NANOTEHNOLOGIJE

UČNI NAČRT PREDMETA/COURSE SYLLABUS

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

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

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

Predavanja /Lectures	Seminar /Seminar	Vaje /Tutorials	Klinične vaje /Clinical tutorials	Druge oblike študija /Other forms of study	Samostojno delo /Individual student work	ECTS
30		30			65	5

Nosilec predmeta/Lecturer:	prof. dr. Mitjan Kalin

Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

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. 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:	1. Lecture: - Introduction: definitions, examples, field of work, history. 2. Lecture: - Characteristics of nanotechnologies and specifics of nano scale phenomena: differences between nano and 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

- Modeliranje na nano skali: uporaba modeliranja na nano skali: prvi principi in molekularna dinamika. 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.	slip, slip length, calculation models. 13. Lecture: - Nano-scale modeling: application of nano-scale modeling: first principles and molecular dynamics. 14. Lecture: - 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 [COBISS.SI-ID - 27757573]
2. B. Rogers, J. Adams, S. Pennathur: Nanotechnology - Understanding small systems, CRC Press, 2008 [COBISS.SI-ID - 21440039].
3. B. Bhushan (Ed): Handbook of Nanotechnology, Springer, 2007 [COBISS.SI-ID - 1724004].

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:**
	Knowledge

Znanja Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja in 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.	Z2: In-depth theoretical, methodological and analytical knowledge with elements of research and application in nanotechnology. 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)	70,00 %	Theoretical subject (lectures)
Samostojno delo na vajah	10,00 %	Independent work in tutorials
Laboratorijsko delo na vajah (vključno s poročili)	10,00 %	Laboratory work in tutorials (including reports)
Seminar	10,00 %	Seminar

Ocenjevalna lestvica:	**Grading system:**
5 - 10, pri čemer velja, da je pozitivna ocena od 6 - 10	5 - 10, a student passes the exam if he is graded from 6 to 10

Reference nosilca/Lecturer's references:

Mitjan Kalin:

1. NADEEM, Irfan, FINŠGAR, Matjaž, DRAŽIĆ, Goran, AMBROŽIČ, Bojan, MALOK, Matjaž, CAVALEIRO, Albano, **KALIN, Mitjan**. Macroscale superlubricity with a high load-carrying capacity enabled by nitrogen-doped graphene quantum dots in lubricated silicon-doped amorphous carbon

films. Small structures. First published: 19 May 2025. DOI 10.1002/sstr.202400671. [COBISS.SI-ID 236432131]

2. A. Naseer, M. Evaristo, **M. Kalin**, A. Cavaleiro, Effect of silicon and oxygen co-doping on structure and properties of non-hydrogenated amporphous carbon, Surface and coatings technology 496 (2025) 131616. [COBISS.SI-ID 218270211]
3. NADEEM, Irfan, FINŠGAR, Matjaž, DRAŽIĆ, Goran, MALOK, Matjaž, MORINA, Ardian, **KALIN, Mitjan**. Robust and durable superlubricity enabled by carboxylated graphene quantum dots in lubricated steel contacts. *Carbon*. Jun. 2024, vol. 226, [article no.] 119226, str. 1-16, ilustr. ISSN 1873-3891. https://www.sciencedirect.com/science/article/pii/S0008622324004457, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.carbon.2024.119226. [COBISS.SI-ID 196343811]
4. NADEEM, Irfan, AMBROŽIČ, Bojan, DRAŽIĆ, Goran, KOVAČ, Janez, CAVALEIRO, Albano, **KALIN, Mitjan**. Super-low friction and wear in steel contacts enabled by tribo-induced structural degradation of graphene quantum dots. *Materials & design*. Aug. 2024, vol. 244, [article no.] 113111, str. 1-14, ilustr. ISSN 0264-1275. https://www.sciencedirect.com/science/article/pii/S0264127524004854, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1016/j.matdes.2024.113111. [COBISS.SI-ID 200420867]
5. BRODNIK ŽUGELJ, Blaž, KUZMAN, Mark, **KALIN, Mitjan**. Realna kontaktna površina. V: *SLOTRIB 2024 : Posvetovanje o tribologiji, mazivih in zelenih tehnologijah : 10. junij 2024, Portorož*. [Ljubljana]: Slovensko društvo za tribologijo, [2024]. Str. 1-8, ilustr. [COBISS.SI-ID 201767683]