The Warsaw Doctoral School in Natural and Biomedical Sciences and the Institute of High Pressure Physics PAS cordially invite you to
a **SPOTLIGHT TALK**

Thin films of energy materials with enhanced performance: the role of artificial nanodefects

given by

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on 27th June 2024, 11:30

at the IHPP PAS New Technologies Building,
Al. Prymasa Tysiąclecia 98, seminar room, 2nd floor
Duration: 60+ min

and online via Zoom:

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All Warsaw-4-Phd students (and others) are very welcome!

Abstract

These days, mankind has been starting to face many difficult issues: energy problems, environmental problems, water problems and so on. It is a common feeling that new advanced materials will play an important role in the current challenge to develop alternative and sustainable energy technologies to reduce our dependence on nuclear and fossil fuels and eliminate greenhouse gas emissions. In particular, superconducting and thermoelectric materials seem fitted to solve the energy puzzle since they can provide efficient energy transport and conversion, respectively.
This presentation will highlight the recent development of highly oriented nanostructured films of superconducting and thermoelectric materials with strongly enhanced properties for sustainable energy applications.
Superconducting bulks and single crystals are quite important for the study of the basic physical properties, however for practical applications, like direct current transportation or winding of magnets, development of superconducting wires and tapes based on thin films technology is strongly required. In the past 20 years, introduction of nanosized Artificial Pinning Centers (APCs) was widely used to strongly enhance critical current (J_c) and global pinning force (F_p)

of $YBa_2Cu_3O_x$ (YBCO, T_c = 92 K) and related superconducting materials in magnetic field. Furthermore, nanoengineering approach to control microstructure, distribution, concentration and dimensionality of APCs represents a powerful tool to understand the pinning mechanisms. Nanosized defects of different dimensionality, called artificial pinning centers (APCs), have been introduced in YBCO films fabricated by pulsed laser deposition (PLD). At first, by ablation of mixed $BaSnO_3$-YBCO targets with increasing BSO content (2~9 wt%), we obtained high quality YBCO thin films incorporating BSO in form of nanorods, which are classified as one-dimensional APCs (1D-APCs). YBCO films added with 4 wt% BSO have isotropic J_c = 0.3 MA/cm^2 and F_p^{MAX} = 28.3 GN/m^3 (77K, 3T, B//c) [1], twice of the performance of conventional Nb_3Sn superconductor at 4.2K. Secondly, we tried the incorporation of Y_2O_3 nanoparticles (three-dimensional APCs, 3D-APCs) inside the YBCO film, using surface-modified YBCO targets. Randomly distributed Y_2O_3 particles, which density was proportional to the area of sector, were incorporated in YBCO films. Consistent with the microstructure, J_c was isotropic. The 5.44 A% Y_2O_3 added sample presented F_p^{MAX} =14.3 GN/m^3 (77K, 3T, B//c)) The single vortex dynamics model was used to account for vortex pinning in the samples [2]. Ultimate approach was combination of advantages of 1D- and 3D-APCs pinning, with coexistence of BSO nanorods and Y_2O_3 nanoparticles. Best result was obtained with the combination [(90 nm YBCO+BSO)/(30 nm YBCO+Y_2O_3)]×3 presenting F_p^{MAX} =17.6 GN/m^3 (77K, 2.2T, B//c). Co-existence of random and correlated pinning in the periodically structured 1D+3D APCs-added YBCO films can be discussed on the bases of the global pinning models [3].

Thermoelectrics can convert heat into electrical energy. Efficient, small and light thermoelectric modules are fundamental to recycle waste heat from industrial plant, cars, or even domestic stoves and human body heat.

The nanostructuration of thin films and the introduction of artificial nanodefects has just recently recognized as crucial for the improvement of the performance of thermoelectric thin films, leading to depressed thermal conductivity by enhanced phonon scattering and consequent improved figure of merit ZT. Highlights of the research are: insertion of hydroquinone nanolayers in Al-doped ZnO (AZO) films prepared by atomic layer deposition (ALD): κ_{ALD} (300 K) = 3.56 W/m×K [4]; addition of polymethylmethacrylate (PMMA) particles to AZO films prepared by multi-beam multi-target matrix-assisted PLD (MBMT/MAPLE-PLD): κ_{MAPLE} (300 K) = 5.9 W/m×K and ZT_{MAPLE} (600 K) = 0.07 [5]; formation of nanopores in AZO films prepared by Mist-Chemical Vapor Deposition (Mist-CVD): κ_{porous} (300 K) = 0.60 W/m×K and ZT porous (300 K) = 0.06 [6]; dispersion of Al_2O_3 nanoparticulate in AZO films prepared by surface-modified target PLD: $\kappa_{nanoAl2O3}$ (300 K) = 3.98 W/m×K and $ZT_{nanoAl2O3}$ (600 K) = 0.0007 [7]. Overall, 1/10 ~1/100 depression of κ and 3~5 times ZT enhancement with respect to the typical bulk AZO values was achieved.

In conclusion, these results clarify the crucial role of nanosized artificial defects in the improvement of performance of superconducting and thermoelectric thin films and put in evidence the promise of nanostructured films for future wide-scale energy applications.

References

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