EUROPEAN MASTER PROGRAM

Modules IV and II (part 2). Mechanical applications and optical characterization of Nanofilms

State Technological University "Moscow Institute of Steel and Alloys" and Institute of Spectroscopy of Russian Academy of Sciences
Co-organized by CR5 and CR6
October 19-23, 2009

Mechanical applications (two days of lectures and practical training)

State Technological University "Moscow Institute of Steel and Alloys", Moscow

LECTURES				
No.	**Title**	**Duration**	**Speaker**	**Abstract**
1	**Multicomponent Nanostructured Coatings. Fundamental Principals, Deposition, Characterization and Testing**	1 hour	Prof. D. Shtansky (CR5)	Multicomponent nanostructured coatings for various tribological applications (cutting tools, press-forming tools, load-bearing components, etc) are of interest because of their remarkable combination of properties such as high hardness, appropriate stiffness, thermal stability, high fracture toughness, low wear and friction, impact- and corrosion-resistance. The current topics related to the deposition, characterization, and testing of nanostructured coatings are review. The problems and methods of their solving are considered related to the analysis of the structure in the nanometric scale (crystallite size, phase composition, atomic structure of the grain boundaries, defect structure, and orientation relationships) and the evaluation of the processing-structure-properties relationships. As examples, various groups of films for mechanical engineering and medicine are considered.
2	**Disperse- Strengthened by Nanoparticles Tribological Coatings**	1 hour	Prof. E. Levashov (CR5)	This lecture is devoted on fundamental base of physical methods of deposition been oriented on low temperature pulse electrospark deposition (PED) and chemical reaction assisted electrospark deposition (CRAPED). These methods are considered as applied to advanced protective and tribological coatings deposition. Materials science aspects of consumable composite nanostructured electrode materials synthesis will be discussed: *dispersive-hardening ceramic materials* with effect of simultaneous strengthening of carbide grains and metallic binder result in precipitations; *nanoparticles disperse-strengthened composite materials* with modified structure produced using focused alloying by refractory compounds nanoparticles which are modificators affected to the process of structure formation thought the liquid phase and lock the recrystallization; *nanostructured cemented carbides*. Kinetics and mechanism of coatings deposition, coatings structure and properties on Ti-, Ni-, Fe-alloy substrates. Examples of successful industrial application of PED and CRAPED are demonstrated.

3	**Different approaches to the design of superhard materials and their non-linear mechanical properties and problems during the measurement of their hardness and elastic modulus**	1 hour	Prof. S. Veprek (CR14)	In the first part of my lecture, I shall briefly summarize different approaches towards the design and preparation of super- ($H \geq 40$ GPa) and ultra-hard ($H \geq 80$ GPa) materials. This will include the intrinsically super- and ultra-hard materials where the design is based on the calculation of elastic moduli by first principle methods, hardening by energetic ion bombardment during the deposition of thin films by means of plasma PVD, and design of extrinsically super- and ultra-hard nano-structured materials, such as heterostructures and nanocomposites. The second part will deal with the non-linear mechanical properties (enhancement of elastic moduli and of flow stress of such materials due to large pressure arising during loadings under the indenter). Finally I shall show what kind of problems arises during the measurement of hardness and elastic moduli of such materials and, in particularly, the limits of the automated load-depths-sensing technique ("nanoindentation") when applied to them.
4	**Tribology of carbon-based lubricant coatings**	1 hour	Dr. J.C. Sanchez-Lopez (CR9)	The design of multilayered and nanocomposite coatings structures has allowed to achieve superior hardness, toughness and excellent wear resistance useful for many industrial applications. The optimization of the tribological performance of such materials represents a challenge as depends not only on factors intrinsic to the coatings (chemical composition, microstructure, phase composition, texture…) but, besides, others related to the application conditions (adhesion to the substrate, nature of the counterfaces, environment, load, etc.). In this lecture, some results obtained for carbon-based lubricant coatings: amorphous (a-C, a-C:H, DLC, CN_x) and nanocomposite (combination of nanocrystalline metal carbides and carbonaceous matrixes) are reviewed. By means of different examples it is highlighted the importance of an appropriated knowledge of their structure, chemical composition and rubbing surfaces after contact to understand the tribological behaviour and wear mechanism.
5	**Imaging, image modification, image analysis in (nano-) materials science**	1 hour	Dr. P. Nagy (CR11)	Some basic definitions in digital imaging, image modification and –analysis methods, extended by some interesting „exotic" methods, as 3D reconstruction of real nanostructures, micro CT and similar.
6	**Formability of coated steels**	1 hour	Prof. S. Spigarelli (CR2)	One of the most crucial aspects in the production of sheets coated by thin films is the relationships between the properties of the coating and those of the composite (coating+substrate). In particular, the determination of the “formability” of the coated sheet is essential in all those applications that require secondary sheet-forming operations, such as deep drawing. The formability is the ability of a (coated) metal to be shaped through plastic deformation without undergoing extensive damage, e.g., in the case of coated sheets, cracking, loss of adhesion, etc. This lecture will introduce the fundamental aspects of formability testing; case studies dealing with the investigation of the formability of steel coated sheets will be then illustrated.

7	**Mechanical behaviour of nanofilms and coatings**	1 hour	Prof. E. Gutmanas (CR8)	Methods of evaluation of mechanical behavior of nano-thin films and nanostructured coatings are discussed. This applies to such properties as strength, fracture toughness, hardness and adhesion to the substrate. Experimental results as well as modeling of mechanical behavior of nanostructured single and multiphase phase material s, as well as of nanolaminated coatings are compared with mechanical behavior of micron scale structures.
8	**Characterization of Solid Thin Films and Functional Surfaces of Advanced Materials by Mechanical Contact Testing**	1 hour	Dr. M. Petrzhik (CR5)	The lecture will be focused on contact method of characterization of thin films to estimate their mechanical properties by nanoindentation, i.e. Instrumented Indentation at very low loads. An outlook at the development of the method in the past and in perspective, as well modern studies based on standard practice will be discussed.
9	**Methods of contact and non-contact characterization of surface topography**	1 hour	Dr. Yu. Pogozhev (CR5)	1) Surface roughness parameters 2) Contact methods of surface roughness characterization 3) Optical profilometry as non-contact method of surface roughness characterization. • Principle used in optical profilometry / How optical surface profilers work • Advantages and disadvantages • Optical profiling system «Veeco «WYKO NT1100»
10	**Friction and wear of coated surfaces – from theory to practice**	1 hour	Dr. Irina Bashkova (CR5)	The lecture will be focused on the friction and wear of thin films and coatings. This will include a brief historical introduction, main definitions, fundamental aspects of friction and wear, description of the main wear mechanisms. Various types of tribological coatings will be considered. Finally, various equipments for tribo tests will be described.

10 hours lectures

PRACTICAL TRAINING					
No.	**Topic**	**Duration**	**Teacher**	**Aim**	**Instrument**
1	**Nanoindentation**	1.5 hours	Dr. M. Petrzhik, (CR5)	Determination of hardness and Young' modulus of thin films and the near surface layer of bulk materials using nanoindentation	Nano-Hardness Tester, CSM Instr., Switzerland
2	**Scratch Testing**	1.5 hours	Dr. M. Petrzhik, (CR5)	Evaluation of the adhesive/cohesive strength, scratch resistance, and mechanisms of coating failure during scratch testing	Revetest, CSM Instr., Switzerland
3	**Surface Topography**	1.5 hours	Drs. M. Petrzhik, Yu. Pogozhev, (CR5)	Comparative analysis of the surface roughness using mechanical (contact) and optical (non-contact) profilometry	Surface Roughness Tester SJ-402, Mitutoyo, Japan. AFM-objective, CSM Instr., Switzerland. Optical Profiling System WYKO
4	**Friction and Wear**	1.5 hours	Drs. M. Petrzhik, I. Bashkova (CR5)	Characterization of tribological properties of nanostructured coatings under different conditions: 1. at room and elevated temperatures; 2. in air and under various solutions	Tribometer (pin-on-disc and reciprocal modules), CSM Instruments; High-temperature Tribometer, CSM Instruments

6 hours practical training

Optical characterization (two days of lectures and practical training)

Institute of Spectroscopy of Russian Academy of Sciences

142190 Troitsk, Moscow region

LECTURES				
No.	**Title**	**Duration**	**Speaker**	**Abstract**
1	**IR spectroscopy of dielectric thin films on metal substrate**.	1 hour	Prof. E.A.Vinogradov (CR6)	Optical properties of thin dielectric or semiconductor films on a metal surface are discussed in a great number of works. In some of them changes in the optical properties of free films (films without substrates) due to their contact with a metal are considered, in others changes in the characteristics of surface plasmons of a metal due to the presence of thin films on its surface are considered. However, such approach, though it is necessary in most cases, is not correct, generally speaking, as because the properties of both classes of excitations are modified due to the interaction of dipole - active excitations in the thin film with conduction electrons in the metal substrate. However, experiments always yield data on the properties of the whole structure, in our case of a sandwich "vacuum - film - metal". The electromagnetic field of this mixed polariton is determined by elementary excitations of every medium of the structure. The investigations carried out show that radiative surface states, i.e. polaritons of film - vacuum and film - substrate interfaces, rather than vibrational states in the bulk of the film are responsible for light absorption by thin films of dielectrics (semiconductors) on metal substrates. Dipole moments of transverse optical phonons in the bulk of the thin film, apparently, undergo strong metal quenching as the total dipole moment is parallel to the film plane and is compensated practically by its image. In this lecture we will discuss experimental and theoretical results of investigation of IR spectroscopy data obtained on thin films on different substrates.
2	**Surface polariton spectroscopy**	1 hour	Prof. V.A.Yakovlev (CR6)	The lecture will be focused on the optical characterization of thin films using surface polariton spectroscopy. The surface polariton excitation, propagation along the interfaces and detection will be discussed. The special attention will be paid on the obtaining of the dielectric functions of the films from surface polariton spectra.
3	**Raman spectroscopy of condensed matter**	1 hour	Prof. B.N. Mavrin (CR6)	Theory and applications of Raman spectroscopy will be summarized: the conservation of energy and momentum, the energy schemes, the Raman polarizability, selection rules, symmetry attributions, mode assignements, examples of Raman spectra in crystals, films and nanostructures. Surface enhanced resonance Raman scattering. Example of monitoring the quality of carbon coatings.

4	**Experimental methods of Raman spectroscopy**	1 hour	Dr. V.N. Denisov (CR6)	The plan of the lecture on the Raman instrumentation: lasers, double monochromators and stray light, multichannel detectors and triple spectrographs, holographic notch filters, the intensity and frequency calibrations, Raman scattering schemes, Raman microscopy, Raman imaging, remote sensing.
5	**Atom nanolithography based on method of atom optics**	1 hour	Prof. V.I. Balykin, (CR6)	Atomic and molecular nanostructures on a surface of a solid are key components in modern technologies. At present, the most developed method for surface nanostructure creation is optical photolithography. An alternative for optical photolithography is a method based on *atom optics.* One of the important trends in atom optics is development of basic elements, which are similar to familiar devices of light optics, such as atom lenses, mirrors, beamsplitters and interferometers. Among many possible applications of atom-optical elements, a potentially important one is micro- and nanofabrication of material structures, usually referred to as *atom lithography*. Methods of atom lithography are founded on deposition of atoms from a beam sharply focused by an atom lens, generated by a spatially inhomogeneous field of laser radiation.
6	**Single molecules as a spectral nanoprobe for characterization of processes in condensed matter**	1 hour	Dr. A.V. Naumov, (CR6)	The lecture demonstrates the great possibilities of single molecules spectroscopy for the study of dynamical processes in disordered solids on microscopic level. We will present new approach based on the synchronous control of spectral characteristics of a great number of single molecules and consequent statistical analysis of measured spectral parameters.

6 hours lectures

PRACTICAL TRAINING					
No.	Topic	Duration	Teacher	Aim	Instrument
1	**Raman study**	1.5 hours	Dr. V.N. Denisov, (CR6)	Measurement of Raman spectra and their interpretation	Multichannel Raman spectrometer with triple monochromatization
2	**Fourier-Raman study**	1.5 hours	Prof. B.N. Mavrin, (CR6)	Measurement of Raman spectra with IR excitation and their interpretation	Fourier-Raman spectrometer RFS 100/S, Bruker
3	**IR Fourier study**	1.5 hours	Dr. N.N.Novikova, Prof.V.A.Yakovlev (CR6)	Measurement of IR transmittance spectra of a film on IR Fourier spectroscopy and their interpretation	The Vacuum FT-IR Spectrometer IFS 66 v/s “Bruker”, Germany
4	**IR Fourier study**	1.5 hours	Dr. N.N.Novikova, Prof. V.A.Yakovlev (CR6)	Measurement of IR reflectivity spectra of a film on IR Fourier spectroscopy and their interpretation	The Vacuum FT-IR Spectrometer IFS 66 v/s “Bruker”, Germany

6 hours practical training