Contributing Factors in Cathode Placement for Confocal Sputtering

John G. Anderson, David Konopka Denton Vacuum LLC

Keywords: Confocal, Sputtering, Cathode, Source to Substrate

Abstract: Sputtering has proven to be a useful method to apply thin films. The need to sputter thin films for research and limited production applications has led to a useful approach of cathode placement. Confocal placement of multiple cathodes around a single substrate provides the system user the benefits of maximum cathode efficiency, reproducible uniform films, and the possibility of multiple material depositions and co-deposition of multiple materials all within a single vacuum chamber.

Introduction: Sputtering can be done with a variety of cathode orientations. A target larger than the substrate mounted directly above the substrate generally provides good uniformity. Cathodes with rotating magnets can provide improvements to deposited film uniformity. Rastering a substrate under rectangular cathodes has also been a proven deposition technique. However, these approaches have limitations. If multiple materials are to be applied to a substrate, the target must be changed after every deposition. These designs typically preclude co-sputtering, the simultaneous sputter deposition of two or more materials.

A different deposition technique is to sputter with multiple cathodes mounted confocally around a single substrate. Confocal sputtering requires that the cathode be mounted at an angle (θ) relative to the vertical (y) axis (See figure 1). With the cathodes positioned confocal to the substrate, the outer area of the substrate would receive more coating material than the inner areas. Simple rotation of the substrate around its own axis eliminates this non-uniformity. As the outer region of a rotating circle has more distance to cover than the inside, points on the substrate's edge have a faster linear velocity. Therefore a point towards the outside of the rotating substrate will be exposed to the plasma for a shorter period of time than a point close to the center. When the cathode is properly positioned, the balance of the cathode's angle and the rotating stage will balance these two factors and allow for high uniformity films. It is commonplace for confocal sputtered films to have better than ±5% non-uniformity.

Target efficiency is another advantage of confocal sputtering. Due to the orientation of the cathode the target size can be one half of the diameter of the substrate.

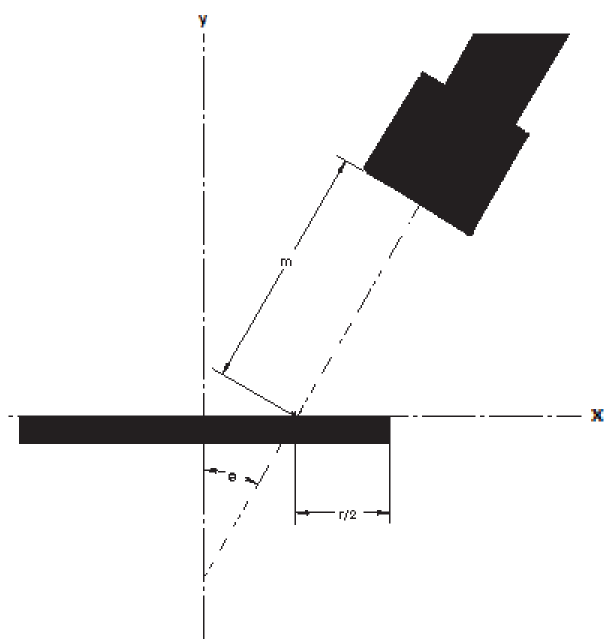

Figure 1: Diagram of stage and cathode placement showing the cathode's angle (θ) relative to the y axis, the instection point of the confocal line and the stage (r/2) along the x axis, and the source to substrate distance (m)

Because the cathode is offset from the substrate, the user is now able to add more cathodes to the system. Multiple cathodes are placed such that their centers would all be equidistant and tangent to circle drawn parallel to the substrate. This gives real advantages over parallel sputtering - now the user can deposit multiple layers of different material without breaking vacuum. This also gives the user capability to co-deposit and make complex films. The number of cathodes that can be mounted in any confocal system is limited by the unique geometry of the cathode position in addition to the size of the substrate. (discussed in Tradeoffs section).

Confocal Cathode Placement: When positioning a cathode confocally, a line is drawn that runs through the center of the cathode (parallel to the particle flow) and intersects the y axis. To optimize uniformity across the entire substrate stage this line intersects the substrate stage at a distance of one half of the radius (r/2) from the center. When the r/2 distance and the angle θ are chosen, the cathode becomes constrained such that it can only move along the confocal line (m). For the most efficient confocal sputtering, θ is set at 30°.

In order to maintain optimal placement, the user can adjust the source to substrate distance in small increments to improve film uniformity.

Confocal Alignment: When a cathode is placed directly above a substrate, the uniformity distribution is parabolic. As shown in Figure 2, the y axis represents % non-uniformity, while the x axis represents the position on the substrate (0 being the center of the substrate). As the throw (source to substrate) distance increases, the parabola widens, and the coating becomes more uniform over larger samples. However, a larger throw distance also decreases the deposition rate considerably.

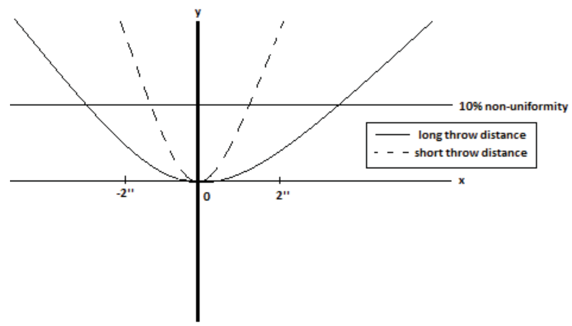

Figure 2: Graph showing % non-uniformity (y) across the diameter of a substrate (x)

When sputtering confocally, the cathode is placed at an angle θ relative to the y axis. By sputtering in this orientation, the parabolic distributions are also rotated. This means that the section of the parabola that can be modeled as a straight line lays across the face of enabling uniformity equal to or better than ± 5%.

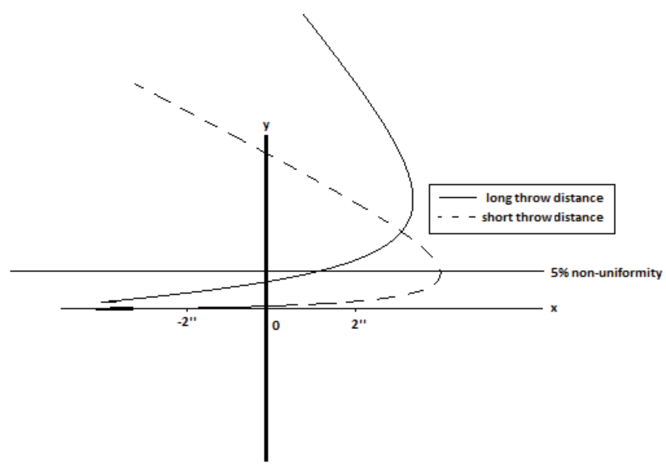

Figure 3: Graph showing uniformity distribution in a confocal arrangement (non rotating).

Important Factors: There are three key factors that affect confocal sputtering. The first is the cathode's angle, θ, relative to the y axis. This will affect the rotation of the parabolic uniformity distribution.

The second factor is the source to substrate, or throw, distance. Contrary to the top down sputtering method, a longer throw distance will lead to a greater non-uniformity and an overall poorer coating. A wider parabola has a longer curved region. When the parabolas are rotated (see figure 3), the % non-uniformity greatly increases near the outside edge of the substrate. By keeping the throw distance shorter, the % non-uniformity is kept to a minimum. It is accepted that the ideal throw distance is 4''.

The third factor is the point where the confocal line intersects the substrate. For the best uniformity this point is designated as one half of the radius from the center of the substrate. Moving in or out from this point increases non-uniformity.

Tradeoffs: Users frequently want to put many layers of different materials on one substrate. The best way to do this is to put several cathodes in one chamber. Starting with a specific substrate size and moving up to the physical size of the cathodes and the area required to operate shutters at each cathode, it becomes clear that there is a minimum distance between each cathode. As cathodes are added, the chamber must be made larger (both taller and wider) to accommodate the spacing. This also means that the throw distance must increase with the number of cathodes (as shown in figure 4). The longer throw distance will yield a less uniform, and reduced quality film.

In practical application, confocal designs with three of four cathodes deliver highly uniform films at good deposition rates. When more than four cathodes are configured, throw distance increases which in turn compromises uniformity, deposition rates, and film properties.

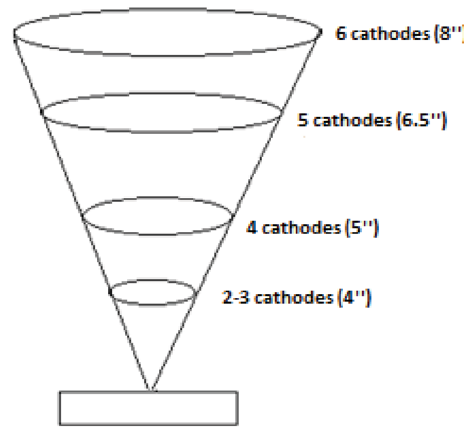

Figure 4: Diagram showing placement rings and distance from substrate as cathodes are added to the system. This particular example shows the distances for a 6'' substrate being coated by 3'' cathodes

Cathode adjustability: The best method for arranging the system's geometry is to have each cathode mounted on its own flange. This allows the user to make small adjustments around a fixed height stage. Some systems are designed such that the cathodes are fixed in place, and the height of the substrate is variable. While this may appear to be just as effective, it does not meet the criteria for proper confocal cathode positioning. As the height of the table is adjusted, the intersection point of the cathode line and the substrate will move away from r/2 for all of the cathodes.

Another option is to have flex-mount cathodes installed in the system. Denton Vacuum's flex-mount cathode allows the head to pivot ±45° about the stalk. Flex-mount cathodes give the user the ability to make fine adjustments to their sputtering geometry to maximize film uniformity. Flex mount cathodes also allow the user to switch between confocal and straight down cathode placement.

Denton Flex-Mount Cathodes

Conclusions: Confocal cathode arrangements enable the deposition of multiple materials in a single vacuum chamber with a high degree of film uniformity. When sputtering confocally, the system should be configured such that the cathodes are mounted 30° relative to the y axis, the distance between the cathode and the substrate should be 4'', and the confocal line should intersect the substrate at a distance of r/2 from the substrate's center. Adding too many cathodes compromises the precise geometry required to deposit uniform films. The angle will decrease from 30° and the centerline will no longer intercept the substrate at the proper distance.

As cathodes are added to a vacuum chamber of a given size, the distance between the cathode and the substrate will increase beyond 4'' resulting in lower deposition rates and reduced film quality. Users concerned about film quality should limit the number of cathodes in the system rather than increase the throw distance.

It is important that the user have height adjustable cathodes and should never rely on a variable height stage for high quality coatings. For the maximum controllability and film quality, flex-mount cathodes mounted on individual flanges should be used.