Penetration of Electrons in Aluminum Oxide Films

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The practical range of low-energy electrons in thin Al_2O_3 films has been measured. Films ranging in thickness from 85 to 5000 A were investigated. Results are in close agreement with the predictions of Bethe and the results obtained by Hoffman for 1000–3000 A Al_2O_3 films. The practical range-energy relation obtained was found to be $R=0.0115E^{1.35}$, where R is expressed in mg/cm² and E in kev.

INTRODUCTION

A KNOWLEDGE of the penetration depth of low-energy electrons is basic in understanding processes occurring due to the interaction of these electrons with solids. Little information is available on the transmission of low-energy electrons in solids.[1–4] Measurement of the electron range is made difficult because of the necessity of preparing and handling extremely thin uniform layers of the solid. Recent reports[5–8] indicate that uniform aluminum-oxide films can be prepared by anodizing aluminum foil and then etching away the aluminum. It was found to be possible to prepare and mount on sample holders Al_2O_3 films ranging in thickness from 85 to 5000 A.

EXPERIMENTAL PROCEDURE

It has been shown that the Al_2O_3 film thickness is almost proportional to the anodizing voltage.[5–7] The findings here are in general agreement with other observers and are shown in Fig. 1. These results were obtained by weighing large area samples on a microbalance.

The Al_2O_3 films were mounted on washer-type sample holders having an inside diameter of 0.25 in. These samples were mounted in the experimental tube as shown in Fig. 2. The tube was continuously pumped on a Hg diffusion pump system and could be baked to 450°C before making measurements. During measurements the pressure in the tube was about 10^{-8} mm of Hg. The electron beam was deflected magnetically onto the sample or into the auxiliary Faraday cage for measurement of the primary beam current. The Faraday cage shield was kept 45 volts negative with respect to sample and cage in order to reduce effects due to secondary emission. A beam current of about 10^{-9} ampere was used.

Since Al_2O_3 has a high resistivity, charging of the sample could occur.[2,8] However, it was found that the secondary emission ratio was above unity up to approximately 12 kev, therefore the sample should remain at sample holder potential by secondary emission. Also, it was found that transmission results were the same if the beam current was increased or decreased by a factor of 100, thereby indicating the absence of charging.

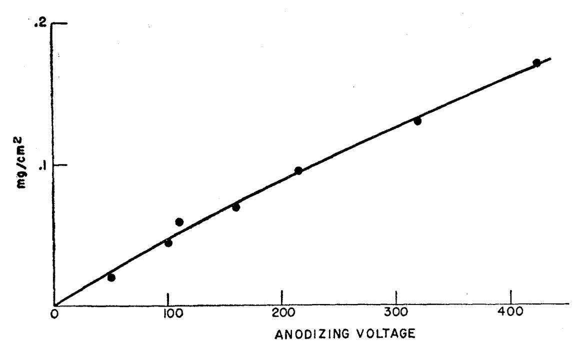

FIG. 1. Aluminum oxide thickness *vs* anodizing voltage.

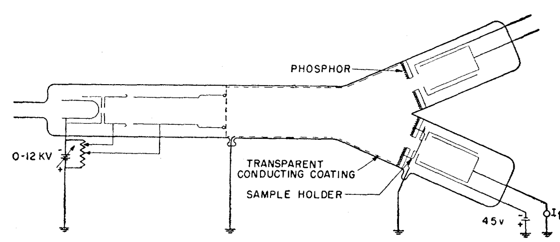

FIG. 2. Experimental tube.

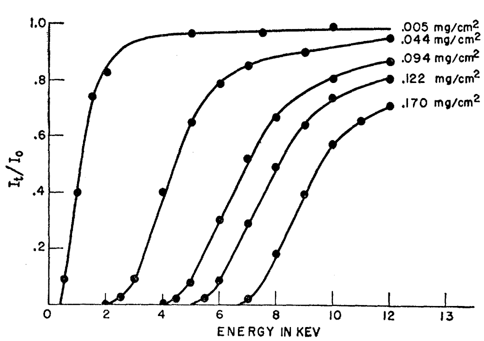

FIG. 3. Electron transmission curves for five different Al_2O_3 samples.

[1] M. Davis, Phys. Rev. **94**, 243 (1954).
[2] R. O. Lane and D. I. Zaffarano, Phys. Rev. **94**, 960 (1954).
[3] M. Davis, Nature **175**, 427 (1955).
[4] J. R. Young, J. Appl. Phys. **27**, 1 (1956).
[5] L. Harris, J. Opt. Soc. Am. **45**, 27 (1955).
[6] G. Hass, J. Opt. Soc. Am. **39**, 532 (1949).
[7] W. Walkenhorst, Naturwissenschaften **34**, 373 (1947).
[8] O. Hoffman, Z. Physik **143**, 147 (1955).

RESULTS AND DISCUSSION

The fraction of electrons transmitted through five of the samples for different energy electrons is shown in Fig. 3. These results are similar to those obtained by other observers. The almost linear steep slope region of these curves was extrapolated into the abscissa and this intercept taken as the practical range of the electrons.

The range-energy results obtained are given in Table I and plotted in Fig. 4, solid points. The open circle points are the results obtained by Hoffman for Al_2O_3.[8] The curve in Fig. 4 was obtained from graphical integration of Bethe's expression[9] in the manner described by Lane and Zaffarano.[2] The dE/dx values for aluminum, $I=150$ ev, and oxygen, $I=92$ ev, were calculated separately to obtain the total dE/dx rather than using the averaging procedure described by Lane and Zaffarano.[2] The range-energy results are described quite accurately by $R=0.0115E^{1.35}$, where R is expressed in mg/cm² and E in kev. It was not expected that integration of Bethe's expression would fit the experimental results so well at these low energies. However, it has been pointed out by others[10,11] that the Bethe expression should still be fairly accurate at lower energies.

TABLE I. Energy-range results.

Energy kev	Range mg/cm² Al_2O_3
0.30	0.003
0.45	0.005
0.90	0.010
1.45	0.018
1.85	0.022
2.75	0.044
3.80	0.067
4.65	0.094
5.00	0.091
5.30	0.113
5.80	0.122
5.75	0.129
7.25	0.170

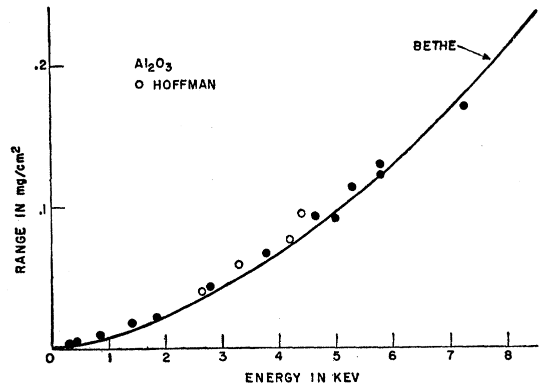

FIG. 4. Range-energy results for Al_2O_3, curve calculated from Bethe's expression.

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[9] H. A. Bethe, *Handbuch der Physik* (Verlag Julius Springer, Berlin, 1933), Vol. 24, p. 521.

[10] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 263 (1937).

[11] M. F. Mott, Proc. Cambridge Phil. Soc. **27**, 553 (1931).