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CONCEPT OF ELECTRON BEAM PHYSICAL VAPOUR DEPOSITION TEST STAND WITH SPECIFIC FUNCTIONAL PROPERTIES

KONCEPCJA BUDOWY STANOWISKA DO TECHNOLOGII ELECTRON BEAM PHYSICAL VAPOR DEPOSITION O SPECYFICZNYCH CECHACH UŻYTKOWYCH

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EB-PVD, surface engineering, electron gun, modular test stand

Słowa kluczowe:

EB-PVD, inżynieria powierzchni, działo elektronowe, modułowe stanowisko badawcze

Summary

EB-PVD technology is currently the subject of intense material engineering investigations, because its application enables the procurement of specific functional materials, especially materials with increased antiwear properties. The efficiency of such tests can be significantly increased by the application of test stands, allowing for the realisation of investigations on a wide range of materials with an easy selection and alteration of process parameters and the

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application of various methods of additional plasma ionisation. The article presents the concept of such a stand that assumes the inclusion of an electron gun into the test stand itself. Additionally, the conditions of the integration of this element with the test stand are shown. The inclusion of the gun does not change the functionality and modularity of the stand.

INTRODUCTION

Recently, there seems to be a significantly growing need for devices that allow for the procurement of surface layers with the use of infusible materials including, *inter alia*, ceramics and dielectric materials, for the evaporation of which a high energy electron beam can be used. These types of beams are obtained in specialised Electron Beam (EB) guns **[L. 1]**. Application of an electron gun in a stand for PVD processes allows for the realisation of various types of EB-PVD technologies. EB-PVD technology with vapour ionisation has both strong supporters and opponents alike. The main disadvantages of this method are the high costs of production of specialised test stands and high expectations towards the personnel assigned to their operation **[L. 2]**. However, a dynamic development of EB-PVD technologies for the production of nanometric surface layers is expected. Another field of the application of EB-PVD technologies concerns the procurement of layers with Thermal Barrier Coatings (TBCs) **[L. 3]**.

The more complex of the stands can have more than one electron gun. The application of several guns allows for the mixture of base materials for the production of advanced plasma to be obtained. Simultaneous evaporation of numerous materials with the use of independent electron beams enables the content of this mixture to be freely modified. The full control over the mixture's content is not possible when only one electron gun is used. Any attempt to evaporate materials constituting a mixture of different elements of a single batch to be inserted in the melting pot with the use of one gun only faces the problem of irregular sputtering of individual ingredients **[L. 4]**. In order to maintain full control over the evaporation process, individual ingredients (in separate melting pots) need to be sputtered with the use of independent electron beams. Application of numerous melting pots and one electron gun with a specialised deflection system allowing for a quick shift of the electron beam from one melting pot to another does not in fact enable the procurement of a homogenous mixture of these materials. This stems from the fact that only one ingredient is evaporated at a given moment. Concentration of the currently evaporated ingredient in comparison to other ingredients grows significantly. The structure of the stand equipped with several electron guns facilitates full control over the process of obtaining mixtures of vapours of selected materials.

Proper control over the shift of the electron beam on the surface of the material is a very important element of the system for the evaporation of materials. For that purpose, specialised beam deflection systems are built **[L. 5]** as well as electron gun supply systems **[L. 6]**. In many solutions two deflection circuits are built. Static deflection allows for the determination and selection of a suitable melting pot, whereas dynamic deflection should enable operation in numerous modes to ensure optimum control over the evaporation process. This can be obtained by the alteration of transverse shapes of the beam and the modification of their parameters **[L. 7]**.

The connection of the electron gun with other plasma sources (i.e. arc or magnetron) increases the functional possibilities of the stand. Technological possibilities can be significantly improved by the application of a module enabling the realisation of ion nitriding processes, which allows for the production of different surface layers (including hybrid layers) in one continuous technological process **[L. 8]**.

The application of the modular structure of the stand enables its easy future extension and modification. Therefore, individual modules need to have a form of independently functioning devices that can be controlled using a local industrial network and provide safety monitoring. Modifications of the stand to the needs stemming from the development and testing of novel technological solutions require software changes. A crucial element of such a solution is constituted by the necessity to unify the assembly of individual modules to technological roll passes of the vacuum chamber. The number of simultaneously operating modules for the creation of plasma is connected with the structure of the vacuum chamber and the possible number of technological roll passes.

Work with the electron beam is connected with the emission of harmful ionisation radiation. This requires the construction of a working chamber out of materials that can ensure the proper level of protection against this radiation. In the case when typical plasma sources that are characteristic for other PVD devices are used, additional covers need to be applied to prevent the radiation from entering the environment outside the working chamber. After every exchange of the module or other form of modification of the stand, the level of ionisation radiation needs to be carefully checked inside and outside the stand. People operating the device need to be equipped with personal dosimeters, which indicate the amount of ionisation radiation absorbed, and undergo regular health checks.

PVD STAND

A specialised PVD stand is intended for the investigations on cutting-edge technological and hardware PVD solutions. It was developed in a modular form, which is highly advantageous due to easy and quick stand modification possibilities. Using local industrial networks (e.g. Modbus), the number of connections within the stand between individual modules can be visibly minimised. Full control with the use of a local network enables the minimisation of connections limited to ensuring the supply for individual modules and crucial signals of locks and securities stemming from the necessity to ensure a high level of safety of operation. Signals connected with blocking individual modules that are most important from the point of view of safety are realised through hardware; whereas, other signals are transmitted via the local industrial network.

An important advantage of the stand is the easy extension possibility that enables new modules to be added. Correct operation of the new module is ensured through the introduction of software changes. To make this task easier, the control programme can also be of a modular structure and equipped with functions of quick and convenient configuration allowing for the unused modules to be switched off and the newly added modules to be incorporated into the programme.

Basic modules of the PVD stand **(Fig. 1)** are connected with ensuring vacuum and working atmosphere. The systems of vacuum pumps and the system for the measurement of vacuum in selected areas both constitute the vacuum module. This module allows for the automatic creation of a vacuum in the working chamber. The second important module is the gas process module, through which the dosing system of technological gases ensures the proper working atmosphere in the vacuum chamber.

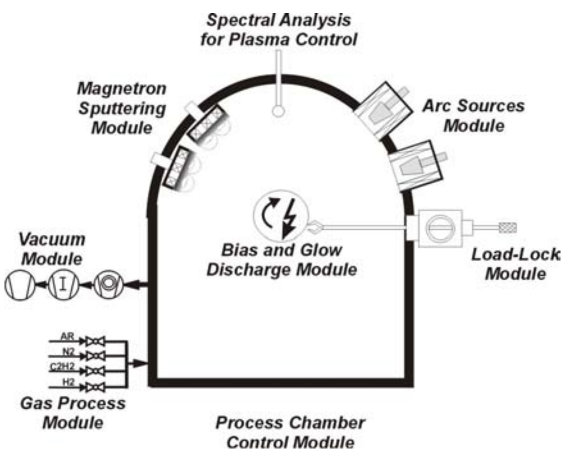

Fig. 1. Configuration of the modular PVD stand
Rys. 1. Konfiguracja modułowego stanowiska PVD

Another module crucial for the creation of a minimum configuration of the stand is constituted by the process chamber control module, whose objective is to ensure the proper functioning of the environment connected with the working chamber. Its additional task, apart from the control over the chamber cooling and heating media, is the operation of all the units installed in the chamber, which includes the operation of shutters, screens, and stroboscopes, and control over the drives of the turntable of the working stand.

In order to improve its technological possibilities, the test stand is equipped with additional units that are used in classic PVD technologies. For the realisation of basic functions, plasma creation with arc sources module is used. Another plasma source is the plasma creation with a magnetron-sputtering module. Both of the modules are used in typical devices for the realisation of the processes of the application of surface layers with the used of PVD methods. Another element used for the extension of the test stand is constituted by the surface polarisation module (-Bias), which is used together with material sputtering in the arc and magnetron sources.

The advanced PVD stand is also equipped with other modules characteristic for classic PVD devices. One of them includes the glow discharge module that allows for the realisation of ion nitriding processes. This module can be produced in a standard version or in connection with the spectral analysis and plasma control module. The types and numbers of modules applied depend on the types of technologies to be realised in the stand.

Another crucial and necessary module of the test stand is the control and visualisation module. This system is based on the modular PLC controller enabling its further development and modification. Its inseparable element is constituted by the operator panel – Human Machine Interface (HMI). Depending on the level of complexity and development of the stand, the user panel can have the form of an industrial operator panel or its function can be overtaken by PC equipped with specialised software.

EB-PVD STAND

In the case of an EB-PVD stand, an electron gun (EB) module needs to be added. This configuration allows for the development of a test stand for EB-PVD technologies **(Fig. 2)**. However, the fact that the working chamber needs to have a specialised structure needs to be taken into consideration. Due to the existence of ionisation radiation, the chamber has to be made of materials that successfully block radiation. This concerns not only the chamber itself, but also the corresponding elements, including, *inter alia,* roll passes, viewports, and casings for plasma sources.

There are many structural solutions for electron guns. An electron gun can work in the direct electron beam emission mode in the direction of a melting pot, or it can be equipped with additional beam deflection systems. The material sputtered from the melting pot can also directly permeate the electron gun, which causes cathode poisoning by the application of sputtered material. For these types of guns, strong electron beam deflection systems need to be applied to prevent the material sputtered from directly influencing the cathode. There are electron guns whose structure minimises the dangers of cathodes being poisoned. This includes structures in which inner beam deflection systems are used, which make the cathode "invisible" from the outside. In this case, the cathode can have a form of a ring cathode with a specialised deflection system ensuring that the material sputtered goes through the central opening in the cathode and settles on the element of the wall directly behind the cathode. In the case of classic electron guns, a wide deflection angle needs to be ensured so that the material sputtered can settle on the sidewalls of the gun rather than the cathode.

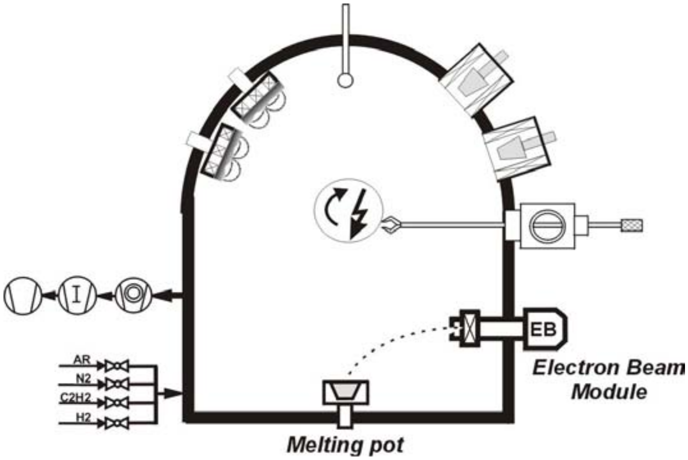

Fig. 2. Advanced modular EB-PVD stand
Rys. 2. Zaawansowane modułowe stanowisko EB-PVD

Configuration of the EB module can significantly vary depending on the technologies to be realised in the stand. A minimum configuration of the EB module has to have an electron gun with supply and control systems. Depending on the type of the electron gun installed, it is necessary to design and install a specialised beam deflection system. One of the options is to buy a specialised electron gun module that includes an electron gun with supply and deflection systems. In such a case, the integration of a module with a stand requires input and output signals of the module to be adjusted to the stand control system. In the case of the installation of only the electron gun, it is crucial to design a specialised high-voltage feeder that would be compatible with the electron gun installed. Additionally, for such a system, a suitable beam deflection system needs to be developed.

To extend the technological possibilities of the EB, a specialised ionisation module can be installed for the evaporation of materials from the melting pot. A central element of the module is constituted by a specially designed electrode with a specialised high-power feeder.

Other important aspects to be considered when designing and constructing an EB-PVD stand include the following:

- The necessity to ensure the regulation of the power and kinetic energy of the electron gun that would be adequate for the properties of the evaporated material;
- The application of advanced electron beam deflection and scanning systems;
- On-line, real time, diagnostic system for the measurement of parameters of the electron beam and the material evaporation process;
- The possibility to apply spectral or XRF methods for the analysis and control of the sputtered layer;
- The installation of effective and safe covers against ionisation radiation and the monitoring of the level of radiation with the use of personal dosimeters for personnel;
- Control of the electron beam penetration area;
- Selectively controlled melting pot cooling processes;
- Additional controlled substrate heating;
- Durability and long operation of both the cathode and the electron gun; and
- Quick and easy removal of the evaporated material from the walls of the working chamber.

Due to the modular structure of the stand, the requirements imposed can be met with no additional influence on the functionality of the stand and the possibility of its further extension.

CONCLUSIONS

An electron gun is the most important part of a test stand for EB-PVD processes, because it decides the structure of the entire stand, regardless of the number of guns. Once properly modernised, modules used in test stands for PVD technologies can be used for the construction of such a device. The number and the type of these modules should be correlated with technologies to be realised and the scope of experiments planned.

The use of modules of the PVD stand in the construction of the EB-PVD stand may result in a cutting-edge test device designed for the realisation of tests leading to the improvement of the quality of technological coatings with the consideration of such parameters as adhesion, density, and stoichiometry.

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Streszczenie

Technologia fizycznego osadzania z fazy gazowej z wykorzystaniem wiązki elektronowej (EB-PVD), dzięki uzyskiwaniu różnorodnych materiałów funkcjonalnych, o zwiększonych właściwościach w szczególności przeciwzużyciowych, jest przedmiotem intensywnych badań inżynierii materiałowej. Efektywność takich badań może być zwiększona poprzez wykorzystanie odpowiednich stanowisk umożliwiających prowadzenie prac z szerokim zakresem materiałów, łatwym doborem i zmianą parametrów procesowych, stosowaniem różnych metod dodatkowej jonizacji plazmy. W artykule przedstawiono koncepcję budowy takiego stanowiska. Zakłada ona włączenie wyrzutni elektronowej do stanowiska badawczego technologii PVD. Przedstawiono warunki integracji tego elementu ze stanowiskiem. Dołączenie wyrzutni zachowuje dotychczasową funkcjonalność i modułowość stanowiska oraz zapewnia uzyskanie specyficznych cech użytkowych dających możliwość powtarzalnej produkcji materiałów komercyjnych oraz prowadzenia prac badawczo-rozwojowych.