RFP-1310

November 13, 1969

A CROSSED-FIELD DISCHARGE DEVICE FOR HIGH RATE SPUTTERING

James R. Mullaly

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(29-1)-1106

VACUUM TECHNOLOGY ASSOCIATES
P. O. Box 3276
Boulder, Colorado 80303

November 13, 1969

RFP-1310
UC-38 ENGINEERING AND
EQUIPMENT
TID-4500–54th Ed.

A CROSSED-FIELD DISCHARGE DEVICE FOR HIGH RATE SPUTTERING

James R. Mullaly

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
P. O. BOX 888
GOLDEN, COLORADO 80401

Prepared under Contract AT(29-1)-1106
for the
Albuquerque Operations Office
U. S. Atomic Energy Commission

CONTENTS

A CROSSED-FIELD DISCHARGE DEVICE FOR HIGH RATE SPUTTERING

James R. Mullaly

Abstract. Described is a high rate sputtering device which utilizes a hemispherical concave cathode (target) and a crossed-field region created by superimposing a cusp magnetic field on the electric field of the cathode. Metal has been sputtered from the cathode at rates up to 2.2 mils per hour for copper under these conditions. Parameters affecting the discharge, and the deposit profiles and rates are discussed.

INTRODUCTION

For many years, it has been known that current in a gas discharge can be increased greatly by applying the proper magnetic field to the discharge. The increased current is due primarily to the increased number of ions produced by electrons forced to take longer paths to reach the anode or chamber walls of the system. The increased path length is caused by a force exerted on the electrons. Identified as the Lorentz Force ($\underline{F}$), the equation is:

$$\underline{F} = -e(\underline{E} + \underline{V} \times \underline{B})$$

e = charge on electron
$\underline{V}$ = electron velocity vector
$\underline{E}$ = electric field vector
$\underline{B}$ = magnetic flux density vector

The increased number of ions are accelerated by the electric field to the discharge cathode (target), which is sputtered at a more rapid rate than the cathode of a diode discharge.

Not only can the deposition rate be increased by the use of a magnetic field, but deposition can be done at a lower pressure. Usually deposits produced at lower pressures are of better quality than the deposits formed at the higher pressures using diode-sputtering devices.

Despite the relative simplicity of crossed-field sputtering devices, only a few working devices have been described in the literature. The patent of Penning (1)[1] issued thirty years ago showed three configurations which were claimed as useful for coating. The Penning cells were small and not particularly suited for coating compared to current technology. One cell however [Figure 1 (a)][2] has had much use in ion-vacuum pumps. The cell noted in Figure 1 (b) is now called a magnetron. The magnetron has been used recently by Wasa and Hayakawa (2) for deposition in magnetic fields (flux density) up to 13,500 gauss. A large inverted magnetron a magnetron with polarities reversed—has been described by Gill and Kay (3). A quadrupole-field, flat-plate device has been described by Kay (4), see Figure 1 (c).

[1]Numerals in parentheses relate to references at end of text.
[2]Illustrations appear at end of report, Page 5.

DISCUSSION

Discharge Geometry and Operation: The apparatus associated with the crossed-field device is shown schematically in Figure 2. It consists essentially of a spherically concave cathode (target), a substrate holder, and coils for the magnetic field. The target is not restricted to spherical shape. If the substrate holder is not at ground potential, an anode such as the ring shown in Figure 2 will be needed.

Exact details of the physics of the cathode discharge are not known. Particularly, no exact information on the electric field in this device has been available. Nor are data about the magnetic field known precisely when the device operates at high currents. Such limited knowledge is typical of what exists about any discharge. Although Penning cells have been studied for over 30 years and offer some clues, many questions still remain unanswered.

Nevertheless, a simple useful model of this discharge can be formulated. The electric field in a glow discharge with a spherically concave cathode has been discussed by Thomson (5). The conclusion drawn about the electric field lines can be visualized as noted in Figure 3; i.e., the electric field lines pass between the cathode wall and the center of radius. The field lines focus somewhere outside the cathode. The focusing can be visually seen with a spherically concave cathode in an abnormal glow discharge.

The magnetic field for this device is produced by passing current in opposite directions through each coil. The magnetic field lines (solid) are noted in Figure 3. This magnetic field is called a quadrupole field by Kay (4) and a single-cusp magnetic mirror by plasma physicists (6). This field was used 30 years ago in connection with glow discharge studies (7). The magnetic flux density was usually 200 gauss or less for experiments with this device. Coil and field details are given in the last section of the report.