LASERSKA OBDELOVALNA TEHNOLOGIJA

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Laserska obdelovalna tehnologija
Course title:	Laser Processing Technology
Članica nosilka/UL Member:	UL FS

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

Univerzitetna koda predmeta/University course code:	0566821
Koda učne enote na članici/UL Member course code:	6061-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:	izr. prof. dr. Peter Gregorčič, prof. dr. Matija Jezeršek

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

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Mehatronika in laserska tehnika, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Mechatronics and laser technology, 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. Uvod - Pregled vsebine, ciljev in kompetenc - Predstavitev dela na laboratorijskih vajah - Predstavitev ocenjevanja 2. Interakcija laserske svetlobe s snovjo - Makroskopski pogled, - interakcija na nivoju osnovnih delcev: kovine in dielektrik. - Vplivi na absorpcijski koeficient 3. Toplotni pojavi - Absorpcija, - modeli tranzientnega prevoda toplote (1D model, gaussov izvor v polneskončnem prostoru, točkovni izvor v polprostoru) taljenje, odparevanje in ionizacija - hitrost laserskega odparevanja 4. Fotokemični pojavi - Vezne energije molekul in kristalnih struktur - Vdorna svetlobna globina - Modifikacija in ablacija materiala - UV laserji - Primeri uporabe 5. Optodinamski pojavi - Pretvorba svetlobne v mehansko energijo - Pojavi v trdni snovi - Pojavi v zraku (zvok, udarni val) - Pojavi v tekočini - Primeri uporabe: prenos snovi, laserska propulzija, diagnostične metode 6. Sistemski parametri laserskih obdelav - Optični parametri (valovna dolžina, kvaliteta, moč, energija, repeticija,…) - Tehnološki parametri (fokusiranje, materialne lastnosti, pozicioniranje, …) - Področja uporabe posameznih tipov laserjev 7. Lasersko vrtanje - Tehnike vrtanja, - Komponente sistema, - Procesni parametri, - Modeliranje procesa, - Primeri sistemov, - Prednosti in slabosti 8. Lasersko rezanje - Tehnike rezanja, - Komponente sistema, - Procesni parametri, - Modeliranje procesa, - Primeri sistemov, - Prednosti in slabosti 9. Lasersko graviranje - Tehnike graviranja, - Komponente sistema, - Procesni parametri, - Modeliranje procesa, - Primeri sistemov, - Prednosti in slabosti 10. Lasersko varjenje - Tehnike graviranja, - Komponente sistema,	1. Introduction - Review of the content, goals and competencies - Presentation of lab work - Presentation of assessment 2. Interaction of laser light with matter - Macroscopic view, - interaction at the level of basic particles: metals and dielectrics. - Effects on absorption coefficient 3. Thermal phenomena - Absorption, - transient heat transfer models (1D model, Gaussian origin in semi-infinite space, point source in semi-space) melting, evaporation and ionization - speed of laser evaporation 4. Photochemical phenomena - Binding energies of molecules and crystal structures - Penetration depth of light - Modification and ablation of the material - UV lasers - Examples 5. Optodynamic phenomena - Conversion of light into mechanical energy - OD phenomena in solids - OD phenomena in air (sound, shock wave) - OD phenomena in liquid - Uses: substance transfer, laser propulsion, diagnostic methods 6. System parameters of laser processing - Optical parameters (wavelength, quality, power, energy, repetition,…) - Technological parameters (focusing, material properties, positioning,…) - Areas of application of individual types of lasers 7. Laser Drilling - Drilling techniques, - System components, - Process parameters, - Process modeling, - Examples of systems, - Pros and cons 8. Laser cutting - cutting techniques, - System components, - Process parameters, - Process modeling, - Examples of systems, - Pros and cons 9. Laser engraving - Engraving techniques, - System components, - Process parameters, - Process modeling, - Examples of systems, - Pros and cons 10. Laser welding - Welding techniques,

- Procesni parametri, - Modeliranje procesa, - Primeri sistemov, - Prednosti in slabosti 11. Laserski inženiring površin - Teoretične osnove laserskega mikrostrukturiranja, - vplivi na omočljivost površin, - lasersko barvanje in oksidacija. 12. Laserski 3D tisk - Laserska stereolitografija, - lasersko selektivno sintranje in pretaljevanje, - direktno lasersko ulivanje, - primerjava z nelaserskimi tehnikami. 13. Laserski medicinski sistemi in posegi - Interakcija laserske svetlobe s tkivi, - pregled laserjev, ki se uporabljajo v medicinskih sistemih, - tehnike vodenja snopa do ciljnega tkiva, - primeri. 14. Diagnostika obdelovalnih procesov - Popis procesnih parametrov, - Senzorji za nadzor laserskih procesov (temperaturni, optični, zvočni/ultrazvočni), - Primeri 15. Adaptivno krmiljenje laserskih procesov - Povratne zanke v laserskih obdelavah, - Krmilni algoritmi na osnovi primarnih/sekundarnih izhodnih parametrov, - Primeri	- System components, - Process parameters, - Process modeling, - Examples of systems, - Pros and cons 11. Laser surface engineering - Theoretical basis of laser microstructuring, - effects on surface wettability, - laser painting and oxidation. 12. Laser 3D printing - Laser stereolithography, - Selective laser sintering and melting, - direct laser casting, - comparison with non-laser techniques. 13. Laser Medical Systems and Interventions - Interaction of laser light with tissues, - review of lasers used in medical systems, - techniques for guiding the laser beam to the target tissue, - examples 14. Diagnostics of machining processes - List of process parameters, - Sensors for controlling laser processes (temperature, optical, sound / ultrasonic), - Examples 15. Adaptive control of laser processes - feedback loops in laser processing, - Control algorithms based on primary and secondary output parameters, - Examples

Temeljna literatura in viri/Readings:

1. W.M. Steen, Laser Material Processing (4th Edition), Springer Verlag, 2010, [COBISS.SI-ID 11579419]
2. E. Kannatey-Asibu, Principles of laser materials processing, John Wiley & Sons, 2009. [COBISS.SI-ID 11303451]
3. Dieter Schuoecker, High Power Lasers in Production Engineering, Imperial College Press, 1999. [COBISS.SI-ID 3776539]

Cilji in kompetence:	**Objectives and competences:**
Cilji: 1. Spoznavanje principov interakcije med lasersko svetlobo in snovjo. 2. Seznanitev z nekaterimi laserskimi obdelovalnimi procesi in pripadajočimi optomehatronskimi sistemi. 3. Vpliv laserskih parametrov na učinkovitost in kakovost procesa. 4. Seznanitev z metodami nadzora procesa. Kompetence: 1. S1-MAG: Sposobnost za opredelitev, razumevanje temeljnih znanstvenih problemov in ustvarjalno reševanje strokovnih izzivov na področju laserskih obdelav.	Objectives: 1. Understanding the principles of interaction between laser light and matter. 2. Introduction with some laser processing processes and associated optomechatronic systems. 3. Impact of laser parameters on process efficiency and quality. 4. Introduction with process control methods. Competences: 1. S1-MAG: The ability to define and understand fundamental scientific problems and to creatively deal with professional challenges in the field of laser processing.

2. S8-MAG in S9-MAG: Sposobnost iskanja virov, kritične presoje informacij, samostojnega nadgrajevanja pridobljenih znanj in poglabljanja znanja na posameznih specializiranih področjih laserskih obdelav. Ter usposobljenost za delo v skupini in interdisciplinarno povezovanje.. 3. P2-MAG: Obvladovanje temeljnih teoretičnih kakor tudi aplikativnih znanj, ki so bistvena za obvladovanje tehničnega področja laserskih obdelovalnih tehnologij.	2. S8-MAG and S9-MAG: The ability to find sources, critically evaluate information, independently upgrade the attained knowledge and deepen the knowledge in the individual specialised fields of laser processing. The ability for teamwork and for interdisciplinary networking. 3. 3. P2-MAG: Using the fundamental theoretical and applied knowledge, crucial for having command of technical field of laser processing.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanja: Z2: Poglobljeno teoretično, metodološko in analitično znanje z elementi raziskovanja, ki je osnova za zelo zahtevno strokovno delo na področju laserskih obdelovalnih procesov. Spretnosti: S2.2 Načrtovanje in vodenje delovnega procesa na podlagi ustvarjalnega reševanja problemov, povezanih z laserskimi obdelovalnimi tehnologijami.	Knowledge: Z2: Thorough theoretical, methodological and analytical knowledge with elements of a research work that form a basis for very demanding professional work in the field of laser machining processes. Skills: S2.2 Planning and managing of the working process on the basis of creative solving of problems that are linked to the teaching and training of the laser processing technology.

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 razloženi sistematiki. P3 Avditorne vaje, kjer se teoretično znanje s predavanj podkrepi z računskimi primeri. P4 Laboratorijske vaje z namenskimi didaktičnimi pripomočki (preklopno krmiljenje zapornice, tekočega traku, PID krmiljenje procesa, laserski merilni sistem, laserski obdelovalni sistem). P5 Uporaba študijskega gradiva v obliki e-verzij: predstavitve predavanj, zbirke nalog z vaj, navodil za izvedbo laboratorijskih vaj P14 Virtualni eksperimenti P15 Uporaba video vsebin kot priprava na vaje	P1 Auditorial lectures with solving selected field-specific theoretical and applied use cases. P2 Presenting the content according to the explained system. P3 Auditorial exrecises, in which theoretical content from the lectures is supplemented with practical examples. P4 Laboratory exercises with special-purpose didactic devices (description needs to be added, max. two lines per device). P5 Application of study material (description needs to be added, max. one line per material, e.g. textbook, e-book, printed lecture presentaions, etc.). P14 Virtual experiments. P15 Application of videos for preparations to the lectures and exercises.

Načini ocenjevanja:	**Delež/Weight**	**Assessment:**

Skupno oceno predmeta tvorita ocena teorije in vaj. Ocena teorije: - Računski del: 50%.	25,00 %	The course grade is combined of an exercise grade and a theory grade. Theory: - Practical part: 50%.
- Teoretični del: 50%.	25,00 %	- Theoretical part: 50%.
Ocena vaj: - Delo na laboratorijskih vajah (predpriprava, sodelovanje in samostojnost): 50%.	25,00 %	Exercises: - Work on exercises (preparation, colaboration, individual work): 50%.
- Poročilo o opravljenih vajah: 50%.	25,00 %	- Report for exercises: 50%.

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:

Matija Jezeršek:

1. BREŽAN, Tine, FRANCIOSA, Pasquale, **JEZERŠEK, Matija**, CEGLAREK, Dariusz. Fusing optical coherence tomography and photodiodes for diagnosis of weld features during remote laser welding of copper-to-aluminum. Journal of laser applications. 2023, vol. 35, str. 1-10, ilustr. ISSN 1042-346X. https://lia.scitation.org/doi/10.2351/7.0000803, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=143900, DOI: 10.2351/7.0000803. [COBISS.SI-ID 138309123]
2. KRAVANJA, Gaia, BELYAEVA, Inna A., HRIBAR, Luka, DREVENŠEK OLENIK, Irena, SHAMONIN, Mikhail, **JEZERŠEK, Matija**. Laser micromachining of magnetoactive elastomers as enabling technology for magnetoresponsive surfaces. Advanced materials technologies. May 2022, vol. 7, art. no. 2101045, 8 str., ilustr. ISSN 2365-709X. https://onlinelibrary.wiley.com/doi/10.1002/admt.202101045, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=145561, DOI: 10.1002/admt.202101045. [COBISS.SI-ID 81234691]
3. TAŠIČ MUC, Blaž, VELLA, Daniele, LUKAČ, Nejc, KOS, Matjaž, **JEZERŠEK, Matija**. Amplification of high-intensity pressure waves and cavitation in water using a multi-pulsed laser excitation and black-TiOx optoacoustic lens. Biomedical optics express. Jun. 2022, vol. 13, iss. 7, str. 3993-4006, ilustr. ISSN 2156-7085. https://opg.optica.org/boe/fulltext.cfm?uri=boe-13-7-3993&id=477059, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=137543, DOI: 10.1364/BOE.46071 [COBISS.SI-ID 112319235]
4. HRIBAR, Luka, GREGORČIČ, Peter, SENEGAČNIK, Matej, **JEZERŠEK, Matija**. The influence of the processing parameters on the laser-ablation of stainless steel and brass during the engraving by nanosecond fiber laser. Nanomaterials. [Online ed.]. Jan. 2022, vol. 12, iss. 2, str. 1-20, ilustr. ISSN 2079-4991. https://www.mdpi.com/2079-4991/12/2/232, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=134385, DOI: 10.3390/nano12020232. [COBISS.SI-ID 93100547]
5. VELLA, Daniele, JERNEJČIČ, Urban, KUKOVIČ, Jernej, ZORMAN, Anže, **JEZERŠEK, Matija**, LUKAČ, Nejc, LUKAČ, Matjaž. Enhanced hair removal based on the "avalanche effect" of the AvalancheLase® hair removal laser system. LAHA : journal of the Laser and Health Academy. 2021, vol. 2021, no. 1, str. 1-5, ilustr. ISSN 1855-9913. https://www.laserandhealthacademy.com/en/journal/?id=6988. [COBISS.SI-ID 97767427]

Peter Gregorčič:

1. SENEGAČNIK, Matej, **GREGORČIČ, Peter**. Diffraction-driven laser surface nanostructuring : towards patterning with curved periodic surface structures = Matej Senegačnik, Peter Gregorčič. Applied Surface Science. [Print ed.]. Feb. 2023, vol. 610, str. 1-10, ilustr. ISSN 0169-4332. https://www.sciencedirect.com/science/article/pii/S0169433222030148, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=142582, DOI: 10.1016/j.apsusc.2022.155486. [COBISS.SI-ID 129205507]
2. **GREGORČIČ, Peter**. Comment on "Bioinspired reversible switch between underwater superoleophobicity/superaerophobicity and oleophilicity/aerophilicity and improved antireflective

property on the nanosecond laser-ablated superhydrophobic titanium surfaces". ACS applied materials & interfaces. Jan. 2021, vol. 13, iss. 2, str. 2117-2127, ilustr. ISSN 1944-8244. https://pubs.acs.org/doi/10.1021/acsami.9b23462, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=124481, DOI: 10.1021/acsami.9b23462. [COBISS.SI-ID 17112859]

3. SENEGAČNIK, Matej, KUNIMOTO, Kohei, YAMAGUCHI, Satoshi, KIMURA, Koki, SAKKA, Tetsuo, **GREGORČIČ, Peter**. Dynamics of laser-induced cavitation bubble during expansion over sharp-edge geometry submerged in liquid - an inside view by diffuse illumination. Ultrasonics Sonochemistry. May 2021, vol. 73, str. 1-16, ilustr. ISSN 1350-4177. https://www.sciencedirect.com/science/article/pii/S1350417721000018, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=125585, DOI: 10.1016/j.ultsonch.2021.105460. [COBISS.SI-ID 46704131]
4. SENEGAČNIK, Matej, JEZERŠEK, Matija, **GREGORČIČ, Peter**. Propulsion effects after laser ablation in water, confined by different geometries. Applied physics. A, Materials science & processing. Feb. 2020, vol. 126, iss. 2, str. 1-12, ilustr. ISSN 0947-8396. https://link.springer.com/article/10.1007%2Fs00339-020-3309-y, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=114833, DOI: 10.1007/s00339-020-3309-y. [COBISS.SI-ID 17026587]
5. PETKOVŠEK, Martin, HOČEVAR, Matej, **GREGORČIČ, Peter**. Surface functionalization by nanosecond-laser texturing for controlling hydrodynamic cavitation dynamics. Ultrasonics Sonochemistry. 2020, vol. 67, str. 1-10, ilustr. ISSN 1350-4177. https://www.sciencedirect.com/science/article/pii/S1350417719313173?via%3Dihub#!, https://repozitorij.uni-lj.si/IzpisGradiva.php?id=116529, DOI: 10.1016/j.ultsonch.2020.105126. [COBISS.SI-ID 17154075]