Increasing Sputter Rates

When sputtering dielectric targets using RF power, it is quite possible for the maximum deposition rate on the substrate to be less than 0.1 Å/sec. That is, depositing a film 100nm thick may take over 2½ hours. It is no surprise, therefore, that we are frequently asked, “How can I increase the sputter rate?”

Actually, what the questioner wants is to increase the deposition rate, but we’re not about to argue semantics with a frustrated researcher.

(But to segue into semantics for a moment: we will use sputter as the adjectival form, as in sputter yield, sputter rate, sputter gun, rather than sputtering yield etc.)

In this issue we review ways to increase deposition rates and look at conditions where maximizing one parameter inadvertently affects something else.

While the substrates can be static or rotating, these suggestions apply only to circular sputter guns with flat disc targets and stationary magnet assemblies. Sputter guns with targets of other shapes and configurations, moving magnet assemblies, and linear sputter guns, have their own performance attributes that are not directly addressed here.

Sputter Yield

First, we must understand that each material has its own characteristic sputter yield – the number of atoms (or molecules) leaving the target for each ion that hits it. The sputter yield value depends on: the material; the mass of the incoming ion; the voltage through which the ion is accelerated; and its angle of incidence on the target.

For Ar+ ions striking a target at 45° through a potential of 500eV, the sputter yields of most elements are between 1 - 10, roughly. (See the National Physics Labs calculated list: http://www.npl.co.uk/nanoscience/surface-nanoanalysis/products-and-services/sputter-yield-values )

Materials that are chemical compounds such as oxides can have much lower sputter yields! For example, Maissel and Glang’s book Handbook of Thin Film Technology quotes the sputter yield for SiO₂ as 0.13 and Al₂O₃ as 0.04.

Extending the concept of sputter yield, we will later refer to a material’s sputter rate, which is its sputter yield multiplied by the ion current to the target.
always appears to be the ‘easy option’ when faced with low deposition rates.

Unfortunately, arbitrarily increasing power has many adverse effects. All power applied to the gun must dissipate somewhere in the system. It is claimed that roughly 75% ends up heating the gun’s cooling water. That is, 75% of the total power dumped into the target’s front face must transfer through the target to reach the water! Clearly, the target’s thermal conductivity, thermal coefficient of expansion, mechanical strength characteristics, and melting point, are critical issues.

• Thermal conductivity helps determine the temperature difference between the target’s front and rear faces. The larger that difference the higher the thermal stress in the material.

However, shorter throw distances (and, therefore, higher substrate temperatures) can have beneficial effects too:

• Films may grow as successive monolayers (called Frank—van der Merwe growth, a frequently desirable nucleation mode)
• The film’s tensile stress may be reduced
• Film adhesion may improve due to the higher energy of arriving atoms
• Films may be ‘densified’ by bombardment with higher energy plasma ions and ‘hot’ neutrals

Increasing Power

Doubling the power applied to the target roughly doubles the sputter rate and this film uniformity at shorter distances may be worse.

In addition, at shorter throw distances substrates may see: higher energy sputter particles; more stray electrons; more plasma ions and ‘hot’ neutrals; and higher thermal radiation heat transfer from the plasma and target surface. So the adverse effects of a shorter throw distance include:

• Excessive substrate outgassing
• Increase in compressive stress in the growing film
• Films beneath the present one damaged by electron bombardment
• Substrate melting!

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Power & Power Density

Although we quote the power applied to a target, the critical quantity is really power density, which is the power applied divided by the target’s surface area. Let us suppose the target in a 5cm (2") gun accepts 100W maximum power. Then, how can the same target material in a 10cm (4") gun accept 400W?

The table shows that despite the large change in maximum power, the two targets have identical power densities.

<table>
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<th>Diameter</th>
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<tr>
<td>cm</td>
<td>cm²</td>
<td>W</td>
<td>W/cm²</td>
</tr>
<tr>
<td>5</td>
<td>19.6</td>
<td>100</td>
<td>100/19.6 = 5.1</td>
</tr>
<tr>
<td>10</td>
<td>78.5</td>
<td>400</td>
<td>400/78.5 = 5.1</td>
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**Maximum Power Levels**

So, how do I find the ‘appropriate maximum power’ for my target?

With patience and a ‘trick’. The first time a new target material is sputtered, slowly ramp the power until the power density (see Power & Power Density) on the target is:

- Highly conductive (e.g., Al, Cu) 15 W/cm²
- Moderately conductive (e.g., Ti, NiCr) 9 W/cm²
- Conductive oxide (e.g., ITO, AZO) 3 W/cm²
- Ceramic insulator (e.g., HfO₂, BaTiO₃) 3 W/cm²
- Low melting metal (e.g., In, Sn) 2 W/cm²

Let the target soak for a minute or two at whatever power that turns out to be. Then slowly increase power (not power density) by 5W and monitor the voltage for another minute. If it remains stable, ramp up another 5W and watch it for another minute.

Continue these 5W ramp/1 minute voltage monitoring steps until the voltage starts to rise. Immediately back off the power by 5W and monitor the voltage. If it remains stable for 5 minutes, you have found the appropriate maximum power for that target in that sputter gun. If, however, the voltage still rises, back off in further increments of 5W until it does stabilizes. (But note Caveat to the Trick.)

_Motto: If in doubt when starting out, make it your propensity to lower power density!_

**Sputter Gas Pressure**

Lowering the sputter gas pressure causes a modest increase in deposition rate by a two-fold mechanism:

- Sputtered atoms leaving the target will undergo fewer thermalizing collisions. They are less likely to scatter 'sideways' and a larger percentage will continue to the substrate, slightly increasing the deposition rates.
- In power control mode, using either RF or DC power, the plasma-to-target voltage will increase slightly. Ions bombarding the target will, therefore, have a higher energy which slightly increases the sputter yield and consequently the sputter rate.

One potential side-effect of lowering the gas pressure is a change in film uniformity. Whether it improves or worsens is typically not predictable because there are many factors involved. But one obvious aspect is a reduction in the number of thermalizing collisions.

**Caveat to the Trick**

Reactive metal targets such as Al and Mg are initially covered by a thin oxide coating. Before that layer ‘burns’ off, the target will arc, spit, and most importantly, run at a low voltage. Once that oxide layer has gone, the voltage will rise sharply to a new level.

It is this ‘clean target’ voltage level that you are trying to stabilize with the trick – not the initial low voltage.
An adverse effect of lower gas pressure/higher plasma-to-target voltage combination is the greater likelihood of arcs occurring near the target.

### Increasing Target Size

As a method of increasing deposition rate, this option is not easily implemented and is expensive since it requires a new sputter gun, sufficient room to install it in the chamber, and possibly a larger power supply.

For a given power density (see Power & Power Density), the larger the target diameter the higher the sputter rate. The explanation is simple. A larger target diameter means a larger sputter trench area and, for a given power density, increased trench area means increased sputter rate.

### Number of Guns

The majority of R&D deposition systems have more than one sputter gun installed. Typically, the user installs different target materials in each gun. However, putting the same target material on two or more guns and operating them simultaneously can double, triple, etc. the sputter rate and resulting deposition rate.

The drawback is, many multi-gun systems were not built for co-deposition work and have just one power supply. Buying additional supplies for simultaneous operation may make this option expensive.

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### Conclusion

Yes, there are ways to increase deposition rates. Unfortunately the easy winding-up-the-power option, if misused, at best leaves your targets looking a little sad. At worst, your sputter gun splutters to a stop, water leaks into the chamber, or the power supply fries. No, I jest! At worst, all three happen simultaneously.

As always, if you have questions or comments email techinfo@lesker.com and they will be forwarded to the author.

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Cerium oxide target bonded to copper backing plate but sputtered at a power that melted the indium bond and cracked the target

3" diameter Indium tin oxide target sputtered at 1000W (roughly 7x the maximum recommended power)

Aluminum doped zinc oxide target given the ‘tough love’ treatment of inadequate cooling (at the 10:00 o’clock position) and excessive power

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