

Physical Vapour Deposition Fundamentals and Technical Aspects

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ABSTRACT

The principles of the physical vapour deposition processes (PVD; evaporation, sputting, and ion plating) are presented and compared with each other with respect to coating properties, deposition rate and process control. The significance of coating sources and vacuum equipment for hard materials coatings is discussed.

1. Introduction

Since the beginning of technical development, men tried to improve the surface properties of materials by coating them in order to get a bright, colourful, illustre, corrosion-resistant or wear-resistant surface. Examples might be the gold leaf coating of statues and iron hoops on wodden wheels. The modern technology would be unthinkable without coatings. Well-known techniques are e.g. hot-galvanizing, hot-dipping, electroplating and plasma spraying. With the increasing demand for thin layers of outstanding properties in many fields and with the enhanced vacuum technology the deposition of coatings from the vapour phase becomes more and more

important and is increasingly used in a wide-spread field of applications. The deposition processes can principally be divided into CVD (chemical vapour deposition) and PVD (physical vapour deposition). In CVD processes the coatings were formed by chemical reactions of molecules of the reacting gaseous species on the substrate surface (e.g. $\text{TiCl}_4(\text{g}) + \text{CH}_4 = \text{TiC}(\text{s}) + 4 \text{HCl}(\text{g})$). Such reactions normally need substrate temperatures of 800 °C and higher. By additional application of plasma discharges (PACVD = Plasma-Assisted CVD) and/or metal-organic compounds as starting materials the substrate temperatures can be lowered to about 400 °C. In contrary, the PVD processes need no specific substrate temperature. Especially

because of this fact, PVD processes gain increasing importance in recent time. Furthermore, they show the advantage of an easy process control, of large variability with respect to coating composition and properties by suitable choice of process parameters, of a low degree of impurities and, last not least, of low environmental pollution. In the present paper the fundamentals of the different PVD processes and the influence of the different process parameters on the properties of the coatings will be discussed. Special emphasis will be laid on the deposition of hard coatings. Finally, some remarks are made on the technical realization of the PVD processes.

Hard coatings (e.g. nitrides, carbides, oxides) are mostly deposited by "reactive" PVD processes, i.e. the metal component is transferred into the gas phase by evaporation or ion bombardment (sputtering) while the metalloid component is introduced as a gas into the reaction vessel (e.g. N_2 , CH_4 , O_2). The compound layer is basically formed on the substrate surface by the reaction of the deposited (condensed) metal atoms with the gas component. In some cases also hard material targets can be used as starting material, which are evaporated or sputtered.

2. PVD Processes

For the deposition of thin films a number of plasma- and ion-assisted vacuum deposition techniques were developed. These processes can principally be divided into three types, i.e. evaporation, sputtering, and ion plating. All three processes can be run as reactive processes.

The efficiency of the processes and the properties of the films depend on the specific deposition apparatus, on the gas phase, and on the voltages applied to the different electrodes. According to a specific purpose, different processes can be preferable. In most cases of technical application all three processes basically are ion plating techniques because high-energetic particles are impinging the negatively biased substrate as a result of the partial ionization of the gas phase. For a more general information see refs. [1] [2].

2.1 Evaporation and activated reactive evaporation

In the evaporation process, vapours are produced from a material located in a source which is heated by direct resistance, eddy currents, electron beam or an arc discharge. The process is usually carried out in a vacuum of typically 10^{-5} - 10^{-6} mbar. Fig. 1 illustrates schematically the evaporation process. The

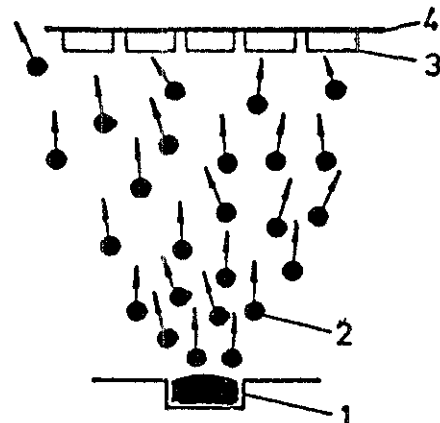


Fig. 1 Evaporation process (schematically)

- 1) source, 2) Metal atoms, 3) substrate,
- 4) substrate holder

atoms evaporated from the source undergo an essentially collisionless line-of-sight transport prior to condensation on the substrate, which is normally at ground potential.

The intensity distribution follows a cost-law (Fig. 2a) and depends on the source and power. Shaped parts have to be moved continuously during the coating procedure in order to avoid shadowing effects and to guarantee a uniform coating. The evaporation rates are strongly material- and temperature-dependent. The disadvantage occurring in alloy deposition can easily be seen, when the vapour pressures of the different components are strongly differing from each other. Fig. 2b shows some vapour

pressure-temperature curves.

In the case of reactive evaporation, the vacuum chamber is filled with a (flowing) low-pressure reactive gas atmosphere (e.g. N_2 , O_2 , $CmHn$, 10^{-3} mbar). The molecules of which react with the evaporated metal atoms and form the desired compound. The evaporation technique is markedly improved by introducing a glow discharge in the space between source and substrate (activated evaporation, Fig. 3). Electrons emitted from the source are accelerated towards a positive electrode (+ 200 V) and ionize the reacting species. The substrate itself is not negatively biased, but acts as a cathode with respect to the positive electrode. A certain

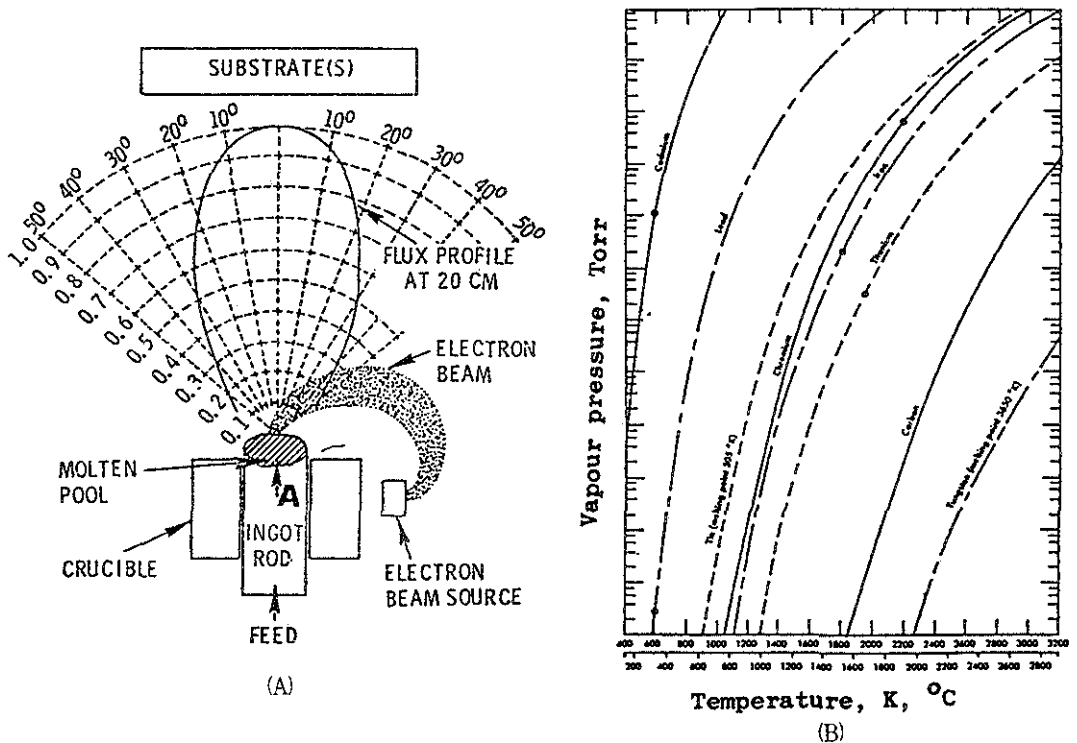


Fig. 2 Electron beam evaporation

- A) Distribution characteristics of an electron beam evaporation source
 B) Vapour pressure of metals as a function of reciprocal temperature

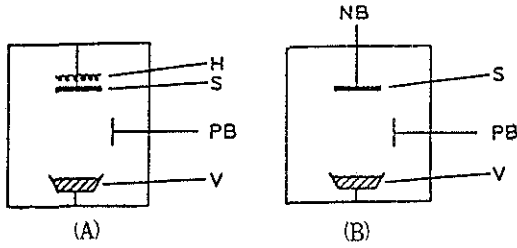


Fig. 3 Activated evaporation (schematically)
 A) Activated reactive evaporation (ARE)
 B) Biased activated reactive evaporation (BARE)
 (V) evaporator, (S) substrate, (H) heater, (PB),
 (NB) positive, negative bias

percentage of the impinging species now impinges as ions. Applying a negative bias to the substrate results in an impact of accelerated ions on the substrate surface (BARE - Biased Activated Reactive Evaporation).

2.2 Sputtering

In the sputtering process, metal atoms are sputtered from the target surface in a glow discharge process at pressures of $20^{-3} - 5 \times 10^{-2}$ mbar. Fig. 4a illustrates schematically the conventional diode sputtering. The plasma consists of neutral and ionized argon atoms. By a negative potential of 1 - 5 kV at the target, Ar^+ ions are accelerated towards the target surface and sputter metal atoms predominantly by impuls transfer. The sputtered atoms condense at the substrate which also acts as anode. The sputter yield depends on target material, inert gas, and ion energy (see Fig. 5).

Because of the higher pressure in the reaction chamber the sputtered atoms undergo multiple collisions during the transfer from source to substrate, thus producing a reasonably uniform thickness of coating in part also "around the corner". This is advantageous for coating

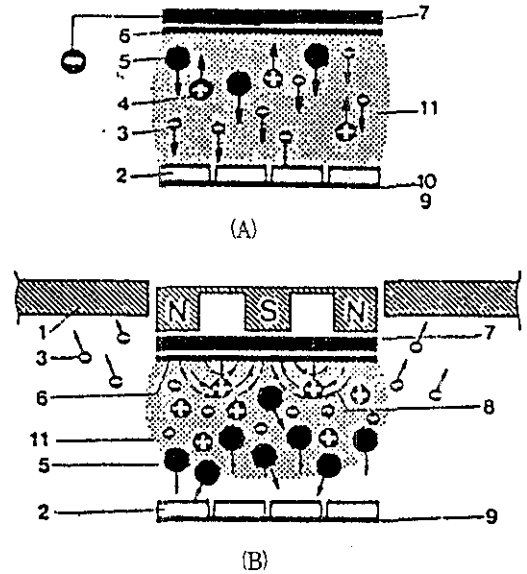


Fig. 4 Sputter deposition
 A) Diode sputtering
 B) Magnetron sputtering
 1) receiver wall, 2) substrate, 3) secondary electrons, 4) plasma ions, 5) metal atoms, 6) target, 7) cathode, 8) magnetic field, 9) substrate holder, 10) anode, 11) plasma

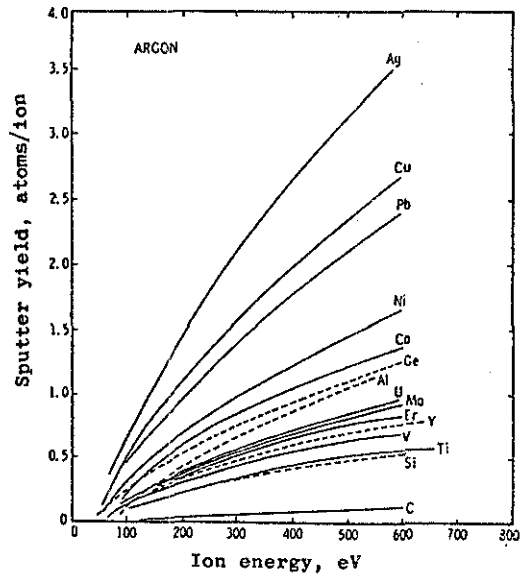


Fig. 5 Sputter yield of metals as a function of energy Ar^+ ions [5]

of shaped parts; the substrate motion, therefore, can be less complex than in the evaporation process. In reactive sputtering, a reactive gas is added to the sputtering atmosphere.

The schematic illustration of the diode sputter process (Fig. 4a) also shows that the substrates are exposed to an intensive bombardment by secondary electrons in addition to the atom and ion impingement. This results in a marked substrate heating which can be advantageous in some cases but complicates the use of conventional diode sputtering for substrates not stable at higher temperatures as in the case of microelectronics.

The deposition rate of diode sputtering, however, is often too low for a technical coating process [13]. This disadvantage is ruled out by the use of a magnet in the backside of the target as it is shown in Fig. 4b. In the high-rate sputtering (magnetron sputtering) the plasma is concentrated in a space near the target surface. The power transferable to the target is increased because of the interaction of the electrical field (perpendicular to the target surface) and the horizontal component of the magnetic field (parallel to the target surface). By the Lorentz force the electrons are forced to follow cycloidic paths resulting in an increased degree of ionization of the plasma. Also a part of the sputtered metal atoms is ionized. In comparison with the diode sputter process, the electron bombardment of the substrate is avoided or completely stopped. The electrons normally lead to grounded construction parts or auxiliary anodes.

The temperatures reached in a non-cooled substrate are in the range of 50 - 250 °C, but

can easily be elevated by appropriate techniques. Negative biasing of the substrates results in an additional ion bombardment (metal, argon, reactive gas), the advantages of which are discussed more in detail.

Coating of shaped parts by magnetron sputtering is markedly improved by a double cathode arrangement (Fig. 6a). Fig. 6b shows a comparison of the geometric relations for charged particle density, deposition rate and reactive gas partial pressure for both magnetron types. The abscissa represents the distance of the working part (here: sphere). For a single magnetron the deposition rate decreases with increasing distance target-substrate. The coating thickness, therefore, cannot be uniform at all parts of the work piece. This effect is even enhanced by shadowing effects. In reactive processes different film compositions result from the different deposition rates, because the partial pressure of the reactive gas can be assumed to be homogeneous in the total discharge space. The stoichiometry, however, depends on the ratio of impinging metal atoms and gas molecules. TiN layers, for example, can show different colours and hardness numbers across the coated surface. In comparison, the double cathode exhibits a central regime of widely uniform coating conditions due to the superposition of the different magnitudes. The width of this zone depends on the specific process parameters and is subject of process optimization and device conception. The extension of the plasma can be modified, so that the substrate is placed within or out of the plasma and, therefore, is heated more or less intensively resulting in a "hot" or "cold" coating process.

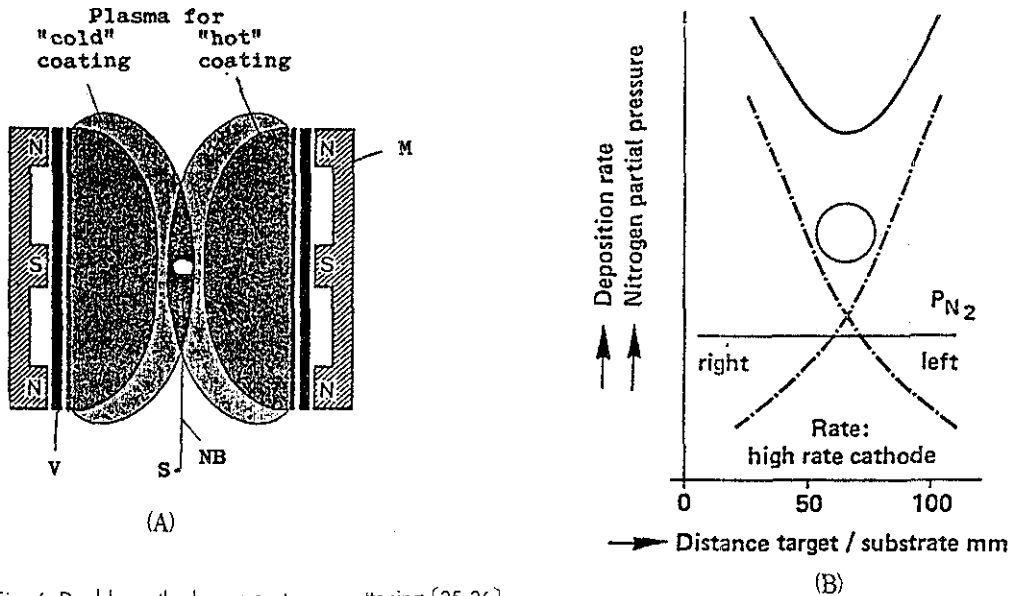


Fig. 6 Double cathode magnetron sputtering [25,26]

(A) Schematic arrangement of target and substrate

(B) Deposition rate, charged particle density, and N_2 partial pressure as a function of target/substrate distance substrate

V, target, S substrate, M Magnet, NB negative bias

2.3 Iron plating

Ion plating is a generic term applied to atomistic film deposition processes in which the substrate surface and the depositing film is subjected to a flux of high-energy particles causing changes in the interfacial region or film properties compared to the non-bombarded deposition. The ion plating process basically is independent of the source of the material to be depositing and on the origin of the bombarding species. In contrast to evaporation and sputtering, the substrate or substrate holder generally is negatively biased. The vacuum chamber is filled with an inert gas or an inert/reactive gas mixture. In the original version (Mattox [14]) a glow discharge is formed by applying a high negative voltage (3 - 5 kV) to the substrates

(Fig. 7). This voltage causes a simultaneous resputtering. The continuous ion bombardment essentially yields the following effects: (i) Increasing adhesion, (ii) reduction of impurity

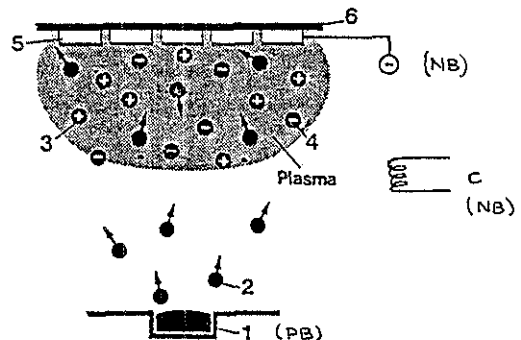


Fig. 7 Ion plating (schematically)

1) source, 2) metal atoms, 3) plasma ions,

4) electrons, 5) substrates, 6) substrate holder,

(C) hot cathode, (PB), (NB) positive and negative bias

incorporation, (iii) denser film structure, (iv) smoother film surface, (v) at pressures of 5×10^{-3} – 5×10^{-2} mbar an advantageous scattering of the species to be deposited yielding a better throwing power as already mentioned above for the sputter process.

The hollow cathode electron beam evaporation source, the arc evaporation source and the low-voltage electron beam evaporation source are particularly suitable for ion plating, because a high degree of in-situ ionization of the source material is caused by the low energy of the electrons used. An additional ionization, as used in other techniques, is not necessary.

The *hollow cathode evaporation source* consists of a refractory metal tube, in the interior of which a dense plasma in the inert atmosphere is created with assistance of a magnetic field. Electrons of about 200 eV are extracted and accelerated towards the target source (Fig. 8a). The evaporating atoms pass the space of high electron density and are ionized to a high degree due to the favourable electron energy.

The *arc evaporation source* shows similarly favourable conditions. An arc discharge is formed between the target material (cathode) and a suitably shaped anode (Fig. 8b). The arc is fed by the evaporating material, so that such a discharge can be maintained also under high-vacuum conditions. The arc moves randomly or in steered form across the cathode surface. Due to the high energy densities in the cathode spot, material (ions, atoms, droplets) is removed from the solid cathode. The cathode does not melt and, therefore, can be mounted in any position. The processes described take place only at the evaporator; the substrates, however, can be surrounded by a glow discharge. Due to the high degree of ionization of 20 to more than 50 % [15], no additional ionization is necessary in this ion plating process. Compound deposition by reactive ion plating is possible when a reactive gas is added.

Another favourable source is the *low voltage electron beam evaporator (Balzers process, Fig. 8c)*. The electrons are extracted from an

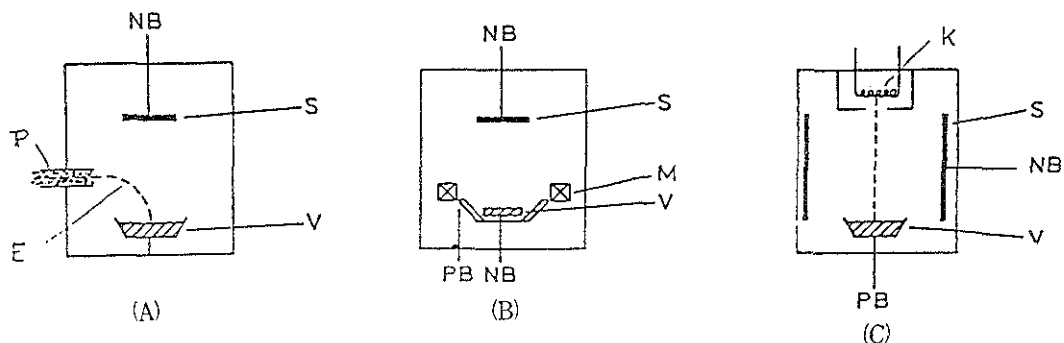


Fig. 8 Evaporation sources for ion plating (schematically)

(A) Hollow cathode electron beam evaporator (B) Arc evaporator

(C) Low-voltage electron beam evaporator

(V) evaporator, (P) plasma, (M) magnetic coil, (E) electron beam, (K) hot cathode, (S) substrate, (PB), (NB) positive, negative bias

electron source (heated cathode) and accelerated to the target. The beam is focused by a Helmholtz coil [16].

Other evaporation sources, like boats or high voltage electron beam evaporators need auxiliary equipment for enhanced ionization.

Ion plating using a magnetron sputter source (magnetron sputter ion plating) needs a special optimization of the magnetic field and sputtering power, in order to extend the ionization originally limited to the near-target space into the substrate area providing there a sufficiently high ionization. The above-mentioned double-cathode arrangement yields ionization degrees of up to 50 % in TiC coating [17].

In contrast to the original concept of a glow discharge as an ionization aid, the substrate bias needs to be only in the range of -50 to -200 V. This reduces edge heating (e.g. in tool

coating) and resputtering of material at that places of three-dimensional parts needs that the material flux deeply reaches into the space in front of the target. This means in practice, that coating should be done at pressures as low as possible. The low gas pressure reduces the probability for recombination of the charged particles during the flight from target to substrate, and also the thermalization of the high-energetic sputtered atoms. Fig. 9 shows the distance after which atoms of different mass (Al, Ta) are thermalized as a function of gas pressure and initial energy. E.g. 2.5 cm (5 V) and 5 cm (1000 eV) for Al at 10^{-2} mbar Ar [18].

3. Comparison of PVD Processes

A general comparison of the different PVD processes with respect to their technical application is extremely difficult, because the large number of process parameters actually allows only the discussion of a specific coating problem. Nevertheless, in the following some general statements shall be given, which can help in selecting the appropriate process.

3.1 Film morphology

The influence of the substrate temperature on the morphology of evaporated films was first described in a structure zone model by Movchan and Demchysin [19] (Fig. 10). At low temperatures a porous structure of individual polycrystalline, tapered crystallites is formed (zone I). At intermediate temperatures the columnar crystallites are densely packed and the film shows a relatively smooth surface

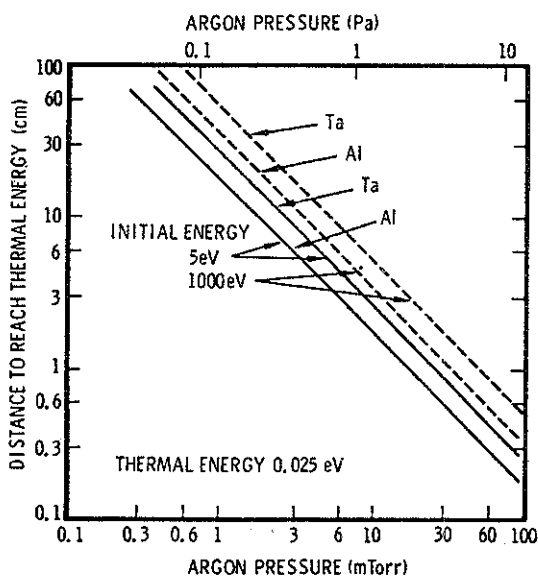


Fig. 9 Maximum distance for the thermalization of different ions as a function of argon pressure [12]

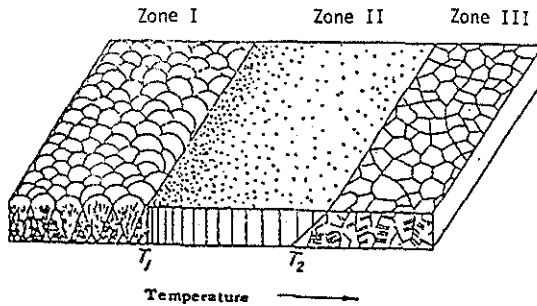


Fig. 10 Structure zone model for evaporated films according to Movden and Demchisin [19]

(zone II). At very high substrate temperatures a recrystallized structure of large equiaxed grains is formed. The structure formed during deposition is closely related to the surface diffusion of the condensing atoms. The transition temperatures T (related to the melting temperature T_m) lies in the range of $T/T_m = 0.3$ and $0.45 - 0.5$ for metals and $T/T_m = 0.22 - 0.26$ and $0.45 - 0.5$ for oxides. Increasing substrate temperatures yield a denser film. The transition temperatures are shifted to lower temperatures when the deposition is performed in an ionized atmosphere.

The gas pressure during deposition also influences markedly the film morphology. This is demonstrated in Thornton's extended structure zone model for sputter-deposited metal layers [20] (Fig. 11). The transition temperatures are shifted to higher values with increasing Ar pressure. A transition zone T is introduced additionally and characterized by densely packed fibrous grains. An increasing energy of the condensing particles reduces the porosity of the films, i.e. the transition temperatures are shifted to lower values. This enables the tailored deposition of films with specific properties also on less

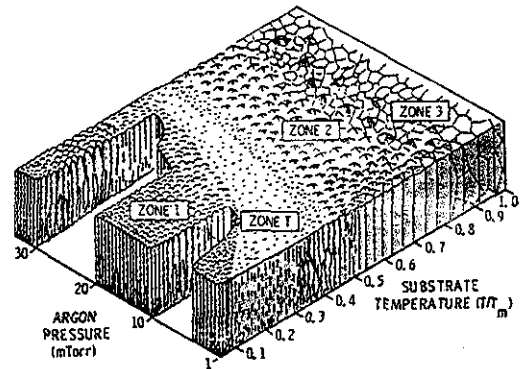


Fig. 11 Structure zone model for sputtered metal films according to Thornton [20]

temperature-resistant substrates. Sputter] deposited layers normally show a higher density than evaporated films.

A marked increase in density is also obtained by deposition in an ionized atmosphere and negative biasing of the substrate. This is demonstrated in Fig. 12 showing the fracture surface of a $3 \mu\text{m}$ thick TiN layer deposited with and without negative bias, i.e. with and without ion bombardment [21].

3.2 Film purity

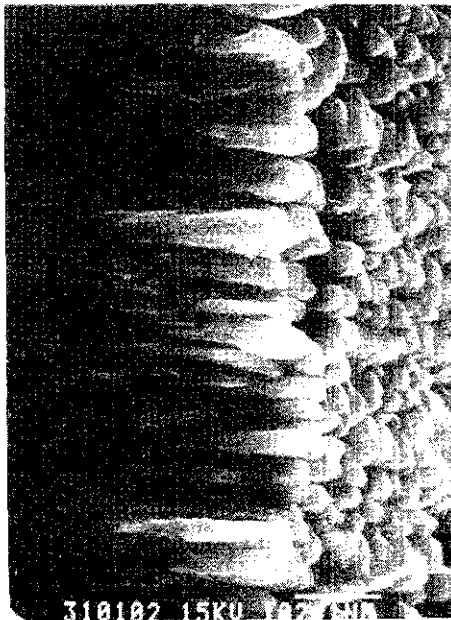
In the ion plating process and biased sputtering some of the deposited material is removed by the resputter effect of the impinging high-energy ions. Loosely bonded gases and light foreign atoms are removed by this process, and the condensation of the coating material takes place on a high-purity and activated surface.

3.3 Substrate temperature

The energy transferred to the substrate from the heated source by thermal radiation normally can be neglected in evaporation pro-



(A)



(B)

Fig. 12 Fracture surface of sputtered TiN films [21]
 A) Dense structure (ion bombardment)
 B) Porous structure (strongly reduced ion bombardment)

cesses as well as the heating by electron back sputtering except for a very high target power and very long deposition periods. In conventional (diode) sputtering a substrate heating is hardly avoidable because of the high electron current to the positive substrate. The substrate temperature can rise to 300 – 500 °C within few minutes. In contrast, magnetron sputtering allows a low temperature deposition, because the electrons do not reach the substrate surface. In the ion plating process markedly higher temperatures are reached due to the intensive ion bombardment and because the substrates normally are not cooled (300 – 500 °C).

By the same reason sputter cleaning of the substrate is combined with an increase of the temperature.

3.4 Deposition rate and film thickness

The deposition rate of metals and alloys in the evaporation process using powerful electron beam guns (max. 1 $\mu\text{m/s}$) exceed that of the magnetron sputter process by more than one order of magnitude. Diode sputtering exhibits rates again lower by a factor of up to 30. At the present state of engineering the limit of film thickness realizable by PVD processes is governed by economical aspects. Tribological layers with a thickness of few μm can be deposited by evaporation as well as by ion plating or magnetron sputtering. Markedly thicker layers up to 100 μm can be produced in reasonable deposition times only by high-power electron beam evaporators.

In reactive sputtering the choice of the process parameters plays a crucial role. A too high reactive gas pressure can lead to compound

formation on the target surface (e.g. target nitridation) causing a drastic reduction of the deposition rate (see also below).

3.5 Adhesion

The adhesion of thin films is of special importance for wear-resistant coatings. Various investigations showed that the adhesive forces are as stronger as cleaner the surface is. This state can be influenced in the ion plating and sputter processes. Dependent on the energy of the impinging neutral and ionized particles, the bombardment of the surface results in a number of effects, leading to an in-situ cleaning of the substrate of film surface.

In the evaporation process the kinetic energy of the condensing atoms lies in the range of the thermal energy (0.1 - 0.3 eV). In sputtering the average energy of the particles is higher by a factor of 5 - 100 due to the momentum transfer in the impact of the inert gas ions. The condensation of high-energy particles is favourable for good adhesion. In the ion plating process the particle energies can be increased up to several kV by applying appropriate bias voltages to the substrate. The limits of the intensity of ion bombardment are given by the allowable substrate temperature (heating effect), degree of ionization and possible resputtering effects.

3.6 Alloy deposition

A specific advantage of the sputter deposition process is sputtering of alloys without any additional process control and deposition without a change in composition. Thermal sources, and to a certain extent also arc evaporators, show problems in deposition of alloys with

components of strongly differing vapour pressures. The material with the higher vapour pressure is preferentially deposited. The use of separate evaporators principally solves this problem, but an extremely thorough temperature control is necessary and differences in the composition are found in large-area deposition due to the distribution characteristics of the different sources (Fig. 13). The same difficulty also holds for the reactive deposition of multicomponent compounds like $(Ti,Al)N$, $(Ti,V)N$, $(Ti,Hf)N$ or $(Ti,Al,V)N$.

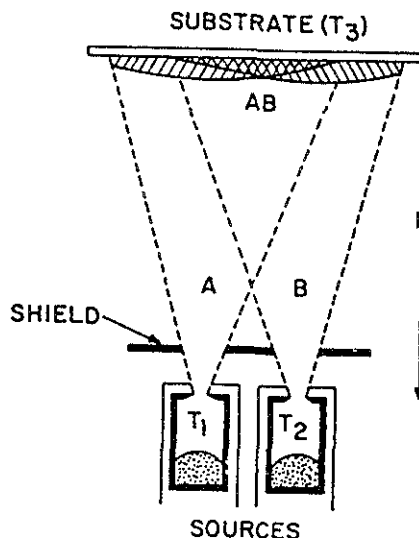


Fig. 13 Evaporation of alloys from two sources [2]

3.7 Multilayers

The deposition of multilayers on the base of reactive processes is easily possible by an exchange of the reactive gas atmosphere, e.g. $Ar-N_2$ by $Ar-C_2H_2$. This holds for all reactive deposition processes. By appropriate control of the partial pressures also films with concentra-

tion gradients can be produced. Multilayers based on different metal compounds, e.g. TiN-VN, need several targets. Basically, only sputter systems with alternatively used targets and substrate transfer have been proved to be successful.

3.8 Process control

The major problem in the use of thermal evaporators is the temperature control of the source, because slight temperature variations cause marked changes in the evaporation rate. Such a control is relatively slow. In sputtering and arc evaporation the process is controlled by power control which acts practically without time-lag. In the case of reactive sputter deposition additional problems arise from the control of the optimum reactive gas partial pressure. In recent times partial pressure control is successfully realized by quadrupole mass spectroscopy or photoemission spectroscopy.

4. Technical Realization

The technical coating of substrates with hard material thin films by PVD processes is normally done in batch coating systems, the conception of which is determined by the type of the source. Other important factors are type and dimension of the vacuum components (e.g. pumps). Finally, the productivity of the devices plays a more and more important role resulting in an increasing demand for in-line systems.

4.1 Sources for coating deposition

From the above-mentioned facts follows that evaporation sources essentially are point

sources. The diameter is in the order of few cm. The sources are classed into solid or liquid evaporants. Sources with a liquid evaporant like heated crucibles, electron beam evaporator, low-voltage electron beam evaporator or hollow cathode electron beam evaporator are mounted in the center of a base plate of the vacuum chamber. The evaporation always occurs in the upward direction. Corresponding to the distribution characteristics the substrates are mounted above the source and moved on planetary gearings during the deposition. In systems using the low-voltage electron beam evaporator, the substrates are vertically arranged on rotating substrate holders along the wall of the recipient, thus yielding a uniform film thickness.

The arc evaporator represents a solid material evaporator in spite of the momentary presence of a liquid phase in the cathode spot. The spot diameter is smaller than 1 mm, while the diameter of the arc source normally is also in the range of few cm. The arc source can be mounted in any position and, hence, several sources can be adjusted to complex-shaped and large substrates. The mentioned formation and deposition of "droplets" causes a certain roughness of arc-evaporated films which, however, in many cases has no unfavourable effects.

Small magnetron sputter sources can also be regarded as point-like source. The erosion, however, principally covers a certain area. No liquid phase is formed and, hence, no droplet formation occurs. Small magnetron sources find their application predominantly in microelectronics, while they are not generally adopted in hard coating devices. For large-area hard coating

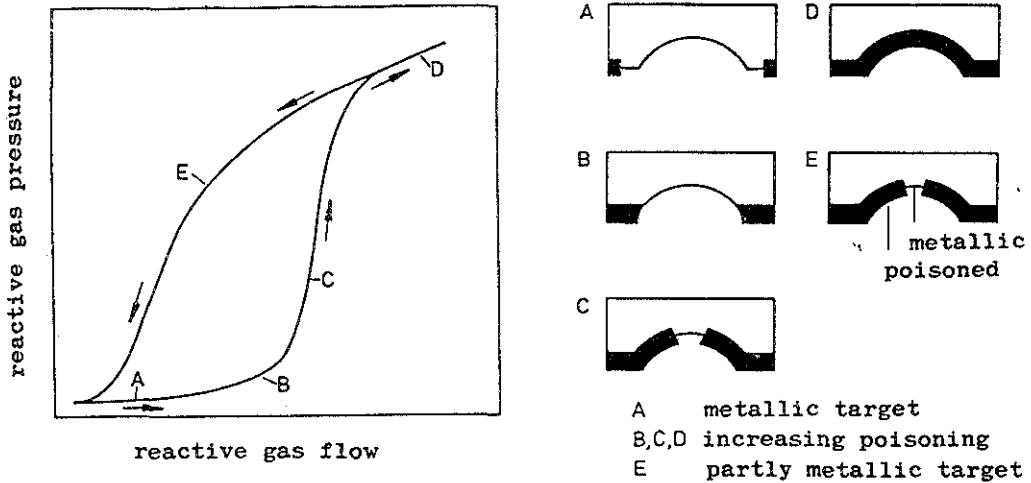


Fig. 14 Critical conditions in reactive sputter process(22)

deposition only line sources on the base of magnetron sputter and arc evaporator sources are successfully used. Magnetron sources are nowadays produced with length of more than 3.5 m and find their application in many fields of PVD coating, e.g. of architectural glass, displays or foils. The targets can be composed from several separate parts or made in one piece. Normally the targets are clamped to the water-cooled cathode holder enabling an easy exchange.

Using sputter and arc sources several runs can be made with on target while liquid sources need recharging of the source material after each coating cycle.

4.2 Target materials

In the beginning of PVD technology the targets were generally fabricated by melting techniques. These processes yield a satisfactory purity (typically >99.9 %) and a shrinkhole-free material. Limitations, however, exist with

respect to the alloy composition. New materials like TiAl need the application of powder metallurgical techniques. Hot pressing alone often does not give high-density targets. That can only be obtained by new P/M methods like hot isostatic pressing (HIP). High-density materials are especially needed for reactive deposition of multicomponent coatings. While arc evaporation in part suffers from the droplet formation, the groove formation in the target is the strongest disadvantage of the magnetron sputtering. De-

4.3 Vacuum systems

Most of the coating devices nowadays are equipped with a *pumping system* consisting of rotary pump, roots pumps and oil diffusion pumps. Oil diffusion pumps need condensation devices like baffles in order to avoid backstreaming of oil vapour into the receiver, which causes carbon contamination of the films and in many cases also a decreased adhesion. Turbomolecular pumps generally preclude this problem.

While in vacuum systems with evaporators the *pumping speed* essentially determines the pumping time and the residual pressure, the pumping speed often is the process-determining parameter. In flow-controlled reactive deposition processes, the above-mentioned target compound formation can result in an increasing compound coverage of the erosion zone. This causes an increasing reactive gas pressure which, in turn, accelerates the compound formation and decreases again the sputter rate. Adjusting the reactive gas flow to lower values yields a non-covered target surface only after the sputter rate is again strongly increased and the reactive gas pressure decreases markedly yielding too low metalloid composition in the deposited film. Fig. 14 illustrates this hysteresis effect schematically [22]. The actual pressure increase is much lower when high pumping-speed systems are used [23] (Fig. 15). Additionally, Fig. 16 shows the effect of the target reaction on the deposition rate of TiN for two different pumping

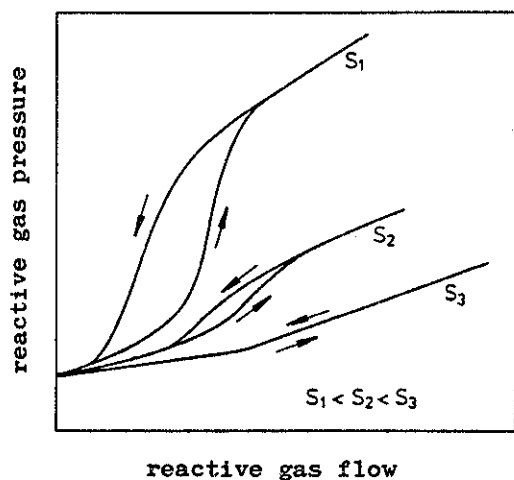


Fig. 15 Effect of pumping speed on the hysteresis loop in reactive sputtering [23]

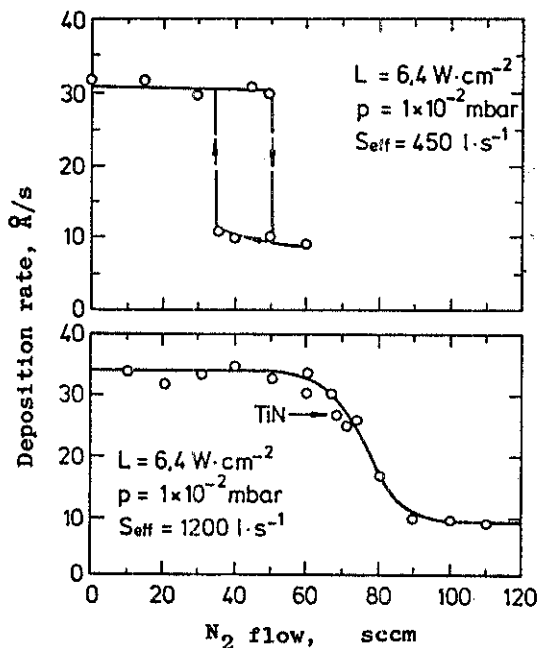


Fig. 16 Sputter rate of TiN as a function of N_2 flow at low and high pumping speed [24]

speeds. The deposition process is much less sensitive to slight variations of the reactive gas flow.

4.4 In-line systems

For reactive deposition evaporation source are used only in batch devices. The demand for an increased productivity and the deposition of multilayers, however asks for in-line systems as known from microelectronics and large-area coatings. Cycles of typically 2 - 30 min are chosen. A special advantage of in-line systems is the leading and unloading via hock modules reducing venting and re-evacuating of the chamber only cleaning and target exchange procedure. Fig. 17 schematically shows an in-line systems.

With respect to technical application, only

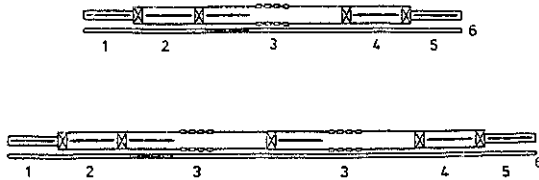


Fig. 17 In-line system for reactive magnetron ion plating (schematically) [27]
 1) loading module, 2) lock module, 3) process moduls, 4) lock-module, 5) unloading module, 6) automatic pallet return system

magnetron and arc sources are meaningful in in-line systems for reactive depositions and alloy coatings.

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