Numerical Investigation of Non-metal Impurities on the DS Grown mc-silicon Ingot: Effect of Argon Flow Rate

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ABSTRACT

The numerical simulation has been carried out on the directional solidification (DS) system for the growth of multi-crystalline silicon (mc-Si) ingot. During the growth period, different rate of argon flow has been investigated. Oxygen and Carbon decrease when the argon flow rate increases. In the overall growth process, the argon gas flow rate is divided into N/3 hours for different cases. Case-A (1/3) growth period 10 LPM for 8 hrs remaining hours fixed 20 LPM, Case-B (2/3) growth period 10 LPM for 16 hrs remaining hours fixed 20 LPM, Case-C full growth period 20 LPM for the complete duration 24 hrs. We detect that evaporation of SiO and CO gas at the melt-free surface decrease with increasing the concentration of different argon gas flow in the different solidification process.

INTRODUCTION

In a silicon crystal growth technique, multi-crystalline silicon (mc-Si) is produced by the directional solidification (DS) method due to its low cost and more successful for producing larger-sized mc-Si ingots for solar cell applications. The concentration of impurities and their distribution affect the quality of the mc-Si ingot and also affect the photoelectric conversion efficiency. The major impurities like oxygen and carbon. The injection of argon gas into the furnace chamber affects the impurities transport on the melt-free surface.

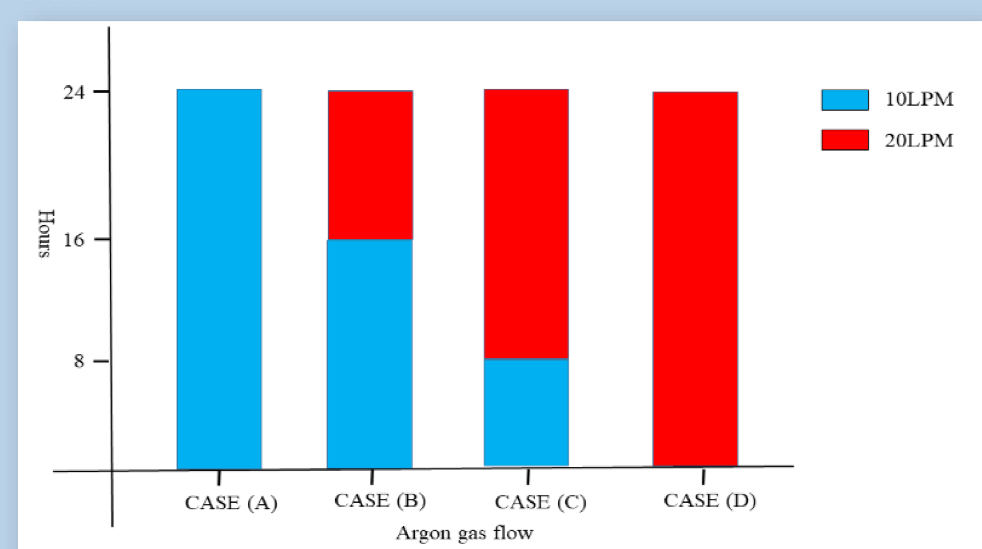
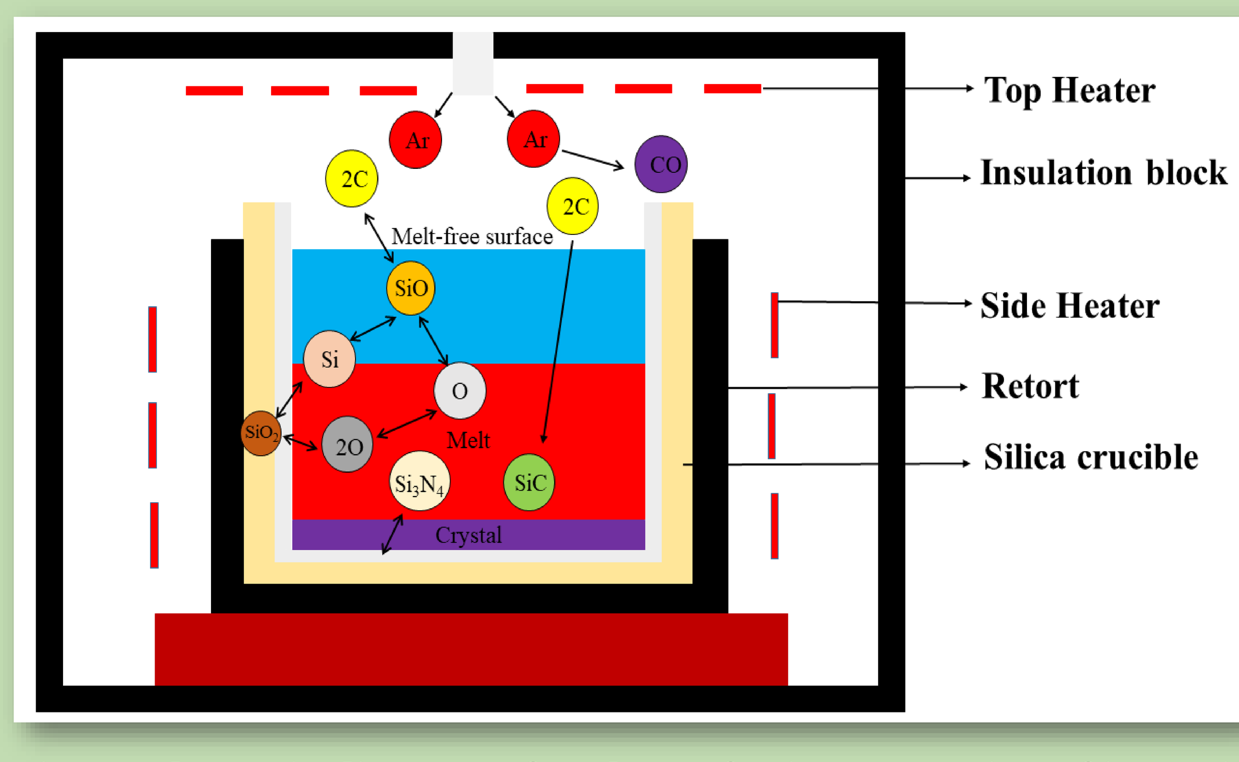


Fig.1. Graphical representation of argon gas flow with different patterns

IMPURITY TRANSPORTATION



Chemical reaction
SiO_2 (s) ↔ Si (m) + 2O (m)
Si (m) + O (m) ↔ SiO (g)
SiO (g) + 2C (s) ↔ CO (g) + SiC (s)
CO (g) ↔ C (m) + O (m)
O (m) ↔ O (s)
C (m) ↔ C (s)

Fig.2. Schematic diagram of pathway for incorporation of impurities

(1) The oxygen gets dissolved in the silicon melt from the silicon nitrate-coated silica (SiO_2) crucible.

(2) Then the oxygen atom gets combined with the silicon atom from the melt and evaporates as SiO gas at the gas/melt interface.

(3) CO gas is formed when the SiO gas at the gas/melt surface reacts with the graphite materials.

(4) Then the CO gas gets back diffused through the gas surface and gets segregated as C and O in the melt surface.

(5) The C and O atoms in the silicon melt get segregated in the crystal.

RESULT & DISCUSSION

Oxygen:

Initially, melt and crystal are contact with the silica crucible-wall which releases the oxygen (O) atoms. The segregation coefficient of O is higher than the growing crystal, hence the O atoms are diffused into the melt and its concertation may be increased at the bottom melt portion. At the same time, concertation of SiO gas can be effectively removed by the argon gas flow, which leads to a minimum amount of O concentration near the melt surface.

Carbon:

The source of the C atoms from the graphite insulation wall. These C are diffused and floated into the silicon melt due to the low segregation coefficient of 0.7, resulting in a relatively high C concentration at the free-melt interface. The evaporation of SiO is split into two components (SiC, and CO). The CO gas evaporated from the melt surface and it can be consumed by the argon gas. The different flow rate was used to controlled the concertation of the C concentration in the silicon ingot.

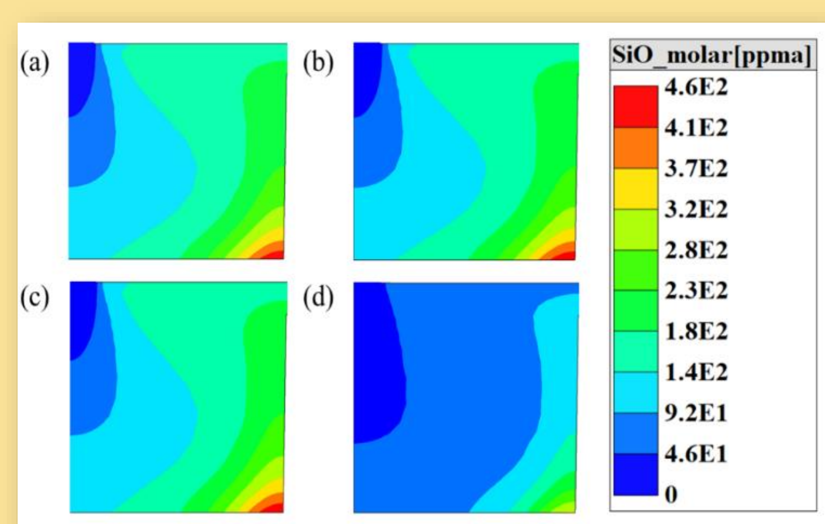


Fig.5 SiO concentration at 25% solidified

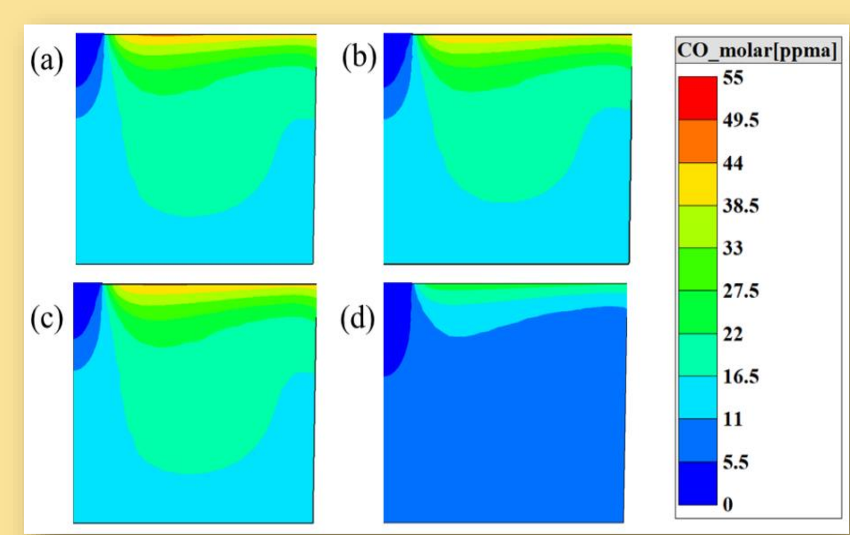


Fig.6 .CO gas concentration at 25% solidified

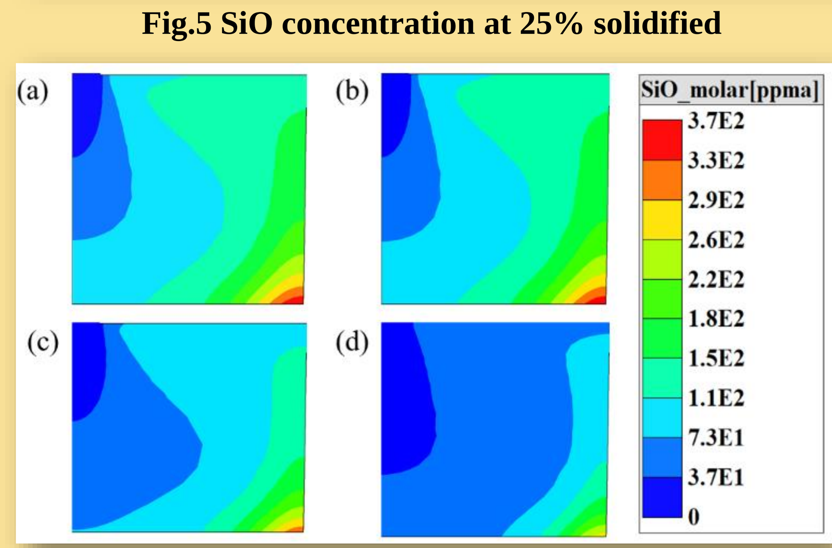


Fig.7 . SiO concentration at 50% solidified

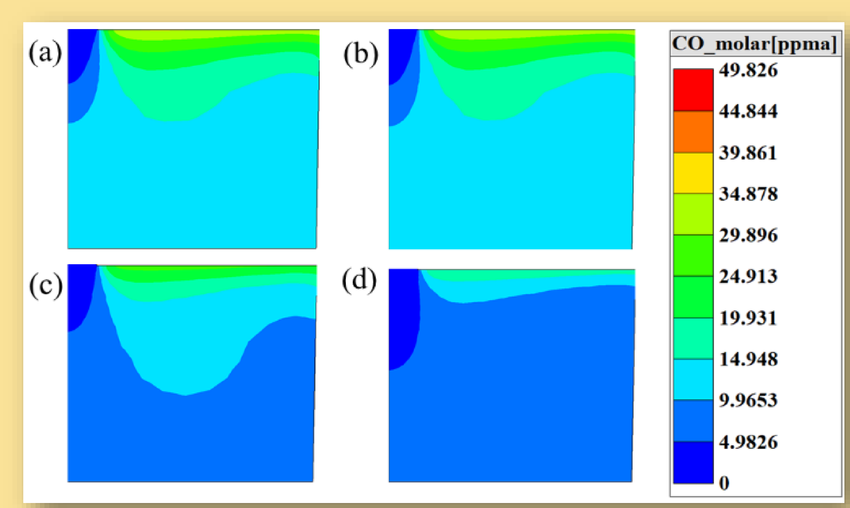


Fig.8 .CO gas concentration at 50% solidified

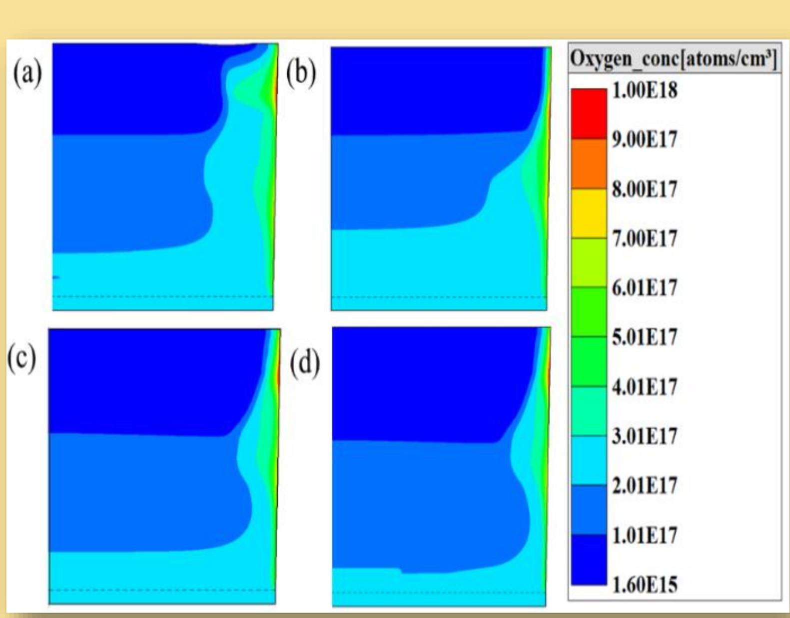


Fig.3 Oxygen concentration at 75% solidified

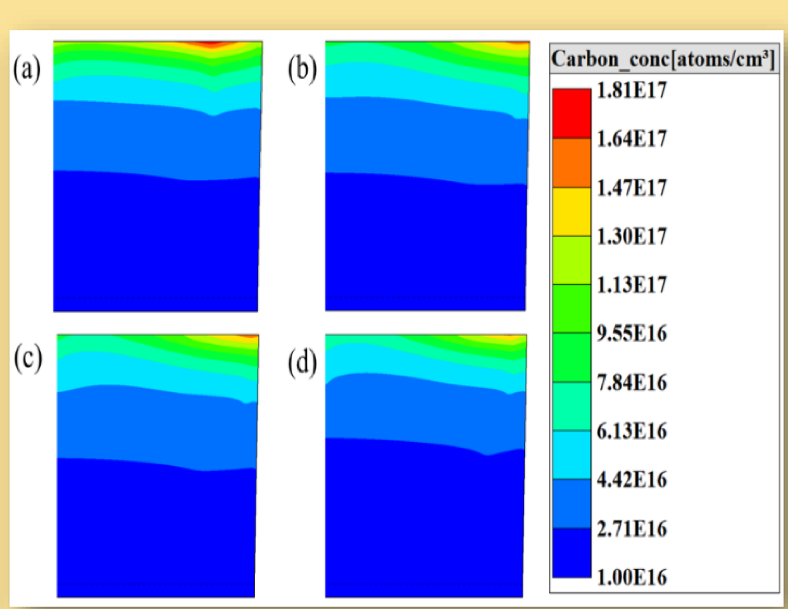


Fig.4 Carbon concentration at 75% solidified

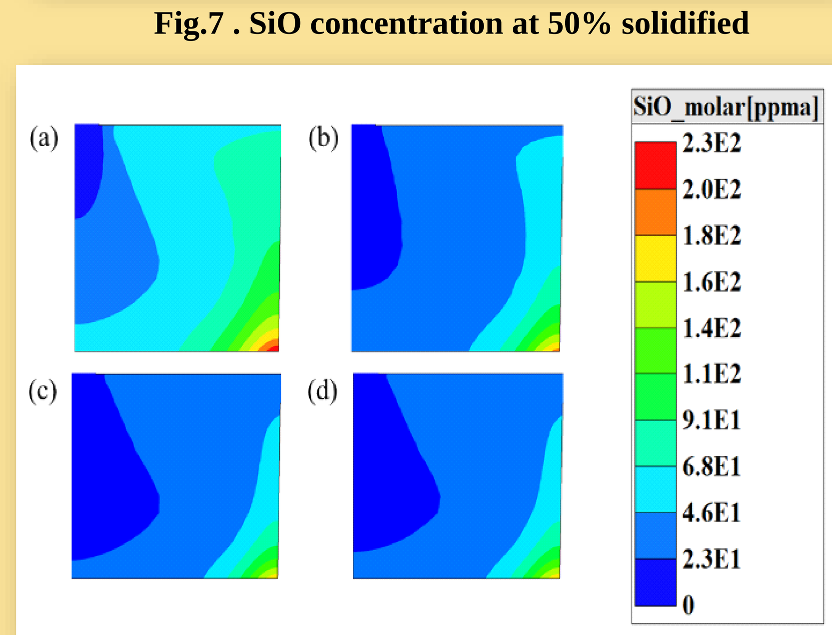


Fig.9 .SiO concentration at 75% solidified

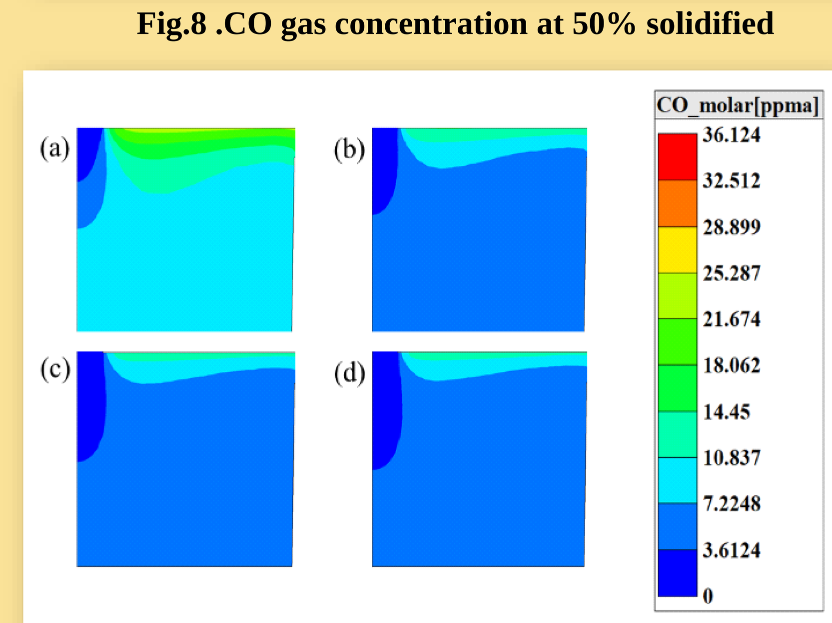


Fig.10 .CO gas concentration at 75% solidified

CONCLUSION

Global simulations including coupled oxygen and carbon transport in a directional solidification furnace and the effect of argon gas flow on impurity distributions in the furnace were investigated. The O atoms that have been dissolved are transferred into the silicon melt. Some of the O atoms segregate into the developing crystal at the c-m contact because the oxygen segregation coefficient (K_O) is larger than 1. The carbon segregation coefficient (Kc) is significantly less than 1, hence majority of C atoms are transported into the silicon melt.

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