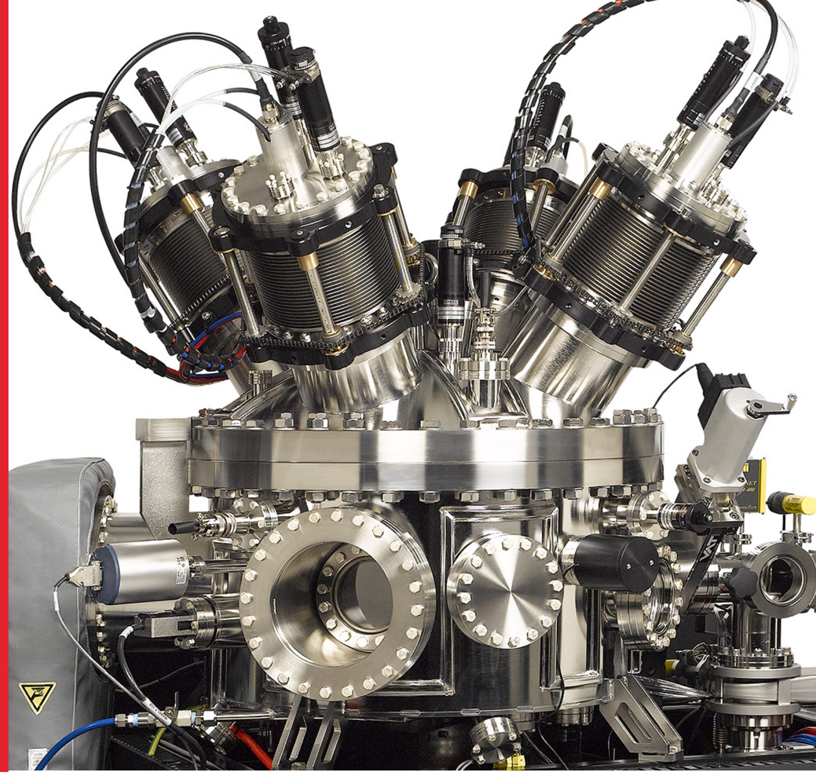
Cost-Drivers for Thin Film Deposition Tools

A Guide for Customizable Systems



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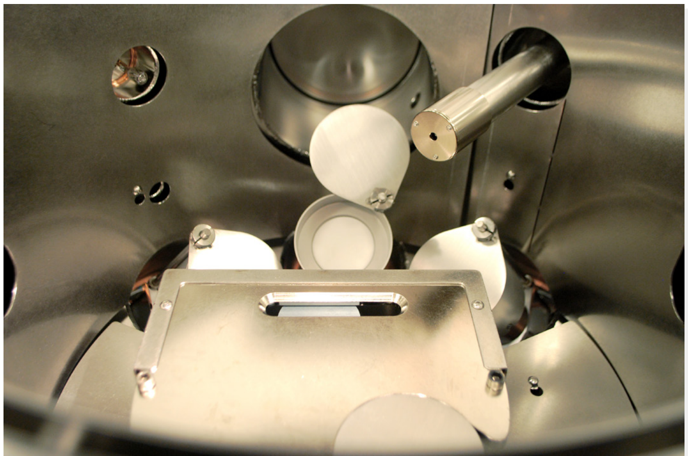

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About PVD Products

PVD Products is the premier supplier of custom-made thin film deposition systems. We design every system to meet our customers' specific requirements, based on desired material properties and process complexity, range of substrate size, manufacturing tolerances, and throughput requirements.

Introduction

Each customer has specific needs in a thin film deposition tool. The applications vary from simple metal deposition onto silicon substrates for device applications to tribological coatings, multi-layer optical coatings, reel-to-reel applications, etc. Because our deposition coaters are completely customizable, the number of options can be overwhelming.

Even with the wide variety of deposition technologies and systems available, certain advanced research or proprietary production recipes demand customized deposition systems.

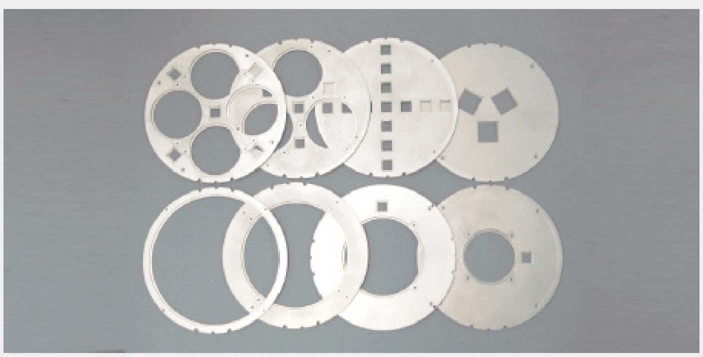
Drivers for customization can include:

- Substrates, sources and targets
- Variety of coatings required
- Complexity of coatings required
- Need for multiple deposition methods
- Space limitations
- Existing technology integration
- Coating run frequency
- Throughput

Capabilities must be balanced against capital and maintenance costs. In this guide we will describe a few of the primary design choices and how they affect cost in PVD Products' sputtering, evaporation, and pulsed laser deposition systems.

It's important to emphasize that many factors noted below are generalizations. There are many interconnections and dependencies among features. These factors make it impossible to set a firm cost until the final design takes shape. This guide will help universities, national labs, start-ups and Fortune 500 companies to understand the cost-drivers on the desired system's value so that there are reasonable expectations of what you can afford as you begin the design process.

Top Cost-Drivers for Sputtering Systems



Substrate size

The direct cost of substrate size relates only to its surface area, and for most materials is relatively small compared to the cost of the deposition system. The indirect cost of the substrate size, though, has enormous consequences on the overall system cost.

The substrate size drives the cost of almost every design factor of the deposition system, including such things as the size of the chamber, pumps, and valves; the size of the substrate heater (if required) and input power; and, for instance, the size of the magnetrons and their associated power supplies.

Base vacuum of chamber

The base vacuum of a deposition chamber will also drive the cost of the system. Some high volume, low value-added coaters use a base vacuum in the range of 10^{-5} Torr. Other systems will require a much better base vacuum. This may drive the size and type of pumps that are used or add time to the pump-down cycle. PVD Products usually recommends either turbo or cryo pumps for most sputtering applications. If the sputtering process requires UHV pressures (P < ~5 x 10^{-9} Torr or below), this can also add significant cost. Pumping toxic materials such as Se or PH_3 adds complexity and affects price.

Wafer heating, RF bias, and manipulation

Many applications require substrates to be cooled to liquid nitrogen temperatures or heated to very high temperatures, sometimes in excess of 900°C. Also, in order to achieve excellent film uniformity, substrate rotation is typically used. In some cases, planetary-type substrate holders are used with multiple gears and motor drives, feedthroughs, etc. These can be used in both heated and cooled applications.

RF bias placed on the substrate is typically used for precleaning and for reactive deposition of oxides and nitrides. Care must be taken in the design of the system to provide proper dark space shielding to confine the plasma to the desired area.

Load locks

Load locks are usually a cost-effective solution to increase the throughput of your deposition system. By using a load lock, the throughput can be easily increased multi-fold. Load locks come in single wafer or multi-wafer varieties. A manual single wafer load lock is most common for R&D and provides fast substrate turnaround times, without having to wait for the main chamber to pump down to base vacuum. In production applications, automated multi-wafer load locks, robotic handlers, and large load locks with larger pumps can very quickly increase the cost of systems. For instance, when coating flat panel displays, one would typically use a multi-wafer load lock for inserting uncoated glass substrates into the chamber and a similar load lock on the opposite side of the deposition chamber for removing the coated glass substrate. Such systems greatly increase throughput, but come with a high cost.

Film type

Sputtering allows the user to deposit pure metals, oxides, nitrides, carbides, etc. A number of oxides and nitrides can be deposited in a reactive deposition mode. These can require pulsed DC or AC power supplies which are expensive compared to a standard DC supply. Also, RF power supplies are more expensive than that of similarly sized DC supplies and provide much lower deposition rates. In some cases, using a DC/DC or RF/RF switch to run separate sources one at a time can cut down on the overall cost of power supplies required. Selecting the right type and number of supplies will keep the cost of the system reasonable. Over-specifying the size of a power supply will drive the costs up. Also, multi-layer films and co-deposition are easy to implement in magnetron sputtering systems.

It is important to remember that the power specification provided by vendors for a magnetron is usually based on using a copper target, which has very high thermal conductivity and can handle a large power density. Most other targets tolerate much less power and thus, smaller power supplies may make sense.

In-situ metrology

Typical sputtering tools may include a Quartz Crystal Monitor (QCM) for calibration of deposition rates of multiple magnetrons prior to deposition of actual thin films. In some cases, QCM’s can be used for continuous deposition rate monitoring. Other techniques such as spectroscopic in-situ ellipsometry for real-time thickness measurement, Reflection High Energy Electron Diffraction (RHEED) for monitoring epitaxial film growth, and multi-beam optical sensors (MOS) used for monitoring in-situ stress can be incorporated into a sputtering system.

Substrate size

The direct cost of substrate size relates only to its surface area, and for most materials is relatively small compared to the cost of the deposition system. The indirect cost of the substrate size, though, has enormous consequences on the overall system cost.

The substrate size drives the cost of almost every design factor of the deposition system, including the size of the chamber, pumps, and valves; the size of the substrate heater and power; and the size of the electron beam (e-beam) source and its associated power supplies. Furthermore, if ion beam assisted deposition is used, then larger substrates will drive the size and cost of the ion source. Some applications require very long depositions—20 hours or more. These applications require much larger e-beam sources with crucibles or troughs with sufficient volume to hold enough material to last the entire deposition.

Wafer heating, ion beam assist, and substrate manipulation

A number of applications require substrates to be cooled to liquid nitrogen temperatures or heated to very high temperatures, sometimes in excess of 900°C. Also, in order to achieve excellent film uniformity, substrate rotation is typically used. In some cases, planetary-type substrate holders are used with multiple gears and motor drives, feedthroughs, etc. These can be used in both heated and cooled applications.

Ion beam cleaning or ion beam assisted deposition (IBAD) is very common in evaporation systems. There are many types of ion sources to select from, and the specific application will help determine the best ion source for your application. IBAD can provide densification of films, control of film stress, enhanced oxide or nitride growth, etc.

Some applications call for the incoming evaporated material to land at a glancing angle (GLADS) on the substrate surface. This requires the ability to change the incident angle of the substrate with respect to the evaporated flux at the same time as rotating the substrate and possibly heating or cooling it. Such systems are available and can be fully load lock compatible. However, the more complex the substrate motion, the more expensive the tool will be.

Base vacuum of chamber

The base vacuum of a deposition chamber will also drive the cost of the system. Some high volume, low value-added coaters use a base vacuum in the range of 10^{-5} Torr. Other evaporation systems will require a much better base vacuum. This will drive the size and type of pumps that are used or extend pump-down time. PVD Products usually recommends cryopumps for electron beam evaporation as they provide a very high pumping speed for water vapor, which is the typical gas specie in the chamber below ~5 x 10^{-5} Torr down to typical base pressures.

The type of e-beam source can also drive the price. If UHV conditions are required, then an all-metal multi-pocket e-beam source may be needed. These types of sources are more expensive than standard multi-pocket e-beam sources.

Load locks

Load locks are usually a cost-effective solution to increasing the throughput of your deposition system. By using a load lock, the throughput can be easily increased multi-fold. Load locks come in single wafer or multi-wafer varieties. A manual single wafer load lock is most common for R&D and provides fast substrate turnaround times, without having to wait for the main chamber to pump down to base vacuum. In production applications, automated multi-wafer load locks, robotic handlers, and large load locks with larger pumps can very quickly increase the cost of systems. For instance, when coating flat panel displays, one would typically use a multi-wafer load lock for inserting uncoated glass substrates into the chamber and a similar load lock on the opposite side of the deposition chamber for removing the coated glass substrate. Such systems greatly increase throughput, but come with a high cost.

Film type

Evaporation is typically used for deposition of most metals, basic oxides, nitrides, and fluorides. Multilayer films can easily be deposited, and with two or more electron beam sources co-evaporation is possible. Oxides and nitrides can also be deposited with an ion-beam assisted deposition.

In-situ metrology

Almost all evaporation systems will utilize at least a single Quartz Crystal Monitor (QCM) for closed-loop feedback to the electron beam power supply to keep the deposition rate constant and monitor actual film thickness. In systems that require long depositions (thick films), multi-layers, or UHV Systems where you don't want to open the chamber often, QCM heads with multiple crystals should be considered. Other techniques such as spectroscopic in-situ ellipsometry for real time thickness measurement, Reflection High Energy Electron Diffraction (RHEED) for monitoring epitaxial film growth, and multi-beam optical sensors (MOS) used for monitoring in-situ stress can be incorporated into an electron beam system. Other techniques such as Electron Impact Spectroscopy and atomic absorption rate monitors are also available but come with a high price tag.

Top Cost-Drivers for Pulsed Laser Deposition (PLD) Systems

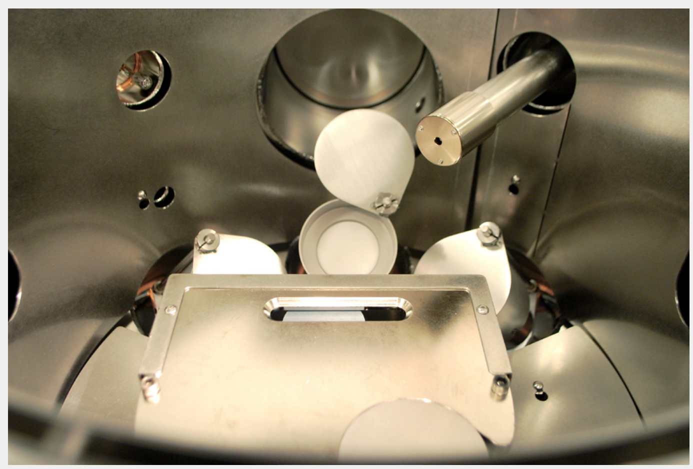
Substrate size

Like sputtering, the direct cost of substrate size in PLD relates only to its surface area, and for most materials is relatively small compared to the cost of the deposition system. The indirect cost of the substrate size, though, has enormous consequences on the overall system cost.

The substrate size drives the cost of almost every design factor of the deposition system, including the size of the chamber, pumps, and valves; the size of the substrate heater and power; and the size of the laser used. The laser cost can be as much as 30 to 50% of the cost of the PLD system, depending on the application. The larger the substrate size, the more power is required to keep the deposition rate at a reasonable level. Also, larger targets are usually preferable for large area PLD applications. For example, trying to coat a 200 mm diameter wafer with a 1" or 2" target will lead to very poor film uniformity and irreproducible results.

Film type

PLD is used to deposit a very wide range of materials. Most users are depositing a wide range of multi-component oxide materials such as YBCO, $BaSrTiO_3$, etc. However, basic oxides such as CeO_2, TiO_2, HfO_2, Ta_2O_5, etc. can easily be deposited by PLD. Carbides and nitrides have also been deposited via PLD. Variants of PLD such as Matrix Assisted Pulsed Laser Evaporation (MAPLE) and Resonant IR Pulsed Laser Evaporation (RIRPLE) have been used to deposit a wide variety of polymer and biological thin films.



Base vacuum of chamber

The base vacuum of a deposition chamber will also drive the cost of the system. Typical base pressures of PLD systems are in the 10^{-7} to 10^{-9} Torr range. Turbo pumps are usually the pump of choice for PLD systems.

Wafer heating and manipulation

A number of applications require substrates to be cooled to liquid nitrogen temperatures or heated to very high temperatures for epitaxial films, sometimes in excess of 900°C. Also, in order to achieve excellent film uniformity, substrate rotation and laser beam rastering are typically used. In some cases, planetary-type substrate holders are used with multiple gears and motor drives, feedthroughs, etc. These can be used in both heated and cooled applications.

Laser selection

Pulsed laser deposition is routinely conducted with a wide variety of lasers. Most PLD is carried out using an excimer laser with KrF gas emitting at 248 nm and pulse lengths ˜20 nsec. Other lasers, such as Q-switched Nd:YAG's, whose frequency can be quadrupled to lase at 266 nm, will provide low average power with a Gaussian beam shape, which is usually bad for the PLD process. However, these lasers are commonly used. Other lasers, such as fs and ps lasers, are also being evaluated and vary in cost from $100,000 to well over $750,000. Thus, one must have a good reason to select one of these more exotic lasers for a specific application. As noted above, MAPLE and RIRPLE typically use lasers in the IR range. Thus, Nd:YAG, Er:YAG, and a variety of lasers that are tunable in the IR have been used.

The power requirements of the laser are another selection the user must make. For excimer lasers, as substrate size grows the average deposition rate will drop for a fixed power laser. PVD Products recommends between 7 and 30 Watt lasers for substrates up to 2" in diameter, 30 watt lasers for substrates up to 4" in diameter, and higher power lasers for larger areas in order to obtain useful deposition rates for most materials. Of course, if very thick films are desired or materials with low deposition rates are used, higher power lasers than those suggested above may be required. Nd:YAG lasers operating on the fourth harmonic have low power and should only be used for small area deposition. Both ps and fs lasers come in all sorts of power levels, and prices and requirements should be carefully considered in order to choose the right laser for your application.

Load locks

Load locks are usually a cost-effective solution to increasing the throughput of your deposition system. By using a load lock, the throughput can be easily increased multi-fold. Load locks come in single wafer or multi-wafer varieties. A single wafer load lock is most common for R&D and provides fast substrate turnaround times, without having to wait for the main chamber to pump down to base vacuum. In production applications, multi-wafer load locks, robotic handlers, and large load locks with larger pumps can very quickly increase the cost of systems. For instance, automated multi-wafer load locks for inserting uncoated wafers into a system allow the system to run unattended for a long period to time with proper software. Such systems greatly increase throughput, but come with a high cost.

In-situ metrology

Laser deposition is used in a number of applications to grow very high quality epitaxial films. Thus, like MBE, RHEED is incorporated as the one metrology tool that provides a clear indication of how the film being deposited. However, the pressure in PLD is orders of magnitude higher than that in MBE. This requires the RHEED gun to include two stages of differential pumping and the RHEED screen to be re-entrant within the chamber to minimize the overall path of the electron beam. Considering that RHEED is an expensive tool to start with, adding differential pumping, valves, vacuum gauges, and leaded glass for safety drives the cost up quickly. Growing epitaxial films usually requires high substrate temperature, so the heater power supply needs to run DC to minimize magnetic field fluctuations when carrying out RHEED. Other metrology such as in-situ ellipsometry and Auger Electron Spectroscopy can also add significantly to the overall cost of a machine.