STOPPING POWERS OF HEAVY IONS IN SILVER*

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ABSTRACT

With the method of Rutherford backscattering of heavy ions from heavy substrate, the stopping powers of ^{11}B, ^{12}C and ^{19}F in silver film were measured at energies from 0.11—0.53 MeV / u. The results are compared with the previous experimental data and the semiempirical calculations of TRIM-90.

Keywords: RBS Stopping power Heavy ions

1 INTRODUCTION

The stopping powers of ions in solids are widely used in the fields such as physical researches and nuclear technique applications. However, until present the experimental data and the theoretical understandings of the stopping powers are still quite limited, especially in the energy region of 0.1— 0.5 MeV / u, where the measurements are very scarce. The method mostly used in determining the stopping powers is the transmission method[1]. But impracticable the applications of self-supporting foil target make this method very difficult in many cases. An alternative is the Rutherford backscattering (RBS) method[2] which uses film targets with substrate. The target must be chosen carefully in order to get useful backscattering spectrum. Firstly, only pure isotope should be used since the kinematic factors K would be different if different isotopes exist in the target. This isotopic effect is negligible for light particle (such as proton or alpha) scattering, but could be significant if heavy ions are employed. Secondly, the target isotope must be much heavier than the impacted ion in order to get large K value which can facilitate the experiment detection.

For isotopic material Ag (52 % ^{107}Ag and 48 % ^{109}Ag), it is clear that the spectrum of heavy ions would be damaged by the isotopic effect if the above mentioned normal

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RBS method is used. Therefore we have considered a modified RBS method which uses the backscattering energy spectrum from a heavy substrate instead of observing directly the target. In the present work, pure heavy isotope ^{197}Au was used as substrate, onto which was evaporated isotopic material Ag film, the energy loss of various heavy ions in Ag film were extracted through the energy shift of ^{197}Au RBS spectra.

2 EXPERIMENTAL

2.1 Preparation of target samples

The heavy single isotope Au was firstly evaporated onto several silicon wafers. The thickness of Au films was about 40 nm. The isotopic material to be measured (i.e. Ag in our present experiment) was then evaporated onto some of the Au films and silicon wafers. The schematic representation of target samples is shown in Fig.1. The thickness of Ag film was determined to be 60.8 ± 2 nm with the α particle backscattering method[2].

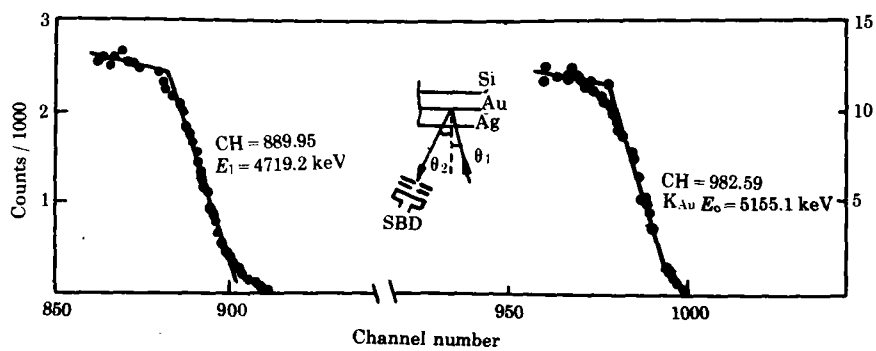

Fig.1 Schematic representation of RBS method for the measurement of energy loss of heavy ions in isotopic materials

2.2 Experimental procedure

The experimental arrangement is shown in Fig.1. The silicon barrier detector (SBD) was placed at 163° relative to the beam direction and at a distance of 7 cm to the target center. The target was placed at angles of $\theta_1 = 0°$ and $\theta_2 = 17°$. A collimating aperture of 3 mm in width was installed in front of the SBD to limit the detection angle divergence. The experimental data were collected by the CANBERRA S-88 multiparameter analyzer and the IBM micro-computer.

Table 1

Ion charge and energy used in the experiment

Ion	^{4}He	^{11}B	^{12}C	^{19}F
Charge	1+	1+, 2+, 3+	1+, 2+, 3+	2+, 3+, 4+
Energy / MeV	2.0	1.5—5.5	1.5—6.0	2.8—7.5

The ion beams were generated by the 2× 1.7 MV tandem accelerator in Peking University. The charges and energy ranges of the ions are listed in Table 1.

At each ion energy, the RBS spectra from ^{197}Au substrate both covered and uncovered by Ag film were measured. An example of the spectrum is shown in Fig.1.

3 RESULTS AND DISCUSSIONS

3.1 Basic formula

The energy shift $\triangle E$ of Au RBS spectra was determined using the least squares' fit of straight line method. The stopping power $S(E_x)$ was derived from the formula of Warters[2]

$$S(E_x) = [S]/[(K/\cos\theta_1) + (1/\cos\theta_2)] \quad (1)$$

where θ_1 and θ_2 are the angles between the sample normal and the direction of the incident beam and of the scattered particle, respectively. K is the kinematic factor and $[S]$ is the energy loss factor. We have then

$$[S] = \triangle E / x \quad (2)$$

here $\triangle E$ is the energy loss, and x denotes the thickness of target film. The value of energy response to $S(E_x)$ in equation (1) could be written approximately as follows

$$E_x = [(K/\cos\theta_1)E_0 + (1/\cos\theta_2)E_1] / [(K/\cos\theta_1) + (1/\cos\theta_2)] +$$
$$\triangle E / 2/[(K/\cos\theta_1) + (1/\cos\theta_2)] \times [(-K/\cos\theta_1) + (N/\cos\theta_2)] / (K + N) \quad (3)$$

In our treatment, $N = \triangle E_{out} / \triangle E_{in} = 1$.

In order to investigate the errors induced by Warters' approximation, the experimental stopping powers were used as the first order values to calculate the energy shift $\triangle E_{cal}$, through the comparison of experimental energy shift $\triangle E_{exp}$ to $\triangle E_{cal}$, we could get the second order stopping power[3]:

$$S^{(2)}(E_x) = S^{(1)}(E_x)\,(\triangle E_{exp} / \triangle E_{cal}) \quad (4)$$

Through the simulation by a computer to high order values, the "correct" stopping powers were obtained. In the present treatment, we evaluate the second order values as experimental stopping powers for ^{11}B and ^{12}C and the 4th order values for that of ^{19}F[3].

3.2 Results and comparisons

From Table 2 it can be seen that for ^{11}B, the experimental data are in agreement with the semiempirical calculations by TRIM-90 within the experimental error at energies lower than 0.33 MeV / u, but systematically higher than that of TRIM-90 at energies higher than 0.33 MeV / u; for ^{12}C and ^{19}F, the experimental results are well in agreement with the predications of TRIM-90. The present experimental results are compatible with those of the previous experiments[5,6], but the latter is not enough.

The errors of present measurement include the uncertaities of film thickness (~ 3 %), geometrical factors (~ 1 %), and the position of high energy sides of RBS spectrum (~1 %). The total uncertainty is less than ±4 %.

Table 2

Stopping powers dE / dx for ^{11}B, ^{12}C and ^{19}F ions in Ag film determined in the present work. The uncertainty is less than ±4 %. For comparison the semiempirical results by TRIM−90 are also listed MeV /(mg · cm^{-2})

^{11}B			^{12}C			^{19}F		
MeV / u	dE / dx	TRIM 90	MeV / u	dE / dx	TRIM 90	MeV / u	dE / dx	TRIM 90
0.17	1.731	1.778	0.25	2.477	2.474	0.11	2.559	2.686
0.19	1.802	1.841	0.27	2.479	2.508	0.12	2.756	2.819
0.21	1.865	1.891	0.29	2.483	2.535	0.13	2.930	2.942
0.23	1.919	1.931	0.31	2.489	2.555	0.14	3.083	3.056
0.25	1.966	1.961	0.33	2.496	2.570	0.15	3.217	3.162
0.27	2.007	1.985	0.35	2.505	2.581	0.16	3.333	3.260
0.29	2.042	2.002	0.37	2.516	2.588	0.17	3.433	3.351
0.31	2.071	2.014	0.39	2.528	2.593	0.18	3.518	3.435
0.33	2.096	2.021	0.41	2.543	2.603	0.20	3.648	3.583
0.35	2.117	2.032	0.43	2.560	2.610	0.22	3.735	3.709
0.37	2.134	2.040	0.45	2.580	2.615	0.24	3.791	3.816
0.39	2.149	2.045	0.47	2.602	2.616	0.26	3.826	3.906
0.41	2.162	2.047	0.49	2.626	2.616	0.28	3.851	3.981
0.43	2.173	2.047	0.51	2.654	2.614	0.30	3.879	4.045
0.45	2.184	2.045	0.53	2.684	2.611	0.32	3.921	4.099

4 CONCLUSION

It is shown that with the method of heavy ion backscattering on heavy substrate, the energy loss of heavy ions in isotopic targets can be measured. The method is easy to manipulate, applicable to various ions and to relatively large energy range, and can attain a high accuracy.

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