Dynamical Clean Surface Prepared by
Continuous Evaporation

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Atomically clean surface of lead is prepared by continuous evaporation of pure lead metal during measurment. The cleanliness of this dynamical surface has been investigated by measuring the mean charge of backscattered He ions. Theoretical mean charges calculated on the model of mixed gas of evaporated lead atoms and adsorbed contaminating atoms agree fairly well with the experimental data.

1. INTRODUCTION

In order to investigate the charge changing processes of fast projectiles passing through solid media, it is necessary to use solid targets with atomically clean surfaces. So called "practical surfaces", which have only been treated by mechanical and chemical cleanings, give the same charge changing data, irrespective of the kind of solid material.[1,2] There are three kinds of methods which can provide atomically clean surfaces; raising temperature of solid target,[3,4] evaporating pure material onto target surface[1,5,6] and bombarding target surface by heavy ions.[7] Although atomically clean surfaces can be provided by these methods, surrounding gas molecules begin to be adsorbed on the clean surfaces as soon as these treatments are stopped. In order to prevent the accumulation of surace contamination for about 1 hour, which may be the order of typical experimental time, the surrounding gas pressure must be kept as low as the order of 10^{-10} Torr.

For not so low gas pressure the adsorbed contaminating molecules must be "berry in" with continuously evaporated pure material in order to obtain clean surfaces. This dynamically prepared clean surfaces are useful, for example, for backscattering measurment of charge state distributions (CSD) of fast ions. With this method we have measured some CSD of fast He ions for various materials.[8] In the present paper, measurement of cleanliness of continuously evaporated surfaces are reported.

2. EXPERIMENTAL

The CSD of He ions backscattered from solid are measured with the combination of an analysing magnet and a position sensitive detector (PSD).[9] In Fig. 1 is illustrated the arrangement in the target chamber. A ceramic evaporator ($30\phi \times 50$) with tungsten winding are placed in front of the target. The evaporation rate is controlled by adjusting

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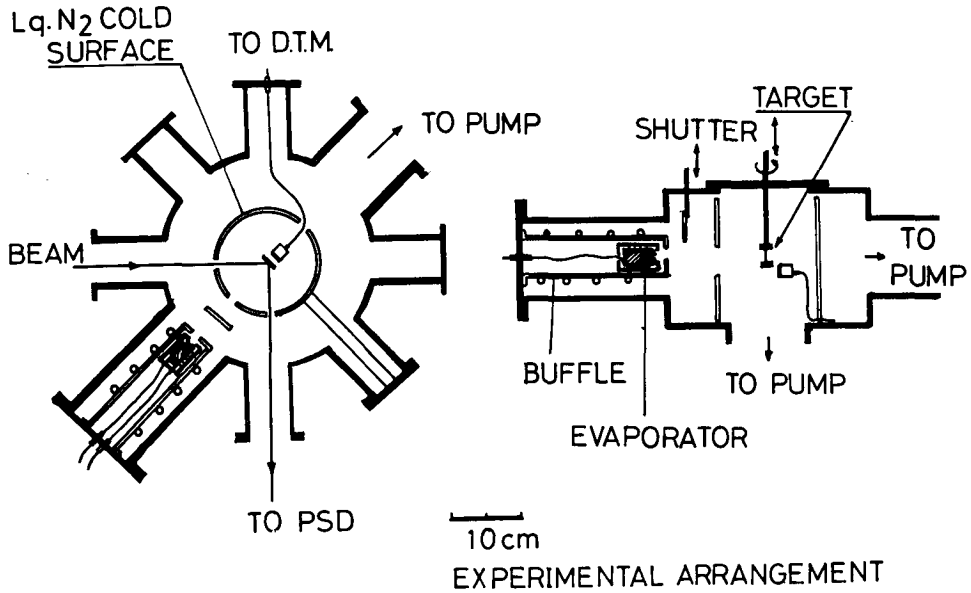
Fig. 1. Experimental arrangement.

the heater current, and the temperature of the evaporator is monitored by a thermo-couple. The evaporator is surrounded by a cylindrical ceramic tube which is supported inside the water cooled cupper buffle, which protects the system from heat radiation. An evaporation rate is measured by a quartz oscillating microbalance (D. T. M.-200; Sloan). The sensor head of D. T. M. is placed near the target and directed to the evaporator. The linearity of growth of evaporated layer which assures the constant evaporation rate is checked by the recorder connected with D. T. M..

For practical convenience, the measure of evaporation rate α is defined as follows,

$$\alpha = (M_t/m_t)/N_{res} , \qquad (1)$$

where M_t is increase in target mass duing evaporation per unit time per unit area, m_t is atomic mass of evaporated material and N_{res} is number of gas molecules which collide on the target surface per unit time per unit area. The quantity M_t is written as the sum of evaporated atoms and contaminating ones,

$$M_t = n_t m_t + n_c m_c , \qquad (2)$$

where n_t and n_c are number of sticked atoms of evaporated material and of contaminating one, respectively, and m_c is atomic mass of contaminating material. The number n_c is the product of sticking probability, s, and number of contaminating atoms, N_{con}, colliding on the target surface per unit time per unit area,

$$n_c = s N_{con} . \qquad (3)$$

When the amount of contamination is negligibly small compared with that of evaporated material, the numerator of Eq. (1) represents the number of target atoms evaporated

onto the surface.

For calculating CSD of ions passing through the evaporated layer, the following quantity γ is necessary,

$$\gamma = n_t / n_c . \tag{4}$$

From Eqs. (1)–(4), we have the relation between α and γ,

$$\gamma = (\alpha/s) (N_{res} / N_{con}) - (m_c/m_t) . \tag{5}$$

In the present case, target is lead and contaminating substance is something like carbon or oxygen, m_c/m_t in this equation can be neglected so that γ is proportional to α/s. The sticking probability s depends on the surface condition, that is, s is a function of α. When α is sufficiently large, surface is considered to be clean. For clean surface the sticking probability s was found to be unity.[8] Therefore, for large α the relation of γ and α become linear.

The evaporation rate α is changed over wide range, $10^{-5} - 10^{1}$, in the present experiment.

3. THEORETICAL

The charge state fractions ϕ_i are determined by the following differential equations,

$$d\phi_i/dx = \sum_{j \neq i} \phi_j (n^t \sigma^t_{ji} + n^c \sigma^c_{ji}) - \sum_{j \neq i} \phi_i (n^t \sigma^t_{ij} + n^c \sigma^c_{ij}) , \tag{6}$$

where σ_{ij} is the cross section of charge changing from charge state, i to j and upper suffices t and c denote the target and the contamination, respectively. The equilibrium CSD, F_i, are derived by solving equations $d\phi_i/dx = 0$. For MeV He ions the neutral fraction is negligibly small (less than 5%), so that it is sufficient to take into account only two charge states ($i = 1, 2$). In this case, the equilibrium CSD and equilibrium mean charge $\bar{q}$ are written as follows,

$$F_i(\gamma) = (1 + \gamma K)^{-1} (F^c_i + \gamma K F^t_i) , \tag{7}$$

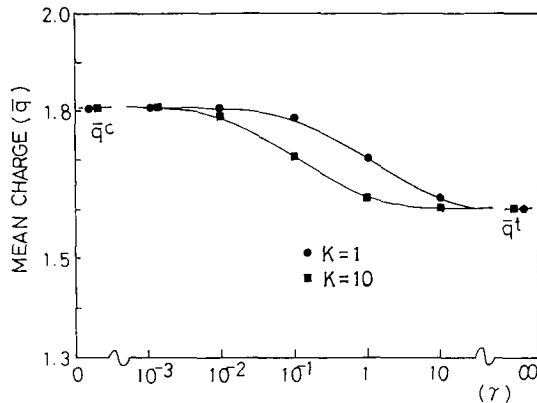$$\bar{q}(\gamma) = (1 + \gamma K)^{-1} (\bar{q}^c + \gamma K \bar{q}^t) , \tag{8}$$

Fig. 2. Calculated mean charges of 1 Mev He ions as a function of parameter γ.

where upper suffices t and c denote the target and contamination, respectively. The quantity K in these equations is defined as

$$K = (\sigma_{12}^t + \sigma_{21}^t) / (\sigma_{12}^c + \sigma_{21}^c) \ . \tag{9}$$

In Fig. 2, the calculated mean charges $\bar{q}(\gamma)$ of 1 MeV He ions are shown as a function of γ. For MeV He ions the dominant terms in K are loss cross sections, so that the value of K is considered to be 1-10.

4. RESULTS AND DISCUSSION

Experimental mean charges of 1.0 MeV He ions for lead target are shown in Fig. 3 as a function of parameter α. Three independent measurements have been made to check the reproducibility. The data with open and full circles have been taken with the experimental arrangement described in section 2. The difference of these two data is due to the experimental error in determining α. The data with open triangles have been obtained with different arrangement, in which the evaporator is set just below the target. The mean charges for "practical surface" and for clean surface are reproduced very well by these measurements within the experimental errors. The feature of change of mean charge with parameter α is similar to that with parameter γ as mentioned in sectoin 2. These data support the mixed gas model for describing the CSD of MeV He ions in the solid media.

Mean charges are calculated for two kinds of contaminations, carbon and oxygen atoms. The number of contaminating atoms is estimated by using the partial pressure data of Caswell[10] under the assumption that the molecules which contain the contaminating atom are decomposed on the surface. The sticking probability for these atom is assumed to be unity for clean surface. By using experimental cross sections of 1 MeV He ions for C, O and Pb atoms,[11,12,13] the values of K for carbon and oxygen contaminations are evaluated to be 15 and 8, respectively. In Fig. 3 are also shown these calculated mean charges. A solid line and a dashed line denote the mean charges for oxygen and carbon contaminations, respectively. By comparing these lines to experimental points, it is suggested that contamination atom is possibly oxygen.
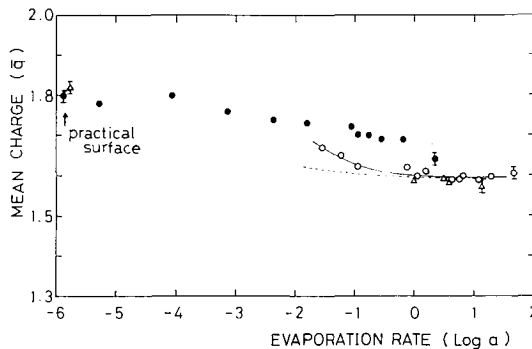

Fig. 3 Mean charges of 1 MeV He ions emerged from lead surface.

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In summary, the present work shows that atomically clean surface can be prepared by continuous evaporation method without using extremely good vacuum. The CSD of fast ions emerging from solid is found to be useful for measuring the cleanliness of the surface.

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REFERENCES

(1) J. A. Phillips, *Phys. Rev.* **97**, 404 (1955).
(2) Y. Kido, M. Asari, A. Nakata and F. Fukuzawa, *Nucl. Instrum. & Method*, **143**, 601 (1977).
(3) R. Behrisch, W. Eckstein, P. Meischner, B. M. U. Scherzer and H. Verbeek, "Atomic Collision in Solid, vol.1," New York, Plenum Press, 1975, p315.
(4) Y. Kido, Y. Kanamori, and F. Fukuzawa, *Nucl. Instrum. & Method*, **164**, 565 (1979).
(5) K. H. Berkner, I. Bornstein, R. V. Pyle and J. W. Stearns, *Phys. Rev. A.* **6**, 278 (1972).
(6) W. Eckstein and F. E. P. Matschke, *Phys. Rev. B.* **14**, 3231 (1976).
(7) H. D. Hagstrum and C. D. Amico, *J. App. Phys.* **31**, 715 (1960).
(8) Y. Haruyama, Y. Kanamori, T. Kido and F. Fukuzawa, *J. Phys. B*, **15**, 779 (1982)
(9) F. Fukuzawa, *Phys. Lett.* **43A**, 147 (1973).
(10) H. J. Caswell, *IBM J. Res. Dev.* **4**, 130 (1960).
(11) Y. Kanamori, Y. Haruyama, T. Kido, A. Itoh and F. Fukuzawa, to be published.
(12) A. Itoh, M. Asari, and F. Fukuzawa, *J. Phys. Soc. Japan*, **48**, 943 (1980a).
(13) A. Itoh, K. Ohnishi, and F. Fukuzawa, *J. Phys. Soc. Japan*, **49**, 1513 (1980b).