Claims

1. A method of manufacturing a p-type silicon single crystal, comprising the steps of:
- preparing a silicon melt to which boron as a main dopant, a first sub dopant which is an n-type impurity and smaller in segregation coefficient than said boron, and a second sub dopant which is a p-type impurity and smaller in segregation coefficient than said first sub dopant have been added; and
- growing a silicon single crystal having resistivity not lower than 6 Ωcm from said silicon melt with a Czochralski method.

2. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 4.9 and not higher than 52.4.

3. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of

said main dopant in said silicon melt is not lower than 1.2 and not higher than 13.4.

4. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 25.1 and not higher than 261.2.

5. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is arsenic and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 11.7 and not higher than 72.2.

6. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is arsenic and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by

concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 3.1 and not higher than 18.3.

7. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is arsenic and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.4 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 57.9 and not higher than 324.0.

8. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 24.2 and not higher than 27.0.

9. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 30.8 and not higher than 33.8.

10. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 6.2 and not higher than 6.9.

11. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 7.8 and

not higher than 8.5.

12. A p-type silicon single crystal which is grown from a silicon melt, comprising:
- boron as a main dopant;
- a first sub dopant which is an n-type impurity and smaller in segregation coefficient than said boron; and
- a second sub dopant which is a p-type impurity and smaller in segregation coefficient than said first sub dopant,
- the p-type silicon single crystal having a resistivity which is not lower than 6 Ωcm.

13. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 4.9 and not higher than 52.4.

14. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of

said main dopant in said silicon melt is not lower than 1.2 and not higher than 13.4.

15. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 25.1 and not higher than 261.2.

16. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is arsenic and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 11.7 and not higher than 72.2.

17. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is arsenic and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by

concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 3.1 and not higher than 18.3.

18. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is arsenic and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.4 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 57.9 and not higher than 324.0.

19. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 24.2 and not higher than 27.0.

20. The p-type silicon single crystal according to claim 12, wherein

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 30.8 and not higher than 33.8.

21. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 6.2 and not higher than 6.9.

22. The p-type silicon single crystal according to claim 12, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 7.8 and

not higher than 8.5.

23. A silicon wafer which is obtained by slicing a p-type silicon single crystal according to any of claims 12 to 22.

Claims

1. A method of manufacturing a p-type silicon single crystal, comprising the steps of:

- preparing a silicon melt to which boron doping as a main dopant, a first sub dopant which is an n-type impurity and smaller in segregation coefficient than said boron, and a second sub dopant which is a p-type impurity and smaller in segregation coefficient than said first sub dopant have been added; and
- growing a silicon single crystal having resistivity not lower than 6 Ωcm from said silicon melt with a Czochralski method,

wherein either

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 4.9 and not higher than 52.4; or wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said

second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 1.2 and not higher than 13.4; or wherein

- said first sub dopant is phosphorus and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 25.1 and not higher than 261.2; or wherein
- said first sub dopant is arsenic and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 11.7 and not higher than 72.2; or wherein
- said first sub dopant is arsenic and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second

concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 3.1 and not higher than 18.3; or wherein

- said first sub dopant is arsenic and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.4 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 57.9 and not higher than 324.0.

2. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 24.2 and not higher than 27.0.

3. The method of manufacturing a p-type silicon single crystal

according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 30.8 and not higher than 33.8.

4. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 6.2 and not higher than 6.9.

5. The method of manufacturing a p-type silicon single crystal according to claim 1, wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and

- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 7.8 and not higher than 8.5.

6. A p-type silicon single crystal, comprising:
- boron doping as a main dopant;
- a first sub dopant which is an n-type impurity and smaller in segregation coefficient than said boron; and
- a second sub dopant which is a p-type impurity and smaller in segregation coefficient than said first sub dopant, and

having a resistivity not lower than 6 Ωcm, wherein either
- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 4.9 and not higher than 52.4; or wherein
- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing

concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 1.2 and not higher than 13.4; or wherein

- said first sub dopant is phosphorus and said second sub dopant is indium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.5 and not higher than 1.2 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 25.1 and not higher than 261.2; or wherein
- said first sub dopant is arsenic and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 11.7 and not higher than 72.2; or wherein
- said first sub dopant is arsenic and said second sub dopant is gallium, and

- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.5 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 3.1 and not higher than 18.3; or wherein

- said first sub dopant is arsenic and said second sub dopant is indium, and

- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.6 and not higher than 1.4 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 57.9 and not higher than 324.0.

7. The p-type silicon single crystal according to claim 6, wherein

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and

- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said

main dopant in said silicon melt is not lower than 24.2 and not higher than 27.0.

8. The p-type silicon single crystal according to claim 6, wherein

- said first sub dopant is phosphorus and said second sub dopant is aluminum, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 30.8 and not higher than 33.8.

9. The p-type silicon single crystal according to claim 6, wherein

- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.79 and not higher than 0.81 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 6.2 and not higher than 6.9.

10. The p-type silicon single crystal according to claim 6, wherein

- said first sub dopant is phosphorus and said second sub dopant is gallium, and
- a first concentration ratio calculated by dividing concentration of said first sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 0.89 and not higher than 0.91 and a second concentration ratio calculated by dividing concentration of said second sub dopant in said silicon melt by concentration of said main dopant in said silicon melt is not lower than 7.8 and not higher than 8.5.