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Domino Platform: PVD Coaters for Arc Evaporation and High Current Pulsed Magnetron Sputtering

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Abstract. AlTiN and CrN coatings were deposited in hybrid DOMINO platforms by magnetron sputtering (DC-MS, DC-MS+HCP-MS, HCP-MS) and vacuum arc evaporation. The ion cleaning was done by the AEGD process. The coating rates and the energy efficiency of both deposition processes were compared. The roughness effects of the different coating types were discussed. Preliminary results of the change of pulse characteristics during simultaneously running of HCP-MS plus vacuum arc evaporation are shown.

Keyword: Arc, sputtering; HCP-MS, energy, roughness, hybrid

1. Introduction

The vacuum arc evaporation and the magnetron sputtering are the PVD deposition methods of Sulzer Metaplas to produce tribological and other functional coatings. The application of vacuum arc evaporation is the dominating PVD method for tool coatings and high performance component coatings. Besides advanced hard coatings also upgraded arc evaporators like APA (Advanced Plasma Assisted) are available. Classical DC-magnetron sputtering (DC-MS) is mainly used for a-C:H:Me coatings or for the deposition of interlayers for a-C.H:X coatings. Although the DC-magnetron sputtering process often results in smoother coatings the number of coating systems in industrial use is much lower than that of the arc evaporation. The reasons for that are the advantages (stability, productivity, costs, and coating properties) of the arc evaporation process in industrial scale.

Brief description of the arc evaporation deposition process

The vacuum arc evaporation is a self-sustaining discharge under vacuum condition. The arc process starts with the striking of a high current, low voltage arc on the surface of a cathode. The current density within a cathode spot (diameter ca. 10 µm) goes up to 10^7 A/cm^2 assuming a minimal spot current of 10 A [1]. The temperature at the cathode spot is extremely high resulting in a jet of vaporized cathode material. The localized cathode spot exists only for a short period of time. The spots jump to another area. The plasma jet consists of multiple charged ions, neutral atoms and macro-particles (droplets). A high level of ionization depending on the cathode material (30-100%) is observed [3]. Reactive gases are used to deposit nitrides, carbonitrides, oxynitrides and oxides. The reactivity is also given at low temperature due to excitation, dissociation and ionization. To eliminate the emitted droplets different filter systems are used [3].

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Brief description of the magnetron sputtering deposition process
The DC magnetron sputtering (DC-MS) is based on the atomization of the target material by an energetic bombardment of its solid surface by ions. The sputtering process is possible in either under vacuum condition, or in inert gas or in reactive (inert plus reactive) gas atmospheres. The electrical conductivity of the target material has to be sufficient high. The ionization is mostly dominated by the sputter gas ionization (mostly Ar). Two discharges are of special interest:

- A) The triggered self-sustained magnetron sputtering without a gas burning is the plasma of ionized sputtered atoms [4].
- B) The high current pulsed magnetron sputtering HCP-MS burning in a discharge consisting of a mixture of ionized argon with a high ionization of the sputtered atoms [5], [6], [7]. This higher ionization level of the magnetron sputtering process opens up new possibilities to tailor coating properties. The HCP-MS processes have different trade names: HIPIMS, HIPIMS+, HPPMS, MPP, HIPAC and others.

A demand of R&D and small volume production systems to run HCP-MS processes is obvious. The solution provided by Sulzer Metaplas is the DOMINO platform (mini, S, L type) configured with both HCP-MS and APA arc evaporators as hybrid systems. Preliminary results of both processes as well as of the hybrid process will be presented.

Figure 1. METAPLAS-DOMINO platforms for the hybrid set up: HCP-MS and vacuum arc evaporation with different chamber and magnetron sizes: HIPAC (High Ionized Plasma Assisted Coating: a trade name of Sulzer Metaplas for HCP-MS).

2. Experimental set up

Two important industrial coating types were deposited: AlTiN coatings using a target composition developed by Sulzer Metaplas (Al66at%Ti34at%) [8] and CrN coatings using pure Cr targets. Two different deposition methods were applied: magnetron sputtering and arc evaporation. Magnetron sputtering of the AlTiN coatings was made in the DOMINO mini using two magnetrons mounted in a closed field configuration. The magnetron with an unbalanced magnetic field set up had a size of 7.5 cm in width and 450 mm in length. The used pulse unit allowed a maximum voltage of 1000V/1000A. The magnetron discharge was running in 3 different modes: two magnetrons in the DC-mode, one magnetron in DC mode and the other in HCP-mode (HIPAC), both magnetrons in the HCP-mode. The distance between the substrates and the target surface was 60 mm. The bias voltage was set to 50 V, the total pressure was about 1 Pa, Ar:N_2 flow of 120:120 sccm. The average power applied to each target was constant with 7 KW (20 W/cm^2). Fig. 2 illustrates the different pulse modes.

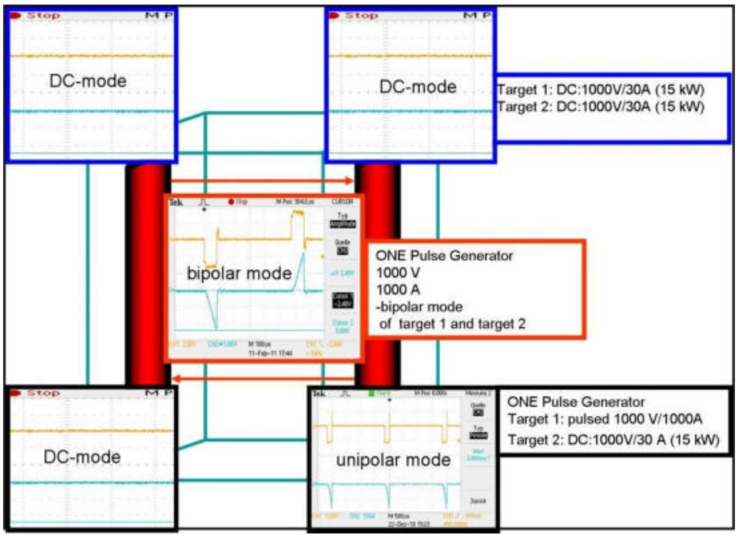

Figure 2. Possible modes of magnetron sputtering in the DOMINO mini.

To compare the growth rate with the growth rate of the arc evaporation also AlTiN-coatings were deposited by industrial standard parameter. The distance to the substrate holder was 140 mm. CrN coatings were deposited by HCP-MS and vacuum arc to compare the adhesion level and roughness of the coatings in a DOMINO S system. The deposition parameters were the following: total pressure 0,9 Pa, Ar:N_2 flow of 250:80 sccm, bias 50V, pulse parameters 150 µs on 1500 µs off (f= 606 Hz). The CrN arc coatings were deposited under industrial standard parameters. The ion cleaning was carried out by AEGD (Arc Enhanced Glow Discharge) before HCP-MS and arc evaporation [9]. Preliminary investigations of pulse shape modifications during the hybrid process combining HCP-MS and vacuum arc evaporation using a silicon sputtering target and Cr arc cathodes were done by oscilloscope measurements in the DOMINO S using targets of 7.5 cm in width and 70 cm in length.

3. Results

3.1. Deposition rate of AlTiN coatings in HCP-mode

Fig. 3 shows the deposition rates achieved by magnetron sputtering in the different operation modes. The highest deposition rate was measured for DC-sputtering (14 A, 500V) with a current density of 0.04 A/cm^2. A decrease was observed when operating in the mixed mode; one target with DC-MS and the other by HCP-MS. A sharp drop was measured when a high peak power was applied at both magnetrons running in the HCP-mode. The pulse parameters for the high ionized plasma operation were 80 µs on, 500 µs off (f=1724 Hz). The maximum peak current with 600 A results in a current density of 1.8 A/cm^2 and the maximum peak power of about 1 170 W/cm^2.

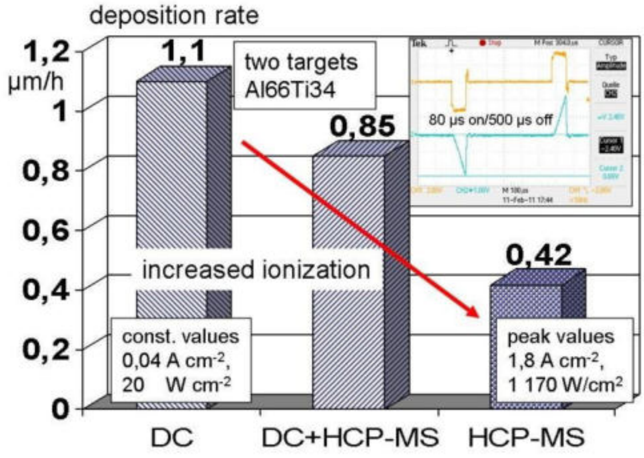

Figure 3. Deposition rate of AlTiN in different sputtering modes (3-fold rotation).

3.2. Energy consumption and deposition rate

A standard industrial (Al66at%Ti34at%)N coating was deposited by two APA evaporators in order to compare the energy consumption to get a specific deposition rate of the different sputtering modes with the energy consumption of the arc evaporation. The same substrate holder was used (3-fold rotation). The deposition rate was measured over a height of about 310 mm (magnetron: ca. 70% of the target length, arc: ca. rim of the arc evaporators). The measured deposition rate [nm/h] was divided by the total energy consumption of the particle sources [KW]. The results are shown in Fig. 4.

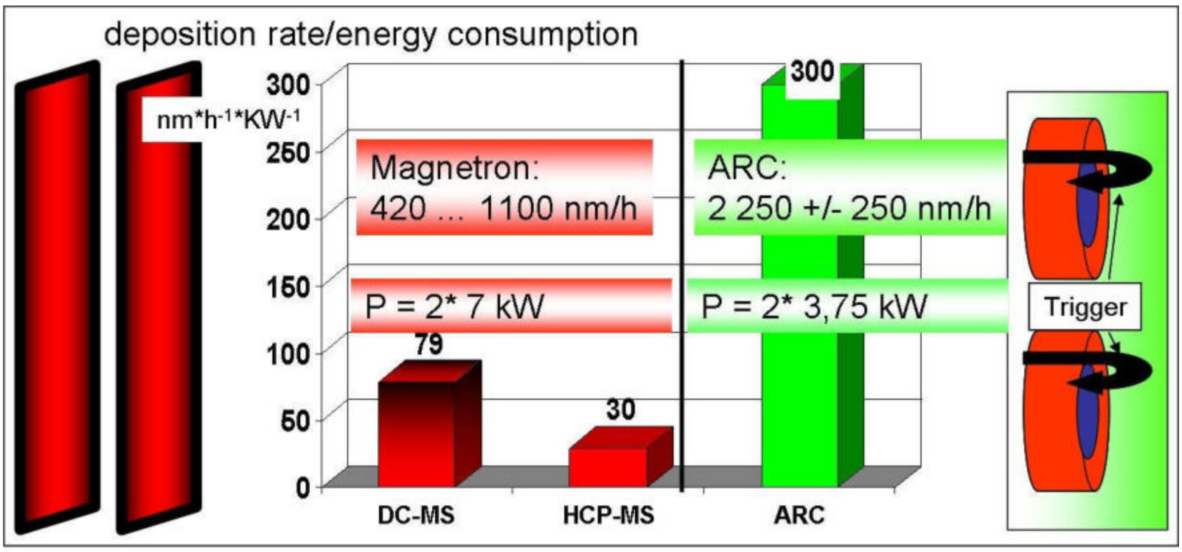

Figure 4. Deposition rate divided per energy consumption of different sputtering modes and arc evaporation.

Obviously the energy consumption to get the same deposition rate increases if the sputtering is switched from the DC- mode to the high ionized HCP-mode. The energy consumption to get the same deposition rate increases by a factor of 2.5. The outstanding low energy consumption of the arc is significant. The required energy to get the same deposition rate like the HCP-MS is up to 10 times lower than for the HCP-MS.

3.3. Roughness

The adhesion and the roughness for CrN coatings deposited by HCP-MS and arc evaporation are shown in Fig. 5. Both coating methods show the same high adhesion achieved after AEGD-ion cleaning. The roughness is typically much lower for the HCP-MS coating than for the arc coating. The roughness of the arc coating decreases significantly when applying an industrial standard post treatment (brushing). However it is still slightly higher than that of the HCP-MS coating.

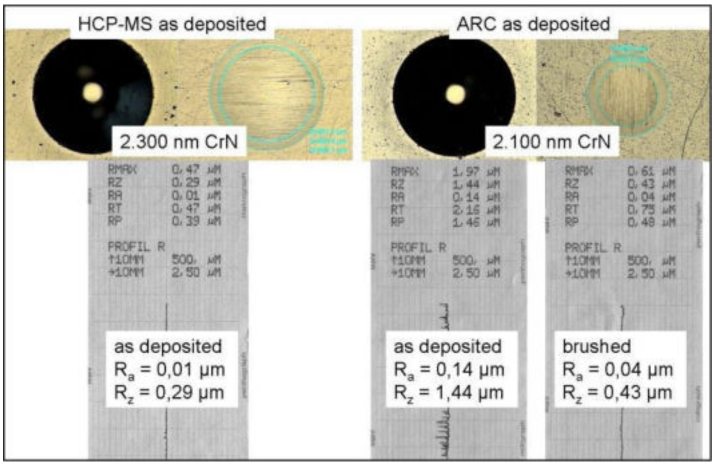

Figure 5. Roughness of as deposited CrN coating: HCP-MS in as deposited state, arc in as deposited and post treated state.

3.4. Delay of pulse current

Fig. 6 shows two pulse forms for a Si-target (f=500 Hz, 150 µs on) in the reactive mode which have significantly different delay times of the current rise. If the silicon target is running without the arc evaporation than the delay time is of about 25 µs. If the arc evaporators are switched on, than that delay time is nearly zero. Strong plasma activation is always present in the chamber resulting in a fast current increase.

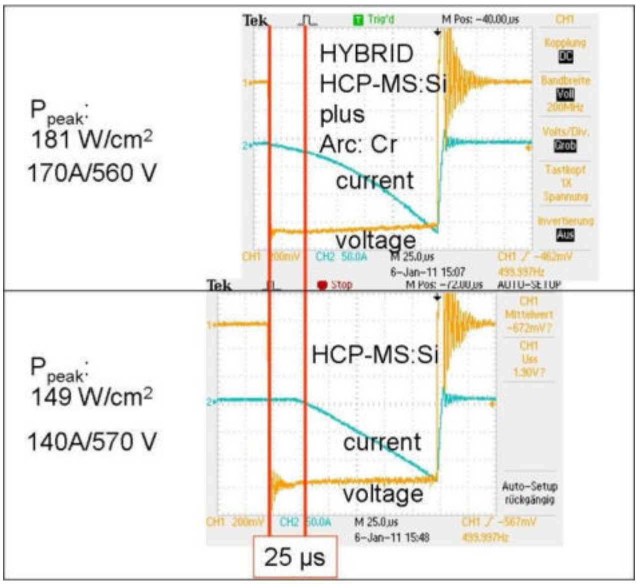

Figure 6. Delay time of the current in reactive HCP-MS of SiNx process and in a reactive hybrid process by HCP-MS of Si and Cr by arc evaporation.

4. Discussion

Table 1 shows selected general process data's and industrial relevant data's for DC- MS, HCP-MS and arc evaporation. In addition to the well known data's the energy consumption is added. It has to be pointed out that this comparison is made under the view of industrial applications of hard coatings for wear and friction reduction.

4.1. What are the advantages of HCP-MS compared to Arc for wear/friction reduction coatings

- A) It has been shown that HCP-MS is able to produce well adherent and smooth coatings. That means for micro tools and components it is an alternative to the filtered vacuum arc evaporation. It should be mentioned, that the low roughness requires both an optimization of process parameters and a clean surrounding inside and outside the chamber, otherwise growth defects will be generated by dust particles [10].
- B) The target material variety is larger than for the arc evaporation. Thus HCP-MS is the solution for target materials which are difficult or not evaporable by the vacuum arc evaporation, e.g. TiB2, SiC, B4C.

4.2. What are the disadvantages of HCP-MS compared to Arc for wear/friction reduction coatings?

- A) It has been shown that the deposition rate is significantly lower than that of the arc evaporation. The shown decrease of the deposition rate of HCP-MS in comparison to DC-MS is caused by the high power densities applied in the described experiment. The process parameters shall be tailored to apply an optimum of power densities for the required coating properties and by adjusting the reactive gas process to maximize the deposition rates.
- B) In addition, the energy consumption to get the same deposition rate is up to a factor 10 higher than for the arc evaporation. This tendency was also shown for Cu coating processes [2].

4.3. Which potential does hybrid systems have?
The DOMINO platform has both the possibility to deposit coatings either by pure HCP-MS and its combination with DC-MS or by arc evaporation to find the optimal coating process for different applications. It should be mentioned, that the droplet content and the resulting roughness of an arc deposited coating is acceptable for a lot of applications without any post treatment. In several applications like for forming tools and plastic moulds a post treatment has to be applied. One not in detail investigated potential of HCP-MS is the hybrid process with vacuum arc evaporation. The possibility to use target materials which are difficult or not evaporable by arc opens the window to deposit dedicated nanocomposites by doping or multilayers (also in the nanoscale) as well as top layers. First steps were done by Sulzer Metaplas.

Table 1. Basic comparison of arc and magnetron deposition.

	Target material flexibility	Ioni-zation	Rate	Energy efficiency	Main application wear/friction	* Classical hard coatings	*DLC with PVD process
DC-MS	++++	+ max 10%	+++	++	DLC parts decoration (tools)	5%	99 %
HCP-MS	+++	++ may exceed 50% [7]	++	+	not defined smooth and dense coatings	?	?
DC-Arc	++ limited arc materials	+++ up to 100 % [2,3]	++++	++++	tools, components (decoration)	95%	1%
Arc Filter	++ mostly carbon	++++ 100%	+	+	Components (tools)	less 1%	less 1%

*percentage of application is estimated from market observation, not based on statistical evaluation

5. Summary and conclusions

- 1. The DOMINO platform gives the possibility to investigate specific process parameters and coating properties for DC-MS, HCP-MS in comparison to the arc evaporation.
- 2. The DOMINO platform allows to run HCP-MS and vacuum arc evaporation as a hybrid process.
- 3. The deposition rate of HCP-MS is lower than that of DC-MS and significantly lower than that of the vacuum arc in the investigated configuration.
- 4. The energy consumption to get a specific deposition rate is for HCP-MS higher than for DC-MS and much higher than for the vacuum arc evaporation (up to factor 10).
- 5. Preliminary investigations of the pulse shape during simultaneous operation of arc evaporation and HCP-MS show a significant change in the pulse form.

References

[1] Siemroth P., Schultrich B., Schülke T., Surf. Coat. Techn. 74-75 (1995)92-96
[2] Rother B., Vetter J., Wiss. Z. d.TU Karl-Marx-Stadt 31(1989) H3, p. 433-445
[3] Boxman R.L., Martin P.L., Sanders D.M.: Handbook of vacuum arc science and technology, Noyes Publications, New Jersey, 1995
[4] Dorodnov A.M, Petrosov B.A, Sov. Phys. Tech. Phys 26(3)1981, 304
[5] Khodachenko G.V., Mozgrin D.V., Fetisov I.K. patent RU2058429, 1993
[6] Helmersson U., Lattemann M., Bohlmark J., Ehiasarian A.P., Gudmundsson J. P., Thin Solid Flms, 513(2006) 1-24
[7] Anders A., Surf. Coat. Techn. 204(2010) 2864-2868
[8] Vetter, J., Journal of Advanced Materials. Band 31, Nr. 2, 1999, S. 41–47
[9] Vetter J., Perry A.J., Surf. Coat.Techn. 61(1993)305-309
[10] Vetter J., Stüber M., Ulrich S., Surf. Coat. Techn. 168(2003) 169-178