UČNI NAČRT PREDMETA / COURSE SYLLABUS	
Predmet:	Keramični materiali in tehnologije za integrirane senzorje fizikalnih veličin
Course title:	Ceramic Materials and Technologies for Sensors of Physical Quantities

Študijski program in stopnja Study programme and level	Študijska smer Study field	Letnik Academic year	Semester Semester
Senzorske tehnologije, 3. stopnja	/	1	1
Sensor Technologies, 3rd cycle	/	1	1

Vrsta predmeta / Course type Izbirni / Elective

Univerzitetna koda predmeta / University course code: ST3-533

Predavanja Lectures	Seminar Seminar	Vaje Tutorial	Klinične vaje work	Druge oblike študija	Samost. delo Individ. work	ECTS
30	**30**			**30**	**210**	**10**

**Navedena porazdelitev ur velja, če je vpisanih vsaj 15 študentov. Drugače se obseg izvedbe kontaktnih ur sorazmerno zmanjša in prenese v samostojno delo. / This distribution of hours is valid if at least 15 students are enrolled. Otherwise the contact hours are linearly reduced and transfered to individual work.*

Nosilec predmeta / Lecturer: Doc. dr. Tadej Rojac

Jeziki / Languages:	**Predavanja / Lectures:**	Slovenski ali angleški / Slovene or English
	Vaje / Tutorial:	Slovenski ali angleški / Slovene or English

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisits:**
Zaključen študij druge stopnje ustrezne (naravoslovne ali tehniške) smeri ali zaključen študij drugih smeri z dokazanim poznavanjem osnov področja predmeta (pisna dokazila, pogovor).	Completed second cycle studies in natural sciences or engineering or completed second cycle studies in other fields with proven knowledge of fundamentals in the field of this course (certificates, interview).

Vsebina:	**Content (Syllabus outline):**
• Aktualne tehnološke rešitve integriranih keramičnih senzorjev fizikalnih veličin. • Smernice razvoja funkcijskih senzorskih materialov: keramični piezoelektriki, piezouporovni kompozitni materiali, temperaturno odvisni uporovni kompozitni materiali, električno prevodni debeloplastni in tankoplastni materiali. • Sodobne strategije simulacijsko podprtega načrtovanja senzorskih struktur. • Napredne tehnologije izdelave senzorskih elementov in struktur (volumenska keramika, večplastne strukture, debele in tanke plasti). • Individualno poglobljena analiza izbranega	• Up-to-date technological approaches for integrated ceramic sensors of physical quantities. • Development trends in functional sensor materials: piezoelectric ceramics, piezoresistive composite materials, temperature-dependent resistive composites, electrically conductive thick- and thin-film materials. • Advanced strategies of modelling-supported design of sensor structures. • Advanced technologies of ceramic sensors fabrication (bulk, multilayers, thick films, thin films). • Individual analysis of a case study related to the topic of the student's PhD research: selection of a

realnega primera iz študentove disertacije: izbor primernega senzorskega materiala in inovativne tehnologije za izdelavo senzorja, napoved delovanja in eksperimentalno ovrednotenje senzorja in njegovih karakteristik.	suitable sensor material, an innovative technology for sensor realization, prediction of the sensor response and experimental characterization of the sensor and its operation.

Temeljna literatura in viri / Readings:

- Y. Imanaka, Multilayered low temperature cofired ceramics (LTCC) technology, Springer, 2005.
- Z. G. Ye, Handbook of advanced dielectric, piezoelectric and ferroelectric materials, CRC, 2008.
- S. Tadigadapa and K. Mateti, Piezoelectric MEMS sensors: State-of-the-art and perspectives, Meas. Sci. 20, 092001, 2009.
- V. Sharapov, Piezoceramic sensors, Springer, 2011.
- S. T. McKinstry and R. E. Newnham, Materials engineering: Bonding, structure, and structure-property relationships, Cambridge University Press, 2018.
- Izbrani članki predvsem v revijah Science, Advanced Functional Materials, Sensors and Actuators, Journal of the American Ceramic Society/ Targeted selection of papers from Science, Advanced Functional Materials, Sensors and Actuators, Journal of the American Ceramic Society.

Cilji in kompetence:	**Objectives and competences:**
Cilji Študent: • razume principe delovanja senzorjev fizikalnih veličin, • pozna funkcijske lastnosti keramičnih materialov za različne vrste senzorjev, • izbere primerno tehnologijo za določen tip senzorja, • napove, izmeri in analizira ključne karakteristike senzorja. Kompetence Študent: • izbere material z ustreznimi funkcijskimi lastnostmi, • načrta in izdela demonstracijski senzorski element ali strukturo ob upoštevanju danih tehnoloških okvirov, • eksperimentalno ovrednoti delovanje senzorja.	Objectives: • understanding of principles of operation of sensors of physical quantities, • knowledge of functional properties of ceramic materials for different sensor types, • ability to select a suitable technology for an individual sensor, • ability to predict, measure and analyse sensor characteristics. Competences: • ability to select the material with appropriate functional properties, • ability to design a demo sensor element or structure within given technological boundaries, • ability to experimentally verify the sensor operation.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanje in razumevanje: • poznavanje materialov za senzorske elemente, • poznavanje naprednih tehnologij izdelave integriranih keramičnih senzorjev, • razumevanje principov delovanja senzorjev, • sposobnost povezovanja znanj o materialih in sodobnih tehnologij za reševanje konkretnega primera v okviru doktorskega študija.	Knowledge and understanding: • knowledge of sensor materials, • knowledge of advanced technologies of integrated ceramic sensors fabrication, • understanding of principles of sensor operation, • ability to correlate knowledge and skills in materials science and advanced technologies to solve a case-study related to the PhD research.

Metode poučevanja in učenja:	**Learning and teaching methods:**
Interaktivna predavanja. Individualno voden študij, ki vključuje reševanje realnega primera in predstavitev rezultatov v obliki seminarske naloge.	Interactive lectures. Individually guided study which includes a case-study and presentation of results as a seminar.

Načini ocenjevanja:	Delež (v %) / Weight (in %)	**Assessment:**
Seminarska naloga, ki vsebuje zagovor reševanja izbranega primera.	60 %	Seminar which includes the case-study.
Ustni izpit.	40 %	Oral exam.

Reference nosilca / Lecturer's references:

- ROJAC, Tadej, BENČAN, Andreja, DRAŽIĆ, Goran, SAKAMOTO, Naonori, URŠIČ, Hana, JANČAR, Boštjan, TAVČAR, Gašper, MAKAROVIČ, Maja, WALKER, Julian, MALIČ, Barbara, DAMJANOVIĆ, Dragan. Domain-wall conduction in ferroelectric $BiFeO_3$ controlled by accumulation of charged defects. *Nature materials*, ISSN 1476-1122, 2017, vol. 16, no. 3, str. 322-327, doi: 10.1038/nmat4799. [COBISS.SI-ID 29936679]
- KHOMYAKOVA, Evgeniya, ŠADL, Matej, URŠIČ, Hana, DANIELS, John, MALIČ, Barbara, BENČAN, Andreja, DAMJANOVIĆ, Dragan, ROJAC, Tadej. Self-poling of $BiFeO_3$ thick films. *ACS applied materials & interfaces*, ISSN 1944-8244. [Print ed.], 2016, vol. 8, no. 30, str. 19626-19634, doi: 10.1021/acsami.6b05885. [COBISS.SI-ID 29643559]
- ROJAC, Tadej, DRNOVŠEK, Silvo, BENČAN, Andreja, MALIČ, Barbara, DAMJANOVIĆ, Dragan. Role of charged defects on the electrical and electromechanical properties of rhombohedral $Pb(Zr,Ti)O_3$ with oxygen octahedra tilts. *Physical review B, Condensed matter and materials physics*, ISSN 1098-0121, 2016, vol. 93, no. 1, str. 014102-1-014102-11, doi: 10.1103/PhysRevB.93.014102. [COBISS.SI-ID 29234983]
- ROJAC, Tadej, URŠIČ, Hana, BENČAN, Andreja, MALIČ, Barbara, DAMJANOVIĆ, Dragan. Mobile domain walls as a bridge between nanoscale conductivity and macroscopic electromechanical response. *Advanced functional materials*, ISSN 1616-301X, 2015, vol. 25, no. 14, str. 2099-2108, doi: 10.1002/adfm.201402963. [COBISS.SI-ID 28359975]
- BALÁŽ, Peter, ROJAC, Tadej. Hallmarks of mechanochemistry : from nanoparticles to technology. *Chem. Soc. rev.*, 2013, vol. 42, issue 18, str. 7571-7637, doi: 10.1039/C3CS35468G. [COBISS.SI-ID 26654759]