ANGSTROM SCIENCES
40 S. Linden Street, Duquesne, PA 15110 USA T: +1-412-469-8466 F: +1-412-469-8511 angstromsciences.com

“GENERALITIES ON TARGET SET-UP”

So...let's start of by addressing any confusion that may exist between looking at the performance ratings of a cathode and the performance ratings on targets. There are subtle differences.

Regardless of construction type (indirectly-cooled or directly cooled), all of our cathode bodies are rated to handle powers that far exceed the listed rating in the technical data sheet. The power rating of a cathode is influenced by the materials of construction and the efficiency of the water cooling.

However, how much power you can effectively "apply" to a ***target*** that is affixed to a cathode is highly dependent on the nature of the target material (melting point and thermal conductivity) and how well the target is thermally coupled to the cooling water cavity (monolithic target vs. target bonded to a backing plate v. a target clamped to a backing plate). The effective power is generally quite a bit lower than the rated power for a cathode.

The optimum/ideal situation is for a monolithic target that is directly water cooled as in this case, the thermal conductivity of the target and it's melting point will control the upper limit of the applied power (however, not all materials lend themselves to monolithic target fabrication and this is generally the most expensive way you can execute the process).

The second most efficient manner to remove heat from the process is to metallurgically bond the target to a removable (typically copper) backing plate. This solves the problem of trying to machine a monolithic target out of materials that are incompatible with this technique (eg., silicon). However, the maximum applied power will still be limited by the bulk properties of the target material (copper backing plates and solder bonding generally do not add any appreciable thermal resistance on top of the bulk properties of most materials. But, this process is expensive and changing targets requires breaking a water seal (as in the monolithic targets).

For these very reasons, the majority of systems that are sold by every manufacturer for R&D applications use indirectly cooled target assemblies. In this situation, a removable disk of material is clamped to the face of the cathode. Considering the poor thermal transfer across this interface, a significant "de-rating" of the allowable power (again material dependent) comes into play. Obviously “extra” special attention must be applied certain specific classes of materials that have a low melting point (aluminum), are brittle (ceramics and almost every material that is fabricated by consolidating powder(s), are poor thermal conductors (refractory metals), and sensitive to thermal shock (ceramics in general) or worse, subject to all four conditions! Now, there are thermal pastes and thin foils that can improve the heat transfer across a clamped target's interface to a backing plate but these are not "magic" materials. They are simply designed to take a difficult thermal situation and make it "less difficult”. Regardless, it is just sound practice to employ these thermal “agents” whenever a clamped target situation is encountered. A data sheet for Angstroms Sciences’ ON-TECP (available on our website under “Conductive Products” describes the characteristics of a product we strongly recommend.

For these very reasons we suggest a conservative approach to operating cathodes with clamped targets. Our general rule of thumb is that clamped targets should not be run at power levels in excess of 100 watts/square inch. Again this will be material dependent. Highly thermally conductive metals will be capable of operating at or near 100 Watts DC/in^2 in a clamped mode. Poor thermal conductors (such as refractory metals) will operate at slightly lower power densities (approximately 80 W/in^2) mainly because their resistance will rise (the operator will notice a rise in the operating voltage of the target and eventually the voltage will rise to a level where the power supply simply be unable to support a discharge!) if they get too hot.

Now, let's introduce RF into the equation.

In RF applications, the currents are ***much higher*** than in DC, so simply looking at total power can lead to a spectacular miscalculation! A very good rule of thumb is that for any configuration (bonded or clamped), the maximum RF power that can be applied is 1/3 the maximum allowable DC power.

The following is a table that lists the maximum suggested power (please do not confuse this as power density!!!) for a wide range of materials for clamped targets in our 2.0" magnetrons:

<u>All are 2"diameter (clamped targets):</u>

Material	Thickness (inch)	comment	Max DC	Max RF
Al	.250	Oxide layer on surface- may need to start slowly and monitor voltage	500 watts	200 watts
Ag	.250		500 watts	200 watts
Cu	.250		500 watts	200 watts
Au	.125		500 watts	200 watts
Hf	.250		400 watts	150 watts
Pt	.125		500 watts	200 watts
Ru	.250		500 watts	200 watts
Ti	.125	Oxide layer on surface- ramp slowly to assure oxide layer is burned off before ramping up power	500 watts	200 watts
Ti	.250	Oxide layer on surface- ramp slowly to assure oxide layer is burned off before ramping up power	500 watts	200 watts

W	.250		400 watts	100 watts
Si	.250		N/A	150 watts
Cr	.250		500 watts	200 watts
Sn	.125		500 watts	200 watts
ITO (In-Sn-Ox)	.250		150 watts	150 watts
Al_2O_3	.125		N/A	150 watts
Al_2O_3	.250		N/A	150 watts
Ge	.125		400 watts	150 watts
Ge	.250		400 watts	150 watts
Mo	.250		400 watts	150 watts
Nb	.250	Monitor voltage	300 watts	100 watts
Ni	Thin	.020” thick- no backing plate	400 watts	150 watts
Fe	Thin	.010” thick- no backing plate	400 watts	150 watts
Zr	.250		400 watts	150 watts

Note: These readings are for pressures in the 3-5 mTorr range.
Al and Ti may need to run higher to start due to their oxide layer, but once lit off, they can ramp down to the 3-5 mTorr range.
With refractory metals such as Mo, Nb, Hf, Zr, and W that don’t conduct heat well, you need to monitor the voltage so it does not creep up meaning too much resistance and consequently too much power. In this case, ramp down and run at a lower power.
Flatness of the target and backing plate are very important. Routinely check for good thermal contact. Paste and or conductive elastomer can be used to make up for imperfections.
Oxide targets will have tendency to crack because of internal stress or thermal gradient between the backside of the target and cathode. You can bond these materials to a total thickness with backing plate of 0.250”. This enables you to maintain target integrity and continue the process even if the target cracks.
**The powers listed are based on safe limits, understanding that you have a varied amount of users in a University setting. A materials thermal properties and how well it contacts the cathode body can result in the ability to operate at higher powers.*

Now these values are maximum operating powers. However, a reasonable bit of advice to any end user looking to establish a set of stable and safe operating conditions would be to start off on the low end of the power spectrum and then work your way to increasing power levels once you are satisfied that you have a stable process. These power levels can be scaled to our 3.0” and 4.0” guns by simply looking at the ratio of the target areas.

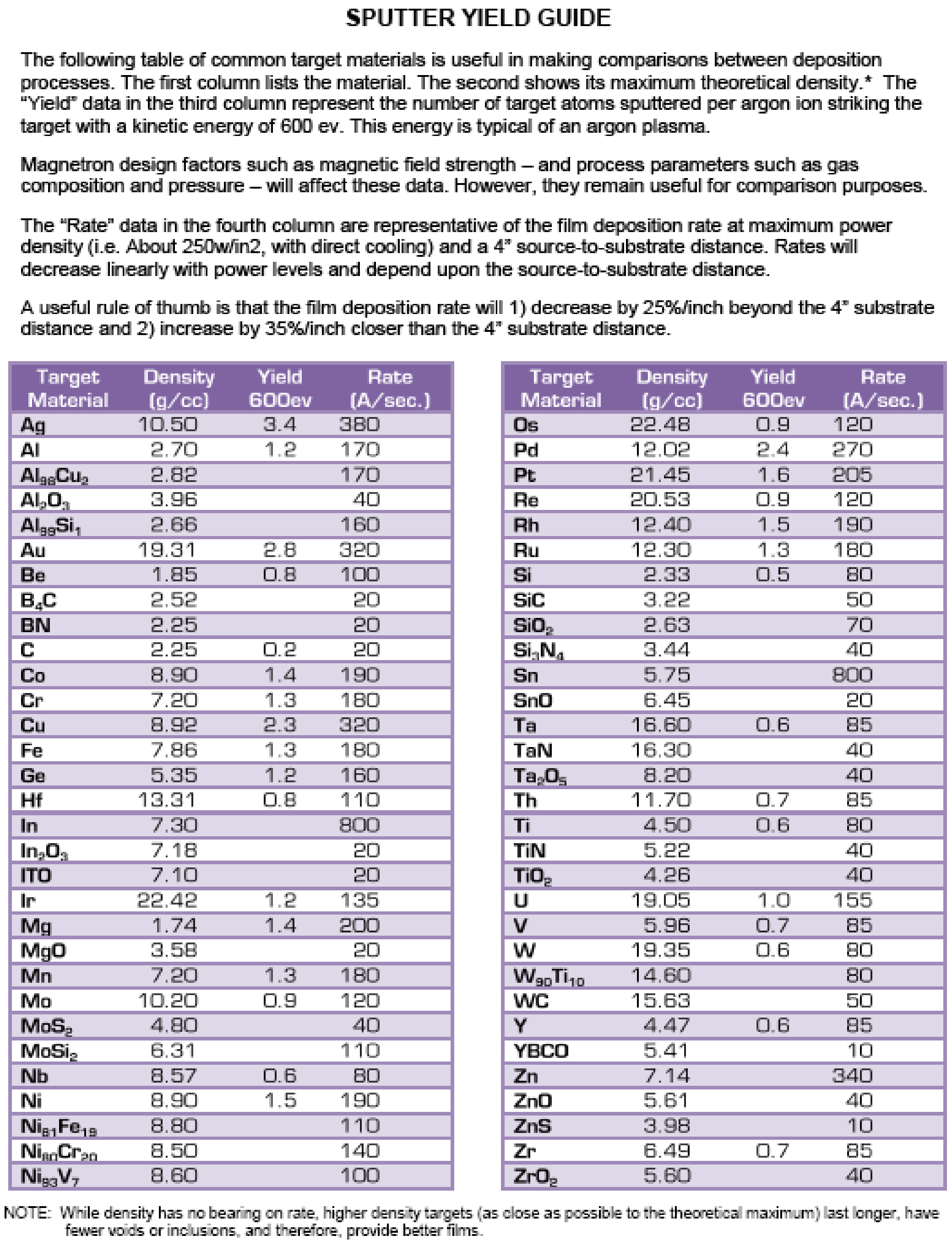
For **bonded** target applications, these power levels will “generally” scale upward by a factor of 2.5!!! This is due to the fact that the targets are now being directly cooled as opposed to a clamped/ indirect-cooled mode.

In the Figures below, you will find examples of both Indirect-Cooled and Direct-Cooled target mounting options.

Now, let’s consider the fact that generally our customers don’t really care about power density, they care about deposition rate!

Here again it is very easy to misunderstand the nature/format of reference material and get into a bit of trouble. Unfortunately, geometry also plays a MAJOR role here as the orientation of cathode with respect to the substrate as well as the source to substrate distance will have a huge impact on the thickness of the measured film.

So let's start off by looking at our "Sputtering Yield Table":



SPUTTER YIELD GUIDE

The following table of common target materials is useful in making comparisons between deposition processes. The first column lists the material. The second shows its maximum theoretical density.* The "Yield" data in the third column represent the number of target atoms sputtered per argon ion striking the target with a kinetic energy of 600 ev. This energy is typical of an argon plasma.

Magnetron design factors such as magnetic field strength – and process parameters such as gas composition and pressure – will affect these data. However, they remain useful for comparison purposes.

The "Rate" data in the fourth column are representative of the film deposition rate at maximum power density (i.e. About 250w/in2, with direct cooling) and a 4" source-to-substrate distance. Rates will decrease linearly with power levels and depend upon the source-to-substrate distance.

A useful rule of thumb is that the film deposition rate will 1) decrease by 25%/inch beyond the 4" substrate distance and 2) increase by 35%/inch closer than the 4" substrate distance.

Target Material	Density (g/cc)	Yield 600ev	Rate (A/sec.)
Ag	10.50	3.4	380
Al	2.70	1.2	170
$Al_{98}Cu_2$	2.82		170
Al_2O_3	3.96		40
$Al_{99}Si_1$	2.66		160
Au	19.31	2.8	320
Be	1.85	0.8	100
B_4C	2.52		20
BN	2.25		20
C	2.25	0.2	20
Co	8.90	1.4	190
Cr	7.20	1.3	180
Cu	8.92	2.3	320
Fe	7.86	1.3	180
Ge	5.35	1.2	160
Hf	13.31	0.8	110
In	7.30		800
In_2O_3	7.18		20
ITO	7.10		20
Ir	22.42	1.2	135
Mg	1.74	1.4	200
MgO	3.58		20
Mn	7.20	1.3	180
Mo	10.20	0.9	120
MoS_2	4.80		40
$MoSi_2$	6.31		110
Nb	8.57	0.6	80
Ni	8.90	1.5	190
$Ni_{81}Fe_{19}$	8.80		110
$Ni_{80}Cr_{20}$	8.50		140
$Ni_{93}V_7$	8.60		100
Os	22.48	0.9	120
Pd	12.02	2.4	270
Pt	21.45	1.6	205
Re	20.53	0.9	120
Rh	12.40	1.5	190
Ru	12.30	1.3	180
Si	2.33	0.5	80
SiC	3.22		50
SiO_2	2.63		70
Si_3N_4	3.44		40
Sn	5.75		800
SnO	6.45		20
Ta	16.60	0.6	85
TaN	16.30		40
Ta_2O_5	8.20		40
Th	11.70	0.7	85
Ti	4.50	0.6	80
TiN	5.22		40
TiO_2	4.26		40
U	19.05	1.0	155
V	5.96	0.7	85
W	19.35	0.6	80
$W_{90}Ti_{10}$	14.60		80
WC	15.63		50
Y	4.47	0.6	85
YBCO	5.41		10
Zn	7.14		340
ZnO	5.61		40
ZnS	3.98		10
Zr	6.49	0.7	85
ZrO_2	5.60		40

NOTE: While density has no bearing on rate, higher density targets (as close as possible to the theoretical maximum) last longer, have fewer voids or inclusions, and therefore, provide better films.

Now there is a lot of data in this table. However, there are a number of assumptions and cross-correlations that are implicit in this data:

1. The data comes from multiple sources. Some of which comes from textbooks (density/sputter yield for a 600 eV Argon ion).
2. Actual deposition rate data for a select subset of the materials listed has been generated/received from multiple sources (internal and external). Using the sputter yield as a predictive calibration for materials where deposition rate data is not available, deposition rates for those non-verified materials have been scaled accordingly.
3. Since not all of the data was collected at the same power and/or source to substrate distance, all of the data has been **normalized** to a hypothetical situation where a power density of 250 W/in^2 is applied to a target and a source to substrate distance of 4” is affected with the target perpendicular to the plane of the substrate. However, ***this does not imply that you can run all of these materials at this power density*** and a thorough understanding of the achievable power densities on specific materials; influenced by the deposition modality (RF or DC) and the target attachment (bonded vs. clamped) is absolutely required to make any estimates of the deposition rate.
4. Actual deposition rate at distances other than 4” will square by the inverse ratio of the square of the distances. As an example for a rate of 1.0 A/sec at a distance of 4.0” the approximate rate at a distance of 6” = $(1.0)(4^2/6^2) = 0.44$ A/sec

Now let’s factor another geometrical consideration; that of confocal sputtering. The classic case of confocal sputtering has the source inclined at an angle of 30 degrees, offset from the centerline by generally ½ the radius of the rotating table/substrate. This generally improves the uniformity as the static uniformity for a small circular cathode is not “spectacular”. Considering the duty cycle of the rotating table and the influence of the cross contamination shields collecting some material, the actual **accumulation rate** on a rotating sample can be reduced by a **factor of three or four** from the static rate that would be calculated for a perpendicular deposition!

Initial target burn in/ramping:

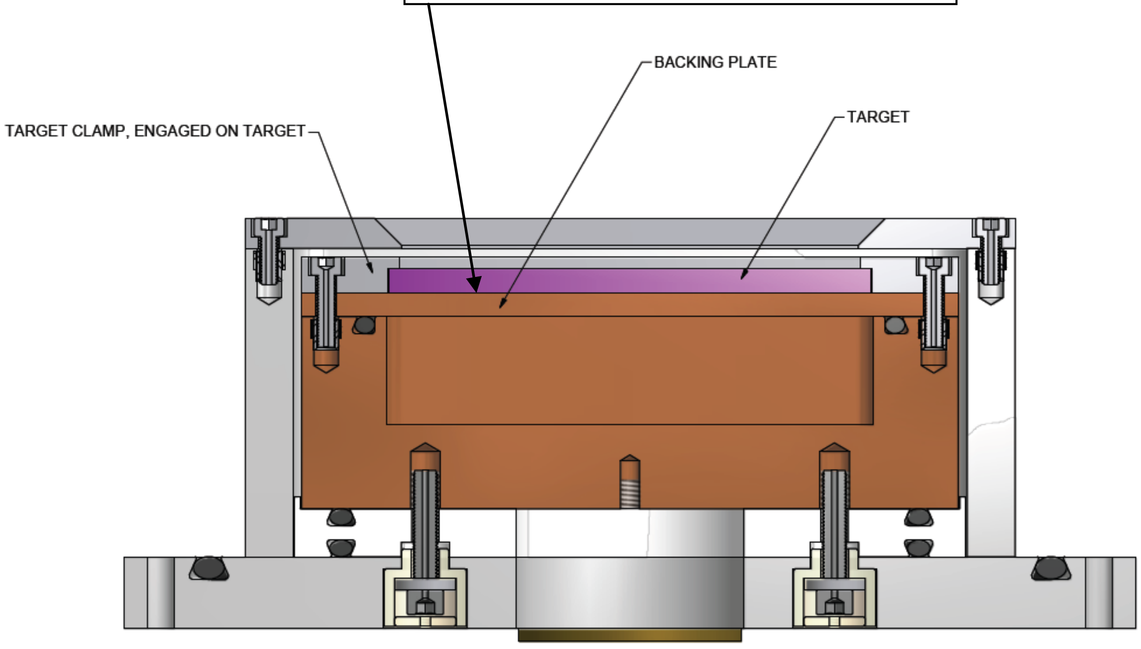
Special care should be taken when installing a fresh target on the sputtering magnetron. Most metals have a native oxide layer that must be removed (gently!!) before the target is useful. Generally, the best method to remove this native oxide is to start at a very low power (you may have to increase the pressure in order to get the plasma to ignite) and then raise the power slowly in 10-20 watt increments until the voltage stabilizes and minimal arcing is observed. Fresh targets will always exhibit excessive arcing until this oxide is eliminated.

For ceramic/brittle targets care must be taken to avoid excessive thermal gradients through the thickness of the target (after all, many are very poor thermal conductors) and a similar ramp to setpoint is generally advised as well.

Figures 1 - 3:

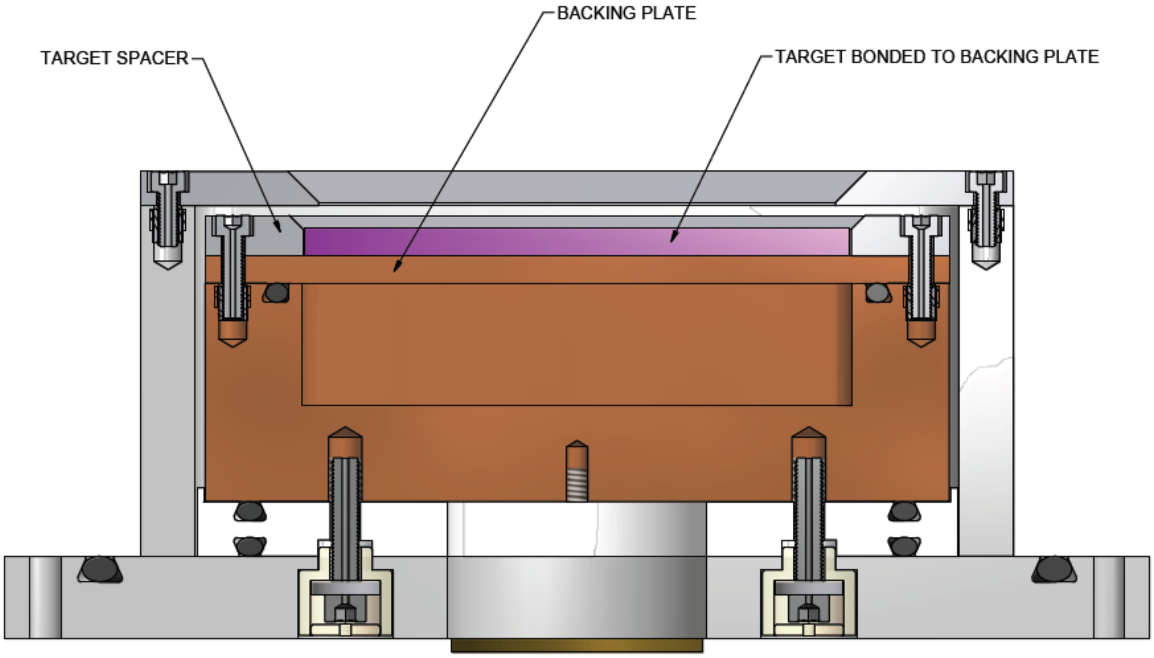
Indirect-Cooled Target Option

***Note:** Conductive paste and or foil between target and backing plate.

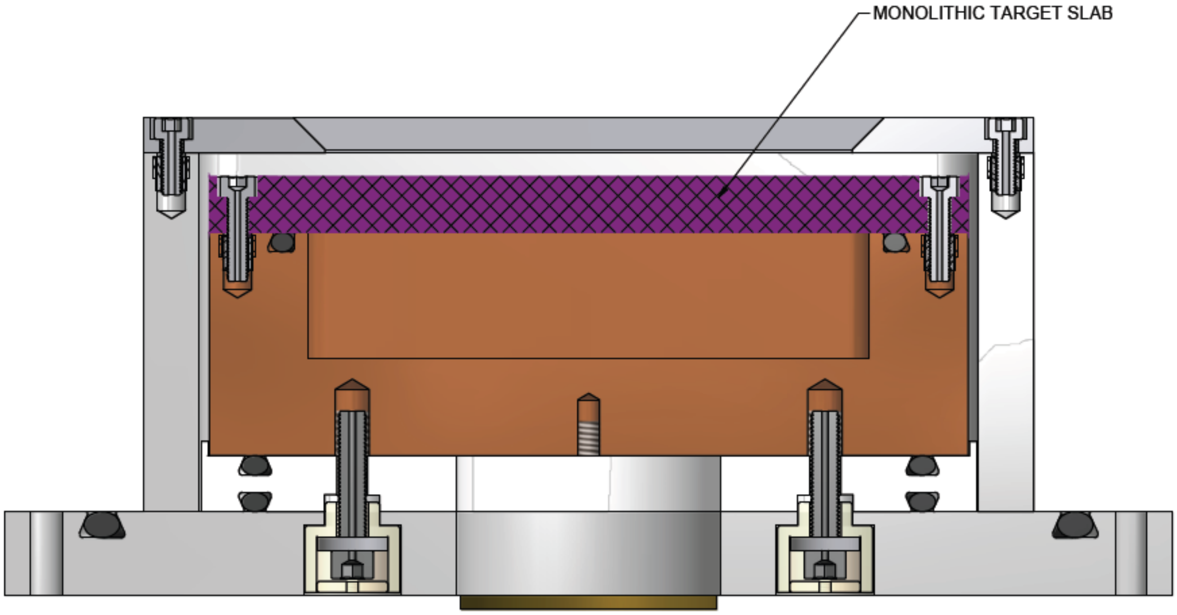


CLAMPED TARGET, INDIRECTLY COOLED

Direct-Cooled Target Options



BONDED TARGET, DIRECTLY COOLED



MONOLITHIC TARGET, DIRECTLY COOLED