

Thermodynamic Study of Boron Oxidation in Metallurgical Grade Silicon Purifying Through Plasma Melting.

Matheus Aquilini (IC), Emílio Cardoso (PG), Maria C. Theodoro (PG), Paulo R. Mei (PQ)

Abstract

Understanding the great variety of applications of silicon based photovoltaic solar panels and verifying that the cost of the silicon used on them is responsible for up to 70%¹ of the total production cost, the group was motivated to develop a route to purify 99% pure silicon up to 99,999% (purity needed for this application). To accomplish this, the rather impure silicon will be treated with a electron beam under high vacuum followed by a second purification step using inductively coupled argon plasma combined with different proportions of reactive gases H₂O, O₂ and H₂, seeking a cheaper and reliable way to produce the high purity silicon needed for the photovoltaic industry.

Key words: silicon, plasma, boron.

Introduction

Some properties of solar panels as being non-pollutant, the absence of moving parts, low need for maintenance and the possibility of installation over roof tops, forests, ships and isolated areas that lack of transmission lines, for example, make their use for electricity production very advantageous when compared with other traditional methods that may require large areas, release gases from burning fossil fuels and so on.

One of the main problems in purifying silicon (Si) up to required standards is the removal of boron (B) and this step requires special attention due to the high energy required to break Si-B bonds and to the electrical properties of boron. Boron has one less electron than silicon, therefore, boron contaminated silicon can be considered p-type semi-conductor, inappropriate for the initial steps in production of photovoltaic solar panels.

Boron cannot be removed by the electron beam treatment due to its low volatility. The reactive plasma may be able to transform the boron present in silicon into more volatile forms of boron, that when exposed to the high temperatures of plasma evaporates out of the initial silicon mass.

Results and Discussion

The initial step in the purifying process is degassing, using an electron beam to bombard the silicon, melting and heating it up to 2300K. This process takes place inside a high vacuum chamber, volatilizing many impurities like calcium, aluminium and phosphorous but not boron.

Studies showed that argon plasma combined with water vapor is capable of generating fragments like H, O and OH. Under the high temperatures generated by the plasma these fragments are capable of reacting with the boron

present in the molten initial silicon mass and generate more volatile species like BO, B(OH)₂ and BOH^{1,2}, although different compositions of the reactive gas would be tested. The treatment would occur in another chamber, designed by the research group, equipped with the plasma torch in which different proportions of H₂O, O₂ and H₂ could be tested. This procedure showed to be capable of reducing boron contamination from 15 to only 2 ppm by itself³. BOH would be the most appropriate species to remove boron, since it is stable and volatile under the extreme conditions found under a plasma torch².

This process would be aided by inductive stirring, provided by a coil placed around the graphite crucible, inside the chamber, where the silicon would be treated, providing mobility to the molten silicon, ensuring that most of the silicon present in the crucible interacts with the plasma, removing the boron while silicon stays liquid in the crucible.

Conclusions

The literature gives evidence that solar grade silicon can be produced from metallurgical grade silicon through the processes described.

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¹ B.P. Lee, H. M.Lee, D.H.Park, J.S.Shin, T.U.Yu, B.M.Moon "Refining of MG-Si by hybrid melting using steam plasma and EMC" *Solar Energy Materials & Solar Cells* v. 95, p. 56–58, 2011.

² Naomichi Nakamura, Hiroyuki Baba, Yasuhiko Sakaguchi and Yoshiei Kato "Boron Removal in Molten Silicon by a Steam-Added Plasma Melting Method" *Materials Transactions* v. 45, No. 3, p. 858-864, 2004.

³ C. Alemany, C. Trassy, B. Pateyron, K.-I. Li, Y. Delannoy "Refining of metallurgical-grade silicon by inductive plasma." *Solar Energy Materials & Solar Cells* v. 72, p. 41–48, 2002.