[0023] In accordance with embodiments of the present disclosure, after polycrystalline silicon is added to the crucible 22 and the heating system 39 is operated to melt-down the polycrystalline silicon, a sample ingot or rod is pulled from the melt. An example sample rod 5 is shown in Figure 2. The rod 5 includes a crown portion 21 in which the rod transitions and tapers outward from the seed to reach a target diameter. The rod 5 includes a constant diameter portion 25 or cylindrical main body or simply "body", of the crystal which is grown by increasing the pull rate. The main body 25 of the sample rod 5 has a relatively constant diameter. The rod 5 includes a tail or end-cone 29 in which the rod tapers in diameter after the main body 25. When the diameter becomes small enough, the rod is then separated from the melt. The rod 5 has a central longitudinal axis A that extends through the crown 21 and a terminal end 33 of the ingot.

[0024] The growth conditions of the sample rod 5 may be selected from generally any of the suitable growth conditions available to those of skill in the art. The sample rod 5 may be grown with a locked seed lift (i.e., fixed pull speed with varying diameter such as +/- about 5 mm) or active seed lift (pull speed varied to maintain target diameter).

[0025] The sample rod 5 has a diameter less than the product ingot that is grown after the sample rod. For example, the diameter of the sample rod may be less than 0.75 times the ~~times the~~ diameter of the product ingot, less than 0.50 times, less than about 0.25 times or less than 0.1 times the diameter of the product ingot. In some embodiments, the diameter of the sample rod is less

[0034] The measurement apparatus 43 of Figure 4 is an example apparatus and any suitable apparatus for securing and/or measuring the resistivity of the rod may be used unless stated otherwise. Use of a rod (e.g., generally ~~s~~ narrow diameter rod such as less than 100 mm, 50 mm or less than 25 mm) and the measurement apparatus 43 allows the resistivity to be measured without slicing the rod into wafers or slugs.

[0035] The resistivity probe may be a two point probe in which both probe tips are contacted with the planar segment 11. The voltage difference is measured across the two probe tips. For example, resistivity may be measured with a two-point probe in accordance with SEMI Standard MF397-0812, entitled "Test Method for Resistivity of Silicon Bars using a Two-Point Probe," which is incorporated herein by reference for all relevant and consistent purposes. The 2-terminal or 3-terminal rectification method may be used to determine the crystal type (i.e., N-type or P-type). Such type determination may be performed in accordance with SEMI Standard MF42-0316, entitled "Test Method for Conductivity Type of Extrinsic Semiconducting Materials", which is incorporated herein by reference for all relevant and consistent purposes. Both 2-terminal and 3-terminal rectification methods are robust methods for very high resistivity silicon.

[0036] The voltage may be measured at various points across the length. The measured voltages and the sample length and average diameter may be used to calculate the resistivity such as by determining the slope of a current-voltage curve (e.g., Example 1 below).

of 20 mm. The sample rod was cropped and ground to form a flat segment that extended from one end to the other end of the rod. The rod was rapid thermal annealed at 800°C for 3 minutes. The resistivity of the ingot was measured by a measurement apparatus similar to the apparatus shown in Figure 4 and with a two-point probe. The differences between the growth conditions are shown in Table 1 below:

	Short Ingot	Sample Rod
Diameter (mm)	207	~17-23
Weight (kg)	31	0.11
Length (mm)	250	200
Process Time (hr)	25	5
Resistivity Sample Preparation Time (hr)	26	6
Total time (hr)	51	11

Table 1: Growth Conditions for Sample Ingot 200 mm in Diameter and a Sample Rod ~17-23 mm in Diameter

[0050] The measured resistivities across the length of the sample rod and the resistivity of a slug from the sample ingot are shown in Figure 6.

[0051] The sample preparation time for the short ingot was 26 hours and involved cropping, mixed-acid etch, rapid thermal anneal, slab cutting, grinding (e.g., with a diamond pad), lapping and measurement with a 4-point probe. The sample preparation time for the sample rod was 6 hours and involved cropping, mixed-acid etch, rapid thermal anneal, flat grinding (with a diamond pad), lapping and measurement with a 2-point probe.

~~WHAT IS CLAIMED IS~~CLAIMS:

1. A method for producing a single crystal silicon ingot from a silicon melt held within a crucible comprising:

adding polycrystalline silicon to the crucible;

heating the polycrystalline silicon to cause a silicon melt to form in the crucible;

pulling a sample rod from the melt, the sample rod having a diameter;

annealing the sample rod to annihilate thermal donors;

measuring a resistivity of the sample rod after annihilation of thermal donors; and

pulling a product ingot from the melt, the product ingot having a diameter, the diameter of the sample rod being less than the diameter of the product ingot.

2. The method as set forth in claim 1 wherein a resistivity of the sample rod is measured by contacting the rod with a resistivity probe.

3. The method as set forth in claim 1 or claim 2 wherein a resistivity of the sample rod is measured without slicing the sample rod into wafers or slugs.

4. The method as set forth in any one of claims 1 to 3 further comprising forming a planar segment on the sample rod, a resistivity of the sample rod being measured on the planar segment.

5. The method as set forth in claim 4 wherein the planar segment extends axially from one end of the sample rod toward a second end of the sample rod.

6. The method as set forth in claim 4 or claim 5 wherein a probe is contacted with the planar segment to measure a resistivity of the sample rod.

7. The method as set forth in any one of claims 1 to 6 further comprising applying a current to the sample rod to measure a resistance of the sample rod.

8. The method as set forth in any one of claims 1 to 7 wherein the diameter of the sample rod is less than 0.75 times the diameter of the product ingot~~, or less than 0.50 times, less than about 0.25 times or less than 0.1 times the diameter of the product ingot~~.

9. The method as set forth in any one of claims 1 to 8 wherein the sample rod has an average diameter, the average diameter of the sample rod being less than about 150 mm~~, less than about 100 mm, less than about 50 mm, less than about 25 mm, less than about 20 mm, from about 5 mm to about 150 mm, from about 5 mm to about 100 mm, from about 5 mm to about 50 mm, from about 5 mm to about 25 mm or from about 10 mm to about 25 mm~~.

10. The method as set forth in any one of claims 1 to 9 wherein the sample rod has a largest diameter, the largest diameter of the sample rod being ~~less than about 150 mm, less than about 100 mm,~~ less than ~~about~~ 50 mm~~, less than about 25 mm, less than about 20 mm, from about 5 mm to about 150 mm, from about 5 mm to about 100 mm, from about 5 mm to about 50 mm, from about 5 mm to about 25 mm or from about 10 mm to about 25 mm~~.

11. The method as set forth in any one of claims 1 to 10 wherein the sample rod has a length of less than

~~about~~ 300 mm~~, less than about 200 mm or less than about 100 mm~~.

12. The method as set forth in any one of claims 1 to 11 wherein the product ingot has a resistivity of at least ~~about~~ 1,500 Ω-cm~~, or at least about 2,000 Ω-cm, at least about 4,000 Ω-cm, at least about 6,000 Ω-cm, at least about 8,000 Ω-cm, at least about 10,000 Ω-cm, from about 1,500 Ω-cm to about 50,000 ohm-cm or from about 8,000 Ω-cm to about 50,000 Ω-cm~~.

13. The method as set forth in any one of claims 1 to 12 wherein the sample rod has a resistivity of at least ~~about~~ 1,500 Ω-cm~~, or at least about 2,000 Ω-cm, at least about 4,000 Ω-cm, at least about 6,000 Ω-cm, at least about 8,000 Ω-cm, at least about 10,000 Ω-cm, from about 1,500 Ω-cm to about 50,000 ohm-cm or from about 8,000 Ω-cm to about 50,000 Ω-cm~~.

14. The method as set forth in any one of claims 1 to 13 comprising determining an average resistivity of the sample rod.

15. The method as set forth in claim 14 wherein the sample rod is secured by a measurement apparatus comprising a clamp that holds the sample rod while contacting the sample rod with a resistivity probe.

16. The method as set forth in any one of claims 1 to 15 wherein the sample rod is annealed at a temperature of at least ~~about~~ 500°C~~, at least about 650°C, at least about 800°C, from about 500°C to about 900°C, or from about 650°C to about 1100°C~~.

17. The method as set forth in any one of claims 1 to 16 wherein a length of the anneal is at least ~~about~~ 5

seconds~~, at least about 30 seconds, at least about 1 minute, at least about 3 minutes, from about 5 seconds to 15 minutes, from about 5 seconds to about 5 minutes or from about 5 seconds to about 3 minutes~~.

18. The method as set forth in any one of claims 1 to 17 wherein the sample rod has an average diameter, the average diameter of the sample rod being less than 25 mm.

19. The method as set forth in any one of claims 1 to 18 wherein the sample rod is annealed in a rapid thermal anneal to annihilate thermal donors.

20. The method as set forth in claim 19 wherein the sample rod is annealed to a temperature of at least 500°C for 5 seconds to 15 minutes.

21. The method as set forth in any one of claims 1 to 20 wherein the sample rod is annealed to a temperature of 800°C or more.

22. The method as set forth in claim 21 wherein the sample rod is annealed for 5 seconds to 15 minutes.

~~18~~23. A method for determining the resistivity of a polycrystalline silicon melt held within a crucible, the method comprising:

pulling a sample rod from the melt;

annealing the sample rod in a thermal donor kill cycle;

applying a current to the sample rod; and

contacting the sample rod with a resistivity probe while applying current to the sample rod to measure the resistivity of the rod.

~~19~~24. The method as set forth in claim ~~18~~23 further comprising forming a planar segment on a surface of the sample rod, the resistivity probe contacting the planar segment to measure the resistivity of the rod.

~~20~~25. The method as set forth in claim ~~18~~23 or claim ~~19~~24 wherein the probe is a two-point resistivity probe.

~~21~~26. The method as set forth in any one of claims ~~18~~23 to ~~20~~25 wherein the sample rod has an average diameter, the average diameter of the sample rod being ~~less than about 150 mm or less than about 100 mm, less than about 50 mm,~~ less than ~~about~~ 25 mm~~, less than about 20 mm, from about 5 mm to about 150 mm, from about 5 mm to about 100 mm, from about 5 mm to about 50 mm, from about 5 mm to about 25 mm or from about 10 mm to about 25 mm~~.

~~22~~27. The method as set forth in any one of claims ~~18~~23 to ~~21~~26 wherein the sample rod has a largest diameter, the largest diameter of the sample rod being ~~less than about 150 mm, less than about 100 mm, less than about 50 mm, less than about 25 mm, less than about 20 mm, from about 5 mm to about 150 mm, from about 5 mm to about 100 mm,~~ from ~~about~~ 5 mm to ~~about~~ 50 mm~~, from about 5 mm to about 25 mm or from about 10 mm to about 25 mm~~.

~~23~~28. The method as set forth in any one of claims ~~18~~23 to ~~22~~27 wherein the sample rod is secured by a measurement apparatus comprising a clamp that holds the sample rod when contacting the rod with a resistivity probe.

~~24~~29. The method as set forth in any one of claims ~~18~~23 to ~~23~~28 further comprising annealing the sample rod prior to measuring the resistivity of the sample rod.

~~25~~30. The method as set forth in any one of claims ~~18~~23 to ~~24~~29 further wherein the sample rod is annealed at a temperature of ~~at least about 500°C, at least about 650°C,~~ at least ~~about~~ 800°C~~, from about 500°C to about 900°C, or from about 650°C to about 1100°C~~.

~~26~~31. The method as set forth in any one of claims ~~18~~23 to ~~25~~30 wherein a length of the anneal is ~~at least about 5 seconds, at least about 30 seconds,~~ at least ~~about~~ 1 minute~~, at least about 3 minutes, from about 5 seconds to 15 minutes, from about 5 seconds to about 5 minutes or from about 5 seconds to about 3 minutes~~.

32. The method as set forth in any one of claims 23 to 31 wherein the sample rod is annealed in a rapid thermal anneal.

33. The method as set forth in claim 32 wherein the sample rod is annealed to a temperature of at least 500°C for 5 seconds to 15 minutes.

34. The method as set forth in any one of claims 23 to 32 wherein the sample rod is annealed to a temperature of 800°C or more.

35. The method as set forth in claim 34 wherein the sample rod is annealed for 5 seconds to 15 minutes.