Matrix Dependence of the Si^{n+} Charge Spectra

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The matrix dependence of the Si^{n+} charge spectra has been studied using an ion micro-analyzer (IMA)^{1), 2)}. Multi-charged ions are observed most frequently in the charge spectra of atoms formed by radioactive decay processes³⁾⁻⁶⁾. They are also observed in the charge spectra of atoms sputtered by bombardment with alpha particles (helium ions)⁷⁾.

This report will describe the matrix dependence of the charge spectra of Si^{n+} ions sputtered from solid targets bombarded with Ar^+ ions.

Phlogopite (insulator) and boron-doped silicon (p-type semiconductor) were used as solid targets. The acceleration voltage of the Ar^+ ions was 15 kV, while the applied voltage of the targets was 3 kV. The effective bombarding energy of Ar^+ ions was 12 keV, and the beam was 700 μm in diameter.

In the mass spectra of both targets, the relative intensities of $^{28}\text{Si}^{n+}$, and $^{29}\text{Si}^{n+}$ and $^{30}\text{Si}^{n+}$ in each charge state were in agreement with the natural abundance ratio within the range of experimental error. Consequently, the contribution from residual gases was regarded as negligible.

The results are shown in Table 1 and Fig. 1. Figure 1 compares the relative intensities of the Si^+ , Si^{2+} , and Si^{3+} ions from phlogopite and the boron-doped silicon targets. In each case, singly-charged ions are most abundant and ions

with higher charges decrease in number as the charge increases.

Multi-charged ions in boron-doped silicon are more abundant than those in phlogopite. The difference in the spectra may be explained in terms of the matrix effect. It is unlikely that the primary ionization caused by Ar^+ ions has

Table 1. Relative Intensities of $^{28}\text{Si}^{n+}$ Ions from Phlogopite and Boron-doped Silicon Bombarded with Ar^+ Ions.

Bombarded Samples	$^{28}\text{Si}^{2+}/^{28}\text{Si}^+$	$^{28}\text{Si}^{3+}/^{28}\text{Si}^+$
Phlogopite	1.5×10^{-3}	3.5×10^{-5}
Si (B)	1.4×10^{-1}	3.5×10^{-3}

Fig. 1. Charge Spectra of $^{28}\text{Si}^{n+}$ Ions from Phlogopite and Boron-doped Silicon Bombarded with Ar^+ Ions.

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a strong matrix dependence. Therefore, the large difference in the relative intensities of Si^{2+} and Si^{3+} ions may be attributed to the difference in the neutralization process at the sites of the ionized Si atoms. In general, the secondary electron ejection coefficients of a certain element are higher in oxides than in metals, and electron mobilities are smaller in oxides than in metals. Thus, phlogopite can supply more electrons available for the "in situ" neutralization of silicon ions than can boron-doped silicon. In other words, multi-charged ions can survive more easily in boron-doped silicon than in phlogopite.

In the cases of most ion, electron and photon bombardments, multi-charged ions are produced in only small quantities, and they are often observed as unstable peaks in the mass

spectra. It is said⁸⁾ that silicon is one of the elements that do not give reproducible results in IMA. The matrix dependence of the charge spectra described here may cast a light on those kinds of problems.

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