Magnetron Sputtering of Thin Films

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Depositing thin films of high quality rapidly and under precise control is done mainly by a process called *sputtering*. The material to be sputtered is in the form of a thin plate called the *target*. The target is mounted in a chamber filled with argon gas at low pressure (typically 1/100000 of atmospheric pressure) . When the target is connected to negative high voltage, a glowing *plasma* forms just above the target surface, much like the glow in a neon sign. Positive argon ions produced in the plasma by collisions of electrons with argon atoms are accelerated toward the negatively-charged target. When the fast-moving ions collide with the target, free atoms of target material are expelled. The object to be coated (called the *substrate*; examples are silicon wafers or aluminum hard drive disks) is mounted in front of the target, and some of the free atoms land on the substrate, building a thin film.

Modern sputtering equipment uses *magnetron* sources, where an artfully arranged magnetic field strongly confines the plasma electrons to move in tight cycloidal paths. This decreases electron leakage from the plasma, so that each electron produces many ions, making the rate of sputtering practical for production.

Early magnetron sources for disk coating typically used a cylindrical coil to produce the magnetic field. This arrangement is easy to design without much calculation, but the plasma ring it produces erodes the target only in a narrow circular groove. Because the target has to be discarded when the maximum erosion depth approaches the initial target thickness, these early sources wasted target material and forced the customer to shut down the coating equipment for frequent target changes, with costly impact on labor requirements and on production.

The simple ring geometry in a circular magnetron allows little freedom for tailoring performance. For instance, if the substrate is moved closer to the target to increase the deposition rate, the film thickness uniformity becomes worse. Even at the optimum spacing, the uniformity is only about ±5% from practical circular magnetrons.

The *rotating magnet* magnetron source overcomes many of these difficulties. In a rotating magnet source, the confining magnetic field is produced by an array of permanent magnets rotating behind the target; Figure 1 **(ed: slide #12)** shows an experimental array. Because the plasma loop or *track* is typically not a circle, it sweeps across a wide area of the target during rotation. This substantially increases target life.

Intevac Vacuum Systems Division (INTEVAC) has greatly advanced the art of designing rotating magnet sources, for use in their hard disk coating equipment. Source performance (*e.g.*, target utilization and thickness uniformity) is sensitively dependent on the shape of the plasma track produced by the magnet array. **INTEVAC** has developed geometric methods for generating a track shape to optimize performance, given constraints such as substrate diameter and target-to-substrate spacing. This method and one of its physical realizations will be issued to **INTEVAC** as a U. S. patent later in 1998.

INTEVAC has designed a rotating magnet source with numerous customer benefits compared to earlier sources: target life is increased by a factor of 4, uniformity is improved to ±3% or better, and erosion occurs over the entire target surface. (Full surface erosion, as demonstrated by the partially used chromium target in Figure 2 **(ed: slide #11)**, constantly cleans the target surface, lessening arcs and consequent particle generation.) Furthermore, all of these capabilities are achieved at a closer substrate spacing (30 mm compared to 50 mm), so that the rate of deposition is higher. Hundreds of these sources have been shipped to **INTEVAC** customers over the past two years.

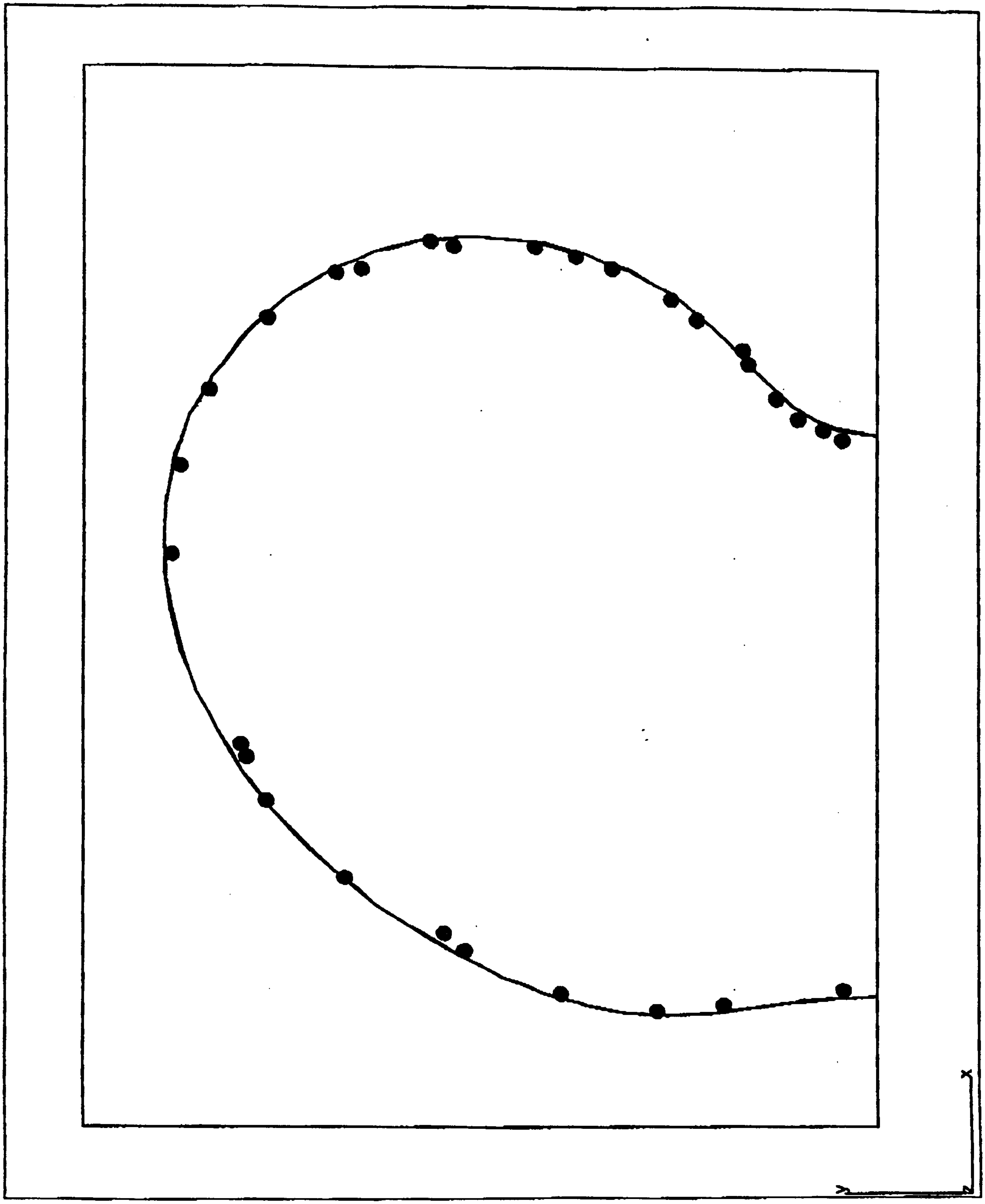
Once the optimal track has been designed, the problem is to design a magnet array that will generate the track. According to the principles of electron confinement, the center of the track follows the locus where the field component perpendicular to the target equals zero ($B_z = 0$).

INTEVAC begins the design by laying out an approximate array. Using **AMPERES** from **Integrated Engineering Software (INTEGRATED)**, the B-H characteristic of the magnets (second quadrant) is entered using the TABLE command. The fields are then calculated at the position of the target surface using **AMPERES**, and the locus $B_z = 0$ is traced out using CONTOURS for B-FIELDz. Comparison with the optimal track suggests how the magnet bars should be moved to give closer agreement. **AMPERES** clearly shows that the locus tends to be pushed out; earlier designers, without **AMPERES**, were puzzled that the locus lay outside the magnet center lines.

A few iterations are usually sufficient to complete the array design, although deep cusps in the track require trials of various configurations. The problems are fairly large, typically 4000 elements and 12000 unknowns; Figure 3 shows the layout of one-half of an experimental array **(ed: slide #3)** (this array is not designed for full surface erosion). Such problems take 4-5 hours to run on a DEC Alpha 255 WorkStation, so that 2 or 3 design iterations can be completed in one day, and it is practical to try a number of configurations in difficult areas.

The symmetry features of **AMPERES** require only half of the array to be calculated. A more subtle aspect of symmetry comes about because **INTEVAC** installs sources in facing pairs so that both sides of the hard disk substrate can be coated at once. The magnets are so powerful that each source produces significant fields at the opposing target, affecting the plasma track. Using symmetry in **AMPERES**, this effect can be taken into account. It is important for performance, because in **INTEVAC**'s design one source alone will not produce full surface erosion; the presence of the opposing source is necessary.

Figure 4 **(ed: hard copy print)** for an experimental array compares the calculated track with points on the locus $B_z = 0$ measured using a gaussmeter probe (hand-held, accounting for much of the scatter). The array itself is not shown, because it is currently under development. Agreement is excellent. The accuracy of the design method and field calculations is so good that **INTEVAC**'s original array prototype met specifications and went directly into production without any modifications; other designers typically have had to "tweak" their protoypes to improve performance.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