AN 452
Uniformity Study of B, Al, P, C, O, Ca and Fe in Upgraded Metallurgical Grade Silicon (UMG-Si) by Secondary Ion Mass Spectrometry (SIMS)

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Introduction

In the past, Si-based solar cells were manufactured primarily from high purity, semiconductor-grade silicon. However, with the worldwide shortage of Si and its high price, lower price alternatives are being sought in order to keep the cost of Si-based solar cells low. One of these solutions is the use of purified metallurgical grade silicon, referred to as Upgraded Metallurgical Grade Silicon (UMG-Si) to mix with high purity Si for solar cell wafer manufacturing. Unfortunately, the purification processes developed thus far are often not producing consistently low levels of impurities throughout the UMG-Si bricks.

Discussion

The following is an example of a set of SIMS analyses designed to characterize the impurity distribution within a UMG-Si brick formed by a particular purification process. Several samples were taken along each of 3 sections from 3 UMG-Si bricks, as indicated in the diagram below. The samples were analyzed using Secondary Ion Mass Spectrometry (SIMS) in order to quantify several elements of importance – B, Al, P, C, O, Ca, and Fe. Analysis precision, based on repeat measurement of control samples or standards is 3-8%.

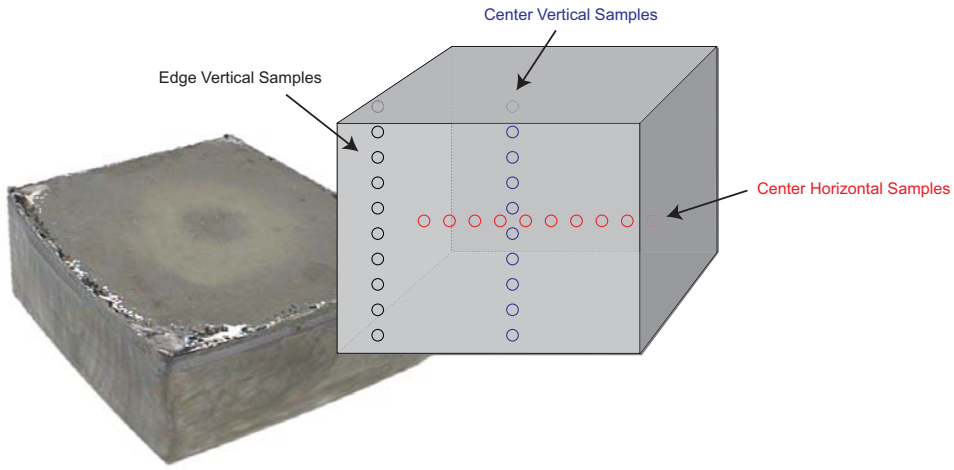


Table 1

Summary of Results

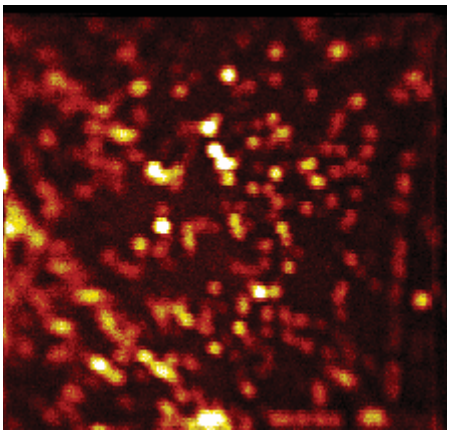
Sample Sequence		B	P	Al	C	O	Ca	Fe
Edge Vertical								
	Ave (atoms/cc)	5.06E+17	2.96E+17	3.04E+17	9.42E+17	1.62E+18	<2E12	< mid E13
	RSD	18.7%	61.9%	119.0%	26.5%	37.0%		
	Max/min	1.8	4.5	12.2	1.9	4.2		
	Trend?	yes	yes	yes	no	yes		
Center Vertical								
	Ave (atoms/cc)	3.71E+17	3.08E+17	7.30E+16	8.68E+17	1.93E+18	<3E12	< mid E13
	RSD	6.0%	25.3%	16.5%	29.4%	14.9%		
	Max/min	1.2	2.1	1.7	2.3	1.5		
	Trend?	yes	yes	yes	no	no		
Center Horizontal								
	Ave (atoms/cc)	2.63E+17	1.97E+17	2.48E+16	8.90E+17	1.81E+18	<3E12	< mid E13
	RSD	11.1%	31.5%	40.7%	32.9%	22.1%		
	Max/min	1.3	2.5	3.8	2.5	1.9		
	Trend?	no	no	no	no	no		

Table 1 is a summary of SIMS analyses for each sample section. The table lists the average impurity concentrations, relative standard deviations (RSD), and maximum impurity concentration divided by the minimum concentration. This last parameter provides an indication of the statistical range of the data. The table also indicates whether or not a directional trend in concentrations was observed along that section. For this particular purification process, the data provided the following conclusions:

- Impurity distributions in the UMG-Si bricks are not uniform and the degree of non-uniformity is element specific.
- Boron is the most uniform of the elements studied.
- Some impurities in some sections show directional trends
- Ca and Fe impurities are extremely low (<ppb levels)

The levels of each impurity and the observed directional trends are pieces of information that can allow the manufacturing company to improve their process or selectively exclude certain regions of the bricks. If the impurity distributions are consistent from brick to brick, the SIMS results also indicate which regions of the block can be analyzed to provide representative impurity concentrations. Since the distance between analysis sites is on the order of several inches, the experiment shows that the location within the brick from which the sample is obtained is a much more critical factor than the actual analysis volume of the chosen technique.

Besides providing concentration values, SIMS can also be used to look at the lateral distribution of impurities within the area of analysis. The image below shows the non-homogeneous distribution of oxygen within the UMG-Si on a micron scale. Note that this oxygen would not be detected by Fourier Transform Infrared Spectroscopy (FTIR) as it is present in precipitate form rather than interstitial.



SIMS image shows that O distribution is not uniform in micron scale. 125µm x 125µm