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EXTREME ULTRAVIOLET SPECTRA OF HIGHLY STRIPPED SILICON IONS*

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INTRODUCTION

We report on a study of foil-excited spectra in the wavelength range 107-374 Å from highly stripped Si ions. Decay-in-flight lifetime measurements involving the most prominent and well resolved features will be reported in a future publication. Many of the lines that have been identified are associated with $\Delta n = 0$ transitions in Si VI - Si XI of the type $2s^2 2p^k - 2s 2p^{k+1}$ or $2s 2p^k - 2p^{k+1}$. A

large number of the spectral features remain unidentified at the present time.

A review of previous spectral investigations on highly ionized Si has been made by Edlén [1]. Some twenty lines in the present spectra have also been recently observed in a solar spectral study by Behring *et al.* [2].

METHOD

High energy Si ion beams (20 and 42 MeV) from the Oak Ridge National Laboratory tandem Van de Graaff accelerator were passed through thin ($\sim 5 \mu\text{g}/\text{cm}^2$) carbon foils which served to excite the ions and strip them further. A 2.2 meter, grazing incidence, vacuum ultraviolet spectrometer dispersed the radiation from the foil-excited beam source. The radiation was dispersed by a gold surface, 300 grooves per millimeter grating and detected by a continuous dynode, spiral electron multiplier located behind the exit slit of the spectrometer. Photon counting techniques were employed to record the spectra. The signal strength was normalized to the radiation diffracted and scattered into a second photon counter located on the normal to the grating (without a defining slit in front of it). Each detector had a 90% transmission wire mesh screen (biased to -800 volts) in front of it to keep out any stray electrons. An 87.5 degree angle of incidence was used and at that angle the grating exhibited a blaze wavelength of 191 Å. The spectra were scanned digitally using discrete settings of the exit slit, the resulting signal being stored in a multichannel scaler which was synchronized with the stepping process.

He I and II and Ar II lines from a hollow cathode light source, mounted on the target chamber opposite the entrance slit of the spectrometer, were used for the wavelength calibration of the spectrometer. The accuracy of the wavelength determinations in this experiment is estimated to be no better than ± 0.2 Å. Most of this uncertainty was introduced by variable doppler shifts resulting from changes in beam steering through the finite sized beam collimators. More stringent collimation is presently being used in our apparatus.

RESULTS

Figure 1 shows a spectrum from $\sim 250 - 350$ Å obtained from foil-excited Si ions accelerated to 20 MeV. Figure 2 compares foil excited spectra obtained using 20 MeV (upper) and 42 MeV (lower) Si ion beams in the wavelength interval 343 - 377 Å. As characteristic of the beam-foil source, the higher incident energy enhances the spectra of more highly stripped ions. Table I lists the present measured wavelengths for 20 MeV incident Si ions along with classi-

fications wherever possible. The identified lines originate in Si V - Si XII at this incident ion beam energy.

REFERENCES

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Figure 1. Portion of foil-excited Si spectrum obtained using 20 MeV Si ions.

Figure 2. Comparison of foil-excited spectra obtained using 20 MeV (upper) and 42 MeV (lower) Si ion beams in the region 343 - 377 Å.

TABLE I. Lines from 20 MeV Foil-Excited Silicon Ions

Measured $\lambda(\text{\AA})$	Intensity ^a	Classification ^b			
		Ion	Configuration	Term	J - J
107.2	W				
107.8	W				
111.6	W				
111.9	VW				
112.4	W				
113.1	W				
114.9	VW				
115.6	VW				
117.7	VW	Si V	$2p^6-2p^5(^2P^o)3s$	$1S - \frac{1}{2}[\frac{1}{2}]^o$	0 - 1
118.2	VW				
118.9	VW	Si V	$2p^6-2p^5(^2P^o)3s$	$1S - \frac{3}{2}[\frac{3}{2}]^o$	0 - 1
119.4	VW				
119.8	VW				
120.3	VW				
120.7	VW				
121.1	VW				
121.9	W				
122.5	W				
123.1	W				
123.5	W				
125.4	VW				
126.0	VW				
126.7	W	Si XII	3p-4d	$2P^o - 2D$	$\frac{3}{2} - \frac{5}{2}$
127.6	VW				
128.0	VW				
129.4	W				
129.7	W	Si XII	3d-4f	$2D - 2F^o$	$\frac{3}{2} - \frac{5}{2}$
130.4	VW	Si XII	3d-4f	$2D - 2F^o$	$\frac{5}{2} - \frac{7}{2}$
131.7	W				
138.8	W				
139.4	W				
140.7	W				
141.5	W				
144.7	W				
146.2	M				
147.1	W				
147.4	M	Si XI	2s3d-2s4f	$3D - 3F^o$	3 - 4
147.8	W				
148.6	W				
149.4	W				
150.6	W				
151.1	W				

TABLE I (continued)

Measured $\lambda(\text{\AA})$	Intensity ^a	Classification ^b			
		Ion	Configuration	Term	J - J
151.7	W				
152.4	W				
153.1	W				
158.1	W				
158.5	VW				
159.3	W				
159.6	W				
160.6	W				
161.3	VW				
162.0	VW				
162.4	VW				
163.4	W				
164.9	W				
165.7	W				
166.2	W				
167.2	W				
168.0	W				
168.5	VW				
169.0	W				
169.7	W				
170.5	W				
172.2	W				
173.1	W				
174.7	W				
175.0	M				
175.8	W				
176.4	W				
176.9	W				
178.5	W				
178.8	W				
180.2	W				
180.9	W				
181.7	W				
182.0	W				
182.5	VW				
183.3	W				
184.5	W				
185.6	W				
186.6	W				
188.3	W				
203.0	VW				
203.9	VW				
204.3	W				
205.4	W				
206.5	VW				

TABLE I (continued)

Measured $\lambda(\text{\AA})$	Intensity ^a	Classification ^b			J - J
		Ion	Configuration	Term	
207.1	W				
207.7	W				
208.2	VW				
209.8	W				
210.2	W				
211.1	W				
211.9	W				
212.5	VW				
213.0	VW				
213.4	W				
214.2	VW				
214.6*	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2D^o - 2P$	$\frac{3}{2} - \frac{1}{2}$
216.4	W				
216.9	M	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2D^o - 2P$	$\frac{5}{2} - \frac{3}{2}$
217.6	VW	Si VII	$2s^2 2p^4 - 2s 2p^5$	$1D - 1P^o$	2 - 1
218.3	W				
220.8	W				
223.5*	W	Si IX	$2s^2 2p^2 - 2s 2p^3$	$3F - 3S^o$	0 - 1
224.1	W				
224.9*	W	Si IX	$2s^2 2p^2 - 2s 2p^3$	$3P - 3S^o$	1 - 1
227.3*	S	Si IX	$2s^2 2p^2 - 2s 2p^3$	$1D - 1P^o$	2 - 1
230.0	VW				
233.1	VW	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2P^o - 2P$	$\frac{3}{2} - \frac{1}{2}$
233.6	VW				
235.5	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2P^o - 2P$	$\frac{3}{2} - \frac{3}{2}$
244.3	W				
245.8	W	Si VI	$2s^2 2p^5 - 2s 2p^6$	$2P^o - 2S$	$\frac{3}{2} - \frac{1}{2}$
249.1	VW	Si VI	$2s^2 2p^5 - 2s 2p^6$	$2P^o - 2S$	$\frac{1}{2} - \frac{1}{2}$
250.6	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2P^o - 2S$	$\frac{3}{2} - \frac{1}{2}$
251.7	W				
252.4	VW				
252.8	W	Si VIII	$2s 2p^4 - 2p^5$	$2D - 2P^o$	$\frac{3}{2} - \frac{1}{2}$
253.9*	M	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2P$	$\frac{1}{2} - \frac{3}{2}$
255.3	W				
256.5*	M	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2P$	$\frac{1}{2} - \frac{1}{2}$
258.3*	VS	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2P$	$\frac{3}{2} - \frac{3}{2}$

TABLE I (continued)

Measured λ (Å)	Intensity ^a	Classification ^b			
		Ion	Configuration	Term	J - J
259.8	W	Si IX	$2s^2 2p^2 - 2s 2p^3$	$1S - 1P^o$	0 - 1
261.3*	M	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2P$	$\frac{3}{2} - \frac{1}{2}$
272.0*	M	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2S$	$\frac{1}{2} - \frac{1}{2}$
277.1*	M	Si X	$2s^2 2p - 2s 2p^2$	$2P^o - 2S$	$\frac{3}{2} - \frac{1}{2}$
278.4	M	Si X	$2s 2p^2 - 2p^3$	$2D - 2P^o$	$\frac{5}{2} - \frac{3}{2}$
280.1	W				
281.3	W				
283.1	VW				
286.0	VW				
286.9	W				
287.4	W	Si X	$2s 2p^2 - 2p^3$	$4P - 4S^o$	$\frac{1}{2} - \frac{3}{2}$
289.0	W				
289.4	W	Si X	$2s 2p^2 - 2p^3$	$4P - 4S^o$	$\frac{3}{2} - \frac{3}{2}$
290.9	W	Si IX	$2s^2 2p^2 - 2s 2p^3$	$3P - 3P^o$	0 - 1
292.3	M	Si X	$2s 2p^2 - 2p^3$	$4P - 4S^o$	$\frac{5}{2} - \frac{3}{2}$
292.9*	W	Si IX	$2s^2 2p^2 - 2s 2p^3$	$3P - 3P^o$	1 - 2
294.7	W				
295.6	W				
296.1*	M	Si IX	$2s^2 2p^2 - 2s 2p^3$	$3P - 3P^o$	2 - 2
297.9	W				
302.0	W				
303.3*	S	Si XI	$2s^2 - 2s 2p$	$1S - 1P^o$	0 - 1
305.5	W				
308.3	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$2P^o - 2D$	$\frac{3}{5} - \frac{5}{2}$
314.2*	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$4S^o - 4P$	$\frac{3}{2} - \frac{1}{2}$
314.7	W				
316.1*	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$4S^o - 4P$	$\frac{3}{2} - \frac{3}{2}$
319.8*	W	Si VIII	$2s^2 2p^3 - 2s 2p^4$	$4S^o - 4P$	$\frac{3}{2} - \frac{5}{2}$
331.1	W				
332.1	W				
332.8	VW				
334.4	VW				
334.9	W				
335.7	VW				
337.1	W				

TABLE I (continued)

Measured λ (Å)	Intensity ^a	Classification ^b			
		Ion	Configuration	Term	$J - J$
338.6	W	Si VIII	$2s2p^4 - 2p^5$	$2_P - 2_P^o$	$\frac{3}{2} - \frac{1}{2}$
342.2	W				
345.0	VW	Si IX	$2s^2 2p^2 - 2s2p^3$	$3_P - 3_D^o$	0 - 1
345.1*	M	Si IX	$2s^2 2p^2 - 2s2p^3$	$3_P - 3_D^o$	1 - 2
347.7*	VS	Si X	$2s2p^2 - 2p^3$	$2_D - 2_D^o$	$\frac{5}{2} - \frac{5}{2}$
349.9*	M	Si IX	$2s^2 2p^2 - 2s2p^3$	$3_P - 3_D^o$	2 - 3
356.2*	S	Si X	$2s^2 2p - 2s2p^2$	$2_P^o - 2_D$	$\frac{3}{2} - \frac{5}{2}$
357.6	W	Si X	$2s2p^2 - 2p^3$	$2_S - 2_P^o$	$\frac{1}{2} - \frac{1}{2}$
358.6	M	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	1 - 2
360.3	W				
360.9	W				
361.4	W	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	0 - 1
361.9	W				
364.7	W	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	1 - 1
365.5	M	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	2 - 2
368.4	W	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	1 - 0
371.6	M	Si XI	$2s2p - 2p^2$	$3_P^o - 3_P$	2 - 1
373.4	W				

^aVW - very weak, W - weak, M - medium, S - strong, VS - very strong.

^bClassification as compiled by Kelly and Palumbo in reference [3].

*Line listed in solar spectrum by Behring et al. in reference [2].