THE SPATIAL DISTRIBUTION OF SECONDARY ELECTRON EMISSION

by

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ABSTRACT

A method is described for experimentally determining the distribution of scattered electrons on the surface of a target irradiated with a fine electron beam. Since the scattered electrons are detected by the conductivity they induce in a thin insulating film, the result gives a more accurate measure of energy dissipation and, hence, secondary electron emission, rather than the scattered electrons. Results have so far been obtained for a silicon target and with beam energies of 15 and 25 kV; the radii of the areas measured came to only one third of the effective range* in each case.

* J. E. Holliday and E. J. Sternglass, J. Appl. Phys., 30, p. 1428 (1959).

INTRODUCTION

In scanning electron microscopy, a picture of the specimen surface is built up by scanning the surface with a fine electron beam and using the signal derived from the emitted electrons to build up an image in a cathode ray tube. The resolution obtained depends not only on the size of the primary beam, but also on the size of the area of emitted electrons. The emitted electrons fall roughly into two classes: the reflected, or backscattered, electrons with energies comparable with the primary beam energy (generally about 15 kV), and the secondary electrons with typical energies of a few electron volts. Either or both of these classes of electrons may be used to form the image. Although some idea of the area of emitted electrons could be obtained by examining micrographs of familiar specimens, the difficulty of preparing an ideal specimen and examining it under completely understood contrast conditions made quantitative measurements difficult.

A method of directly determining the area of emission of backscattered electrons was described by Pease[1] who used this area as a source for a reflection-point projection system. The results were chiefly of interest for scanning electron microscopy using backscattered electron collection.

For high resolution work, however, it is the area of (low voltage) secondary electron emission which is the more important in determining the limitation to microscope performance.[2]

This paper describes a method of determining this area.

EXPERIMENTAL METHOD

The principle of the method is shown in Fig. 1. As the electron beam is moved from left to right, scattered electrons emerging through the thin insulating layer underneath the top electrode create

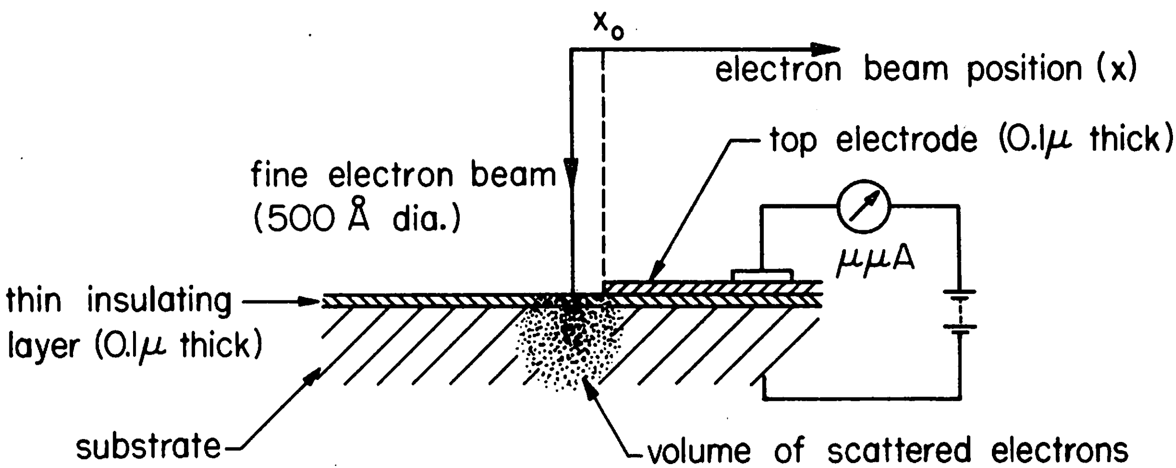

Fig. 1. Schematic view of experimental arrangement.

hole electron pairs in the insulator and cause a current to flow which is recorded in the meter. This effect is frequently known as electron beam induced conductivity and has been described by Pensak,[3] Ansbacher and Ehrenberg,[4] and others. The induced current, I_D, will continue to rise as the area of scattered electrons is moved across the electrode edge (position x_0) until this area is entirely to the right of x_0. Thus, by measuring the distance travelled by the beam to raise I_D to its maximum value, it is possible to obtain an estimate of the area of scattered electrons. This estimate will be in error due to the fact that the lower energy electrons are the more productive of induced current but, since this is also the case for secondary emission yield, the area measured should give a measure of the secondary electron emission. To check this, it was confirmed experimentally that the ratio of secondary electron current to I_D was constant over the range of primary beam energies used.

Experiments so far have been confined to heavily doped silicon substrates with a thermally grown SiO_2 insulating layer 0.10 or 0.15 μm thick. The top electrodes were evaporated aluminum about 0.1 μm thick. By making the top electrode sufficiently small (17 μm x 0.010 in.) it was found that the leakage current could be reduced to a value negligible compared with I_D.

The target assembly was viewed in the scanning electron microscope and a suitably sharp and straight portion of the aluminum electrode edge was selected. The scan generators were then switched off and the beam moved slowly across the edge; the distance moved was known from the magnification calibration of the microscope.

Initial experiments gave inclusive results for two reasons:

1. I_D decreased with time, due possibly to trapped carriers setting up an opposing field;[5]
2. I_D varied with primary current density; it was even found possible to focus the primary electron beam by adjusting the final lens current for minimum I_D.

The first drawback was overcome by adjusting the bias across the insulator so that I_D remained constant; a value of 28 volts across 1500 Å SiO_2, or 22.5 volts across 1000 Å SiO_2, was generally found to be suitable, irrespective of polarity.

The second difficulty was avoided by using beam current of 10^{-11} amps or less. It was then checked experimentally that the induced current was proportional to the primary current and was independent of the primary current density.

EXPERIMENTAL RESULTS

Some results taken from a specimen with a layer of SiO_2 0.1 μm thick and an Al electrode about 0.1 μm thick are shown in Fig. 2. To get sufficient signal, it was found necessary to tilt the specimen by 45°; this is the usual configuration for scanning electron microscopy, but most scanning X-ray microanalyses use a beam that is normal to the surface.

Figure 2(a) shows the results for a primary beam voltage of 25 kV and these can be compared with the results shown in Fig. 2(b) for the same specimen region but with a beam of 15 kV.

It was observed that the values of I_D were more repeatable when the beam struck regions not covered with the top electrode; this may have been due to uneveness in the Al film, but, as a result, values of I_D for beam positions to the left of the electrode edge (i.e., $x < x_0$) were regarded as more significant. It can be seen that I_D has a measurable value for beam positions further from x_0 when $V = 25$ kV than when $V = 15$ kV. For $V = 15$ kV, $I_D = 0.1$ of its value at $x = x_0$ when $x_0 - x = 1.1\ \mu m \pm 0.3\ \mu m$. For $V = 25$ kV, the comparable value of $x_0 - x$ is $2.3\ \mu m \pm 0.3\ \mu m$. Results shown in Fig. 2 are for the most satisfactory specimen, i.e., that with the thinnest SiO_2 and Al layers and with the straightest and sharpest edges, but experiments on six other specimens all gave results which agreed with the above values within the stated accuracy of the experiment, Moreover,

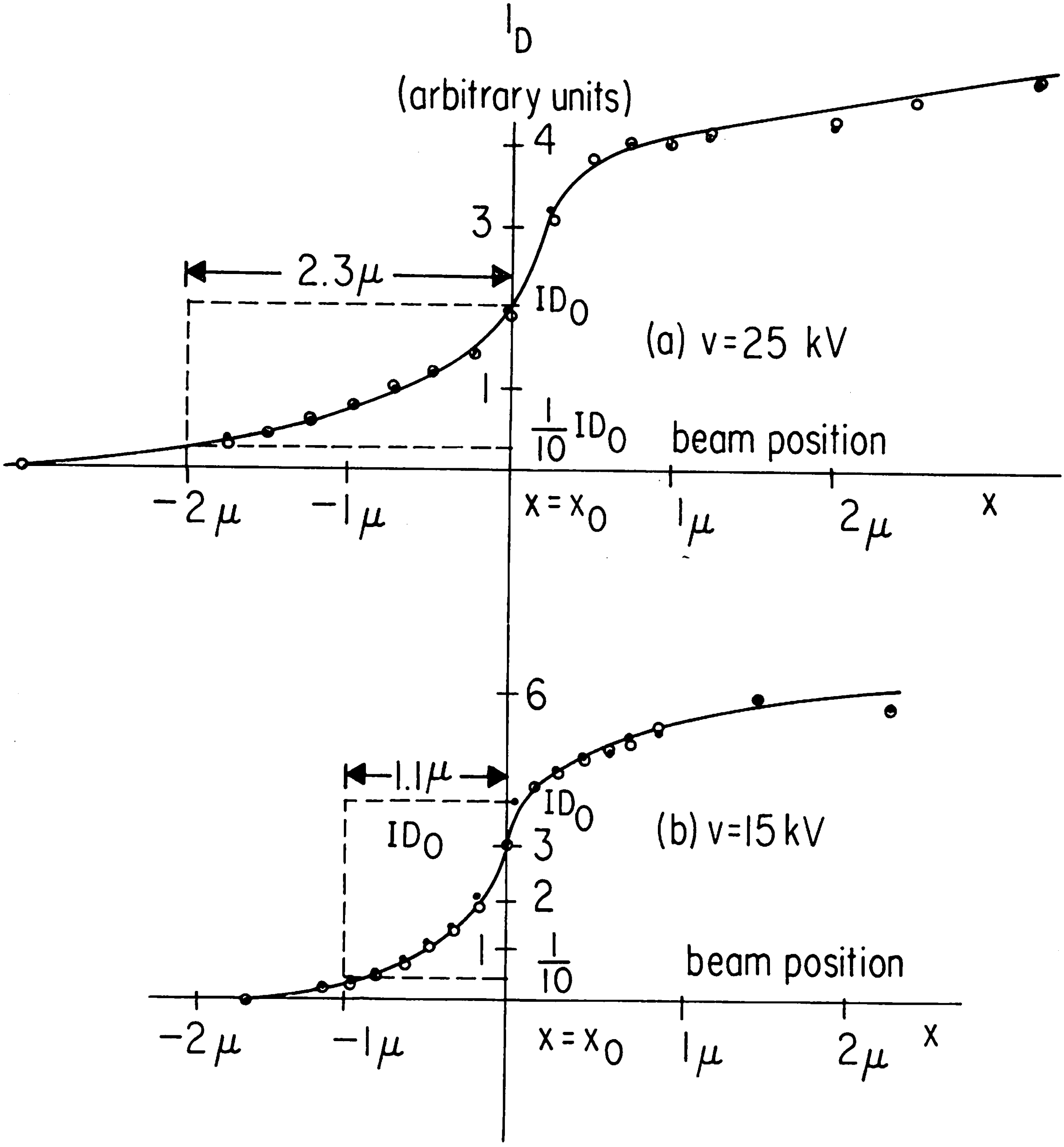

Fig. 2 Measurements of I_D as a function of beam position.

reversing the polarity of the bias, apart from reversing the direction of I_D, made no appreciable difference to the results obtained.

These results suggest that the area of emission of secondary electrons is considerably larger than the corresponding area of back-scattered electron emission.[1] It is also interesting to note that in each case the radius of the emission area is about one third of the effective range of the electron as given by Holliday and Sternglass.[6]

The sources of error in measuring the beam travel are the finite size of the electron beam (0.05 μm dia.), the wobble of the electron beam due to 60 c.p.s. magnetic fields (0.1 μm peak to peak for $V = 15$ kV) and the uncertainty in the position of the electrode edge due to its roughness and thickness (0.2 μm). The accuracy of the values of I_D is ± 10 percent as estimated from the repeatability of its readings; errors may also be due to local variations in the thickness and composition of the SiO_2 film and the substrate and also due to the deposition of contamination by the electron beam.

Two possible sources of error are:

1. Carriers generated away from the electrode diffusing to the electrode region and contributing towards I_D, and
2. The drift field region extending to the left of the electrode edge and again causing carriers generated to the left of the electrode region to contribute to I_D.

However, had these errors been appreciable, the value of I_D when $x = x_0$ would have been greater than one-half I_D max. In fact, it was observed that the value of I_D for $x = x_0$ was generally slightly less than one-half I_D max.

CONCLUSIONS AND FUTURE WORK

A method of determining the distribution of scattered electrons at the surface of a flat target has been demonstrated. Since the method of detecting the scattered electrons depends on their energy in a manner similar to that of secondary emission, it is felt that the method described gives a more accurate measure of the distribution of secondary electrons. Future work will extend the range of beam energies and target materials. It is also planned that a target be prepared in which the substrate is a thin film (about 0.05 μm thick); experiments on such a target would then give an overall measure of the accuracy of the experiment since backscattering from the substrate would be virtually eliminated.

It should be possible to extend the method described to determine the distribution of scattered electrons at any given depth in the target. This could be done by depositing a further thin layer of insulator on the target assembly surface and then the required depth of substrate material. Hence, it is hoped that a complete picture of the distribution of scattered electrons in the target can be built up.

ACKNOWLEDGMENTS

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