UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Nanotehnologije
Course title:	Nanotechnologies
Članica nosilka/UL Member:	UL FS

Študijski programi in stopnja	Študijska smer	Letnik	Semestri
Strojništvo - Razvojno raziskovalni program, druga stopnja, magistrski	Konstruiranje (smer)	1. letnik	2. semester

Univerzitetna koda predmeta/University course code:	0566878
Koda učne enote na članici/UL Member course code:	6028-M

Predavanja	Seminar	Vaje	Klinične vaje	Druge oblike študija	Samostojno delo	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	Mitjan Kalin
Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Konstruiranje, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Design Engineering, which is an elective specialised course in other fields of study.

Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	Prerequisites:
Izpolnjevanje pogojev za vpis v Magistrski študijski program II. stopnje Strojništvo - Razvojno raziskovalni program.	Meeting the enrollment conditions for the Master's study programme of Mechanical Engineering - Research and Development program.

Vsebina:	Content (Syllabus outline):
1. Predavanja: - Uvod: opredelitev pojmov, primeri, področje dela, zgodovina. 2. Predavanja: - Značilnosti nanotehnologij in posebnosti pojavov na nano skali: razlike med nano in makro tehnologijo.	1. Lecture: - Introduction: definitions, examples, field of work, history. 2. Lecture: - Characteristics of nanotechnologies and specifics of nano scale phenomena: differences between nano and

Minituarizacija, fizikalni zakoni, osnove kvantne mehanike, elektromagnetno valovanje, kvantizacija energije, dvojnost energije in snovi, princip nedoločenosti. 3. Predavanja: - Vezi in površinske sile: klasifikacija in lastnosti vezi, intramolekularne vezi, Lennard-Jones potencial, van der Waalsove vezi. Površinske sile med telesi – ključne enačbe. - Sile v tekočinah: elektrostatske, zeta potencial, DLVO teorija, strukturne sile (solvatacijska, hidracijska, hidrofobna). 4. Predavanja: - Prosta površinska energija in omočljivost: površinska energija, površinska napetost. Omočljivost, Youngova enačba, vrste omočljivost, vplivi (Cassie, Wenzel, homogenost, kemijski). Kapilarni učinek in kondenzacija, meniskus. 5. Predavanja: - Adhezija in adsorpcija: adhezijsko delo, adhezija med trdnimi telesi in v vlagi. Adsorpcija, vrste adsorpcije, izoterme. Rast površinskih filmov. 6. Predavanja: - Karakterizacija nanostruktur: optične metode, elektronska mikroskopija, vrstične tipalne metode, spektroskopske metode, difrakcija, kombinirane metode. 7. Predavanja: - Izdelava nanomaterialov: vrste, izdelava, gradnja od spodaj navzgor (ALD, sol-gel, SAM, kemijsko, ...) in od zgoraj navzdol (drobljenje, več vrst litografije). 8. Predavanja: - Vrste nanomaterialov: osnovne razlike in značilnosti, vrste: nanodelci, nanofilmi, nanozrna, nanoporozni, nanožice, nanocevke, fulereni, grafen... 9. Predavanja: - Nanovarnost: zdravstvene nevarnosti nanotehnologij, meritve, zakonodaja, zaščita. 10. Predavanja: - Površinski učinki in nanotrenje: nano površinske lastnosti, realna površina, nanotrenje, modeli, nanokontakti. Super-nizko trenje s trdninami. 11. Predavanja: - Mazanje s tankimi filmi: nanotekočine, mazanje s tankimi filmi, koncepti formiranja tankih mazalnih filmov. Super-nizko trenje s tekočinami. 12. Predavanja: - Nanotribologija v inženirskih sistemih: primeri uporabe nanotribologije. Mejno mazanje v motorjih, v odrezovalnih in preoblikovalnih procesih. Mejni zdrs, zdrsna dolžina, modeli za izračun. 13. Predavanja: - Modeliranje na nano skali: uporaba modeliranja na nano skali: prvi principi in molekularna dinamika.	macro technology. Minituarization, physical laws, fundamentals of quantum mechanics, electromagnetic waves, quantization of energy, duality of energy and matter, the principle of indeterminacy. 3. Lecture: - Bonds and surface forces: classification and properties of bonds, intramolecular bonds, Lennard-Jones potential, van der Waals bonds. Surface forces between bodies - key equations. - Forces in fluids: electrostatic, zeta potential, DLVO theory, structural forces (solvation, hydration, hydrophobic). 4. Lecture: - Free surface energy and wettability: surface energy, surface tension. Wettability, Young's equation, types of wettability, influences (Cassie, Wenzel, homogeneity, chemical). Capillary effect and condensation, meniscus. 5. Lecture: - Adhesion and adsorption: adhesion work, adhesion between solids and in moisture. Adsorption, adsorption types, isotherms. Surface film growth. 6. Lecture: - Characterization of nanostructures: optical methods, electron microscopy, scanning probe methods, spectroscopic methods, diffraction, combined methods. 7. Lecture: - Nanomaterials production: types, fabrication, bottom-up growth (ALD, sol-gel, SAM, chemical, ...) and top-down (crushing, multiple types of lithography). 8. Lecture: - Types of nanomaterials: basic differences and characteristics, types: nanoparticles, nanofilms, nanograins, nanoporous, nanowires, nanotubes, fullerenes, graphene ... 9. Lecture: - Nanoscience: health dangers in nanotechnology, measurements, legislation, protection. 10. Lecture: - Surface effects and nanotubes: nano surface Properties, real surface, nanotubes, models, nanocontacts. Super-low friction with solids. 11. Lecture: - Thin-film lubrication: nanotubes, thin-film lubrication, thin-film lubrication concepts. Super-low friction with liquids. 12. Lecture: - Nanotribology in engineering systems: examples of nanotribology application. Boundry lubrication in engines, in cutting and forming processes. Boundary slip, slip length, calculation models. 13. Lecture: - Nano-scale modeling: application of nano-scale modeling: first principles and molecular dynamics. 14. Lecture:

14. Predavanja: - Nanotehnologija za tribološke rešitve (Viharjenje): analiza sistema, možnosti, koncepti, meritve, izvedba, rešitve, uporaba. Primer. 15. Predavanja: - Uporaba nanotehnologij v tehniki: nanoproizvodnja, nanobiotehnologija, nanosenzorika, nanomehanika, nanotehnologije v baterijah, zdravstvu, avtomobilski industriji, MEMS/NEMS, optika, tekstilstvo.	- Nanotechnology for tribological solutions (Brainstorming): system analysis, possibilities, concepts, measurements, implementation, solutions, application. Example. 15. Lecture: - Application of nanotechnologies in technology: nanotechnology, nanobiotechnology, nanosensors, nanomechanics, nanotechnologies in batteries, healthcare, automotive, MEMS/NEMS, optics, textiles.

Temeljna literatura in viri/Readings:

1. L.Theodore: Nanotechnology - Basic Calculatuions for Engineers and Scientists, Wiley-Interscience, 2006.
2. B. Rogers, J. Adams, S. Pennathur: Nanotechnology - Understanding small systems, CRC Press, 2008.
3. B. Bhushan (Ed): Handbook of Nanotechnology, Springer, 2007.
4. H. Ibach: Physics of surfaces and interfaces, Springer, 2006.
5. B. Bhushan (Ed): Nanotribology and Nanomechanics, Springer, 2005.

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Razumeti temeljne znanstvene in strokovne probleme na nano skali ter jih ustvarjalno reševati 2. Spoznati različne nanotehnologije in njihovo uporabo ter omejitve. 3. Razumeti temeljne fizikalne principe na nano nivoju. 4. Spoznati in razumeti temeljne principe in uporabo nanostruktur in nanomaterialov. Kompetence: 1. S1-MAG: Sposobnost za opredelitev, razumevanje temeljnih znanstvenih problemov in ustvarjalno reševanje strokovnih izzivov. 2. P2-MAG: Obvladovanje temeljnih teoretičnih znanj na področju nanotehnologij. 3. S2-MAG + P1-MAG: Sposobnost samostojne kritične presoje, vrednotenja in analize uporabnosti in omejitev različnih nanotehnologij. 4. P6-MAG + S7-MAG: Sposobnost razumevanja in uporabe temeljnih principov nanostruktur in nanomaterialov.	Objectives: 1. To understand basic scientific and applied problems at the nano scale and enable creative ability to tackle them. 2. To learn about different nanotechnologies and their application and limitations. 3. Understand the fundamental physical principles at the nano level. 4. To learn and understand the basic principles and application of nanostructures and nanomaterials. Competences: 1. S1-MAG: The ability to define and understand fundamental scientific problems and to creatively deal with professional challenges. 2. P2-MAG: Mastering fundamental theoretical knowledge in nanotechnology. 3. S2-MAG + P1-MAG: Ability to independently evaluate, evaluate and analyze the applicability and limitations of various nanotechnologies. 4. P6-MAG + S7-MAG: Ability to understand and apply the fundamental principles of nanostructures and nanomaterials.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja in	Knowledge Z2: In-depth theoretical, methodological and analytical knowledge with elements of research and application in nanotechnology.

uporabe s področja nanotehnologij. Spretnosti: S2.1 Razumevanje postopkov in uporabe nanotehnologij. S2.2 Samostojno vrednotenje in analiza nanostruktur in nanomaterialov. S2.3 Sposobnost osnovnega fizikalnega modeliranja in eksperiemntiranja na nano nivoju in kritična analiza rezultatov.	Skills: S2.1 Understanding the procedures and applications of nanotechnologies. S2.2 Independent evaluation and analysis of nanostructures and nanomaterials. S2.3 Ability to perform basic physical nano-level modelling and experimental techniques with rigorous analyses of results.

Metode poučevanja in učenja:	**Learning and teaching methods:**
P1 Avditorna predavanja z reševanjem izbranih – za področje značilnih – teoretičnih in praktično uporabnih primerov. P2 Obravnava snovi po urejeni in vnaprej določeni sistematiki. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje. P5 Uporaba študijskega gradiva v obliki (e-verzija predstavitve predavanj). P15 Uporaba video vsebin kot priprava na predavanja in vaje	P1 Auditorial lectures by solving selected - typical - theoretical and practical examples. P2 Discussionof the subject according to an orderly and predefined systematics. P3 Auditorial tutorials where theoretical knowledge from lectures is supported by computational examples. P4 Laboratory tutorials. P5 Use of study materials in format (e-version of lecture presentation). P15 Use video content to prepare for lectures and tutorials

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**
Teoretična snov (predavanja)	50,00 %	Theoretical subject (lectures)
Samostojno delo na vajah	20,00 %	Independent work in tutorials
Laboratorijsko delo na vajah (vključno s poročili)	10,00 %	Laboratory work in tutorials (including reports)
Seminar	10,00 %	Seminar

Reference nosilca/Lecturer's references:

Mitjan Kalin:

1. KUS, Maja, KALIN, Mitjan. Influence of additives and their molecular structure on the static and dynamic wetting of oil on steel at room temperature. *Applied Surface Science*. [Print ed.]. Oct. 2019, vol. 490, str. 420-429, ilustr. ISSN 0169-4332
2. ČOGA, Lucija, SIMIČ, Rok, GEUE, Thomas M., KALIN, Mitjan. Additive adsorption on DLC coatings in static and tribological conditions using neutron reflectometry. *Frontiers in mechanical engineering*. Mar. 2019, vol. 5, f. 1- 9, ilustr. ISSN 2297-3079.
3. GOLJA, Viviana, DRAŽIĆ, Goran, LORENZETTI, Martina, VIDMAR, Janja, ŠČANČAR, Janez, ZALAZNIK, Maša, KALIN, Mitjan, NOVAK, Saša. Characterisation of food contact non-stick coatings containing TiO2 nanoparticles and study of their possible release into food. *Food additives & contaminants.Part A.*,

Chemistry, analysis, control, exposure & risk assessment. 2017, no. 3, vol. 34, str. 421-433. ISSN 1944-0049.
4. SIMIČ, Rok, KALIN, Mitjan, KOVAČ, Janez, JAKŠA, Gregor. Adsorption of alcohols and fatty acids onto hydrogenated (a-C:H) DLC coatings. *Applied Surface Science*. [Print ed.]. Feb. 2016, vol. 363, str. 466-476, ilustr. ISSN 0169-4332.
5. LORENZETTI, Martina, DOGŠA, Iztok, STOŠICKI, Tjaša, STOPAR, David, KALIN, Mitjan, KOBE, Spomenka, NOVAK, Saša. The influence of surface modification on bacterial adhesion to titanium-based substrates. *ACS applied materials & interfaces*. [Print ed.]. 2015, vol. 7, str. 1644-1651, ilustr. ISSN 1944-8244.