Section 3
PHYSICS OF RADIOTECHNOLOGY AND ION-PLASMA TECHNOLOGIES

VACUUM-ARC EQUIPMENT AND COATING TECHNOLOGIES IN KIPT

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Basic development stages of vacuum-arc functional coatings formation of on tools, machine and device parts, plastic metal, glass products, natural and artificial diamonds, which have been created at Kharkiv institute of physics and technology are reviewed. Design features and technological capabilities of installations to implement these technologies, plasma generators for the installations and examples of some conceptual developments of technological equipment are also described.

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Vacuum-arc deposition of functional coatings is widely used in many branches of mechanical engineering. Unique capabilities of the method are due to the uniqueness of vacuum arc used as basic technological instrument. Discharge in metal (or graphite) vapor, which is the material of cathode, generates the fluxes of highly-ionized plasma with energy of ions tens of electron volts. Plasma is emitted by micrometer size cathode spot where the temperature is sufficient for evaporation and transformation into plasma of any metal, including refractory metals. Ion flux extracted from the discharge of plasma makes (dependant on cathode material) 4...19% from discharge current. During the contact of the flux with substrate a layer of the cathode material being condensed on its surface. The thickness of the layer (film) is proportional to density of the ion flux to the substrate and exposition time. In presence of reaction gas (nitrogen, oxygen, carbon-containing gas) during the condensation of metallic plasma the layer of metal compound with the gas is synthesized (nitride, oxide, carbide). The high degree of plasma ionization (can make up to 100% for certain materials) allows one to control the motion of plasma fluxes by magnetic fields (focusing, transporting, deflecting). It is also possible to adjust in wide range the energy of condensing ions using electric field applying negative potential to the substrate. This provides the possibility to synthesize coating with designed physical-mechanical, chemical and operational characteristics which are sometimes unique ones. Vacuum-arc method guarantees the excellent adhesion of coatings to the substrate surface. This is attained by cleaning of substrate surface with ion bombardment before the coating deposition. High negative voltage (the order is ~ 1 kV) is applied into the substrate and this voltage accelerates ions to energies sufficient for sputtering base surface layer from impurities. The surface became not only ideally pure but also activated and this provides an extremely proof adhesion of coating to the substrate.

In 1970 scientists of KIPT A.A. Romanov and A.A. Andreev have informed that deposited from plasma of vacuum arc super thin (only several micrometers) layer of molybdenum nitride increases the resistance of lathe turning tool several times. Opinion of institute scientists became divided: ones considered this is a result of experiment noncorrectness, others – the invention of Romanov, who had an aptitude for hoax, the thirds considered this as charlatanism. Meanwhile it was the start of new scientific field in our institute and around the world. It was revealed further that the proposed method has long background. In 1884 Thomas Edison had represented into United States patent office patent application for invention of "Process of coating deposition from electro conducting materials by electric arc between electrodes of this material in vacuum" and in 1877 – 1878 the main ideas of its invention were described in papers by professor Arthur Rite. Conducting experiments with vacuum arc he intended to clean vacuum from mercury vapors. The method of thin films deposition from different metals on glass base has been described in details. One can address to papers of R. Boxman and Metoks [1, 2] for additional details. We may also recognize that invention of Rite and Edison was premature and forgotten for many years. Only in KIPT this method was "reinvented" finally.

In the beginning of 1960 on academician K.D. Sinelnikov initiative the investigation of electro arc discharge as effective mean for getter flash (titanium) to obtain oil free high vacuum was started in the department of plasma physics (under leadership of V.T. Tolok, associated member of Academy of sciences of Ukraine). The works were performed in sector of vacuum technique (head of sector – A.A. Romanov). The real ground for development of new line have proceeded after firing in vacuum the stable direct current arc discharge in 1964 by L.P. Sablev with collaborators. In 1966 the development of vacuum-arc titanium evaporator was completed and in a year later the first vacuum-arc sorption pump was put into operation. Abroad the patent for analogous facility was applied only in a year.

Successes in "pump" development acted as a catalyst for development of another theme: beginning from 1967 A.A. Romanov and A.A. Andreev investigate the possibility of vacuum arc for production of coatings from refractory metals. Vacuum-arc evaporator used for systematic investigation in this field was produced in

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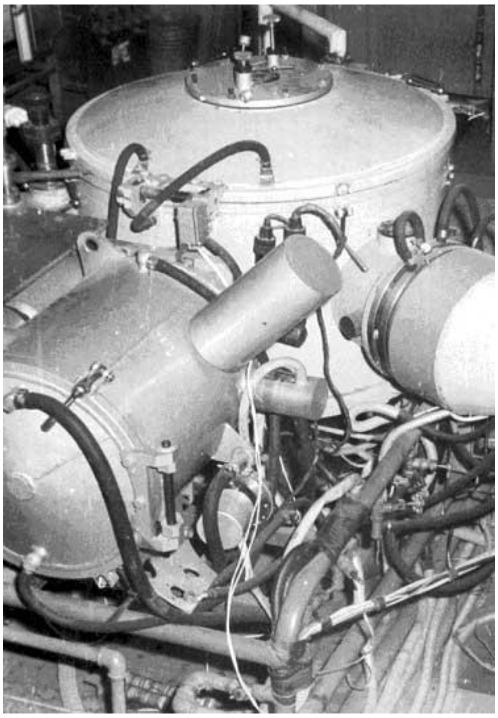


Fig. 1. Bulat-2

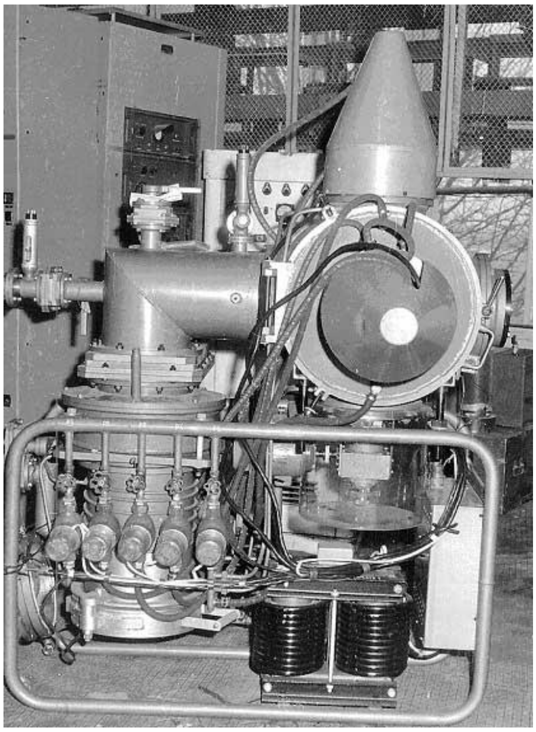


Fig. 2. Bulat-3

1970. With such evaporator with graphite cathodes authors synthesize the film of diamond-like carbon. Obtained results were not published according to "regime" reasons. In 1970 authors of new method synthesized coatings on the base of molybdenum nitride with 32…36 GPa microhardness. This exceeds more than 5…6 times the table values of bulk material microhardness. Testing of piston rings with such coatings for powerful diesel engines in plant named by Malishev shows 10 fold decrease in wear of such rings and operating with them cylinders if compared to standard pair. (According to the confidential reason the obtained results were published only in 10 years). Coatings on cutting tools of high-speed steels increase their resistance in 5…6 times. Good results are obtained for deposition of nature and synthetic diamonds. Management of the department of plasma physics assigns the funds for designing and production of pilot scale installation.

To the end of 1974 two copies of "Bulat-2" installation (Fig. 1) were produced and transferred to Kharkiv factories. This was the first industrial equipment which served as a prototype for all family of vacuum-arc equipment produced in USSR and abroad. New technology was named "CIB" (condensation with ion bombardment). The new technology provides deposition of coatings based on titanium compounds (nitrides) – material which is affordable and cheaper in comparison with molybdenum was also transferred to industry.

Organizing-bureaucratic events were also in progress. May 1974 Decree of State Committee of science and technique at the Council of Ministers of the USSR was published according to which KIPT was determined as the leading institution in program for development and introduction of new technology and equipment for deposition of wear resistant coatings on instruments and parts of machines, for deposition of metal coatings on nature diamonds and synthetic super-hard materials. Enterprises of nine Ministries were coaxed to this activity. The Decree played the decisive role in acceleration of investigation. The small team of enthusiasts was reinforced: scientists V.M. Khoroshikh, V.E. Strelnitskiy, I.I. Aksyonov and V.A. Belous came to the sector and on autumn 1974 the sector was reorganized into a large laboratory. The numerous group of material science specialists under the leadership of V.V. Kunchenko also enter this laboratory. Professor V.G. Padalka was the head of the laboratory.

Based on operational experience of “Bulat-2” equipment the new model "Bulat-3" was produced in the institute (Fig. 2), the first batch of “Bulat-3” (20 specimens) was manufactured by Kharkiv enterprises (1977 – 1978). Since 1979 the serial production starts on factory "Dvigatel" (Tallin) and Kyiv factory of machine-tools and automatic machines.

The members of new laboratory step up the studies, the results of which gave the ideas on physics of processes determining the principal possibilities of new technological lines. Investigation of DC vacuum arc discharge as the main instrument for realization of new method was of great interest. At the same time as "instrumental" line the transition to the solution of new problems starts. Interaction of cathode spot with magnetic fields, characteristics of metallic plasma and its interaction with gaseous target were studied; the reliable methods of discharge initiation and stabilization were developed, effective methods of plasma fluxes formation with designed parameters, the ways of these fluxes focusing, deviation and transportation were developed. The basis of practical material science of vacuum-arc coatings, processes of their deposition on machine elements, on natural diamonds and synthetic super hard materials are developed; activity on synthesis

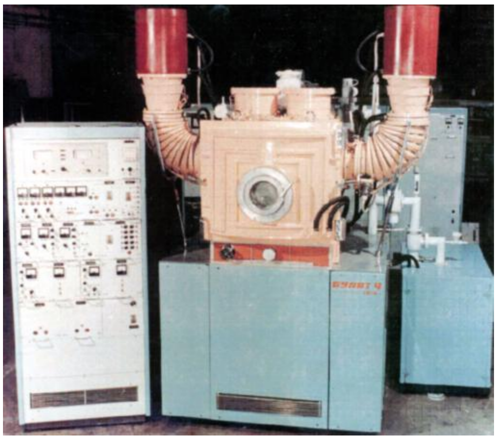


Fig. 3. Bulat-4

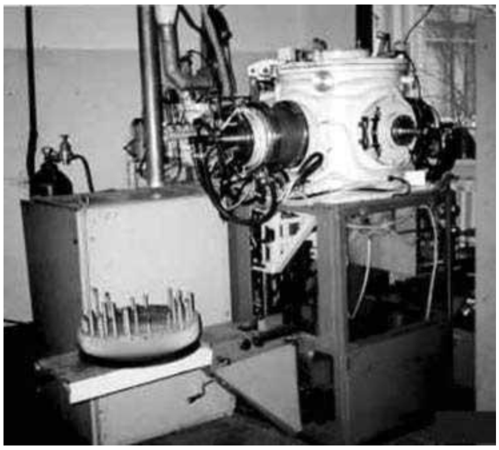


Fig. 4. Bulat-9

of diamond-like carbon films is in progress. Simultaneously with scientific researches experimental-designing and experimental-technological works are in progress. Many new technical solutions were patented. The more important were patented abroad in tens of countries.

On December 1979 the licensing agreement was signed; according to this agreement the American firm "Noble Field" (in future – Multi Arc Vacuum System Inc., or MAVS) obtains the technology of TiN coatings deposition on tools of high-speed steel and "pilot" specimen of "Bulat-3" apparatus. With the patent sale the interest to the new technology in all industrially developed countries grew up strongly. Using the acquired exclusive right on technology, MAVS founded subsidiary companies in many places of the World. In 1982 the license was sold to Czechoslovakia enterprises Narădi Praga (Zhdanize).

At the same time KIPT continues investigation, which guarantees the Institute a leadership in the field of vacuum-arc technology for deposition of coatings on tools and machine components. The characteristics of metallic plasma, kinetics of physical-chemical processes in reaction space are studied, mechanism of cathode erosion is investigated; methods of plasma fluxes cleaning from droplet fraction (macroprticles) are developed; coatings for antierosion and anticorrosion protection of articles are produced; also biologically indifferent coatings for medicine are produced. Unique evaporating systems with controlled motion of cathode spots on surface of extended plate and cylinder cathodes are developed; proposed systems have no principal limits on linear dimensions. New highly effective method of ion modification of surfaces of instrumental and structural steels and alloys into the plasma of "two-stage" arc discharge of low pressure is developed. Production of magnetoelectric separators (filters) for cleaning of plasma from macroparticles of cathode

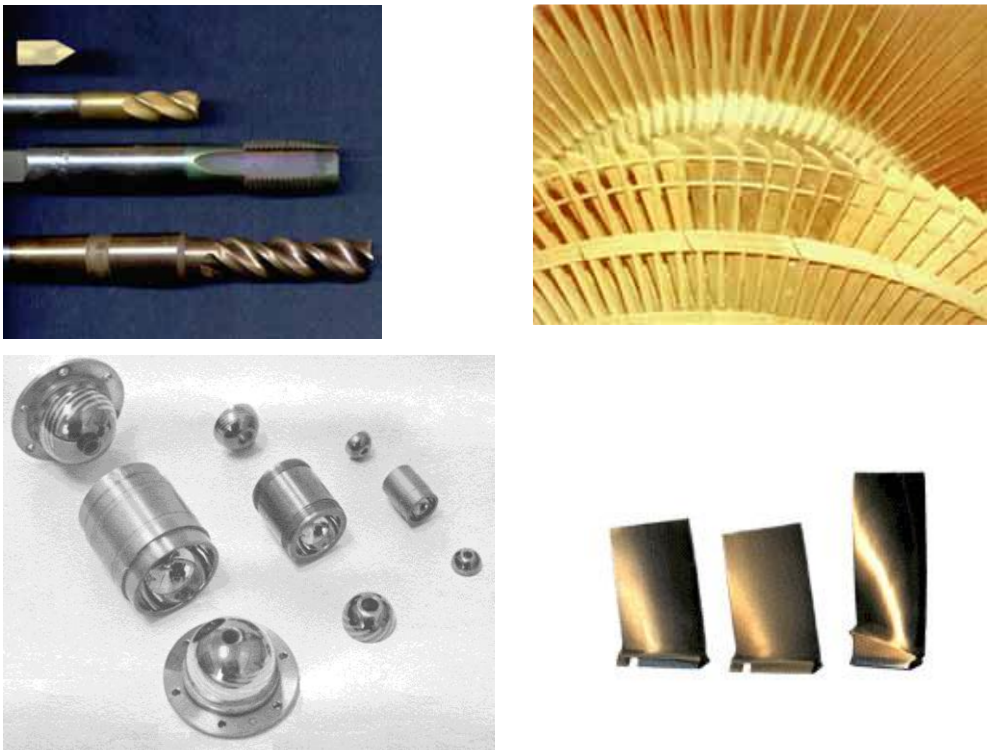
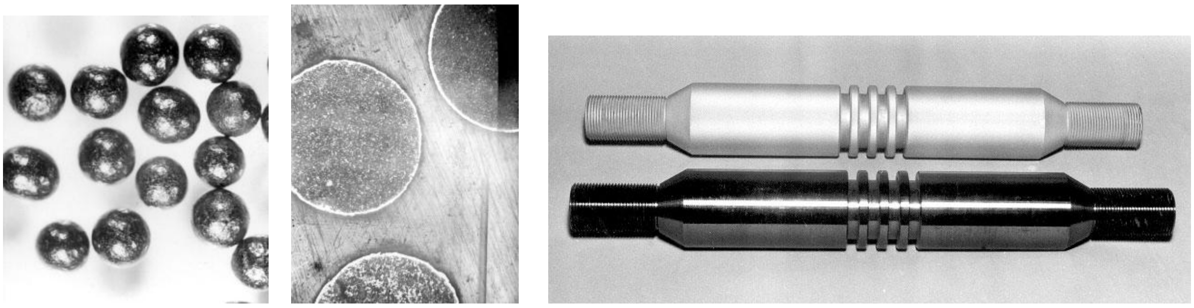


Fig. 5. Instruments, turbine blades and parts of gas-dynamic bearing of gyroscope



a *b*

Fig. 6. Devices with protective anticorrosion coatings: a − micro fuel elements, b − rods of uranium alloy

material provides the decisive success in pioneer line vacuum arc technology of amorphous diamond films synthesis. Works in the field of surface modification of instruments are expanded. Devices with filters (Fig. 3) are developed including automated “Bulat-9” (Fig. 4) which has no analogs as for the technological possibilities. Production of filters solves the problem of synthesis of "wear-free" diamond-like coatings on parts of gas-dynamic suspensions (bearings) (Fig. 5) for new generation of space navigation gyros. V.E. Strelnitskiy was awarded State Prize of the USSR for development of the technology of diamond-like films deposition on gyros parts.

Specialists group under the leadership of V.A. Belous solves very important problem with “Bulat” technology for protection of uranium from atmospheric and hydride corrosion. Solving the problem of long-term storage of uranium articles and other chemically highly active materials requires the development of studies in followings directions:

− development of surface cleaning technology before coating deposition in order to provide its adhesion to substrate;

− production of low-porous non-corrosive coatings compatible with highly corrosive materials;

− development of methods of coating removal from sample conserving their geometry (the need in such procedure arises due to the specific nature of such samples production of studied materials);

− production of equipment for realizing of theses processes.

Using this method on standard "Bulat-6" installation the works of deposition of protective metal-nitride coatings on blades of intermediate stages of steam turbines K-300-240 in JSC “Turboatom” (Fig. 5) were carried out. These turbines have operated more that 150 thousands hours.

In order to solve matrix fuel production problem for NPS of next generation the technologies of protecting coating deposition on microspheres from oxides, nitrides, uranium carbide are under development (Fig. 6). Vacuum-arc modification of equipment on the base of AIR-2 is produced; such modification will allow depositing the coatings on fuel micro-spheres with maximum acceptable single loading ~ 1 kg.

In the frameworks of the program for solution of these problems the method of ion-plasma cleaning of component surface by ions of inert gases was developed. Source of plasma with use of non-independent arc discharge is constructed which operates in stationary conditions with output ion current up to 30 A. Presence of such source allowed to develop the method of ion nitriding and obtain the rates of hardened layers formation of the order 100…150 μm/h at temperature of treated details of 500…550 ºC.

Simultaneously with the works for nitriding the new technology is under development: low-energy ion implantation by immersion into the plasma of arc discharge of low pressure (metallic, gaseous, gas-metallic). Abroad this method is known as PIII (plasma immersion ion implantation). The new method allowed one to increase the corrosion resistance of treated materials in 5…10 times. Developed processes were realized on specially designed equipment based on standard “Bulat” setups.

From the middle of 1980s practically all works for

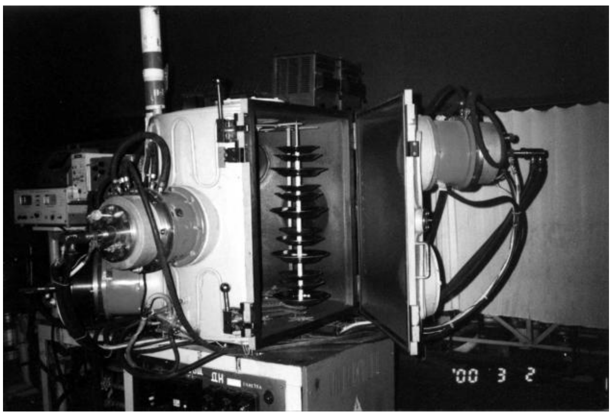


Fig. 7. Bulat-TNP

Fig. 8. Bulat-Nadezhda

Fig. 9. New-York, USA, 2001 (VEECO Instruments, Inc.). Toroidal filter in complex of industrial equipment for production of elements of recording and reading of information

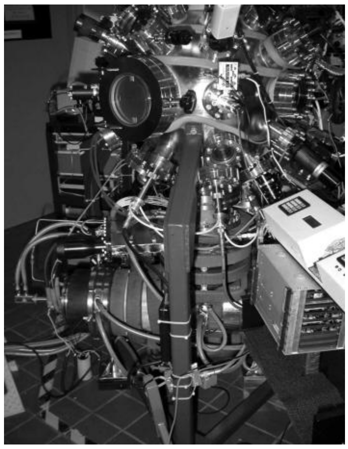


Fig. 10. Right-Patterson aviation base (USA). Laboratory equipment with T-shaped filter

coatings production was concentrated in single department. In 1986 the staff of base laboratory dealing with the “Bulat” problems was transferred into this department. During the 1990s vacuum arc technologies became the main field for two departments (headed by V.A. Belous and G.N. Kartmazov). In this time in the condition of "conversion" and increased attention to saving of natural resources and ecology vacuum technologies and equipment for deposition of protecting and protecting-decorative coatings became preferable as a method alternative to "wet" galvanic procedure which was extremely deleterious for environment.

Returning to 80s it needs to be emphasized that intense physical research of last years were performed at the same time as new design-technological development and its introduction into industry. Resolving still new technological problems the physicists, designers and specialists of Institute experimental enterprise led to production of whole family of “Bulats”: serial installation "Bulat-6" instead the old model "Bulat-3", universal "Bulat-4" plant, equipped with renewable sources of plasma of different types including the source with linear magnetic filters; plant of specific purpose "Bulat-7" for deposition of nitrides (TiN, ZrN) and diamond-like carbon coatings on surfaces of precise parts of friction joints for navigation equipment of rockets and other space apparatuses; plant "Bulat-9" with automatic control of technological processes; special plants for deposition of protecting corrosion-resistant coatings on uranium; plants for metallization of natural and synthetic diamonds "Bulat-3A"; plants with planar vacuum-arc evaporator "Bulat-3K" for deposition of coatings on long-sized samples; plant for complex hardening of instruments (ion-plasma nitriding + coating); plants of "BULAT-TNP" series (Fig. 7) used for surface protection and decoration of specimens made of metal, glass and ceramics in production of every day life articles (consumer goods), for researches

a

b

c

Fig. 11. Faced vacuum arc plasma sources: a − source for equipment of type Bulat-6; b − for deposition of thick coatings; c − source of improved design for facilities of new models

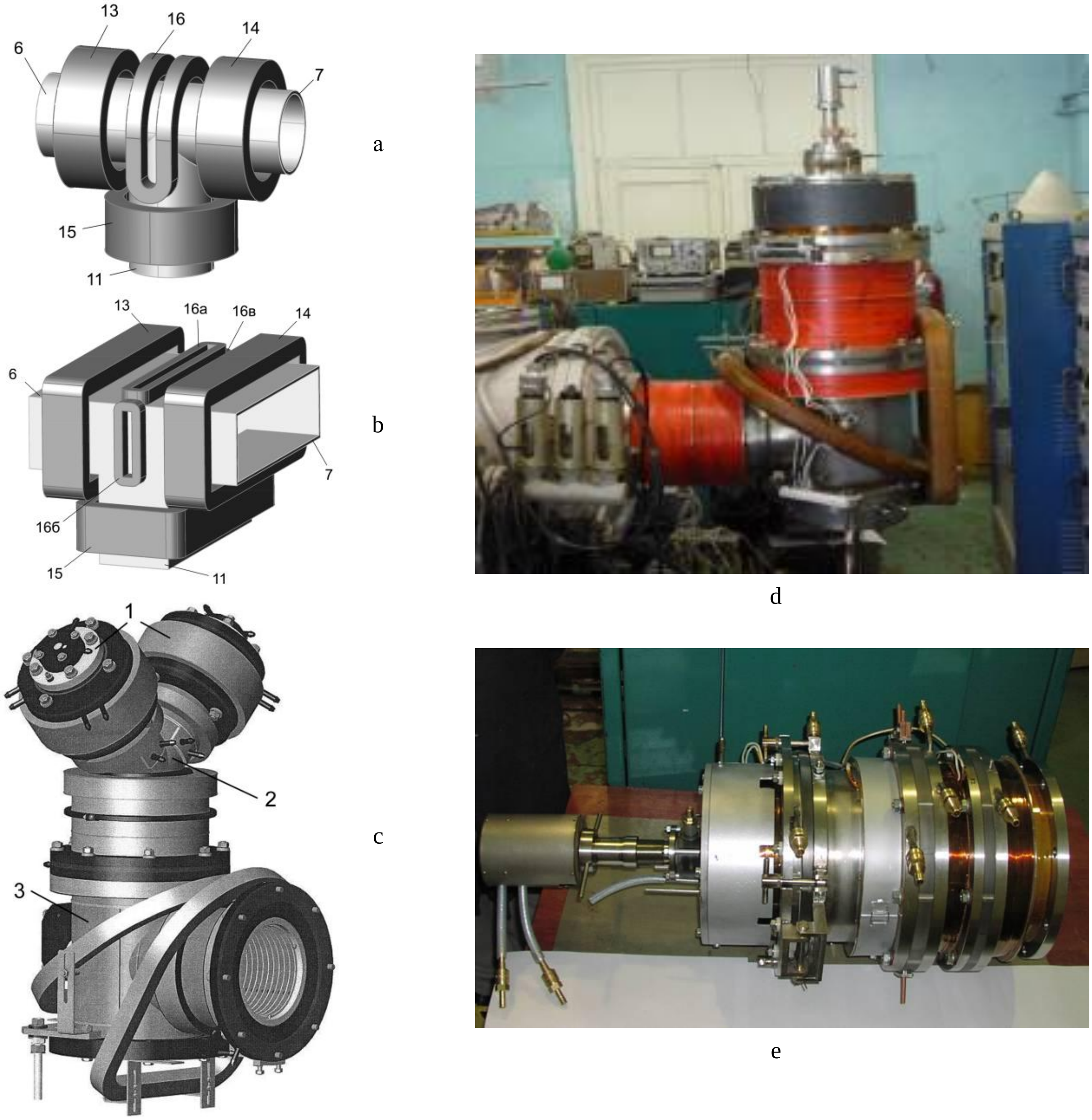


Fig. 12. Plasma filters: a, b − versions of T-shaped filter (13, 14, 15, 16 − coils, 6, 7, 11 − plasma ducts), c − source with (Y + L)-like two-channel filter (1 − plasma source, 2 – Y-like and 3 – L-shaped plasma drivers), d − source with L-shaped filter, e − linear filter

the plant “Nadezhda” is designed (Fig. 8). In the frameworks of GKNT program, VNIIETO (Moscow) develops the equipment IET-8 in cooperation with KIPT.

The wide cooperation of KIPT with other researching center of former USSR: Mosstankin, NIIautoprom, NPO "Rotor" (Moscow), NPO “Azimut” (Leningrad), TZNITI, KhPI (Kharkiv) had played the important role in development of new technological line and its practical application. Some ministries of USSR produce vacuum-arc plants for solution of their special technological problems using the developments of KIPT. These are: plant “Pusk” (NIIautoprom), developed by Kharkiv branch TSNITI, system of series “Union” and VU2MBS (of Kaliningrad and Smorgon production) and assembly with pulsed sources of carbon plasma (Belgorod KB “Ritm”), and plants for coatings deposition on large-scale products (Ukrorgstankinprom, Kharkiv) and assembly for coating deposition on piston rings (NIITavtoprom) and others.

Efficiency of enterprises, equipped with vacuum-arc assemblies, and increasing authority of KIB was also due to training of operators. Beginning from 1977, courses for operator training are opening in Technique house. Unfortunately, in the period of crisis during the 1990s the system was ruined and plants were operated by operators without professional experience.

After USSR break-up our institute suffers critical period. Traditional financing from state budget stopped. The more suitable solution in this situation was organizing of minor enterprises (ME), which produced different products for industrial enterprises and for consumer goods (TNP) (Fig. 7). Such approach had allowed to ensure to pay salary to the institute researchers and use the part of obtained means for

Fig. 13. Baron Thomas von Ardenne (in center) congratulates I.I. Aksenov for Manfred von Ardenne 2003 award for applied physics. To the right – Peter Zimroth

development and improvement of technologies and equipment.

In the second half of 1980s the popularity of KIB was at the apogee. To this time plants of "Bulat" type are widely used by all tool and engineering plants of USSR. Needs of home market in "Bulats" were satisfied at the expense of plants of Kiev and Tallinn production and also plants NNV of some modifications produced in Saratov and Novosibirsk. Specialists of KIPT are worried with development of equipment of new generation based of innovative technical solutions. Western researchers very quickly assimilate the “technology of century”, “technology of future”. Besides "Multi Arc" a number of researching centers works on this problem.

In 1986 the works of KIPT in the field of vacuum arc technologies were awarded with Prize of USSR Soviet of Ministry (laureates: I.I. Aksenov, L.P. Sablev and V.M. Khoroshikh) and by State Prize of USSR (A.A. Romanov, and A.A. Andreev). Next year V.E. Strelnitsky was laureate of State Prize of USSR for works in the field of synthesis of super hard films of diamond-like carbon.

Foreign-trade politics of KIPT as owner of competitive development can't be named successful. But despite the crisis the specialists in the field of coatings continue their activity and develop new method of ion-plasma modification of surface of tool and structural steels and alloys. Just in this period the new filter systems for formation of dropletless fluxes of erosion plasma of vacuum arc were produced. Productivity of new systems was much higher. Test-industrial specimens of long-sized vacuum arc evaporators of planar type are developed. The new for Ukraine works in field of synthesis of polycrystalline diamond films are in progress. Studies of plasma of stationary (direct current) arc discharge of low pressure and processes of formation of nitride and carbonitride coatings are also in progress. Low-temperature processes are of special interest. Processes of duplex treatment of samples (nitriding with subsequent deposition of coating in one technological cycle) are studied also as quenching of articles with multilayer vacuum-arc coatings. New advanced coatings – photocatalytic, anticorrosion (for protection of first wall of fusion plant "ITER" from destructive effect of liquid-metal coolant) are produced; processes of ion implantation of metals into zirconium alloys for improvement of their mechanical properties and corrosion behavior are developed. Possibility to form heat reflecting and protective coatings on glass and plastic material by vacuum-arc method are studied. Technological facilities for electron acceleration by the use of plasma of vacuum arc are produced. Works on improvement of vacuum-arc pumps are in progress.

Important role in surviving of scientific potential of the Institute in the field of ion-plasma technologies is played by contracts with foreign firms and by projects of Science-technology Center in Ukraine (STCU). Developments (Figs. 9 – 12) and significant part of papers in the filed of ion-plasma technologies and surface modifying of materials are the result of

Fig. 14. Beijing State University (China). Equipment for deposition of coatings of diamond-like carbon. From left to right: V.A. Belous, Yan Yi Shi, V.V. Vasiliev, V.E. Strelnitskiy, Van Li

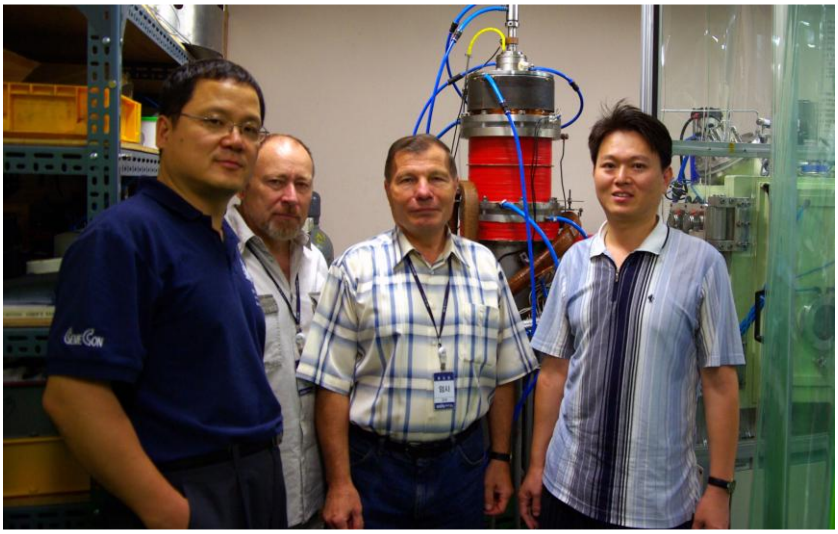


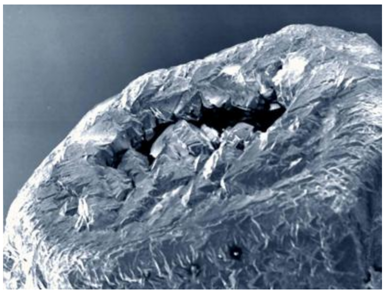
Fig. 15. Curved filter on laboratory equipment (background) in Korea Institute of materials science. V.V. Vasiliev and V.E. Strelnitskiy (in center), with Korean specialists

cooperation of scientists of the institute with foreign partners.

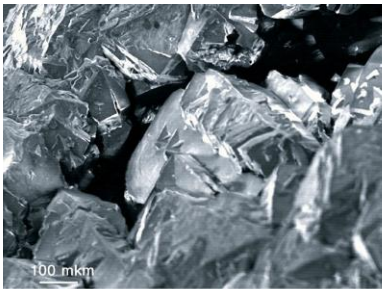
More important result of last decade is the development of filtering magneto-electric systems (Fig. 12) for formation of fluxes of clean vacuum-arc erosion plasma. This development was justified by study in the field of super hard diamond like carbon films (DLC) or amorphous carbon (a-C) [3].

Systematic study of vacuum arc synthesis of such films was started in KIPT by V.E. Strelnitskiy in the beginning of 1970s. Even the first experiments have demonstrated the advantages of vacuum-arc method with regard to the rate of a-C condensate growth, adhesion properties and microhardness. But films obtained by this method have high quantity of coarse defects induced by the presence in condensate fluxes of plasma of macroparticles of cathode material (graphite) of vacuum arc. The density and size of defects were so high that possibility and expediency of new method use was questionable. But the way to overcome the problems related with macroparticles was found. The cardinal solution of the problem became possible with the production of magnetic filters – facility for the removal of macroparticles from plasma. Works for production of theses facilities were started by group of Aksenov in 1974. Invention of plasma filter ("separator") with curvilinear plasma duct curved as quarter of a torus and also with S- and Ω-like plasma ducts (Fig. 10) was registered in 1976 (authors I.I. Aksenov, V.A. Belous, V.M. Khoroshikh, V.G. Padalka). The use of this filter has allowed removing the principle limitations for the use of vacuum-arc discharge for formation of films of high quality. Way for the use of unique possibilities of vacuum arc method in the field of high technologies as instrument for formation of micro- and nanostructure in optics, electronics, fine mechanics was opened up. In 2003 I.I. Aksenov was awarded with Prize of Manfred von Ardenne in the field of applied physics (Fig. 13).

a



b



c

Fig. 16. a − equipment for synthesis of diamond films; b, c − face of synthetic mono crystal with growing polycrystalline diamond

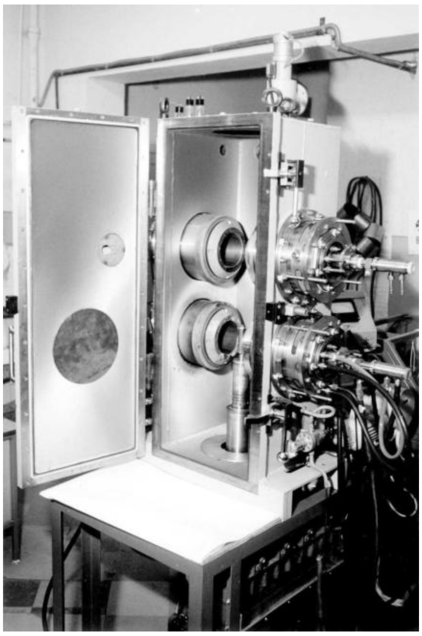


Fig. 17. Equipment for formation of thick (self-carrying) films

Fig. 18. National Academy of Sciences of Ukraine. Academician-secretary of department of mechanics of NASU A.F. Bulat presents the diploma for discovery to doctor of technical sciences deputy director of ISSPMT V.A. Belous

Experimental results on high quality DLC synthesis with use of source of clean carbon plasma of arc discharge in vacuum were published in 1989. This contributed to the start of large-scale investigation in the field of a-C coatings in scientific laboratories round the world. Production of sources of clean erosion plasma had allowed advance vacuum-arc methods of coating synthesis with their unique possibilities in the field of high technologies, in particular, for formation of super-fine (20…30 Å) protecting films of diamond-like carbon in production of systems of data storage in computer techniques. Vacuum arc sources of carbon plasma with magnetic filters developed in KIPT in frameworks of partnership Project STCU are the constituent part of technological equipment for production of systems of magnetic recording and information reading produced by company VEECO Instruments Inc., USA (Fig. 9). Such well-known companies of USA as IBM, SeaGate, manufacturers of electron apparatus and computer technique in Mexico,

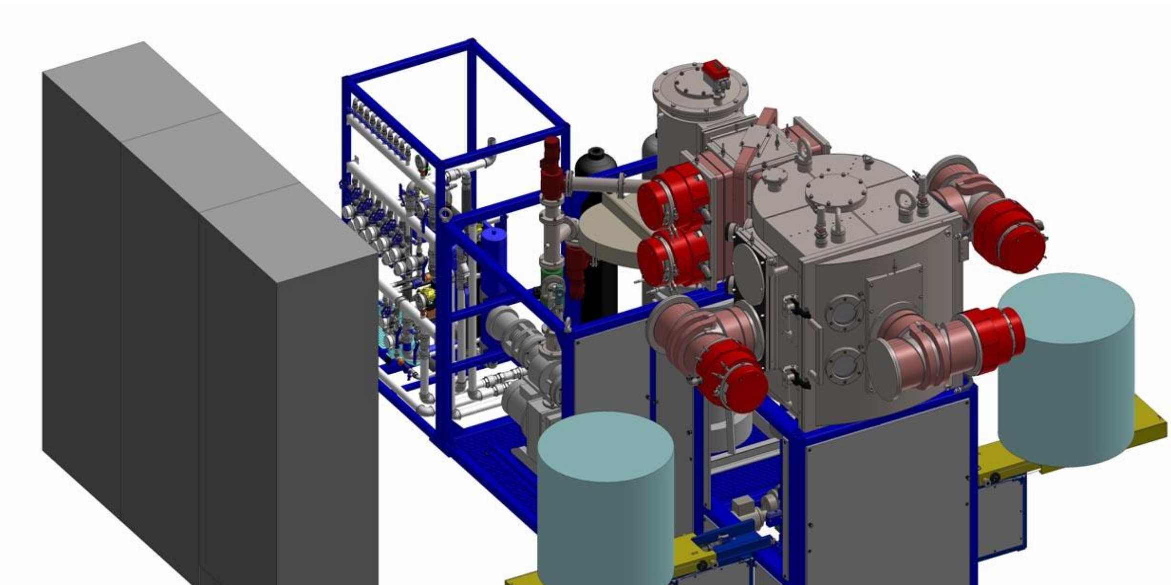


Fig. 19. Concept model of universal equipment with replaced sources of plasma, filters and their combinations. Equipment allows produce one-layer, multi-layers, composite coatings, including nanostructure deposited from filtered and non-filtered plasma

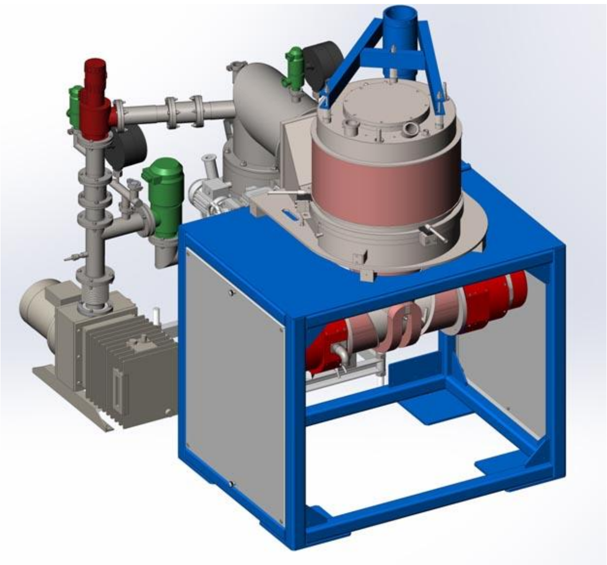


Fig. 20. Concept model of equipment for deposition of protective antierosion coatings on turbine blades and compressors of gas-turbine engines

Philippines are the users of this equipment. The equipment for deposition of a-C coating was sold to China (Fig. 15), South Korea, Armenia.

Specialists of the institute have developed the concept of wide-aperture curvilinear magnetoelectric filters with low aspect ratio (plasma driver inner radius to its radius of curvature). The fruitfulness of the concept was confirmed by the results of development of high-efficiency sources of vacuum-arc plasma with L- and T-shaped filters (Fig. 12). Carrying capacity of filters is higher 50% opposite to 25…30%, characteristic for other well-known developments. Coefficient of efficiency (ratio of output ion current to the current of arc) of new sources is higher 5% opposite to ~ 0.5% characteristic for first plasma sources with curvilinear filter. Coating deposition rate with L- and T-shaped filters constitutes 4 μm/h into the spot of condensation with diameter 20 cm. The same concept is used on production of multi-channel filters allowing to form plasma fluxes cleaned from macroparticles. The flux at such facility outlet represents the homogeneous mixture of several multicomponent fluxes fed into filter mixer from several arc generators with cathodes of different materials. Developments of multichannel filters are interesting due to the increasing investigation in the field of nanotechnologies, nanostructural and nanolayer composite coatings.

Successes in production of sources for filtered plasma had allowed solving the problems of deposition of transparent protecting coatings on plastic materials, in particular, on polyacryl, material used for production of solar batteries. Coatings of aluminum nitride with intermediate layer of a-C protect the base from destructive effect of ultra violet component of solar radiation and atmosphere erosion. The works in this direction became of great importance in relation with investigation and development in the field of the use of energy of solar radiation.

From the beginning of 1990 scientists of V.E. Strelnitsky laboratory start the systematic study in new for Ukraine field – synthesis of polycrystalline diamonds by deposition from plasma of electric discharge of different types: arc in plasma generator with gas vortex stabilization, in microwave plasma generators, into facility with glow discharge in transverse magnetic field. It is difficult to overestimate the prospects of this line: according to the forecast of Japanese specialists the third millennium will be the "diamond millennium". Recently the highest results are obtained with use of last method, based on synthesis in plasma of heavy current glow discharge into the mixture of hydrogen with methane. The rate of diamond layer growth on molybdenum substrate onto the spot with diameter about 60 mm makes ~ 3 μm/h. The methodology of the growth of polycrystalline diamond layer on facet of natural and synthetic diamond with size from some microns to several millimeters is developed (Fig. 16). The proposed procedure may be used for "healing" the surface defects of such diamonds. On healing of large defects with size comparable to facets dimensions the mass of crystal is growing to value twice increasing the initial one. Interest to such

Fig. 21. A.A. Romanov and A.A. Andreev. State Prime of USSR laureates, 1986

Fig. 22. V.E. Strelnitskiy, State Prime of USSR laureate, 1987

Fig. 23. I.I. Aksenov. Prize of Soviet of Ministry of USSR, 1986 and International Prize of Manfred von Ardenne, 2003, laureate in the field of applied physics

works is related with the possibility to heal defects and improvement of quality of crystals of synthetic and natural diamond and also with the possibility of homoepitaxial deposition of diamond layers and formation of monocrystalline diamond coatings with extremely high characteristics, also for use as nuclear radiation detectors.

Last years possibilities of nanostructured films deposition and nanolayer materials are successfully studied. Methodology of such films formation with the use of one- and two channels filtering systems with one cathode of complex composition or two cathodes of different materials is developed. Nanostructured and nanolayer films with high thermal stability, resistance to friction wear, erosion- and corrosion resistance and high optical transparency are obtained (TiN, (Ti,Al)N, (Ti,Si)N, (Ti,Si,Al)N, $(Ti_{0.92}Al_{0.07}Mo_{0.01})N$, $(Ti_{0.88}Al_{0.06}Mg_{0.06})N$, TiN/CrN/TiN-CrN, a-C, a-CN, a-(CH)N, a-CMe).

Distinctions of discharge of new type on the base of vacuum arc – constricted discharge are investigated. On the base of this discharge the principles of technological processes and equipment for complex treatment of structural materials (nitriding + deposition of coating) are developed. Plant for deposition of wear-resistant coatings on inner surfaces of tubes with length up to 8 meters and diameter 80 millimeters is produced.

Development of the process and equipment for formation of thick layers by vacuum arc method may be regarded as special achievement. Multilayer structures (alternating layers of Mo and Nb) with thickness up to 1.5…2 mm (Fig. 17) are obtained. It is intended to use the developed technology for production of nozzles for rocket engines of low thrust. The obtained result is absolutely unique: it was considered early that with the use of vacuum arc it is possible to obtain only thin films.

Specialists of the institute contributed to investigation of Ukrainian scientists in the field of interaction of gamma-radiation with materials in the context of effort for increase of protection from this radiation during container storage of nuclear wastes of nuclear power stations and other objects relate with the use of radioactive materials. The specialists of the department of ion-plasma treatment of materials carried out experiments for vacuum arc formation of multilayer structures on the base of light and hard metals with subsequent study of passage through these metals of gamma-quantum fluxes. In 2012 the discovery "Predictable relation between intensity of gamma-quantum flux passed through the layer of multiphase material and its physical-chemical characteristics" was published. Director general of NSC KIPT, academician of NAS of Ukraine I.M. Neklyudov and deputy-director of ISSPMT V.A. Belous were the members of this team of contributors (Fig. 18).

The last development of the collective is the high-capacity plasma source with linear filter produced on the base of principles noted in early works of I.I. Aksenov and colleagues.

The developed by D.S. Aksyonov software for modeling of the behavior of macroparticles fluxes in plasma ducts also should be noted. This software allows one to optimize configuration of inner surface of plasma duct for minimizing macroparticles passing through the filter. Optimization of filter geometry with the regard of its efficiency for transporting of ion component of filtered flux of plasma is carried out by made for this purpose software-hardware complex which consists of multichannel matrix ion current probe and the software, which is needed for its control, measurement data processing and visualization in real-time mode.

Now the designing of improved concept of facilities (Figs. 19, 20) is in progress; we will use all newest technical solution for cardinal increase of their capacity, quality of deposited coatings, possibility of reconstruction for new technologic process, automated control of all processes starting from loading of treated products to their unloading. The project foresees the possibility to equip the facilities with plasma filters for their use on synthesis of composite micro- and nanostructured coatings.

As it was mentioned above the works of institute scientists were highly appreciated by different State prizes and by the Prize of Soviet of Ministry of USSR in 1986 − 1987 (Figs. 21 − 24).

Summarizing the presented information authors intend to disperse the stereotype: developed in KIPT method of "Bulats" is limited by technique of deposition of "like-gold" coatings for sets of false tooth and equipment of "Bulat" only by facility "Bulat-3". The presented review shows how large the investigation and developments of the Institute in the field of discussed technologies are. Unfortunately, the journal paper doesn’t permit to present the complete report on our activity. For more detailed information you may address the monographs [3−7].

Fig. 24. Presentation of diplomas of Prize of Soviet of Ministry of USSR laureates. From left to right: L.P. Sablev, I.I. Aksenov, N.V. Belan (KhAI), I.N. Vorona, V.M. Khoroshikh, E.G. Goldiner

These monographs describe several lines of works which are more important experimental and theoretical studies and also engineer-technical development of the institute in discussed branch. Methods of formation of metallic plasma fluxes generated by cathode spots of arc discharge in vacuum and in low pressure gas medium are described. Results of investigation of physical processes which are the base of methods of coating deposition and surface modification are presented. Processes in inter electrode vacuum-arc plasma are examined, methods of ignition and stabilization of vacuum-arc discharge in technological plasma sources, physics and technique of formation of plasma fluxes with designed parameters and control of these fluxes are presented. Information on production and study of magnetoelectric filters (including two-channel for deposition of one- and multi-layers coatings) is presented. Data on study of synthesis of micro- and nanostructured coatings, including nanolayer coatings is also presented. Numerous experimental and theoretical material on physics and technology of synthesis of thin and ultrathin films of diamond-like carbon is considered, examples of commercial use of vacuum arc methods for deposition of diamond-like coatings are presented. Firstly are systematically described vacuum arc processes for deposition of corrosion-resistant coatings and surface modification for protection of uranium and other materials of nuclear power from atmosphere and hydride corrosion.

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ВАКУУМНО-ДУГОВОЕ ОБОРУДОВАНИЕ И ТЕХНОЛОГИИ ПОКРЫТИЙ В ХФТИ

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Рассмотрены основные этапы развития вакуумно-дуговых технологий формирования функциональных покрытий на инструменты, детали машин и приборов, изделия из пластика, металла, стекла, на природные и искусственные алмазы, созданные в Харьковском физико-техническом институте. Описаны конструкторские особенности и технологические возможности установок для реализации этих технологий, плазменных генераторов для оснащения установок, примеры некоторых концептуальных разработок технологического оборудования.

ВАКУУМНО-ДУГОВЕ ОБЛАДНАННЯ ТА ТЕХНОЛОГІЇ ПОКРИТТІВ У ХФТІ

І.І. Аксьонов, В.А. Білоус, В.Є. Стрельницький, Д.С. Аксьонов

Розглянуто основні етапи розвитку вакуумно-дугових технологій формування функціональних покриттів на інструменти, деталі машин і приладів, вироби з пластика, металів, скла, природні та штучні алмази, створені у Харківському фізико-технічному інституті. Описані конструкторські особливості і технологічні можливості установок для реалізації цих технологій, плазмових генераторів для оснащення установок, приклади деяких концептуальних розробок технологічного обладнання.