interstitial concentration. At a lower v/G, the diffusion dominates the convection, allowing the incorporation of the fast diffusing interstitials as the dominant point defects. At a v/G close to its critical value (i.e., the transition between vacancy and interstitial dominated material), both the point defects are incorporated in very low and comparable concentrations.

[0034] In accordance with embodiments of the present disclosure, (i) a growth velocity, v, and/or (ii) an axial temperature gradient, G, may be controlled during the growth of an axial segment of the constant diameter portion of the ingot such that the ratio v/G is below the critical value of v/G to cause vacancy concentrations in the ingot to be reduced (or even controlled to be less than a value slightly above the critical v/G).

[0035] The critical v/G generally changes based on the amount of boron doping. Boron shifts the equilibrium to the interstitial regime. With increasing boron concentration (i.e., decreasing resistivity), the vacancy-dominated region shrinks until it disappears entirely at the crystal center (FIG. 3C). In boron doped ingots, it is believed that the vacancy-dominated region may be eliminated at boron doping greater than 8.0×10^{18} atoms/cm^3 (e.g., resistivity of less than 10 mΩ*cm) at all ratios of v/G.

[0036] For boron concentrations of 8.0×10^{18} atoms/cm^3 or less, v/G may be controlled to be below the critical v/G (or even below a value that is slightly above the critical v/G). In accordance with some embodiments of the present disclosure, when the segment of the constant diameter portion of the ingot has a boron concentration

from 5.4 x 10^{18} atoms/cm3 to 8.0 x 10^{18} atoms/cm^3). "Low" excess vacancies indicate that v/G was less than the v/G ranges specified above (v/G was less than 0.20 mm^2/(min*K) for boron concentrations from 2.8 x 10^{18} atoms/cm^3 to 5.4 x 10^{18} atoms/cm^3 and was less than 0.25 for boron concentrations from 5.4 x 10^{18} atoms/cm3 to 8.0 x 10^{18} atoms/cm^3).

Test Lot Number	Excess Vacancy Conc.	Boron Conc. (Lot Range) [at/cm^3]	Oxygen Conc. (target) [at/cm^3]	Dwell time 1150-950°C [min]	Epitaxial defect counts
1	high	(4.60-4.75)*10^{18}	6.45*10^{17}	128	< 3
2	high	(4.67-4.81)*10^{18}	6.25*10^{17}	128	< 3
3	high	(4.32-4.61)*10^{18}	6.25*10^{17}	160	>15
4	high	(4.44-5.00)*10^{18}	6.25*10^{17}	130	>5
5	high	(4.51-5.19)*10^{18}	6.45*10^{17}	132	>5
6	low	(6.05-6.42)*10^{18}	6.25*10^{17}	127	< 3
7	low	(6.91-7.52)*10^{18}	6.25*10^{17}	129	< 3
8	low	(8.89-10.60)*10^{18}	6.25*10^{17}	132	< 3
9	low	(8.83-10.40)*10^{18}	6.25*10^{17}	132	< 3
10	low	(7.76-9.58)*10^{18}	6.25*10^{17}	158	< 3
11	low	(7.46-8.89)*10^{18}	6.25*10^{17}	152	< 3
12	high	(4.68-4.77)*10^{18}	6.45*10^{17}	45	< 3
13	high	(4.51-4.62)*10^{18}	6.25*10^{17}	40	< 3
14	high	(4.90-5.11)*10^{18}	6.45*10^{17}	43	< 3
15	high	(4.82-4.90)*10^{18}	6.45*10^{17}	31	< 3
16	high	(4.68-4.88)*10^{18}	6.25*10^{17}	31	< 3
17	low	(5.83-6.07)*10^{18}	6.25*10^{17}	47	< 3
18	low	(5.95-6.11)*10^{18}	6.25*10^{17}	41	< 3
19	low	(6.75-8.12)*10^{18}	6.25*10^{17}	32	< 3

Table 1: Defect Counts as a Function of v/G (i.e., excess vacancy concentration)

[0059] As shown in Table 1, low defect counts may be achieved when the excess vacancy concentration is low or when the dwell time in the temperature range from