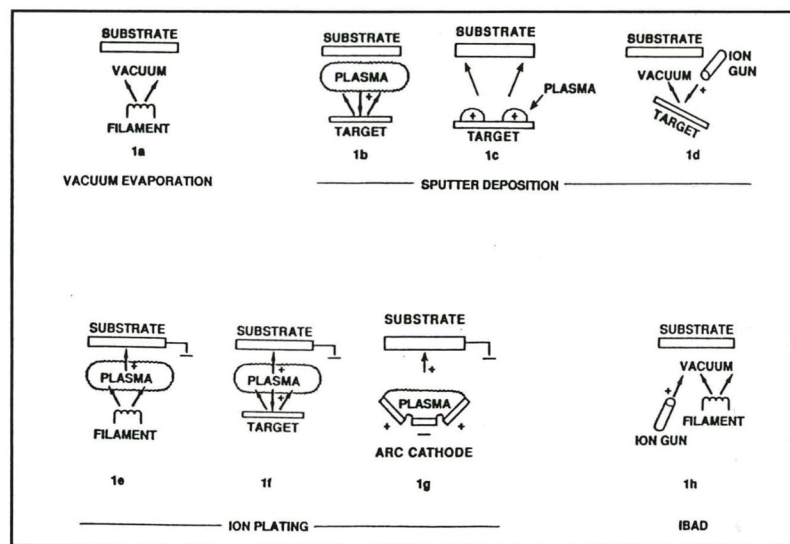


HANDBOOK OF PHYSICAL VAPOR DEPOSITION (PVD) PROCESSING

Film Formation, Adhesion, Surface Preparation
and Contamination Control



by
Donald M. Mattox

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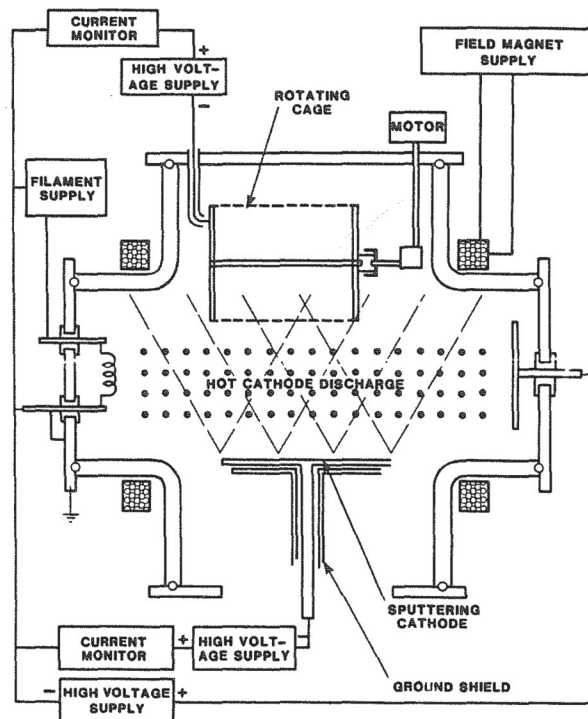


Figure 4-6. Barrel ion plating system configuration with a triode DC discharge.

The DC diode discharge cannot be used to sputter dielectric target materials, since charge buildup on the cathode surface will prevent bombardment of the surface. If there are reactive gases in the plasma their reaction with the target surface can lead to the formation of a surface that has a different chemical composition than the original surface. This change in composition leads to "poisoning" of the cathode surface and thus changes the plasma parameters. In the extreme, poisoning will cause bombardment of the cathode to cease due to surface charge buildup. If an insulating surface forms on the DC cathode, charge buildup will cause arcing over the surface.

The suppression of arcs generated in the DC discharge (arc suppression) are important to obtaining stable performance of the DC power supplies particularly when reactively sputter depositing dielectric films.^[46] Arcing can occur anytime a hot (thermoelectron emitting) spot is formed or when surface charging is different over surfaces in contact with the plasma. Arc suppression is obtained by momentarily turning off the power supply or by applying a positive bias when an arc is detected.

Pulsed DC

When a continuous DC potential is applied to a metal electrode completely covered with a dielectric material, the surface of the dielectric is polarized to the polarity, and nearly the voltage, of the metal electrode. If the surface potential is negative, ions are accelerated out of the plasma to bombard the surface giving sputtering, secondary electron emission, "atomic peening," and heating. However, since the secondary electron emission coefficient is less than one the surface will buildup a positive surface charge and the bombardment energy will decrease then bombardment will cease. This problem can be overcome by using a pulsed DC rather than a continuous DC.

Pulsed DC uses a potential operating in the range 50–250 kHz where the voltage, pulse width, off time (if used), and pulse polarity can be varied.^[47] The voltage rise and fall is very rapid during the pulse. The pulse can be unipolar, where the voltage is typically negative with a no-voltage (off) time, or bipolar where the voltage polarity alternates between negative and positive perhaps with an off time. The bipolar pulse can be symmetric, where the positive and negative pulse heights are equal and the pulse duration can be varied or asymmetric with the relative voltages being variable as well as the duration time.^[48] Figure 4-7 shows some DC waveforms. Generally in asymmetric pulse DC sputter deposition, the negative pulse (e.g., -400 V) is greater than the positive pulse (e.g., +100 V) and the negative pulse time is 80–90% of the voltage cycle and the positive pulse is 20–10% of the voltage cycle.

In pulse DC sputtering, during the positive bias (and off-time), electrons can move to the surface from the plasma and neutralize any charge build-up generated during the negative portion of the cycle. During the negative portion of the cycle, energetic ion bombardment can sputter dielectric surfaces.

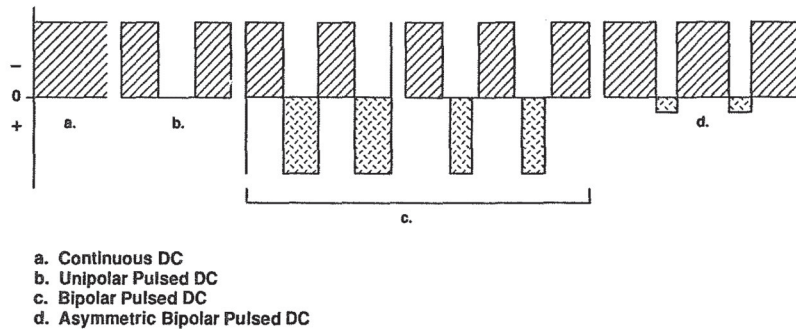


Figure 4-7. DC waveforms.

Pulsed DC power can be obtained by switching a continuous DC or sinewave power supply with auxiliary electronics^[49] or can be obtained from a specially designed pulsed power supply that generally allows more flexibility as to waveform. The pulsed power supply generally incorporates arc suppression that operates by turning off the voltage or by applying a positive voltage when the arc initiates. Pulsed plasmas are also of interest in plasma etching and plasma enhanced CVD (PECVD).^[50]

4.4.4 Magnetically Confined Plasmas

Balanced Magnetrons

In surface magnetron plasma configurations the electric (E) (vector) and magnetic (B) (vector) fields are used to confine the electron path to be near the cathode (electron emitting) surface. An electron moving with a component of velocity normal to the magnetic field will spiral around the magnetic field lines and its direction will be confined by the magnetic field. The frequency of the spiraling motion and the radius of the spiral will depend on the magnetic field strength. The interaction of an electron with the electric and magnetic fields depends on the magnitude and vector orientation of the fields ($E \times B$). For example, if the magnetic field is parallel to a surface and the electric field is normal to the surface an electron leaving the surface will be accelerated away from the surface and will spiral around the magnetic field. There will also be a resulting motion

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Physical Sputtering and Sputter Deposition (Sputtering)

6.1 INTRODUCTION

The physical sputtering (sputtering) process, or pulvérisation as the French call it, involves the physical (not thermal) vaporization of atoms from a surface by momentum transfer from bombarding energetic atomic-sized particles. The energetic particles are usually ions of a gaseous material accelerated in an electric field.^[0a] Sputtering was first observed by Grove in 1852 and Pulker in 1858 using von Guericke-type oil-sealed piston vacuum pumps. The terms “chemical sputtering” and “electrochemical sputtering” have been associated with the process whereby bombardment of the target surface with a reactive species produces a volatile species.^[1] This process is now often termed “reactive plasma etching” or “reactive ion etching” and is important in the patterning of thin films.^[2]

Sputter deposition, which is often called just sputtering (a poor use of the term), is the deposition of particles whose origin is from a surface (target) being sputtered. Sputter deposition of films was first reported by Wright in 1877 and was feasible because only a relatively poor vacuum is needed for sputter deposition. Edison patented a sputter deposition process for depositing silver on wax photograph cylinders in 1904. Sputter deposition was not widely used in industry until the need developed for reproducible,

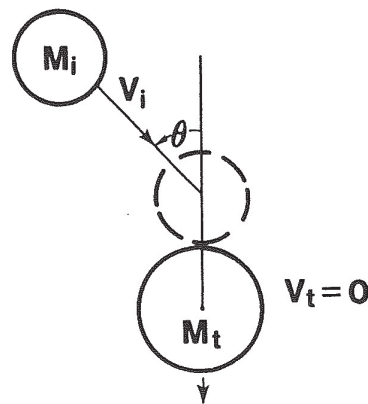


Figure 6-2. Collision of particles.

The maximum energy is transferred when $\cos \theta = 1$ (zero degrees) and $M_i = M_t$. Therefore matching the atomic mass of the bombarding ion to the target atom is important to the sputtering yield. This makes krypton (84 amu), xenon (131 amu) and mercury (201 amu) ions attractive for sputtering heavy elements, and light ions such as nitrogen (14 amu) unattractive. This advantage is typically outweighed by other considerations such as cost of the sputtering gas, health concerns or the desire to perform "reactive sputter deposition" of oxides and nitrides. It is interesting to note that much of the early work on sputtering was done using mercury ions.

Typically argon (40 amu) is used for inert gas sputtering since it is a relatively inexpensive inert gas. Mixtures of argon and nitrogen, argon and oxygen or argon and methane/acetylene are used for sputtering in reactive sputter deposition. In some cases, energetic ions of the target material can bombard the target producing "self-sputtering." This effect is important in ion plating using ionized condensable ions ("film ions") formed by arc vaporization or by post-vaporization ionization of sputtered or thermally evaporated atoms.

6.2.2 Sputtering Yields

The sputtering yield is the ratio of the number of atoms ejected to the number of incident bombarding particles and depends on the chemical bonding of the target atoms and the energy transferred by collision. The

material is removed from the target layer-by-layer. This allows the deposition of some rather complex alloys such as W:Ti for semiconductor metallization,^[86] Al:Si:Cu for semiconductor metallization,^[87] and M(etal)-Cr-Al-Y alloys for aircraft turbine blade coatings.

6.5.2 Reactive Sputter Deposition

Reactive sputter deposition from an elemental target^{[88][89]} relies on: (a) the reaction of the depositing species with a gaseous species, such as oxygen or nitrogen, (b) reaction with an adsorbed species, or (c) reaction with a co-depositing species such as carbon to form a compound. The reactive gas may be in the molecular state (e.g., N₂, O₂) or may be “activated” to form a more chemically reactive or more easily adsorbed species. Typically, the reactive gases have a low atomic masses (N=14, O=16) and are thus not effective in sputtering. It is therefore desirable to have a heavier inert gas, such as argon, to aid in sputtering. Mixing argon with the reactive gas also aids in activating the reactive gas by the Penning ionization/excitation processes.

Typically, a problem in reactive sputter deposition is to prevent the “poisoning” of the sputtering target by the formation of a compound layer on its surface.^[31] Poisoning of a target surface greatly reduces the sputtering rate and sputtering efficiency. This problem is controlled by having a high sputtering rate (magnetron sputtering) and controlling the availability of the reactive gas, such that there will be enough reactive species to react with the film surface to deposit the desired compound, but not so much that it will unduly poison the target surface.

The appropriate gas composition and flow for reactive sputter deposition can be established by monitoring the partial pressure of the reactive gas as a function of reactive gas flow,^{[90]–[93]} or by impedance of the plasma discharge. Figure 6-8 shows the effect of reactive gas flow on the partial pressure of the reactive gas in the reactive sputter deposition of TiN. Under operating conditions of maximum flow and near-minimum partial pressure, the deposit is gold-colored TiN and the sputtering rate is the same as metallic titanium. At higher partial pressures, the sputtering rate decreases and the film is brownish. As the target is poisoned, the deposition rate decreases. When the nitrogen availability is decreased, the target is sputter-cleaned and the deposition rate rises.

The gas composition should be determined for each deposition system and fixture geometry. A typical mixture for reactive sputter

deposition might be 20% nitrogen and 80% argon where the partial pressure of nitrogen during deposition is 2×10^{-4} Torr and the total gas flow is 125 sccm. Gases mixtures are typically controlled using individual mass flow meters on separate gas sources though specific gas mixtures can be purchased. Figure 6-9 depicts a typical reactive sputter deposition system.

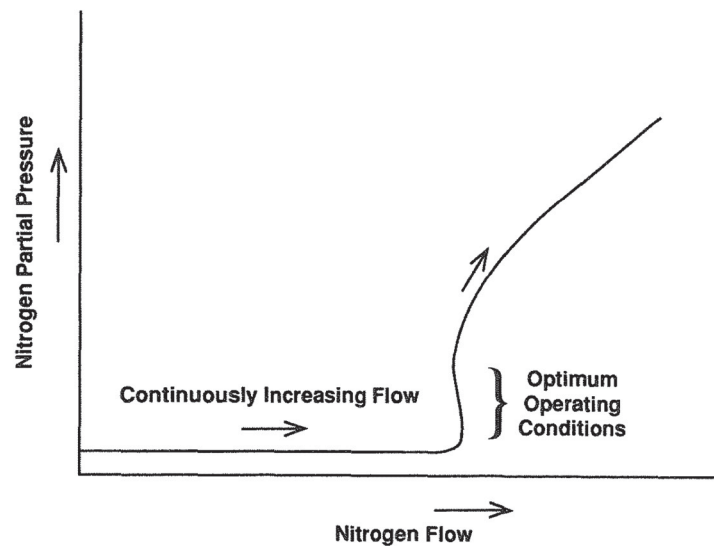


Figure 6-8. Nitrogen partial pressure and flow conditions for the reactive sputter deposition of TiN with constant target power (adapted from Ref. 51).

In reactive deposition, the reactive gases are being pumped (“getter pumping”) by the depositing film material. Since the depositing film is reacting with the reactive gas, changes in the area or rate of the film being deposited will change the reactive gas availability and the film properties. Thus, it is important to use the same fixture, substrate, and vacuum surface areas as well as deposition rate, in order to have a reproducible reactive sputter deposition process. Changes in the geometry (loading factor) or deposition rate will necessitate changes in gas flow parameters.^[90] The gas density (partial pressure) of the reactive gas in the plasma can be monitored by optical emission spectroscopy or mass spectrometry techniques.^{[91]–[93]}

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Since gas pressure is important to the properties of the sputter deposited film it is important that the vacuum gauge be periodically calibrated and located properly and pressure variations in the chamber be minimized.

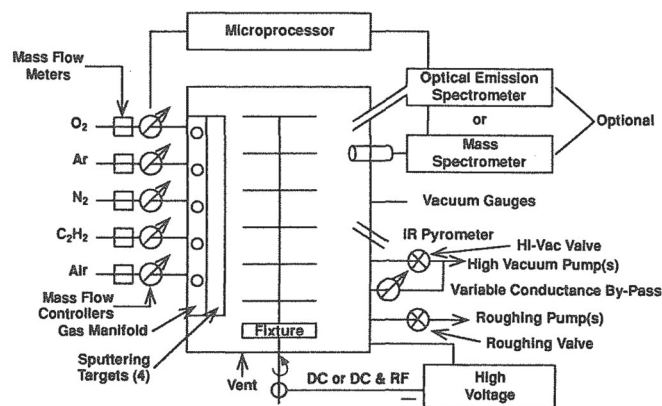


Figure 6-9. Typical reactive sputter deposition system.

In some reactive deposition configurations, the inert gas is injected around the sputtering target and the reactive gas is injected near the substrate surface. This inert "gas blanket" over the target surface is helpful in reducing target poisoning in some cases.

In reactive deposition, the depositing material must react rapidly or it will be buried by subsequent depositing material. Therefore, the reaction rate is an important consideration. The reaction rate is determined by the reactivity of the reactive species, their availability, and the temperature of the surface. The reactive species can be activated by a number of processes including:

- Dissociation of molecular species to more chemically reactive radicals (e.g., $N_2 + e^- \rightarrow 2N^0$ and $NH_3 + e^- \rightarrow N^0 + 3H^0$)
- Production of new molecular species that are more chemically reactive and/or more easily absorbed on surfaces (e.g., $O_2 + e^- \rightarrow 2O^0$ then $O^0 + O_2 \rightarrow O_3$)

- Production of ions—recombination at surfaces releases energy
- Adding internal energy to atoms and molecules by creating metastable excited states—de-excitation at surfaces releases energy
- Increasing the temperature of the gas
- Generating short wavelength photons (UV) that can stimulate chemical reactions
- Generating energetic electrons that stimulate chemical reactions
- Ions accelerated from the plasma to the surface promotes chemical reactions on the surface (bombardment enhanced chemical reactions)

The extent to which a plasma can activate the reactive gases and provide ions for concurrent bombardment depends on the properties of the plasma and its location. In many sputtering systems the plasma conditions vary widely throughout the deposition chamber. This is particularly true for the magnetron configurations where the sputtering plasma is confined near the target. In such a case, a plasma needs to be established near the substrate surface to activate reactive gases and provide ions for concurrent bombardment. This can be done using an unbalanced magnetron configuration, application of an rf to the target, or by establishing a separate auxiliary plasma over the substrate surface.

The reaction probability is also a function of the surface coverage. For example, it is easier for an oxygen species to react with a pure titanium surface than with a $\text{TiO}_{1.9}$ surface. Figure 6-10 shows the effect of reactive nitrogen availability on the electrical resistivity of TiN_x films. The films have minimum resistivity when the composition is pure titanium and when the composition is near TiN .

Another important variable in reactive deposition is concurrent bombardment of the depositing/reacting species by energetic ions accelerated from the plasma (“sputter ion plating” or “bias sputtering”). Concurrent bombardment enhances chemical reactions and can densify the depositing film if unreacted gas is not incorporated into the deposit. Bombardment is obtained by having the surface at a negative potential (applied bias or self-bias) so that ions are accelerated from the plasma to the surface. Figure 6-11 shows the relative effects of deposition temperature and applied bias on the electrical resistivity (normalized) of a TiN_x film.^[94] The lowest resistivity is attained with both a high deposition temperature and concurrent bombardment although a low-temperature deposition with concurrent bombardment comes close.

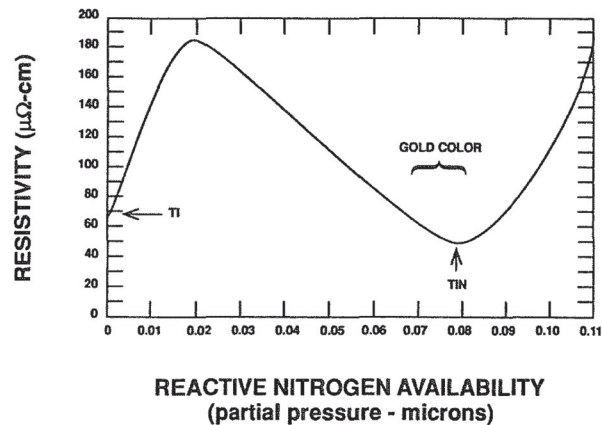


Figure 6-10. TiN resistivity as a function of nitrogen content (nitrogen availability during deposition). (Adapted from Ref. 94.)

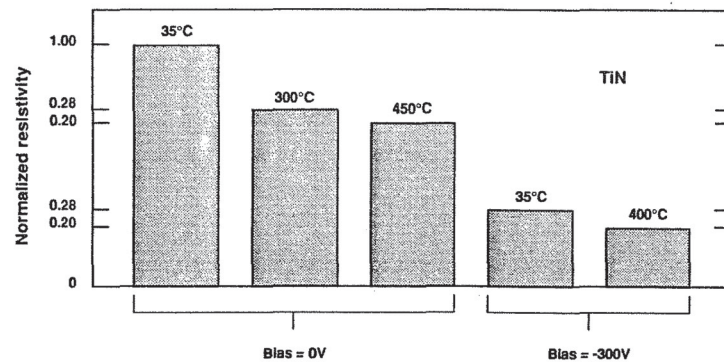


Figure 6-11. TiN resistivity as a function of deposition temperature and concurrent bombardment (adapted from Ref. 94).

Reactive deposition is used to produce colored wear-resistant decorative coatings such as TiN (gold), TiC_xN_y (bronze, rose, violet, or black as x and y are varied) and ZrN (brass). Coatings such as TiN and $(\text{Ti,Al})\text{C}_x\text{N}_y$ are used as wear-resistant coatings on tools, molds, and other surfaces. Reactive deposition is used to produce oxide films such as ZrO_2 and TiO_2 , which are used to form anti-reflection and band-pass coatings on optical

components, indium-tin-oxide (ITO), is a transparent electrical conductor and $\text{SiO}_{1.8}$, is a material of interest as a transparent, moisture-permeation-barrier materials for packaging applications.

The co-depositing material for reactive deposition can be from a second sputtering target. However it is often in the form of a chemical vapor precursor which is decomposed in a plasma and on the surface. Chemical vapor precursors are such materials as acetylene (C_2H_2) or methane (CH_4) for carbon, silane (SiH_4) for silicon, and diborane (B_2H_6) for boron. This technique is thus a combination of sputter deposition and plasma enhanced chemical vapor deposition and is used to deposit materials such as the carbides, borides, and silicides.^[95] It should be noted that co-deposition does not necessarily mean reaction. For example, carbon can be deposited with titanium to give a mixture of $\text{Ti} + \text{C}$ but the deposit may have little TiC .

In reactive sputtering, the injection of the reactive gas is important to insure uniform activation and availability over the substrate surface. This can be difficult if, for instance, the film is being deposited over a large area such as on 10' x 12' architectural glass panels where the sputtering cathode can be twelve feet or more in length. In such an application, it may be easier to use quasi-reactive sputtering from a compound target.

In "quasi-reactive sputter deposition" the sputtering target is made from the compound material to be deposited and a partial pressure of reactive gas in a plasma is used to make-up for the loss of the portion of the gaseous constituent that is lost in the transport and condensation/reaction processes. Typically the partial pressure of the reactive gas used in quasi-reactive deposition is much less than that used for reactive deposition. For example, the gas composition might be 10% oxygen and 90% argon.

6.5.3 Deposition of Layered and Graded Composition Structures

Layered structures can be deposited by passing the substrate in front of several sputtering targets sequentially. For example, X-ray diffraction films are formed by depositing thousands of alternating layers of high-Z (W) and low-Z (C) material with each layer being about 30Å thick.

Layered and graded composition structures can be deposited using reactive deposition. The composition is changed by changing the availability of the reactive gas. Thus one can form layers of Ti-TiN-Ti by changing the availability of the nitrogen. Since nitrogen has been incorporated in the

6.6.4 Ion and Plasma Sources

In some types of reactive sputter deposition, a few monolayers of a pure metal are deposited and then the substrate is passed in front of a source of the reactive species. By doing this repeatedly, a compound film can be built-up. The source for reactive gas is generally a plasma source, such as a gridless end-Hall source, where the gas is activated and, in some cases, reactive ions are accelerated to the substrate (Sec. 4.5.1). An easy configuration for doing this is to mount the substrates on a drum and repeatedly rotate them in front of the sputtering source and the reactive gas source such as with the MetaMode™ deposition configuration.^[101]

6.6.5 Plasma Activation Using Auxiliary Plasmas

Activation of the reactive species enhances chemical reactions during reactive deposition. The plasma used in sputtering will activate the reactive gases but often the plasma volume is small or not near the substrate surface. Configurations such as the unbalanced magnetron can expand the volume. Auxiliary electron sources can be used to enhance the plasma density between the target and the substrate.^[102] Magnetic fields in the vicinity of the substrate can also be used to enhance reactive gas ionization and bombardment. For example using a magnetic field (100G) in the vicinity of the substrate, the ion flux was increased from 0.1 ma/cm² to 2.5 ma/cm² in the unbalanced magnetron reactive sputter deposition of Al₂O₃.^[103]

6.7 TARGETS AND TARGET MATERIALS

For demanding applications, a number of sputtering target properties must be controlled in order to have reproducible processing.^[104] The cost of large-area or shaped sputtering targets can be high. Sometimes by using a little ingenuity, cheaper configurations can be devised such as making large plates from overlapping mosaic tile, rods from stacked cylinders, etc. Conformal targets, which conform to the shape of the substrate, may be used to obtain uniform coverage over complex shapes and in some instances may be worth the increased cost.

6.7.1 Target Configurations

Targets can have many forms. They may have to be of some predetermined shape to fit supplied fixtures or be conformal to the substrate shape. For example conformal targets may be a sector of a cone for coating a rotating cone, hemispherical to coat a hemisphere, axial rod to coat the inside of a tube, etc. The targets may be moveable or be protected by shutters to allow “pre-sputtering” and “conditioning” of the target before sputter deposition begins. Common sputtering target configurations are the planar target, the hollow cylindrical target, the post cathode, the conical target, and the rotating cylindrical target.^{[105][106]}

A single target may be used to deposit alloys and mixtures by having different areas of the target be of different materials. For example, the mosaic target may have tiles of several materials, the rod target may have cylinders of several materials, etc. The composition of the film can then be changed by changing the area ratios. When using this type of target, the pressure should be low so that backscattering does not give “cross-talk” between the target areas. If cross-talk occurs, the sputtering rates may change as one material is covered by the other which has a lower sputtering rate.

Multiple targets allow independent sputtering of materials and can be used to allow deposition of layers, alloys, graded compositions, etc. If both the targets and the substrates are stationary, the flux distribution from each target must be considered. Often when using large area targets, the substrates are rotated sequentially in front of the targets to give layered structures and mixed compositions.

Targets of different materials can have different plasma characteristics in front of each cathode.^[107] This can be due to differing secondary electron emission from the target surfaces. If the substrates are being rotated in front of the sputtering target(s), changes in the plasma may be observed depending of the position of the fixture, particularly if the fixture has a potential on it.

“Serial co-sputtering” is a term used for a deposition process where material from one sputtering target is deposited onto another sputtering target from which it is sputtered to produce a graded or mixed composition. Serial co-sputtering can be done continuously if the second target is periodically rotated in front of the first target and then in front of the substrate.^[108]

giving a porous material, and act as virtual leaks and contaminant sources. Porous targets can adsorb contaminants such as water and introduce a processing variable which may be difficult to control. For materials with poor thermal conductivity, thin targets are more easily cooled than thick targets thus reducing "hot-spots" and the tendency to fracture.

Targets which have been formed by vacuum melting (metals) or chemical vapor deposition (metals, compounds) are generally the most dense. Less dense targets are formed by sintering of powders in a gaseous or vacuum atmosphere with hot isostatic pressing (HIP) producing the most dense sintered product. Sintering sometimes produces a dense surface layer ("skin") but the underlying material may be less dense and this material becomes exposed with use. In some cases, it may be useful to specify the outgassing rate of the target as a function of temperature.

When using alloy or compound targets care must be taken that the target is of uniform composition, that is be homogeneous. This is particularly a problem when sputtering magnetic alloy material such as Co,Cr,Ta; Co,Ni,Cr,Ta; CoCr,Pt; Co,Fe,Tb; or Co,Cr,Ni,Pt where material distribution in the target is extremely important. In some cases, the composition of the deposited material may be different from that of the target material in a reproducible way due to preferential loss of material. Common examples of this problem are: ferroelectric films of BaTiO_3 ,^[113] superconducting films such as $\text{YBa}_2\text{Cu}_3\text{O}_7$, and magnetic materials such as $\text{Gd}_2\text{Fe}_{17}$.^[114] In the case of alloy deposition, the change in composition may be compensated for by changing the target composition so as to obtain the desired film composition.^[115]

Second phase particles in the target can lead to the development of cones on the target surface during use due to the differing sputtering rates of the matrix material and the second phase particles. Also, second phase material in the target appears to influence the nucleation of the sputter-deposited material, possibly due to the sputtering of molecular species from the target.^[116] Second phase precipitates can be detected using electrical conductivity measurements.^[117]

In some cases, metal plates are rolled to a specific thickness to form the sputtering target. This can introduce rolling stresses and texturing that should be annealed before the plate is shaped to final dimensions. Annealing can cause grain growth which may be undesirable.

The grain size and orientation of the target material can affect the distribution of the sputtered material and the secondary electron emission from the target surface. The distribution of sputtered material is important

it may be due to preferential sputtering combined with a high surface mobility of the un-sputtered constituent on the surface. The mobile species form islands on the target surface and they grow with time. A high target temperature contributes to this effect. To restore the target surface the smut can be wiped off.

Surface mobility can also cause the formation of nodules on the surface. For example, sputtering targets of indium-tin-oxide develop nodules on the surface with use. The origin of these nodules is uncertain and they must be machined off periodically.

6.7.7 Target Conditioning (Pre-Sputtering)

Generally the surface of the sputtering target is initially covered with a layer of oxide or contaminants and may be “pre-sputtered” before deposition begins. This pre-sputtering can be done with a shutter between the target and the substrate or by moving the substrate out of the deposition region while pre-sputtering of the target is being performed. When voltage-controlled power is first applied to a metal target, the current will be high and drop as the discharge comes to equilibrium.^[124] The initially high current is due to the high secondary emission of the metal oxide as compared to the clean metal and the high density of the cold gas. As the oxide is removed from the surface and the gas heats up, the current density will fall. This target conditioning can introduce contaminant gas into the plasma. One advantage in using a lock-load deposition system is that the sputtering target can be maintained in a controlled environment at all times and pre-sputtering becomes less of a processing variable from run-to-run.

6.7.8 Target Power Supplies

Target power supplies may be DC, AC, pulsed DC, rf, DC + rf, etc. Continuous DC and AC power supplies are generally the most inexpensive. Unipolar pulsed DC can be generated by chopping (interrupting) the continuous DC. Bipolar DC requires a special power supply. Continuous DC and low-frequency AC power supplies require an arc suppression (quenching) circuitry to prevent voltage transients from feeding back into the power supply and blowing the diodes. Arc suppression can be done by cutting off the voltage or by reversing the voltage polarity for a short period of time.

purity from the supplier. Inert gases can be purified by passing them over a hot bed of reactive material such as titanium or uranium. Commercial gas purifiers are available that can supply up to 5×10^3 sccs. Moisture can be removed from the gas stream by using cold zeolite traps. Gas purifiers should be routinely used on all sputtering systems in order to ensure a reproducible processing gas. Distribution of the gases should be in non-contaminating tubing such as Teflon™ or stainless steel. For critical applications, the stainless steel tubing can be electropolished and a passive oxide formed. Particulates in the gas line can be eliminated by filtration near the point-of-use.

6.9.7 Contamination from Deposited Film Material

When a sputtering system is used for a long time or high volumes of materials are sputtered, the film that builds up on the non-removable surfaces in the system increases the surface area and porosity. This increases the amount of vapor contamination that can be adsorbed and retained on the surface. This source of contamination can be reduced by periodic cleaning and controlling the availability of water vapor during process cycling either by using a load-lock system or by using heated system walls when the system is opened to the ambient (Sec.3.12.2).

The film buildup can also flake-off giving particulate contamination in the deposition system.^[141] Fixturing should be positioned such that particulates that are formed do not fall on the substrate surface. The effects of contamination from this source can be minimized by having the substrate facing downward or sideways during deposition. The system should be periodically “vacuumed” using a HEPA-filtered vacuum cleaner. The use of a “soft-rough” and a “soft-vent” valve minimizes “stirring-up” the particulate contamination in the system.

6.10 ADVANTAGES AND DISADVANTAGES OF SPUTTER DEPOSITION

Advantages in some cases:

- Any material can be sputtered and deposited—e.g., element, alloy or compound.

- Substrate heating from electron bombardment can be high in some configurations.
- Substrates and films may be bombarded by short wavelength radiation and high energy particles that are detrimental to their performance.
- Contaminants on surfaces in the deposition chamber are easily desorbed in a plasma-based sputtering due to heating and ion scrubbing.
- Gaseous contaminants are “activated” in plasma-based sputtering and become more effective in contaminating the deposited film.
- When using chemical vapor precursors the molecules can be dissociated or partially dissociated in the plasma to generate “soot.”
- High energy reflected neutrals in low-pressure and vacuum sputtering can be an important, but often uncontrolled, process variable.

6.11 SOME APPLICATIONS OF SPUTTER DEPOSITION

Some applications of sputter deposited films are:^[142]

- Single and multilayer metal conductor films for microelectronics and semiconductor devices, e.g. Al, Mo, Mo/Au, Ta, Ta/Au, Ti, Ti/Au, Ti/Pd/Au, Ti/Pd/Cu/Au, Cr, Cr/Au, Cr/Pd/Au, Ni-Cr, W, W-Ti/Au, W/Au
- Compound conductor films for semiconductor electrodes, e.g., WSi_2 , TaSi_2 , MoSi_2 , PtSi
- Barrier layers for semiconductor metallization, e.g., TiN, W-Ti
- Magnetic films for recording, e.g. Fe-Al-Si, Co-Nb-Zr, Co-Cr, Fe-Ni-Mo, Fe-Si, Co-Ni-Cr, Co-Ni-Si
- Optical coatings—metallic (reflective, partially reflective), e.g. Cr, Al, Ag
- Optical coatings—dielectric (antireflective and selective reflective), e.g., MgO, TiO_2 , ZrO_2

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- Transparent electrical conductors, e.g., InO_2 , SnO_2 , In-Sn-O (ITO)
- Electrically conductive compounds, e.g., Cr_2O_3 , RuO_2
- Transparent gas/vapor permeation barriers, e.g., SiO_{2-x} , Al_2O_3
- Diffraction gratings, e.g. C/W
- Photomasks, e.g., Cr, Mo, W
- Wear and erosion resistant (tool coatings), e.g., TiN, (Ti-Al)N, Ti(C-N), CrN, Al_2O_3 , TiB_2
- Decorative, e.g., Cr, Cr alloys, copper-based alloys (gold colored)
- Decorative and wear-resistant, e.g., TiC, TiN, ZrN, Ti(C-N), (Ti-Al)N, Cr, Ni-Cr, CrN, HfN
- Dry lubricant films—electrically nonconductive, e.g., MoS_2
- Dry lubricant films—electrically conductive, e.g., WSe_2 , MoSe_2
- Freestanding structures^[143]

6.12 SUMMARY

Sputtering is generally more expensive than vacuum evaporation and the choice of the use of sputter deposition generally involves utilizing one or more of its advantages such as being a long-term source of vapor, allowing a close source-substrate spacing, low substrate heating or providing reactive deposition conditions.

FURTHER READING

Plasma Deposition, Treatment and Etching of Polymers, (R. d'Agnostino, ed.) Academic Press (1991)

Wasa, K. and Hayakawa, S., *Handbook of Sputter Deposition Technology*, Noyes Publications (1991)

Handbook of Ion Beam Processing Technology, (J. J. Cuomo, S. M. Rossmagel, and H. R. Kaufman, eds.), Noyes Publications (1989)