Technical Paper

Method to Design Magnetrons that Match Preferred Erosion Patterns

April 2005

*Richard Stelter, Mike Schilling, Aron Welk,
Christopher Padua, Chun Li and Michael Devine*

Abstract

A new method for analyzing the erosion profiles produced by rotating magnetrons is presented. The average tangential flux is calculated in rings concentric with the rotation axis and plotted versus distance from the rotation axis. Erosion will begin at regions with highest tangential flux. The method is particularly applicable to ferromagnetic targets. Erosion profiles on targets with various magnetron configurations have shown good correlation between modeled and measured data.

Introduction

Despite major advanced in improving the pass-through flux in ferromagnetic targets *(1)*, there is little understanding as to why individual magnet configurations work well as rotating magnetrons. The design of rotating magnetrons has long been considered a "black art", and many functional designs are the result of empirical work *(2)*, with minimal analysis performed in the development stage. There are a number of workable designs available *(3, 4)* based on sweeping the target surface uniformly with the tangential component of flux density, but analytical methods for predicting and processing this data have not been available. In addition, few of existing designs are effective for ferromagnetic targets.

In stationary magnetron configurations, the plasma density is highest where the magnetic field lines are tangent to the target surface *(5, 6, 7)*. Erosion grooves in the target form in these regions. When the magnetron geometry is complex and relative motion is introduced (usually by moving the magnetron), the point at which plasma density is highest sweeps the surface of the target. Control and optimization of plasma density motion profile is key to efficient target utilization, and the magnetic field shape and intensity of the magnetron are key factors in this.

Most coaters sputtering ferrous materials fail to recognize that the target becomes a part of the effective magnetic circuit, and that target dimension, placement, and magnetic properties are important variables. As target erosion progresses, the parameters of the effective magnetic circuit change and magnetic flux is redistributed in the system.

We have developed a method to predict the starting erosion pattern produced by various rotating magnetron configurations. This method applies to both ferromagnetic and non-ferromagnetic target materials.

Distribution of magnetic flux depends on the reluctance in the magnetic components, which is inversely related to magnetic permeability, which varies with the induction level in each finite volume of the target material. As the magnetic path through the target becomes restricted due to erosion, reluctance and flux density rise in that section, and permeability changes. Common PTF (pass through flux) values obtained per ASTM 1761 are single point reference measurements for samples of comparable thickness, but they are of no value in magnetic circuit calculations. To effectively design the magnetic circuit, the B vs. H curve for all ferrous components must be entered as an input variable.

The industry tends to promote black magic by developing empirical coating compositions using proprietary target materials. Secrecy regarding the composition of the magnetic material can be maintained so long as a ring sample of the material can be measured for its magnetic B vs. H characteristics and associated with a non-significant label.

 | ISSN 0737-5921
47th Annual Technical Conference Proceedings (April 24-29, 2004) | Dallas, TX USA

Procedure

In a purely cylindrical magnetron, consisting of a magnet disc surrounded by an oppositely magnetized ring, the component of flux to evaluate would be B_r. However, most rotating magnetron designs are non-symmetrical, making the calculations more involved. Often the magnetic field distribution can be calculated in magnetic modeling software to determine the magnetic field components in the XYZ directions. The same information can be had by a magnetic field mapping of an existing magnetron. In these cases, the tangential component of flux can be calculated for a specific XYZ coordinate through equation 1. *(See Equation 1 on this page)*

The method described here involves calculating the average of B_t as a function of radial position, with the axis of rotation as the reference point. The average of the summation of B_t is plotted with respect to radial position. Erosion on the target will start where B_t is highest.

Consider a small segment on a circle with radius of R, the field on this small section is $B(R,\alpha)$. The angular dimension of the small segment is $d\alpha$. For one rotation, the average field on this circle exerted by this segment is: *(See Equation 2 on this page)*

After one revolution, the average field on this circle is the average field of all the segments and can be expressed as: *(See Equation 3 on this page)*

The B field is very complex, usually difficult to calculate analytically. Numerical methods must usually be used.

Suppose there are N points around the circle with radius R, then: *(See Equation 4 on this page)*

A schematic showing the principles involved are shown in Figures 1 and 2. *(See Figure 1 & 2 on page 3)*

Results and Discussion

Prototypes validating the methodology have been manufactured and tested. The magnetrons were developed to run in an Intevac MDP-250. The target material used here was 410 stainless steel, 6" diameter and .125 thick. The distance from target face to magnetron face was 0.7". (The magnetron tested was designed for a .250 thick CoFeB target with less magnetron to target spacing.)

Sputtering was done for 25 kW-hrs, except in the case of Prototype #1, where severe redeposition at the center required early shutdown. *(See Figure 3 on page 3)*

The target sputtered with Prototype magnetron #1 showed a large area in center with no sputtering.

The target sputtered with Prototype magnetron #2 reduced the area of non-erosion at the center and the erosion groove was moved more towards the outer diameter.

The target sputtered with Prototype magnetron #3 displayed full surface erosion, with minimal redeposition and the erosion groove was closer to the outer diameter than in #2. The erosion profile is shown in Figure 4.

Prototype magnetron #4 is currently under construction. The goal is to increase erosion in the center and reduce pinching effect in the erosion groove. *(See Figure 4 on page 3)*

Equation 1

$$Bt = \sqrt{(Bx^2 + By^2)}$$

Equation 2

$$Bi = \frac{B(R,\alpha)\,d\alpha}{2\pi}$$

Equation 3

$$B = \int_0^{2\pi} \frac{B(R,\alpha)}{2\pi}\, d\alpha$$

Equation 4

$$B = \sum_{n=1}^{N} \frac{B(R,\alpha_n)}{2\pi} * \frac{2\pi}{N} = \frac{1}{N} \sum_{n=1}^{N} B(R,\alpha_n)$$

 | ISSN 0737-5921
47th Annual Technical Conference Proceedings (April 24-29, 2004) | Dallas, TX USA

Figure 1 | Circular magnetron with concentric rings

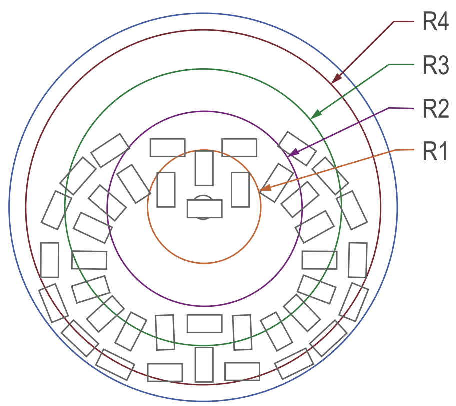


Figure 2 | Tangential flux vs. radial distance

Figure 3 | Erosion profile before and after sputtering

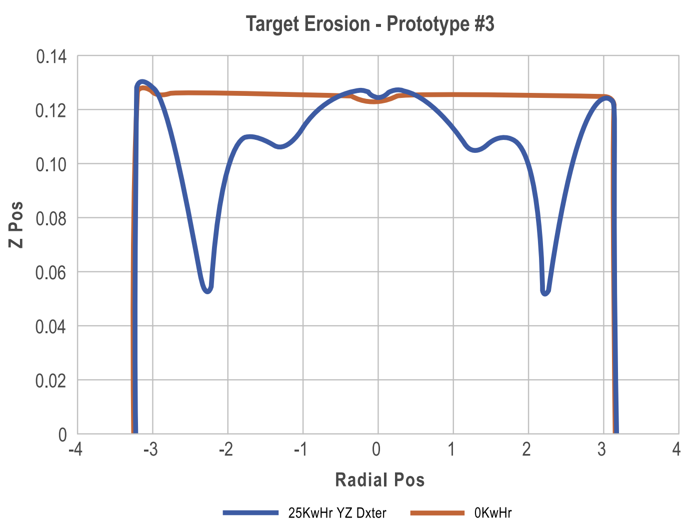
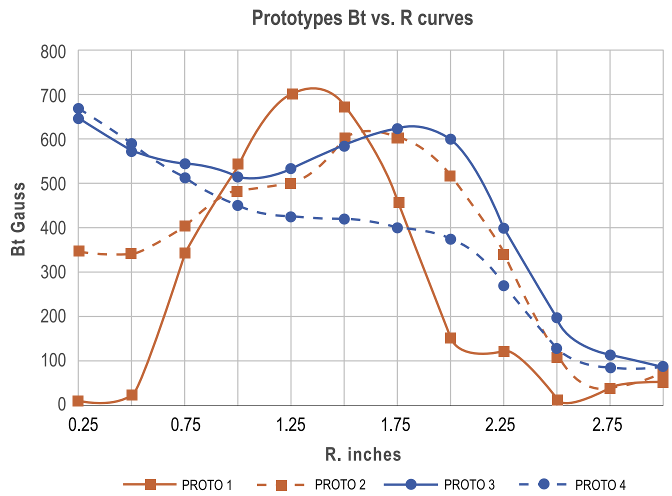


Figure 4 | Tangential flux versus radial distance for various magnetron designs (modeled data)



Conclusions

A new method for evaluating erosion patterns in targets via rotating magnetrons is presented. Good correlation between prediction and performance was found.

References

(1) R.E. Stelter, U.S. Pat. #5,865,970, "Permanent Magnet Structure for use in a Sputtering Magnetron," 1999.

(2) R.J. Kolenkow, C. Armstrong, "The Design of Rotating Magnet Sputter Sources", DataTech, 2, p.101.

(3) R.J. Kolenkow, U.S. Pat. #5,830,327, "Methods and Apparatus for sputtering with Rotating Magnet Sputtering Sources," 1998.

(4) P.H. Ballentine, D. Heimanson and A.T. Stephens II, U.S. Pat. #5,248,402, "Apple-Shaped Magnetron for Sputtering System," 1993.

(5) A.E. Wendt, M.A. Lieberman, H. Meuth, J. Vac. Sci. Technol., A6 3, p.1827, 1988.

(6) J. Goree, T.E. Sheridan, "Magnetic field dependence of sputtering magnetron efficiency," Appl. Phys. Lett., 59(9), p.1052, 1991.

(7) T.E. Sheridan, M.J. Goeckner, J. Goree, "Electron velocity distribution functions in a sputtering magnetron discharge for the ExB direction," J. Vac. Sci. Tech. A 16(4), p. 2173, 1998.

 | ISSN 0737-5921
47th Annual Technical Conference Proceedings (April 24-29, 2004) | Dallas, TX USA

For additional information please contact the nearest Dexter sales office.

North America | 800-345-4082
Europe | +(44) (0)1753-737400
www.dextermag.com | info@dextermag.com

DEXTER
Magnetic Technologies

Printed in the USA