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Sputtering by Ion Bombardment

GOTTFRIED K. WEHNER

Electronic Components Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio

I. INTRODUCTION AND SURVEY

Among the many phenomena which arise when ions strike a solid surface, the disintegration of the material, known as sputtering, is probably one of the least understood. The main reason for this is the lack of reliable quantitative yield data. Experiments and their interpretation are complicated because many gas discharge and solid state parameters are involved, and because sputtering is a very inefficient process. Aside from this, the sputtered atoms leave the surface uncharged, eliminating the possibility for their electrical detection directly. Most of the earlier work was done in the glow discharge, which operates only at relatively high gas pressures. Here complications arise due to the large energy spread, the undetermined angle of incidence of the bombarding ions, and the problems connected with the diffusion of the sputtered material back to the target.

Reliable basic information on sputtering by positive ions is now being collected by either using ion beams or by immersing the target as a separate electrode into a rare gas plasma with low gas pressure. The phenomenon of surface ionization and the measurement of the change of the electronic work function of a collector for sputtered material, have been used as sensitive methods for measuring sputtered amounts. Reliable measurements, especially at low ion energies, require that sputtering must compete with the formation of surface layers (oxides, etc.). This requires either extremely pure discharge conditions or a high density of the bombarding ion current. The advantage of the latter is that large amounts of material are sputtered in a reasonable time, even at low ion energies.

Most experimental results have to be reviewed in the light of the discovery that the angle of incidence is an important and heretofore neglected parameter in sputtering. With a definite angle of incidence, it was found that a definite threshold energy is necessary for sputtering to set in, and is characteristic for every ion-metal combination. These thresholds are linked to the elastic constants of the target material (sound velocity) and to the heat of sublimation. Other interesting information comes from the study of etch-effects caused by sputtering and the investigation of sputtering from metal monocrystals.

Evidence is now definitely in favor of a momentum exchange process, and—at least at low ion energies—the "hot spot" evaporation theory must be abandoned. In recognition of the complexity of such a process, interesting studies have been made with a steel ball model.

The motivation for a better understanding of sputtering stems not only from physical interest; its practical aspects are also of considerable importance. In many gas discharge applications, sputtering is an undesired effect, as it accounts for the formation of deposits which cause poisoning of an oxide cathode or difficulties with insulation, field deformation, changes in light absorption, or secondary electron emission. The disintegration of the active layer of a thermionic cathode or of other electrodes may limit the useful life of such tubes. Etch-effects, gettering, removal of surface layers, preparation of thin layers of materials which are otherwise difficult to evaporate or to deposit, and certain crystal growth possibilities provide a wide field of useful applications.

Earlier results will be summarized and reviewed in the light of new knowledge as is necessary. This should be of benefit to those not closely engaged in our field, which promises to become of increasing interest in solid state and surface studies. The author hopes, thereby, to close a gap which lately developed in the literature. Reference may be made to articles of Mierdel (*1*) and Compton and Langmuir (*2*). Fruth (*3*) lists 113 references for the years 1852 to 1930. The most recent, but rather sketchy and sometimes not accurate survey of the subject is to be found in "Electronic and Ionic Impact Phenomena" by Massey and Burhop (*4*). Glockler and Lind (*5*) emphasize the electrochemical aspects of the problem.

The "Chemical Abstracts" and "Vacuum" list Cathode Sputtering in their subject index. Although much progress has been made in that the gas discharge part of the problem, by becoming fairly well understood, allows emphasis to be shifted more to the solid state problems, the main conclusion here does not differ from that of previous surveys: much more work—especially experimental—will be necessary before it can be said that the phenomenon is fully understood.

II. Measuring Methods

1. General

Information about sputtering depends above all on a reliable measurement of the yield S (number of released atoms per impinging ion) as a function of the parameters involved. Of special interest here is the region of low ion energies (threshold). Early recognized basic parameters are the ion energy, material to be sputtered, its surface condition and temperature, and the nature of the bombarding ions. Fairly new is the discovery that the angle of incidence of the bombarding ions and the orientation of the exposed crystal face are of importance. In the earlier glow-discharge work, these basic parameters were partly obscured by additional ones, such as gas pressure and tube geometry. A correct measurement of the bombarding ion current necessary for absolute yield data requires that allowance be made for the contribution of secondary electrons released by ion bombardment.

The number of sputtered atoms is usually determined by measuring either loss in weight of the target or increase in weight of a collector. The disadvantage of the first method is that initial surface layers, which in some cases are much more resistant to sputtering (most pronounced for oxidized Al, Th, Ta, etc.) and thereby protect the underlying bulk material, cannot be separated. This difficulty can be avoided in the second method by inserting a shutter which is opened under vacuum not before