

MIKROIZDELOVALNE TEHNOLOGIJE

UČNI NAČRT PREDMETA/COURSE SYLLABUS

Predmet:	Mikroizdelovalne tehnologije
Course title:	Micromanufacturing Technologies
Članica nosilka/UL Member:	UL FS

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

Univerzitetna koda predmeta/University course code:	0566829
Koda učne enote na članici/UL Member course code:	6044-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:	doc. dr. Izidor Sabotin, izr. prof. dr. Joško Valentinčič
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Izvajalci predavanj:	
Izvajalci seminarjev:	
Izvajalci vaj:	
Izvajalci kliničnih vaj:	
Izvajalci drugih oblik:	
Izvajalci praktičnega usposabljanja:	

Vrsta predmeta/Course type:	Obvezni strokovni predmet na smeri Proizvodno strojništvo, ki je izbirni strokovni predmet na ostalih smereh./Compulsory specialised course in the study of Production Engineering, which is an elective specialised course in other fields of study.
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Jeziki/Languages:	Predavanja/Lectures:	Slovenščina
	Vaje/Tutorial:	Slovenščina

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	Prerequisites:
Zaključena 1. stopnja.	Finished bachelor study programme.

Vsebina:	Content (Syllabus outline):
1. Uvod: - definicija mikroizdelkov, mikroizdelovalnih procesov in mikroizdelovalnih verig;	1. Introduction: - definition of micro-products, micro-manufacturing processes and micromanufacturing

- mikrosistemske in mikroinženirske tehnologije; - posebnosti na področju mikroizdelave; - izdelki in tržišče; - mikrofluidni sistemi. 2. Kemijski principi nanašanja in odnašanja materiala: - primeri na področju mikrosistemskih in mikroinženirskih tehnologij; - mikrosistemske tehnologije: materiali; - mono- in polikristali; - nekateri postopki suhega in mokrega jedkanja; - izbira primerne postopka; - primeri izdelkov. 3. Mikrosistemske tehnologije: - izdelava v polno; - površinska izdelava; - postopek LIGA; lasersko direktno zapisovanje: CAD-CAM, obdelovalni parametri, fotopolimeri in jedkala; - primeri izdelkov. 4. Mikroelektrokemijsko dolbenje: - mehanizem anodnega raztapljanja, osnovne enačbe odnašanja materiala; - krmiljenje procesa; - značilnosti obdelave; - primeri izdelkov; - stroji - koncepti in pregled trga; - trendi razvoja. 5. Mikroelektroerozijska obdelava: - posebnosti žične in potopne mikroelektroerozije; - mikroelektroerozijsko dolbenje: kinematika, kompenzacija obrabe elektrode; - primeri izdelkov in značilnosti obdelave; - stroji: koncepti in pregled trga; - trendi razvoja. 6. Mikrolaserska obdelava: - sublimacijsko, oksidacijsko in talilno odnašanje materiala; - vloga rezalnih plinov; - pomen frekvence laserskih pulzov; - lasersko dolbenje; - varjenje polimerov; - vrtanje lukenj; - primeri izdelkov in značilnosti obdelave. 7. Mikromehanska obdelava: - izdelava orodij za mikromehansko obdelavo; - mikromehansko dolbenje: kinematika, obdelovalni parametri, nadzor procesa, »fly cutting«; - diamantno struženje: stroji, orodja; - obdelava krhkih materialov; - mikropeskanje: koncepti naprav, šobe, maske; - primeri izdelkov in značilnosti obdelave; - trendi razvoja. 8. Aditivne tehnologije: - postopki primerni za mikroizdelke; - mehanizmi spajanja materiala; - stroji: koncepti in pregled trga; - trendi razvoja.	process chains; - microsystems and microengineering technologies; - specificities in the field of micro-manufacturing; - products and market; - microfluidic systems. 2. Chemical principles of material deposition and removal: - examples in the field of microsystems and microengineering technologies; - microsystem technologies: materials, mono- and polycrystals, some procedures of dry and wet etching, choice of appropriate procedure, product examples. 3. Microsystem technologies (continuation): - bulk micromachining; - surface micromachining; - LIGA procedure; laser direct imaging: CAD-CAM, machining parameters, photopolymers and etchants; - product examples. 4. Microelectrochemical etching: - mechanism of anodic dissolution, basic equation of material removal; - process control; - machining characteristics; - product examples; - machine tools: concepts and market overview; - development trends. 5. Micro EDM: - specificities of wire and die-sinking micro EDM; - micro EDM milling: kinematics, electrode wear compensation; - product examples and machining characteristics; - machine tools: concepts and market overview; - development trends. 6. Laser micromachining: - sublimation, oxidation and melting material removal processes; - the role of cutting gases; - importance of laser pulse frequency; - laser engraving; - welding of polymers; - drilling holes; - product examples and machining characteristics. 7. Mechanical micromachining: - manufacturing of tools for mechanical micromachining; - micromilling: kinematics, machining parameters, process control, fly cutting; - diamond turning: concepts, tools; - treatment of brittle materials; - micro sand blasting: machine tools, nozzles, masks; - product examples and processing characteristics; - development trends. 8. Additive manufacturing technologies: - processes suitable for micro-products; - material joining mechanisms; - machine tools: concepts and market overview;
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9. Stereolitografija za mikroizdelavo: - laserska stereolitografija; - kontinuirana stereolitografija (CLIP); - dvofotonska litografija; - fotopolimeri; - stroji: koncepti in pregled trga; - trendi razvoja. 10. Stereolitografija s projiciranjem maske za mikroizdelavo: - pristopi k gradnji izdelka; - optični sistemi; - model fotopolimerizacije; - primeri izdelkov. 11. Mikrobrizganje: - brizgalna enota za mikrobrizganje; - cikel brizganja; - orodja; - materiali in podatkovne baze; - gradnja modela in simuliranje brizganja. 12. Mikrobrizganje: - nadzor, analiza procesa in odprava napak; - parametri izdelave in značilnosti postopka; - stroji: pregled trga, brizganje na »makro« brizgalnih strojih; - trendi razvoja. 13. Vroče vtiskovanje: - osnovni proces in izpeljanke, materiali in termično okno; - orodja; - značilnosti obdelave; - primeri izdelkov; - stroji: koncepti in pregled trga; - trendi razvoja. 14. Izdelovalne verige: - direktne in indirektno izdelovalne verige; - postavitev ustrezne izdelovalne verige glede na velikost serije, natančnosti izdelave, pogoje v katerih deluje mikroizdelek; - "mehka" orodja; primeri iz prakse. 15. Mikroreaktorski sistemi: - koncept mikroreaktorja: mešalnik, reaktor, separator; - reakcijski čas in čas zadrževanja; - problem majhne produktivnosti: večanje dimenzij in večanje številčnosti; - koncept mikrotovarne.	- development trends. 9. Stereolithography for micro products: - laser stereolithography; - continuous stereolithography (CLIP); - two-photon lithography; - photopolymers; - machine tools: concepts and market overview; - development trends. 10. Mask projection stereolithography: - concepts of product design; - optical systems; - photopolymerization model; - product examples. 11. Micro injection moulding: - micro injection molding unit; - injection cycle; - tools; - materials and databases; - model and simulation of injection molding. 12. Micro injection moulding: - monitoring, process analysis and error correction; - machining parameters and characteristics; - machines tools: market overview, injection molding on "macro" injection molding machines; - development trends. 13. Hot embossing: - basic process and derivatives, materials and thermal window; - tools; - machining parameters and characteristics; - product examples; - machine tools: concepts and market overview; - development trends. 14. Process chains: - direct and indirect process chains; - setup of a process chain based on the batch size, required accuracy, operation conditions of micro-product; - soft tooling; practical examples. 15. Microreactor systems: - concept of microreactor: mixer, reactor, separator; - reaction time and residence time; - the problem of low productivity: scaling up and numbering up concepts; - micro-factory concept.
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Temeljna literatura in viri/Readings:

1. M. Madou: Fundamentals of Microfabrication and Nanotechnology, 3rd edition, CRC Press, 2012 [COBISS.SI-ID [13981238](#)]
2. Yi Qin: Micromanufacturing Engineering and Technology, William Andrew Publishing, 2010. E-knjiga ISBN - 0-8155-1545-6; 0-8155-1980-X; 9786612711763; 1-282-71176-8; 0-08-094740-9
3. V.K. Jain: Introduction to Micromachining, Alpha Science, 2010. [COBISS.SI-ID [33734917](#)]
4. G. Tosselo: Micro injection molding, Carl Hanser Verlag GmbH & Co. KG, 2019. [COBISS.SI-ID [146819075](#)]
5. Gibson, Ian idr.: Additive manufacturing technologies : 3D printing, rapid prototyping and direct digital manufacturing, New York : Springer, 2015. [COBISS.SI-ID [13909019](#)]

Cilji in kompetence:	Objectives and competences:
Cilji: 1. Spoznati mikroizdelovalne tehnologije z vidika fizikalnih procesov in njihovih tehnoloških zmogljivosti. 2. Spoznati uporabo/vlogo mikrotehnologij v sodobnih proizvodnih procesih. 3. Pridobljeno znanje iz literature uporabiti v praksi in predstaviti rezultate. 4. Določiti primerne tehnologije oz. izdelovalne verige za mikroizdelke. 5. Gradnja numeričnih modelov za izvajanje simulacij nekaterih mikroizdelovalnih procesov in za načrtovanje mikrokomponent. Kompetence: 1. S2-MAG, P2-MAG, P3-MAG: Obvladovanje mikroizdelovalnih tehnologij in področji njihove uporabe. 2. S1-MAG, S7-MAG, P1-MAG, P2-MAG: Sposobnost iskanja tehnoloških rešitev za izdelavo mikroizdelkov. 3. S5-MAG, S8-MAG, P5-MAG: Sposobnost iskanja virov informacij, kritične presoje in praktične uporabe. 4. S1-MAG, S7-MAG, P1-MAG, P2-MAG: Sposobnost načrtovanja izdelkov, ki jih je mogoče učinkovito izdelati z mikroizdelovalnimi tehnologijami. 5. S6-MAG + P4-MAG: Sposobnost izvajanja simulacij nekaterih mikroizdelovalnih procesov in uporabe mikrokomponent.	Objectives: 1. To get familiar with micromanufacturing technologies in terms of physical processes and their technological capabilities. 2. To understand the use/role of microtechnologies in modern production processes. 3. Apply the knowledge from the literature to practice and present the results. 4. Identify appropriate technologies and/or process chains for micro product manufacturing. 5. Building of numerical models and performing simulations of some micro-manufacturing processes and for design of micro-components. Competences: 1. S2-MAG, P2-MAG, P3-MAG: Mastering micro-manufacturing technologies and applications. 2. S1-MAG, S7-MAG, P1-MAG, P2-MAG: Ability to find technological solutions for micro-product manufacturing. 3. S5-MAG, S8-MAG, P5-MAG: Ability to search for sources of information, critical judgment and practical application. 4. S1-MAG, S7-MAG, P1-MAG, P2-MAG: The ability to design products that can be effectively fabricated with micromanufacturing technologies. 5. S6-MAG + P4-MAG: Ability to perform simulations of some micromanufacturing processes and use of microcomponents.

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. Spretnosti: S2.1 Obvladovanje zelo zahtevnih, kompleksnih delovnih procesov in metodoloških orodij na specializiranih področjih. S2.3 Sposobnost izvirnih dognanj/stvaritev in kritične refleksije.	Knowledge: Z2: Thorough theoretical, methodological and analytical knowledge with elements of a research work that form a basis for very demanding professional work Skills: S2.1 Mastering very demanding and complex work processes and methodological tools in specialised professional fields. S2.3 Ability of unique innovations and critical reflections.

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. P6 Interaktivna predavanja P7 Študij literature in razprava P8 Izdelava in predstavitev aplikativnih seminarskih nalog P10 Uporaba anket v realnem času P15 Uporaba video vsebin kot priprava na predavanja in 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 exercises, in which theoretical content from the lectures is supplemented with practical examples. P6 Interactive Lectures P6 Interactive lectures. P7 Literature study and discussion. P8 Making and presenting applied seminar exercises. P10 Application of questionnaires in real time. P15 Application of videos for preparations to the lectures and exercises.

Načini ocenjevanja:	Delež/Weight	Assessment:
- Teoretične vsebine (predavanja).	50,00 %	- Theoretical content (lectures).
- Delo na laboratorijskih vajah (vključno s poročili).	20,00 %	- Laboratory work (including reports).
- Seminar.	30,00 %	- 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:

Joško Valentinčič:

- ŠADL, Matej, PRAH, Uroš, KOVACOVA, Veronika, DEFAY, Emmanuel, ROJAC, Tadej, LEBAR, Andrej, **VALENTINČIČ, Joško**, URŠIČ NEMEVSSEK, Hana. Multifunctional flexible ferroelectric thick-film structures with energy storage, piezoelectric and electrocaloric performance. Journal of materials chemistry. C, Materials for optical and electronic devices. [Online ed.]. 2023, 11, str. 10058-10068, ilustr. ISSN 2050-7534. <https://pubs.rsc.org/en/content/articlehtml/2023/TC/D3TC01555F>, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1039/D3TC01555F. [COBISS.SI-ID [160044035](#)]
- VALENTINČIČ, Joško**, ZEIDLER, Henning, BÖTTGER, Toni, JERMAN, Marko. Influence of anode immersion speed on current and power in plasma electrolytic polishing. Micromachines. 2024, vol. 15, iss. 6, [article no.] 783, str. 1-13, ilustr. ISSN 2072-666X. <https://www.mdpi.com/2072-666X/15/6/783>, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.3390/mi15060783. [COBISS.SI-ID [199241731](#)]
- VALENTINČIČ, Joško**, PRIJATELJ, Miha, JERMAN, Marko, LEBAR, Andrej, SABOTIN, Izidor. Characterization of a custom-made digital light processing stereolithographic printer based on a slanted groove micromixer geometry. Journal of micro- and nano-manufacturing. [Print ed.]. Mar. 2020, vol. 8, str. 010911-1- 010911-6, ilustr. ISSN 2166-0468. <https://asmedigitalcollection.asme.org/micronanomanufacturing/article/8/1/010911/1072748/Characterization-of-a-Custom-Made-Digital-Light>, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.1115/1.4046044. [COBISS.SI-ID [17038363](#)]

4. SABOTIN, Izidor, JERMAN, Marko, LEBAR, Andrej, **VALENTINČIČ, Joško**, BÖTTGER, Toni, KÜHNEL, Lisa, ZEIDLER, Henning. Effects of plasma electrolytic polishing on SLM printed microfluidic platform. *Advanced technologies and materials*. 2022, vol. 47, nr. 1, str. 19-23, ilustr. ISSN 2620-0325. <http://journal-atm.org/archive/vol-47-no-1-2022/effects-of-plasma-electrolytic-polishing-on-slm-printed-microfluidic-platform>, DOI: 10.24867/ATM-2022-1-004. [COBISS.SI-ID [132569603](#)]
5. EDAKLAVAN KOROTH, Jithinraj, DEBARD, Maxime, **VALENTINČIČ, Joško**. Influence of electrolyte flow on plasma electrolytic polishing of additively manufactured lattice structures. V: SCHUBERT, Andreas (ur.), STEINERT, Philipp (ur.). 21st International Symposium on Electrochemical Machining Technology : INSECT 2025 : conference proceedings : Chemnitz, 3rd – 4th November 2025. Chemnitz: Chemnitz University of Technology, University Library: University Press, 2025. Str. 147-154, ilustr. ISBN 978-3-96100-259-7. <https://monarch.qucosa.de/api/qucosa%3A99790/attachment/ATT-0/>, DOI: 10.51382/978-3-96100-259-7-18. [COBISS.SI-ID [258755843](#)]

Izidor Sabotin:

1. **SABOTIN, Izidor**, TRISTO, Gianluca, VALENTINČIČ, Joško. Technical model of micro electrical discharge machining (EDM) milling suitable for bottom grooved micromixer design optimization. *Micromachines*. Jun. 2020, vol. 11, iss. 6, f. 1-20, ilustr. ISSN 2072-666X. <https://www.mdpi.com/2072-666X/11/6/594>, Repozitorij Univerze v Ljubljani – RUL, DOI: 10.3390/mi11060594. [COBISS.SI-ID [20114691](#)]
2. VALENTINČIČ, Joško, PEROŠA, Matej, JERMAN, Marko, **SABOTIN, Izidor**, LEBAR, Andrej. Low cost printer for DLP stereolithography. *Strojniški vestnik*. Oct. 2017, vol. 63, no. 10, str. 559-566, si 82, ilustr. ISSN 0039-2480. [Digitalna knjižnica Slovenije - dLib.si](#), DOI: [10.5545/sv-jme.2017.4591](#). [COBISS.SI-ID [15707675](#)], [JCR, SNIP, WoS do 18. 8. 2025: št. citatov (TC): 22, čistih citatov (CI): 21, čistih citatov na avtorja (CIAu): 4.20, Scopus do 24. 6. 2025: št. citatov (TC): 29, čistih citatov (CI): 28, čistih citatov na avtorja (CIAu): 5.60]
3. KITANOVSKI, Andrej, TOMC, Urban, KLINAR, Katja, VALENTINČIČ, Joško, MAJDIČ, Franc, **SABOTIN, Izidor**, MENCINGER, Jure. *Method for heat transfer in the embedded structure of a heat regenerator and the design thereof: United States patent US 12,000,663 B2, 2024-06-04*. Alexandria: United States Patent and Trademark Office, 2024. [35] f., ilustr. <https://worldwide.espacenet.com/patent/search/family/068344965/publication/US12000663B2?q=pn%3DCN112654778A>. [COBISS.SI-ID [14214659](#)]
4. **SABOTIN, Izidor**, VALENTINČIČ, Joško, PLETERSKI, Matej, JERMAN, Marko, LEBAR, Andrej, DREŠAR, Pavel. *An apparatus and a method for loosening a tube section from a tube plate : UK Patent GB 2576062 B, 2021-01-13*. South Wales: Intellectual Property Office, 2021. [18] str., ilustr. [COBISS.SI-ID [17020955](#)]
5. **SABOTIN, Izidor**, JERMAN, Marko, LEBAR, Andrej, VALENTINČIČ, Joško, BÖTTGER, Toni, KÜHNEL, Lisa, ZEIDLER, Henning. Effects of plasma electrolytic polishing on SLM printed microfluidic platform. *Advanced technologies and materials*. 2022, vol. 47, nr. 1, str. 19-23, ilustr. ISSN 2620-0325. <http://journal-atm.org/archive/vol-47-no-1-2022/effects-of-plasma-electrolytic-polishing-on-slm-printed-microfluidic-platform>, DOI: [10.24867/ATM-2022-1-004](#). [COBISS.SI-ID [132569603](#)], [Odprti dostop]