Referring now to FIG. 2, the ingot 113 includes a crown portion 142 in which the ingot

it may be determined whether the parameter falls within a threshold range.

[0059] In some embodiments of the present disclosure, two or more epitaxial wafers sliced from ingots grown from melts having different impurity profiles are imaged by infrared depolarization and their respective infrared depolarization parameters are compared to determine suitability of one or more ingot growth parameters (e.g., one or more impurity profiles) for producing substrates used for epitaxy (e.g., strength and/or slip resistance and optionally after downstream heat treatments). For example, to produce the first epitaxial wafer, after a silicon melt is formed, the seed crystal 122 is contacted with a melt having a first impurity profile (e.g., concentration of oxygen, nitrogen, or boron or other dopants). The seed crystal is withdrawn to form a first single crystal silicon ingot and a first plurality of silicon substrates are sliced from the single crystal silicon ingot. An epitaxial layer is deposited on one of the silicon substrates to form a first epitaxial wafer. The first epitaxial wafer is imaged by infrared depolarization to determine a first infrared depolarization parameter.

[0060] In accordance with embodiment of the present disclosure, a second melt is formed (in the same or different crystal puller or even a different crystal puller apparatus) having a second impurity profile (e.g., different impurity profile such as having a different concentration of one or more impurities). A silicon seed crystal (same or different crystal as before) is contacted with second silicon melt and is withdrawn to grow a second single crystal silicon ingot. The second single crystal

of the impurity profile for epitaxy. Alternatively or in addition, the first and second infrared depolarization parameter may be compared to a threshold parameter (e.g., a parameter in which the slip resistance of the substrate is known to be acceptable). Such threshold parameters may be determined by determining the infrared depolarization parameter of substrates which are known or found to have acceptable slip resistance in epitaxy. In accordance with embodiments of the present disclosure, the first infrared depolarization parameter and the second infrared depolarization parameter are the same parameter.

[0064] In embodiments in which two or more epitaxial wafers are imaged, the epitaxial silicon layers may be formed on each of the silicon substrates under the same process conditions (e.g., process times and temperatures). Use of the same or similar process conditions reduces the influence of the process conditions in the slip performance when comparing wafers.

[0065] Referring now to FIG. 6, in some embodiments, after the epitaxial layer is deposited in step 300 and before imaging 400, the wafer may undergo a heat treatment step 350 (e.g., both wafers are heat treated under the same conditions when more than one wafers are imaged). The heat treatment step 350 may mimic a heat treatment used during downstream device fabrication. For example, the heat treatment may involve heating to up to 1150°C for six or more hours. As shown in FIG. 7, in some embodiments a second heat treatment 375 is performed after the first heat treatment 350 (e.g., heating up to 1150°C for six or more hours). The second heat treatment 375 may

CLAIMS:

1. A method for determining suitability of Czochralski growth conditions to produce silicon substrates for epitaxy, the method comprising:

heating a crucible comprising a charge of silicon to cause a silicon melt to form in the crucible;

contacting a silicon seed crystal with the silicon melt, the silicon melt having a first impurity profile;

withdrawing the silicon seed crystal to grow a first single crystal silicon ingot;

slicing a first plurality of silicon substrates from the first single crystal silicon ingot;

contacting a front surface of a silicon substrate of the first plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrate to form a first epitaxial wafer;

imaging the first epitaxial wafer by infrared depolarization to determine a first infrared depolarization parameter;

heating a crucible comprising a charge of silicon to cause a second silicon melt to form in the crucible;

contacting a silicon seed crystal with the second silicon melt, the second silicon melt having a second impurity profile, the first impurity profile of the first melt being different than the second impurity profile of the second melt;

withdrawing the silicon seed crystal to grow a second single crystal silicon ingot;

slicing a second plurality of silicon substrates from the second single crystal silicon ingot;

contacting a front surface of a silicon substrate of the second plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrate to form a second epitaxial wafer;

imaging the second epitaxial wafer by infrared depolarization to determine a second infrared depolarization parameter; and

determining suitability of the first impurity profile and the second impurity profile to produce substrates for epitaxy based on the first and second infrared depolarization parameters.

2. The method as set forth in claim 1 wherein determining suitability of the first impurity profile and the second impurity profile to produce substrates for epitaxy comprises comparing the first infrared depolarization parameter to the second infrared depolarization parameter.

3. The method as set forth in claim 2 wherein the first infrared depolarization parameter and the second infrared depolarization parameter are the same parameter.

4. The method as set forth in any one of claims 1 to 3 wherein determining suitability of the first impurity profile and the second impurity profile to produce

substrates for epitaxy comprises determining the slip resistance of the substrates.

5. The method as set forth in any one of claims 1 to 4 wherein the first infrared depolarization parameter and second infrared depolarization parameter are each selected from a wafer map, bad fraction variability chart, bad fraction average, total bad fraction, average depolarization value, total of the depolarization value, depolarization contrast, and shear stress equivalent.

6. The method as set forth in any one of claims 1 to 4 wherein the first infrared depolarization parameter and second infrared depolarization parameter are related to the depolarization value.

7. The method as set forth in any one of claims 1 to 6 wherein the first impurity profile and second impurity profile relate to the concentration of oxygen, nitrogen, or boron in the melt.

8. The method as set forth in any one of claims 1 to 7 further comprising:

heat treating the first epitaxial wafer before imaging the first epitaxial wafer; and

heat treating the second epitaxial wafer before imaging the second epitaxial wafer.

9. The method as set forth in any one of claims 1 to 8 wherein the epitaxial silicon layer is formed on the silicon substrate of the first plurality of substrates to form the first epitaxial wafer under the same process conditions at which the epitaxial silicon layer is formed

on the silicon substrate of the second plurality of substrates to form the second epitaxial wafer.

10. The method as set forth in any one of claims 1 to 9 wherein only an annular edge region of the first and second epitaxial wafers is imaged.

11. The method as set forth in any one of claims 1 to 10 comprising:

contacting the front surfaces of a batch of the first plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrates to form a first batch of epitaxial wafers;

imaging each epitaxial wafer of the first batch of epitaxial wafers by infrared depolarization to determine the first infrared depolarization parameter;

contacting the front surfaces of a batch of the second plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrates to form a second batch of epitaxial wafers; and

imaging each epitaxial wafer of the second batch of epitaxial wafers by infrared depolarization to determine the second infrared depolarization parameter.

12. The method as set forth in any one of claims 1 to 11 comprising:

forming a first batch of single crystal silicon ingots from melts having the first impurity profile, the first single crystal silicon ingot being part of the first batch;

slicing a first plurality of silicon substrates from two or more single crystal silicon ingots of the first batch;

contacting the front surfaces of the first plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrates to form a first batch of epitaxial wafers;

imaging each epitaxial wafer of the first batch of epitaxial wafers by infrared depolarization to determine the first infrared depolarization parameter;

forming a second batch of single crystal silicon ingots from melts having the second impurity profile, the second single crystal silicon ingot being part of the second batch;

slicing a second plurality of silicon substrates from two or more single crystal silicon ingots of the second batch;

contacting the front surfaces of the second plurality of silicon substrates with a silicon-containing gas, the silicon-containing gas decomposing to form an epitaxial silicon layer on the silicon substrates to form a second batch of epitaxial wafers; and

imaging each epitaxial wafer of the second batch of epitaxial wafers by infrared depolarization to determine the second infrared depolarization parameter.

13. A method for determining suitability of a silicon substrate for epitaxy, the method comprising:

loading a silicon substrate onto a susceptor disposed within a processing reactor;

contacting a front surface of the silicon substrate with a silicon-containing gas, the silicon-containing gas decomposing to form a first epitaxial silicon layer on the silicon substrate;

contacting a front surface of the first epitaxial silicon layer with a silicon-containing gas, the silicon-containing gas decomposing to form a second epitaxial silicon layer on the first epitaxial silicon layer to form an epitaxial wafer; and

imaging the epitaxial wafer by infrared depolarization to determine an infrared depolarization parameter.

14. The method as set forth in claim 13 comprising heat treating the substrate before imaging the epitaxial wafer.

15. The method as set forth in claim 14 wherein the substrate is heat treated after forming the second epitaxial silicon layer.

16. The method a set forth in claim 14 wherein the substrate is heated after forming the first epitaxial silicon layer and before forming the second epitaxial silicon layer.

17. A method for determining suitability of a silicon substrate for epitaxy, the method comprising:

heat treating the substrate in a first heat treatment step;

heat treating the substrate in a second heat treatment step; and

imaging the substrate by infrared depolarization after the first and second heat treatment steps to determine an infrared depolarization parameter.

18. The method as set forth in claim 17 wherein the first heat treatment is a temperature of up to 1150°C for six or more hours.

19. The method as set forth in claim 18 wherein the second heat treatment is a temperature of up to 1150°C for six or more hours.

20. The method as set forth in any one of claims 17 to 19 wherein the infrared depolarization parameter is selected from a wafer map, bad fraction variability chart, bad fraction average, total bad fraction, average depolarization value, total of the depolarization unit, depolarization contrast, and shear stress equivalent.