UČNI NAČRT PREDMETA / COURSE SYLLABUS	
Predmet:	Dielektrične in toplotne lastnosti nanomaterialov
Course title:	Dielectric and Thermal Properties of Nanomaterials

Študijski program in stopnja Study programme and level	Študijska smer Study field	Letnik Academic year	Semester Semester
Nanoznanosti in nanotehnologije, 3. stopnja		1	1
Nanosciences and Nanotechnologies, 3rd cycle		1	1

Vrsta predmeta / Course type Izbirni / Selective

Univerzitetna koda predmeta / University course code: NANO3-793

Predavanja Lectures	Seminar Seminar	Vaje Tutorial	Klinične vaje work	Druge oblike študija	Samost. delo Individ. work	ECTS
15	**15**			**15**	**105**	**5**

**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: Prof. dr. Vid Bobnar

Jeziki / Languages:	**Predavanja / Lectures:**	slovenščina, angleščina / Slovenian, English
	Vaje / Tutorial:	slovenščina, angleščina / Slovenian, English

Pogoji za vključitev v delo oz. za opravljanje študijskih obveznosti:	**Prerequisits:**
Zaključen študij druge stopnje s področja naravoslovja ali tehnologije ali zaključen študij druge stopnje na drugih področjih z znanjem osnov s področja predmeta.	Completed second cycle studies in natural sciences or technologies or completed second cycle studies in other fields with knowledge of fundamentals in the field of this course.

Vsebina:	**Content (Syllabus outline):**
- Dielektrična polarizacija in teorija dielektrične relaksacije; - Širokopasovne dielektrične meritve (pregled eksperimentalnih metod, študij faznih prehodov in dinamike); - Dielektrične lastnosti polarnih sistemov (tekočih kristalov, nanodomenskih sistemov, relaksorjev, devteronskih stekel, polimerov in polimernih kompozitov, biomaterialov); - Osnove elektromehanske karakterizacije; - Dizajniranje materialov z velikim dielektričnim in elektromehanskim odzivom; - Specifična toplota nanodomenskih sistemov	- Dielectric polarization and dielectric relaxation theory; - Broadband dielectric measurements (the survey of methods, study of phase transitions and dynamics); - Dielectric properties of polar systems (liquid crystals, nanodomain systems, relaxors, deuteron glasses, polymers and polymer composites, biomaterials); - Fundamentals of electromechanical characterization; - Designing materials with high dielectric and electromechanical response; - Specific heat of nanodomain systems (relaxors,

(relaksorjev, nanomagnetov, tekočih kristalov, steklastih sistemov, biomaterialov); - Uvod v kritično obnašanje sistemov; - Elektrokalorični efekt: teorija in eksperiment; - Vpliv kritične točke na energijske pretvorbe pri različnih pojavih (termomehanski odziv tekočekristalnih elastomerov, elektromehanski odziv relaksorskih feroelektrikov, elektrokaloričen odziv anorganskih in polimernih relaksorjev); - Transportne lastnosti nanosistemov (električna prevodnost, transport naboja v nanocevkah in nanožicah, kot npr. DNA, toplotna prevodnost in difuzivnost).	nanomagnets, liquid crystals, glassy systems, biomaterials); - Introduction to critical phenomena; - Electrocaloric effect: theory and experiment; - Influence of the critical point on energy conversions in various phenomena (thermomechanical response of liquid crystal elastomers, electromechanical response of relaxor ferroelectrics, electrocaloric effect in inorganic and polymeric relaxors); - Transport properties of nanosystems (electric conductivity, transport of charge in nanotubes and nanowires, such as DNA, heat conductivity and diffusivity).

Temeljni literatura in viri / Readings:

Zaradi hitro razvijajočega se področja so temeljni študijski viri objavljena znanstvena dela v znanstvenih revijah / Due to a fast growing field the basic readings are recently published scientific works in scientific journals: Nature, Science, Physical Review, Advanced Materials...

Dodatna literatura oz. učbeniki / Additional readings:

- Principles of Thermal Analysis and Calorimetry, Editor: Peter Haines, The Royal Society of Chemistry, Cambridge, 2002, ISBN 0-854-04610-0
- Broadband Dielectric Spectroscopy, Editors: F. Kremer and A. Schönhals, Springer-Verlag Berlin Heidelberg, 2003, ISBN 3-540-43407-0
- Handbook of Applied Solid State Spectroscopy, Editor: D. R. Vij, Springer Science+Business Media, New York, 2006, ISBN 0-387-32497-6
- Ferroelectrics, Characterization and Modelling, Editor: M. Lallart, InTech Open Access Publisher, 2011, ISBN 978-953-307-455-9
- N. F. Mott and E. A. Davis, Electronic Processes in Non-Crystalline Materials, Clarendon Press, Oxford, 2012, ISBN 978-0-19-964533-6

Cilji in kompetence:	**Objectives and competences:**
Namen predmeta je pridobiti znanje o dielektričnih, toplotnih in nekaterih transportnih lastnosti nanostrukturnih snovi ter se seznaniti z najnovejšimi dosežki s teh področij. V predavanjih je podan tudi obširen pregled eksperimentalnih metod in merilnih tehnik. Predmet pripravlja študente za uporabo znanja s področja dielektričnih in toplotnih lastnosti nanomaterialov, razvija komunikacijske sposobnosti in spretnosti, posebej komunikacijo v mednarodnem okolju, in spodbuja kooperativnost oz. delo v skupini.	The aim of this course is to acquire knowledge of dielectric, thermal and certain transport properties of nanostructured materials, and to become acquainted with the latest achievements in these fields. The lectures also give an extensive overview of experimental methods and measurement techniques. The course prepares students to apply knowledge from dielectric and caloric properties of nanomaterials, develops communications skills to present research achievement in the international environment, and stimulates cooperativeness and team work.

Predvideni študijski rezultati:	**Intended learning outcomes:**
Znanje in razumevanje: - Poznavanje dielektričnih in toplotnih lastnosti	**Knowledge and Understanding:** - Knowledge of dielectric and caloric properties of

nanomaterialov - Razumevanje funkcionalnega odziva materialov v bližini kritičnih točk in posledično razumevanje principov dizajniranja materialov z velikim električno-induciranim odzivom. **Prenesljive/ključne spretnosti, drugi atributi:** - Obvladanje raziskovalnih metod in sposobnost uporabe znanja v praksi: • Meritve dielektričnega odziva in transportnih lastnosti • Določitev kaloričnih lastnosti • Elektromehanska in elektrokalorična karakterizacija Razvoj kritične in samokritične presoje.	nanomaterials - Understanding the materials functional response near critical points and, consequently: - Understanding principles for designing materials with high electrically-induced response; **Transferable/Key Skills and other attributes:** - Mastering research methods and the ability to use knowledge in practice: o Measurements of dielectric response and trasnport properties o Determination of caloric properties o Electromechanical and electrocaloric characterization Developing critical and self-critical thinking.

Metode poučevanja in učenja:	**Learning and teaching methods:**
- Predavanja	- Lectures
- Študije primerov	- Case studies
- Seminarji	- Seminar work
- Laboratorijsko delo	- Laboratory work

Načini ocenjevanja:	Delež (v %) / Weight (in %)	**Assessment:**
- seminar	50 %	- seminar
- ustni izpit	50 %	- oral exam

Reference nosilca / Lecturer's references:

[1] A. Matavž, B. Malič, V. Bobnar, Inkjet printing of metal-oxide-based transparent thin-film capacitors, Journal of Applied Physics 122, 214102 (2017) [COBISS.SI-ID 30978087]

[2] L. Fulanović, J. Koruza, N. Novak, F. Weyland, B. Malič, V. Bobnar, Fatigue-less electrocaloric effect in relaxor $Pb(Mg_{1/3}Nb_{2/3})O_3$ multilayer elements, Journal of the European Ceramic Society 37, 5105 (2017) [COBISS.SI-ID 30569511]

[3] Y. Beeran P. T., V. Bobnar, S. Gorgieva, Y. Grohens, M. Finšgar, S. Thomas, V. Kokol, Mechanically strong, flexible and thermally stable graphene oxide/nanocellulosic films with enhanced dielectric properties, RSC Advances 6, 49138 (2016) [COBISS.SI-ID 19525910]

[4] A. Eršte, L. Fulanović, L. Čoga, M. Lin, Y. Thakur, Q. M. Zhang, V. Bobnar, Stable dielectric response of low-loss aromatic polythiourea thin films on Pt/SiO_2 substrate, Journal of Advanced Dielectrics 6, 1650003 (2016) [COBISS.SI-ID 29391911]

[5] A. Abram, A. Eršte, G. Dražić, V. Bobnar, Structural and dielectric properties of hydrothermally prepared boehmite coatings on an aluminium foil, Journal of Materials Science: Materials in Electronics 27, 10221 (2016) [COBISS.SI-ID 29566759]