DETERMINATION OF THE SURFACE BINDING ENERGY OF A Cu/Li ALLOY BY MEASUREMENTS OF ANGULAR DISTRIBUTION OF SPUTTERED ATOMS

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ABSTRACT

A copper based binary alloy containing 16.9 at % lithium has been bombarded with deuterium ions in energy range of 400 eV to 2 keV at the incidence angles of 70° and 80° away from the surface normal. The sputtered flux was condensed on Al−strips arranged arround the target in a cylindrical cup. 1.5 MeV proton backscattering and nuclear reaction $^7Li(p, \alpha)^4He$ were used to detect the collected atoms of Cu and Li simultaneously. The angular distribution of sputtered atoms has been shown to be different for two components and strongly anisotropic for the grazing incidence. According to direct knock − on sputtering model and the experimental results the angle for the maximum differential sputtering yield is dependent on the incidence angle α. the bombarding energy E, the energy transfer factor $\gamma = 4M_1M_2/(M_1 + M_2)^2$ and the surface binding energy U. With the assumption that the sputtered particles are diffracted by a planar barrier the surface binding energies of 2.3 eV for the Li component and 3.0 eV for the Cu component have been determined by fitting the measured angles of preferred ejection to the direct knock − on sputtering model, and the results agree well with a pair − binding model.

Key words: Surface binding energy   Cu/Li alloy   Angular distribution
            Sputtered atoms

The surface binding energy is a very important parameter in sputtering, particularly in the analytical calculation and computer simulation of the sputtering yield, the angular − and energy − distributions of sputtered atoms etc. A planar barrier model[1] has been usually used. In the model the surface normal component of the kinetic energy of an ejected particle must be higher than the surface binding energy to overcome the surface barrier, and the ejected particle undergoes a diffraction. For a multicomponent system the surface binding energy should be different for the different components[2,3] and depend on the partial concentrations at the surface[2,3,4]. Some simple assumptions were also be used[5,6]. In the present paper the surface binding energies of a binary alloy have been determined by the angular distribution of sputtered particles

using light ions with low energy.

Light ions in the keV energy range can not transfer enough energy to the target atoms to create a regular collision cascade, and for the grazing incidence the sputtering events can be understood in a single collision mechanism[6,7]: direct knock out of a surface atom by an incidence ion.

For the direct sputtering the differential sputtering yields were found to be strongly peaked in the forward direction[6~9]. It has been also shown by an analytical calculation based on the direct knock－on collision model that the angle of preferred emission increases with decreasing incidence energy E and energy transfer factor γ and increasing surface binding energy U[1].

Fitting the measured angles of maximum differential sputtering yield to a curve drawn from the analytical calculation, one can derive the surface binding energies for a binary alloy. This has been investigated in this work.

Ⅰ. PRINCIPLE

With the assumption of the planar binding model mentioned above a collision leading to the direct knock out of a surface atom is illustrated in Fig.1, from which the following equation can be drawn[8].
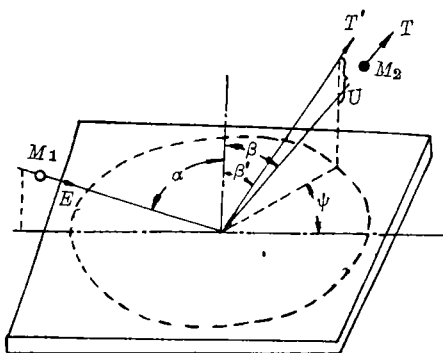

Fig. 1 Geometry of the direct knock－on collision with an assumption of planar binding model

T' and T are the energies of ejected atom before and after diffraction

$$tg^2\beta = \frac{\gamma E/U (\sin\alpha \sin\beta' \cos\psi - \cos\alpha \cos\beta') \sin\beta'}{\gamma E/U (\sin\alpha \sin\beta' \cos\psi - \cos\alpha \cos\beta') \cos\beta' - 1} \tag{1}$$

At the angle of the maximum differential sputtering yield, β_{max}, the normalized energy $\gamma E/U$ can be shown by the function of the corresponding angle β'_{max}.

$$\gamma E/U = \frac{(\sin2\beta' \sin\alpha \cos\psi - \cos2\beta' \cos\alpha)}{(\sin\beta' \sin\alpha \cos\psi - \cos\beta' \cos\alpha) \cos\beta'} \tag{2}$$

Where ψ is the azimuth angle of the sputtered atoms; β and β' are angles of ejection of sputtered particles after and before diffraction respectively. Eqs. (1) and (2) show the ground of determining the surface binding energy U from the measured angle of

the maxmium differential sputtering yield, β_{max}.

II. EXPERIMANTAL

The angular distribution of the sputtered atoms has been measured by the catcher foil technique. The Cu/Li (16.9 at % Li) target in a width of 1.5mm imbedded in a tantalum supporter was bombarded with D^+ ions of 400 eV, 1 keV and 2 kev at the incidence angles of 70^0 and 80^0 to the surface normal. Sputtered atoms were collected on Al−strips arranged around the target in a cylindrical cup.

The collected atoms, Cu and Li, were detected using ion beam methods. 1.5 MeV protons were chosen as the analysis beam, and two Au−Si barrier detectors, mounted at the angles of 165^0 and 135^0 to the incidence respectively, were used to detect the protons scattered by Cu atoms and α particles from the nuclear reaction $^7Li(p, \alpha)$ ^4He simultaneously. 1mm between each two measured points on Al−strips and beam spot in a width of 0.25mm were limited.
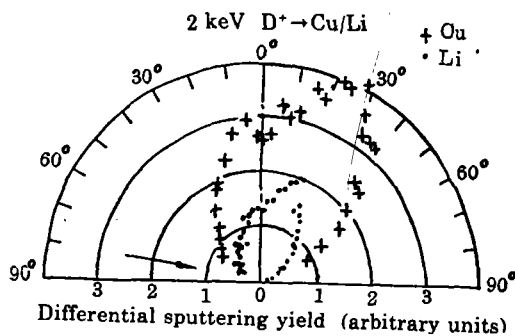
III. RESULTS

Fig. 2 Angular distributions of sputtered atoms Cu and Li due to 2keV D^+ bombarding a Cu/Li alloy at the angle of incidence $\alpha = 80°$
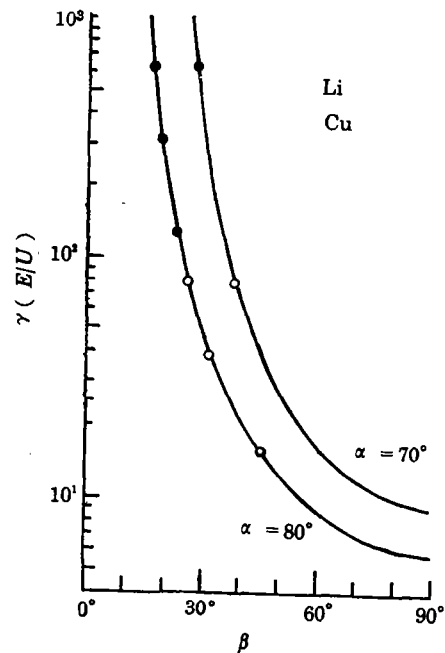
Fig.3 Determining the surface binding energy by fitting the measured angles of preferred ejection to the calculated curves based on the direct knock− on collision model shown in Fig. 1

A strongly anisotropic angular distribution was found with a distinct peak in the forward direction in all the cases of our experiments. An example of the angular distribution is shown in Fig. 2 for 2 keV D⁻ ions sputtering at an incidence angle α = 80'' in the plane of incidence (ψ = 0''). The heavier component Cu is peaked at larger angle. Comparing the measured angles of preferred ejection obtained in different bombarding conditions, one can find that the angle of preferred emission is more away from the surface normal for the heavier component, for the incidence angle being closer to the surface normal and for the lower incidence energy. It is also found that the lower the ion energy, the larger is the separation of the distributions for two components. Scaled with $\gamma E/U$, two curves for ψ = 0'' are drawn in Fig.3 according to Eqs. (1) and (2), and fitted by the experimental results β_{max} and the corresponding parameters E, α and γ. The surface binding energies of 2.3 eV for the component Li and 3.0 eV for the component Cu are derived by the fitting.

IV. DISCUSSION

The analytical theory has been also compared to the evaluated parameter $\gamma E/U$ with the different surface binding energies taken from different binding models[4], some simple assumptions [5] and literature data[10]. It can be seen from the comparing that with the surface binding model of Ref.[3] the results seem to be in the best agreement with calculated curves. For a multicomponent system the surface binding energy of the component i can be defined by a pair−binding model[4] as follows:

$$U_i = \Sigma_j C_j U_{ij} \qquad (3)$$

Where C_j is the surface partial concentration of component j. U_{ij} is the surface binding energy for i atom ejected from the pure material j and with the assumption:

$$U_{ij} = (U_{ii} + U_{jj}) / 2 \qquad (4)$$

The pair−binding model has been shown in Fig.4 for a binary alloy, copper lithium system. It can be seen that the surface binding energies derived from our experiment are in agreement with the model within the accuracy of the experimental data.

In the model the surface binding energy for each component is dependent on the partial concentrations on the surface. For the copper lithium alloy with 16.9 at % Li, the Li concentration has been found about 50% on the first surface layer because of the pronounced surface segregation of lithium[11] Under ion bombardment the surface concentration changes due to balance between sputtering and segregation process, and finally reaches the bulk composition. In our work the dominating sputtering events occur under steady state conditions due to the high fluence bombardment (over 10^{18}D⁻/cm²). The surface binding energy derived by angular distributions of sputtered atoms, naturally, should be corresponding to the condition of the bulk composition. The deviation caused by the compositional changes during the initial sputtering also

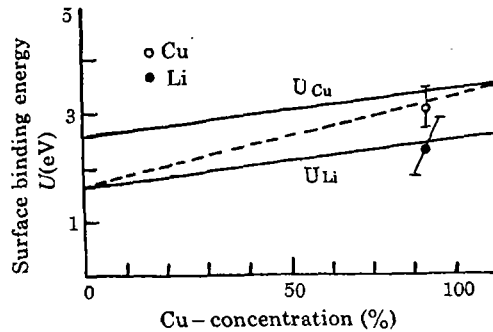remains in the error bars shown in Fig. 4.

Fig.4 Surface binding energy for copper– lithium alloy

Solid lines: based on a pair – binding model from Ref.[3]

dotted line: based on a binding model from Ref.[4]

circle symbols: experimental data

V. CONCLUSION

The angular distributions of sputtered atoms from a copper lithium alloy appeal to be quite different for two components and sharply peaked in the forward direction at grazing incidence using light ions D^+ with different low energies. The sputtering resulting a peaked distribution occurs due to the direct knock – on collision of incidence ions with surface atoms. With an assumption of the planar binding model the surface binding energies for each component of a binary alloy can be determined by the measurements of angular distributions.

The experimental results are in good agreement with a pair – binding model, and the surface binding energies, 2.3 eV for Li component and 3.0 eV for Cu component are determined under the condition of the bulk concentration.

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