

SSMS ANALYSIS OF LOW CARBON CONTENTS IN CRYSTALLINE SILICON

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Carbon in silicon plays an important role in oxygen precipitation for the intrinsic gettering of undesirable impurities in silicon devices. Therefore, accurate measurements of carbon concentrations below 500 ppb atomic are necessary in order to control the oxygen precipitation process. Mass spectrometric, nuclear physical, and optical measurements have been carried out on carbon containing silicon from the Siemens, Czochralski and floating zone processes. The mass lines of singly or multiply charged ions of silicon samples were measured simultaneously on the ion-sensitive Q plate at the exit of a modernized spark source mass spectrometer, type 21-110 (Consolidated Electrodynamic Corporation, USA). Selected mass lines of silicon isotopes were used to identify the mass of the carbon isotopes and to calibrate the carbon concentration (Fig. 1). Repeated SSMS measurements of the carbon content were evaluated with a relative sensitivity coefficient of unity by use of the singly charged ions of the major isotope, ¹²C, and selected singly and multiply charged ions of the minor silicon isotopes, ²⁹Si and ³⁰Si (Fig. 2). The CPAA is used as a reference method by means of the nuclear reaction ¹²C(d,n)¹³N. The SSMS and CPAA measured carbon concentrations, [C]_{ssms} and [C]_{cpaa}, reveal a linear relationship over a broad range of values with a slope $rsc_C = [C]_{ssms}/[C]_{cpaa}$ of 0.77 ± 0.04 ($2\sigma_{rsc,C}$) (Fig. 3). This relative sensitivity coefficient allows to measure quantitatively the carbon concentration in silicon by calibrated SSMS above the detection limit of 5 ppb atomic. It has been shown by the ¹²C(d,n)¹³N calibrated SSMS method that carbon concentrations can as well be measured by the FTIR within an uncertainty ($2\sigma_F$) of 15 percent of the conversion coefficient F predicted by ASTM F 1391-93 [1]. In the concentration range below 100 ppb atomic calibrated SSMS measurements show that the FTIR measured carbon content seems to be systematically too low by at least 10 ppb atomic. It is presumed that these differences in carbon concentration are caused by the FTIR reference sample for subtracting the two-phonon lattice band and by the fact that the FTIR method measures only the substitutional fraction of carbon concentration in the silicon lattice.

[1] 1998 Annual Book of ASTM Standards, Vol. 10.05, F 1391-93, p. 465, American Society for Testing and Materials, Philadelphia (1998).

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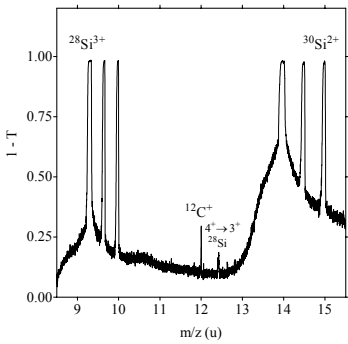


Fig. 1. Mass spectrum of carbon and silicon ions of floating zone silicon # FZ-7 for an ion exposure of 3×10^{-8} C.

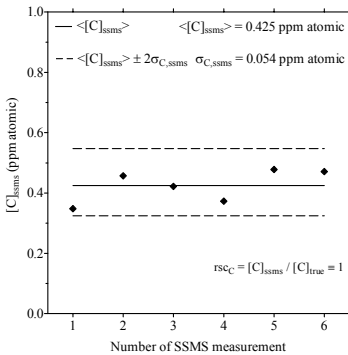


Fig. 2. Repeated measurements to calculate the mean value $\langle [C]_{ssms} \rangle$ and the standard deviation $\sigma_{C,ssms}$ atomic of the carbon concentration in floating zone silicon # FZ-7.

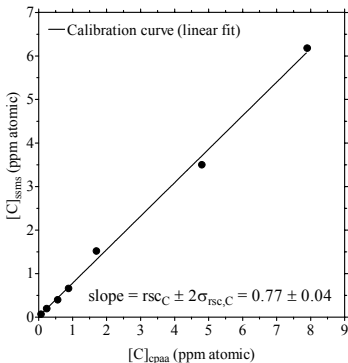


Fig. 3. Relation between SSMS-measured carbon content, $[C]_{ssms}$, and CPAA-measured carbon content, $[C]_{cpaa}$, in silicon with the SSMS relative sensitivity coefficient, which is defined as $slope\ rsc_C = [C]_{ssms}/[C]_{cpaa}$.